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Concrete utopianism in integrated assessment models: Discovering the philosophy of the shared socioeconomic pathways

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ABSTRACT

The Shared Socioeconomic Pathways (SSPs) are at the forefront of climate change science today. As an influential methodology and method, the SSPs guide the framing of numerous climate change research questions and how these are investigated. Although the SSPs were developed by an interdisciplinary group of scientists in a well-documented process, there is no apparent consensus in the literature that answers the question, "What is the philosophy of science behind the SSPs?" To investigate, the paper applies a systematic thematic qualitative content analysis to the dataset of published papers that establish the rules and expectations for using the SSPs. The research determines that there is no obvious and concise statement on the epistemological and ontological foundation of the SSPs. However, based on the evidence identified in the dataset, SSPs are implicitly, though not explicitly, consistent with a critical realist and concrete utopian philosophy as coined by Roy Bhaskar. This is the first paper to discuss the philosophical underpinning of the SSPs.

1. Introduction

This article argues that climate change science has quietly made a resounding philosophical shift. The rigid ontology and epistemology of mainstream climate science research methods, built on a positivist and reductionist worldview, gave way to a contrasting philosophical underpinning, to critical realism. The vehicle for this shift is the recently rolled out Shared Socioeconomic Pathways (SSPs) scenario framework.

The SSPs are scenario narratives of plausible climate change futures that are characterized by challenges to climate change mitigation and challenges to climate change adaptation [3]. A group of climate researchers invited to serve the Intergovernmental Panel on Climate Change developed and disseminated the SSPs to the broader research community. Over three hundred published papers using the SSPs are published to date.[1] The scenario narratives and their quantifications can be combined with an array of future Representative Concentration Pathways (RCPs) for greenhouse gas concentrations in the atmosphere [4] and selected Shared Policy Assumptions [5] to frame climate change (and sustainability) research. The qualitative and quantitative elements of the SSPs are publicly and freely available online.[2] The aim of the SSPs is to better understand plausible future outcomes of the "complex interactions of the climate system, ecosystems, and human activities and conditions" [6]. The SSPs are used for climate change research using Integrated Assessment Models and other types of analyses to inform policymakers about the likely and possible social, environmental, and economic outcomes of future climate change.

Transparency is an essential component of "doing" science, both in the construction of research and the evaluation of research results [7]; therefore, making known the philosophy of science of the SSPs is a contribution to the community of climate change scientists who use them. As a result, this research aims to answer the following questions:

1 Are the SSPs a methodology or a method? This question is relevant because a methodology establishes rules and practices in a discipline. There can be many methods belonging to the same methodology.
2 Did the SSP community define its philosophy? If so, how and where is it documented? The article's hypothesis is that the philosophy of science behind the SSPs is critical realism. Does the data support or negate this hypothesis?

To answer these research questions, a Systematic
Thematic Qualitative Content Analysis was employed to discern the philosophical meanings embedded in the dataset of thirty-three peer-reviewed scientific journal articles published between 2010 and 2016 that form the "intellectual capital" of the SSPs' community. This dataset

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[1] A current listing of published SSP works is available at https://depts.washington.edu/iconics/publications/.
[2] The International Institute for Applied Systems Analysis maintains the SSP Database at https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about.

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of published papers establish the rules and expectations for using the SSPs.

The research determines that there is no obvious and precise statement on the epistemological and ontological foundations of the SSPs in the dataset. A deeper level of analysis is needed to determine if evidence of an underlying philosophy of science could be discerned from the relevant literature. An analysis of the dataset finds that the SSPs are consistent with the critical realist and concrete utopian metatheory of social science as coined by Roy Bhaskar. This is the first paper to discuss the philosophical underpinning of the SSPs and is a new contribution to the field.

The remaining sections of the paper are organized as follows. Section 2 reviews the relevant literature. Section 3 provides a brief history of the SSPs. Section 4 is an overview of critical realism and concrete utopianism. Section 5 describes the theoretical framework, research design and methods, and dataset. Section 6 discusses the results, providing examples of the Qualitative Content Analysis findings. Section reflects on the findings.

2. Literature review

The ongoing discussions in the literature about how scientists construct and use knowledge of the future in climate change research are the context of this paper. Specifically, the current debates about the utility of IAMs and critique of the narrow scope of climate models. These critiques can be divided into at least three threads, philosophical methodological, inadequacy of integrated assessment models (IAMs), and the science / policy gap, e.g., [8–20].

- Philosophical and methodological facets of climate change research are contested and critiqued in the literature. For example, Esbjörn-Hargens (2010) and Parker (2006) both discuss the complexity and uncertainty in climate change research, and both advocate ontological pluralism and methodological pluralism, respectively. Murphy (2011) questions if the demands for interdisciplinary climate change research incorporate multiple epistemological and cultural viewpoints. McDowall and Geels (2017) observe that the positivist philosophies of many models introduces “underlying assumptions and blind spots” that hobble their ability to capture complex social changes. Heymann and Dahan Dalmedico (2019) discern the historical epistemological and political roots of IAMs. They conclude that the “culture of prediction” of the post 1990s created a new ontology of governance by conflating the use of knowledge tools and the creation of political meaning”, which they see as dangerously politics and policy driven. Mahoney and Hulme (2016) and Miguel (2017) note that climate modeling is an extension of geopolitical maneuvering of nation states, to further their epistemic sovereignty.
- Authors also critique IAMS as generally inadequate. Petersen (2000) raises concerns with computer simulation of climate systems including uncertainties built into climate change models due to ignorance and unpredictability. Rosen and Guenther (2015) critique the capacity of to generate long-term economic estimates. They categorically state that “Because of these serious technical problems [of IAMs], policymakers should not base climate change mitigation policy on the estimated net economic impacts computed by [them].” Anderson and Jewell (2019) states that incremental change near economic equilibrium that is the modus operandi of IAMs is not suited to the economic revolution needed to address climate change. Hulme introduces “climate reductionism”, embodied in models, that makes climate the main cause of a complex system's “behavior and response”, marginalizing other “factors that may be more important than climate or perhaps just less predictable” [18].
- The gap between scientific rhetoric and policy reality resulting in “too little too late” climate policies at international and local scales is discussed at length. Anderson (2012) points out the demand/consumption changes that could result in rapid reduction of carbon dioxide emissions. Vink, et al. (2013) argues that understanding “forms of power” and “forms of knowledge” in climate change governance is lacking, leading to a disconnect between science and policy. Geden et al. (2019) and others assert that despite the repeated findings of IAMs that negative carbon dioxide technologies emissions are necessary to reduce climate change impacts, little research and development or regulatory initiatives promoting these technologies exist [19,21].

The aforementioned articles highlight that the construction and use of climate change models has been a contested space for many years. Several of the drivers for creating the SSPs such as uncertainty and the need for improving long-term projections of social change are recurring themes in the literature. In contrast, this paper does not challenge climate change research or the SSPs. It focuses on the conspicuous lack of clarity on the SSP's philosophical stance. McDowall and Geels (2017) comment that “there is value in further reflection on the underlying philosophical assumptions associated with the various modeling approaches, and how these assumptions relate to the transitions field.” This study undertakes this task for the SSPs.

3. A brief history and description of the SSPs

This section overviews the history of climate modeling leading to the SSPs, followed by a description of the SSPs. The roots of the concerted effort to develop future scenarios lie with the International Panel on Climate Change (IPCC) and the integrated assessment modeling (IAM) community [6] For example in 1992, the IPCC Working Group III was asked to review and assess the socioeconomic literature relevant to climate change for the IPCC's Second Assessment Report. [2] The Working Group III's report succinctly describes the dilemma of climate researchers, then (and now), as follows.

> “Decision-making related to climate change must take into account the unique characteristics of the ‘problem’: large uncertainties (scientific and economic), possible non-linearities and irreversibilities, asymmetric distribution of impacts geographically and temporally, the very long time horizon, and the global nature of climate change with the associated potential for free riding. Beyond scientific uncertainties…. and impact uncertainties…. socioeconomic uncertainties relate to estimates of how these changes will affect human society…”[2]

A detailed history of how climate research reached these conclusions is beyond the scope of this article. Specialized research focusing on the history and philosophical critique are referenced in Section 3.1 to provide the reader with sufficient background to understand the emergence of the SSPs.

3.1. History of climate modeling from a philosophy of science perspective

Edwards offers a historical review of technical climate modeling from conceptual models of the 1800′s to present-day IAMs [22]. Hulme's history of climate change science interprets a “widespread pattern of methodological climate reductionism as it is applied to many different dimensions of the imagined future” furthered by the “hegemony of model predictions” [18]. The philosophical critique of modeling, including Hulme, is deftly discussed in the 2019 article, “Epistemology and Politics in Earth System Modeling: Historical Perspectives". A few excerpts from this article are reproduced here to briefly review historical developments until today.

- “Climate modeling emerged from a specialty garnering little attention outside the climate modeling community to a prime example of powerful science with great public relevance, having a huge impact on perceptions, discourse and politics.” [21]
- The 1945–1970 models began with a “deep belief pervading this era

that all systems, natural and social could be understood, modeled and controlled, provided sufficient resources." [21]
- The 1970–1990 period introduced complexity. "Complexity, which scientists formerly held to be reducible into elementary units, turned out to be irreducible." [21]
- Climate projection culture arose as a feature of the IPPC in the early 90′s.
- "There has always been distant and abstract objectives of reduction in climate negotiations, without incorporating the concrete (material and social transformations, the technologies or the financial instruments that are dispensable to achieve them." [21]

3.2. Shared socioeconomic pathways

Before the SSPs, the IPCC used socioeconomic scenarios from its Special Report on Emissions Scenarios (SRES) [23]. The SRES were implemented in integrated assessment models (IAM) and used for IPCC estimates. In 2006, "[T]he IPCC decided at its twenty-fifth session… not to commission another set of emissions scenarios, leaving new scenario development to the research community"[6], with a new "internal logic" for socioeconomic scenarios for the RCPs [4]. The new scenarios that resulted are the SSPs [24]. Today, the International Committee on New Integrated Climate Change Assessment Scenarios (ICONICS) is responsible for developing and promoting the SSPs [25].

The innovation of the SSPs is to place the socioeconomic factors derived from human choice, behaviors and policies, human institutions and human social structures, parallel to radiative forcing (a measure of energy trapped by the earth's atmosphere causing warming) [26,27]. "socioeconomic scenarios constitute an important tool for exploring the long-term consequences of anthropogenic climate change and available response options" [28]. In SSP models, the socioeconomic factors feed into and feedback from the natural environment, reflected in a range of societal and ecological outcomes.

Each of the five SSPs narratives is imagined as a plausible future with baseline assumptions for: economic development and lifestyle; policies and institutions; the pace and direction of technological change; and human impact on the environment and the pace of human natural resource use [29]. For example, SSP1, titled Sustainability, proposes a world open to increasing shares of renewables and other low-carbon energy carriers, thus the scenario has low challenges to mitigation. On the opposite end of the spectrum, SSP5, titled Fossil Fuel Dependent, presents high challenges to mitigation [29] Fig. 1, reproduced with permission from [30] maps how the five scenarios relate to each other in the socioeconomic challenge space.

The scenarios are modelled with the quantified projections of 'driving forces' (GDP, GDP per capita, Population, and Urbanization) [31]. These projections were developed by different teams with similar assumptions guided by the narratives. Population estimates are based on "fertility, mortality, migration and educational transitions" [32]. GDP estimates are "based on a convergence process and places emphasis on the key drivers of economic growth in the long run: population, total factor productivity, physical capital, employment and human capital, and energy and fossil fuel resources (specifically oil and gas)"[33]. Future urbanization for each country was quantified using nine alternatives selected to match each SSP "based on the range of various historical urbanization experiences" [34]. The long-range projections for these variables are publicly available from the SSP Database.

Fig. 1. Map of SSPs in relationship to each other and socioeconomic challenges for climate change mitigation and adaptation. Source: [30].

Table 1 and Table 2, reproduced with permission from [30], display most of the SSP's key assumptions. Table 1 is a summary of demographic and human development assumptions. Table 2 clusters the "Economy & Lifestyle and Policies & Institutions elements" by SSP [30]. These tables are reproduced here to inform the reader of the breadth and depth of the quantitative and qualitative socioeconomic characteristics that are at the heart of all SSP analyses.

In summary, an assessment of the history of the SSPs identifies three main points: 1) An international and multidisciplinary group of scientists conceived of and developed the SSPs. 2) The SSPs are not an update to previous scenarios. They are a new proposed "solution" created in response to the lack of explanatory power of climate change science at the time, circa 2010. 3) Researchers observed that past models failed to grasp complexity, uncertainty, and integrating the human dimension of climate change adequately.

In her 2010 article "Putting the Earth system in a numerical box? The evolution from climate modeling toward global change", Amy Dahan Dalmedico critically observes climate change modeling history. She compares the IPCC socioeconomic scenarios pre-2007 to the seeds of today's SSPs. She states, "Scientists confronted with climate change have managed, in just a few short years, to develop a methodology that, while neither holistic nor systemic to begin with, has laid down a path that provides a de facto response to the holistic aspiration – an analytical process that moves towards complexity." [35]

Perhaps, the researchers developing the SSPs were compelled to act because they understood that climate change is a threat to life on earth [36]. Further, observed climate change effects demonstrate that human knowledge of the earth's systems is incomplete and possibly fallible. Faced with the realization that existing methodologies and methods were inadequate, the researchers developed new ones. When explanatory power fails, there is room for new ontologies and methodologies such as the SSPs.

Table 1: Source: [30]

Table 2: Source: [30]

4. Critical realism and concrete utopianism

An in-depth examination of Critical Realism (CR) is beyond the scope of this paper. The general intent of this section is to familiarize the reader with CR, its basic tenets, and history in order to prepare the reader to recognize CR in the dataset. In this section, CR is defined, and its key characteristics are described in plain language with intuitive examples. Although the term Concrete Utopianism used herein is based on Bhaskar (2010, 2016), its historical roots are in the writings of Ernst Bloch. Therefore, a brief discussion linking Bloch's conception of concrete utopia in the context of social transformation and Bhaskar's use of the term in the context of climate change research concludes the overview of CR.

CR is defined as not only a philosophy of science but "a movement in philosophy, social theory and cognate practices" [37]. It is not easy to summarize, particularly since many interpretations and strains exist. For the purposes of this paper, CR is narrowly defined as a philosophy of science developed by Roy Bhaskar [1,38–40]. The following publications inform an understanding of CR [1,39,41–46]. The summary of

Table 1

Summary of assumptions regarding demographic and human development elements of SSPs. See KC and Lutz (2014) for the definitions of country fertility groupings for demographic elements. Country groupings referred to in table entries for human development are based on the World Bank definition of low-income (LIC), medium-income (MIC) and high-income (HIC) countries.

SSP element	SSP1			SSP2			SSP3			SSP4			SSP5		
	Country fertility groupings for demographic elements														
	High fert.	Low fert.	Rich-OECD	High fert.	Low fert.	Rich-OECD	High fert.	Low fert.	Rich-OECD	High fert.	Low fert.	Rich-OECD	High fert.	Low fert.	Rich-OECD
Demographics															
Population															
Growth	Relatively low			Medium			High		Low	Relatively high		Low	Relatively low		
Fertility	Low	Low	Med	Medium			High	High	Low	High	Low	Low	Low	Low	High
Mortality	Low			Medium			High			High	Med	Med	Low		
Migration	Medium			Medium						Medium			High		
Urbanization															
Level	High			Medium			Low			High	High	Med	High		
Type	Well managed			Continuation of historical patterns			Poorly managed			Mixed across and within cities			Better mgmt. over time, some sprawl		
Human development															
Education	High			Medium			Low			V.low/uneq.	Low/uneq.	Med/uneq.	High		
Health investments	High			Medium			Low			Unequal within regions, lower in LICs, medium in HICs			High		
Access to health facilities, water, sanitation	High			Medium			Low			Unequal within regions, lower in LICs, medium in HICs			High		
Gender equality	High			Medium			Low			Unequal within regions, lower in LICs, medium in HICs			High		
Equity	High			Medium			Low			Medium			High		
Social cohesion	High			Medium			Low			Low, stratified			High		
Societal participation	High			Medium			Low			Low			High		

Table 2

Summary of assumptions regarding Economy & Lifestyle and Policies & Institutions elements of SSPs. Country groupings referred to in table entries are based on the World Bank definition of low-income (LIC), medium-income (MIC) and high-income (HIC) countries.

SSP element	SSP1	SSP2	SSP3	SSP4	SSP5
Economy & lifestyle					
Growth (per capita)	High in LICs, MICs; medium in HICs	Medium, uneven	Slow	Low in LICs, medium in other countries	High
Inequality	Reduced across and within countries	Uneven moderate reductions across and within countries	High, especially across countries	High, especially within countries	Strongly reduced, especially across countries
International trade	Moderate	Moderate	Strongly constrained	Moderate	High, with regional specialization in production
Globalization	Connected markets, regional production	Semi-open globalized economy	De-globalizing, regional security	Globally connected elites	Strongly globalized, increasingly connected
Consumption & Diet	Low growth in material consumption, low-meat diets, first in HICs	Material-intensive consumption, medium meat consumption	Material-intensive consumption	Elites: high consumption lifestyles; Rest: low consumption, low mobility	Materialism, status consumption, tourism, mobility, meat-rich diets
Policies & institutions					
International Cooperation	Effective	Relatively weak	Weak, uneven	Effective for globally connected economy, not for vulnerable populations	Effective in pursuit of development goals, more limited for envt. goals
Environmental Policy	Improved management of local and global issues; tighter regulation of pollutants	Concern for local pollutants but only moderate success in implementation	Low priority for environmental issues	Focus on local environment in MICs, HICs; little attention to vulnerable areas or global issues	Focus on local environment with obvious benefits to well-being, little concern with global problems
Policy orientation	Toward sustainable development	Weak focus on sustainability	Oriented toward security	Toward the benefit of the political and business elite	Toward development, free markets, human capital
Institutions	Effective at national and international levels	Uneven, modest effectiveness	Weak global institutions/ natl. govts. dominate societal decision-making	Effective for political and business elite, not for rest of society	Increasingly effective, oriented toward fostering competitive markets

key tenets of CR in this section relies on the aforementioned publications.

CR offers that science is a social practice defined by key principles of ontology, epistemology, methodology and purpose. It offers a perspective on how we understand: 1) existence/reality (ontology); 2) the limits of scientific knowledge (epistemology); 3) what way should scientific knowledge be produced (methodology); and 4) the ultimate aim of scientific research. Bhaskar's CR is based on a critique of the positivism and rationalism that is dominant in the social science and neoclassical economics [47] and much of climate change science today.

4.1. Summary of CR's key principles

The foundation of CR is a realist view of the world (ontology). The world, its objects and mechanisms exist (intransitive knowledge), independent and regardless of whether humans perceive them or have the ability to measure them (transitive knowledge). There are countless intuitive examples of the realist account of transitive knowledge provided by nature. For example, the actual number of animal species on the planet earth is unknown by humans at any point in time. Human observers are eager to identify new species, as regularly occurs, because they believe that unknown species exist and someday, they may become known. Likewise, the ontology applies to the social world. There may be real social mechanisms, for example sexism, that guide human

Table 3
Descriptions of Elements of Causation and Stratified Ontology as Applied in "Concrete Utopianism in integrated assessment models: Discovering the Philosophy of the Shared Socioeconomic Pathways"[39,45,46].

Key elements	Real	Actual	Empirical
Mechanisms: Objects, agents, phenomena, social rules, etc. that are explanatory and causal for events that may or may not be empirical (measurable).	X		
Structures: Social systems and interrelations, rules of action, the ways and means that are legitimate at a given point in time.	X		
Agents: Thinking people, not necessarily rational. People "moving, doing, thinking, deliberating, believing, intending, loving, cooperating, and so forth" [43].	X		
Conditions: Other mechanisms that influence the causal mechanisms. Conditions state under what conditions mechanisms once activated have a certain result or not.	X		
Events: Consequences of activated structures and causal mechanisms in the context of conditions. Events do not have to follow a pattern of regularity, but can do so.	X	X	
Experiences: Events that humans can perceive and measure empirically	X	X	X

behavior toward measurable outcomes. If sexism was not identified for the observed and measured outcome, its influence would still exist and could become known in future. On the other hand, a Positivist ontology would only recognize the existence of the causal mechanisms presently labelled empirically by science. Bhaskar points out that anti-Realist Positivists and Interpretivist confuse reality with human knowledge of it, an epistemic fallacy. The distinction is that human knowledge/science can be and often is fallible because there are causal mechanisms at work that researchers do not see or understand [45,46,48]. The build-up of atmospheric carbon dioxide and other greenhouse gasses from human activities resulting in trapped solar radiation causing significant climate change on a planetary scale is an example of human imperfect knowledge and potential fallibility.

Briefly and simply stated, a CR ontology divides reality into "stratified" domains, Real, Actual, and Empirical [39]. The domain of the Real includes everything– the entire human and natural world. Bhaskar divides the Domain of the Real into Objects, Structures and Mechanisms. Table 3 defines Objects, Structures and Mechanisms. Real Objects and Structures have unactualized or actualized power to change each other in seen and unseen ways. An unlit match has the inherent capacity or power to ignite, whether it is burning at this moment or not. Results due to actualization, for example the burning match, are Events (or Effects) and belong to the Domain of the Real and the Domain of the Actual. The match may spontaneously combust. Humans experience some Events, meaning that they are observed and can be measured. Such as the heat from the burning match. Therefore, Experience belongs to the Domains of the Real, the Actual and the Empirical. The stratified ontology concept is a fundamental tenet of CR, distinct from Positivist and Interpretivist philosophies of science.

CR research seeks to explain complex causality – the connections and feedbacks between structures and mechanisms that cause events under certain conditions [45]. Table 3 describes the main elements of complex causality and their place in a stratified ontology. CR literature uses different terminology for objects, agents, and mechanisms. Wynn et al. (2008) notes that there are multiple definitions for "mechanism" in use that are inconsistent and sometimes overlap with the term "structure" [44]. Some literature refers to objects as structures [45]. In this analysis, objects are part of mechanisms. Collier (1994) uses the term "social mechanism," seemingly for structure. In general, CR distinguishes agents from structures because agents have their own causal power. Morgan explains, "Agents occupy roles or positions in social relations and draw upon them to engage in particular activity, creating effective causation. Agents act under multiple influences and may have a wide range of reasons for acting." In this analysis, agents are distinct from structure but inexorably linked. Collier (1994) explains the concept as follows: "there is a generative social mechanism determining what happens—*that mechanism works only through the actions of human agents* [emphasis added]"[46]. Each terms' meaning was clearly defined for the purpose of this analysis to signpost the features of CR complex causality.

Complex causality from a CR perspective includes unique features that sets it apart from other philosophies of science's understanding of causation. Bhaskar notes that causality for CR is "retroduction", "the imaginative activity in science by which the scientist thinks up causes … generative mechanisms which, if they were real, would explain the phenomenon in question" [39]. An overview of features of complex causality includes:

- Open systems vs. closed systems;
- No presumption of infinite regularity of observed events;
- Importance of temporal and spatial conditions; and
- Emergence.

CR embraces complex causality rather than ignores or tries to eliminate it by assuming closed rather than open systems. Almost all real world systems that are researched are open systems [1]. Exogenous mechanisms and structures may be at work. A closed system laboratory experiment with known mechanisms controlled for interference in which outcomes can be repeated at any point in time is not the goal of social science. A complex causality explanation does not depend solely on regularity of repeated experiments or linear relationships. Andrew Sayer clarifies CR's view of explanatory power, "Explanation depends instead on identifying causal mechanisms and how they work and discovering if they have been activated and under what conditions." [45]. Event regularities (causes and effects) are also observed and used in explanation in CR, with the caveat that they reflect the events generated by mechanisms under specific conditions over an observed time. Lawson called these "demi-regularities" [49]. The same mechanisms could cause different outcomes in response to different conditions or points in time. Therefore, Events are temporally and spatially bound. Building on Archer's discussion of time, Morgan describes path dependency and time lags in the context of economics. He writes, "When agents do (or fail to do) something they do so in the context of the products of previous cycles of activity, which provide a context of structural conditioning." [43]. A fitting summation of complex causality that links this discussion to the most critical element of CR in this analysis, the concept of emergence is articulated by Sayer, "Given the variety and changeability of the contexts of social life, this absence of regular associations between 'causes' and 'effects' should be expected." [45]. Emergence is to expect the unexpected.

Considering Emergence in CR is acknowledging a world of black swans that belie human comprehension of the complex socioeconomic and environmental systems that we study. Emergence is simply something new, previously unknown to humans. The CR concept of emergence does not mean "statistically improbable." New phenomena are continuously emerging on all stratified ontological levels because structures and mechanisms are continuously interacting in the real world; actualizing in multiple ways causing events under certain conditions. This is a general description of emergence that does not make the distinction between epistemic and ontological emergence [39]. Emergence is a constant feature of nature and communities; therefore inherent to open socioeconomic environmental systems.

4.2. What is concrete utopianism?

Concrete Utopianism (CU) is a CR concept described in the context of climate change science by Bhaskar in the 2010 Book "Interdisciplinarity and Climate Change: Transforming Knowledge and Practice for Our Global Future" [1]. This book was edited by well-known critical realists Roy Bhaskar, Cheryl Frank, Karl Georg Høyer, Petter Naess, and Jenneth Parker. The book was written in the last years of Bhaskar's life- he died in 2014. Bhaskar began developing CR in the mid 1970's and many philosophers debated and contributed to the philosophy over the years. Notably, by 2010 CR was a fully mature idea when he published his analysis of climate change research. Bhaskar authored the first chapter of the book, "Contexts of interdisciplinarity: Interdisciplinarity and climate change," in which he calls on CU. The posthumous 2016 book, "Enlightened Common Sense: The Philosophy of Critical Realism" expands on the theme of CU in a more general sense and is presented at the end of this section. The CU discussion intentionally relies heavily on quotes from [1] in order to transmit directly Bhaskar's meaning in direct relation to climate change.

There are three quotes from Bhaskar's chapter of "Interdisciplinarity and Climate Change" that set the stage for this analysis. In the first quote on page 22, Bhaskar diagnoses the "problem" of climate change science as reliance on inadequate philosophies that lead to inadequate methodologies. In the second quote on pages 22 and 23, Bhaskar prescribes his solution to the problem of climate change science, offering his conception of "Concrete utopianism."

> Quote 1: Perhaps the biggest obstacle to successful interdisciplinary research work, and therefore to the understanding of complex open-systemic phenomena such as climate change, lies in the way in which woefully inadequate metatheories and methodologies continue to inform the practices of the various disciplines which continue to seek to understand such phenomena in an actualist, reductionist and often still fundamentally mono-disciplinary way. [1]

The italicized text in the second quote captures the spirit of the SSPs. Particularly, the words "we think alternatives to what is actualized on the basis of given possibilities which could be actualized in another" [1]. Archer demonstrates that Bhaskar's CU incorporates "(real) possibilities" not "fantasies and wish-fulfillment" [50]. Bhaskar connects CU to his recurring theme of the purpose of social science should be emancipatory (pursuing freedoms, human flourishing). CU is about "real, but non-actualized possibilities inherent in a situation" [37,40].

> Quote 2: The full development of the theory of explanatory critique understands it as involving a complex of explanatory critique, what I have called concrete utopianism and a theory of transition, in dialectical unity with an emancipatory axiology of transformative practice. *In this ensemble, concrete utopianism plays a crucial role. It involves thinking how a situation or the world could be otherwise, with a change in the use of a given set of resources or with a different way of acting subject to certain constraints. This mode of thinking forms the basis of an ethics oriented to change, in which we think alternatives to what is actualized on the basis of given possibilities, possibilities which were actualized in one way but could be (or might have been) redeployed or actualized in another* [Emphasis added]. [1]

The third quote, on page 23, links the term Concrete Utopianism to its historical roots. Bhaskar did not coin the term "concrete utopianism", philosopher Ernst Bloch did, [37]. The German Marxist philosopher, Ernst Bloch, posed concrete utopia as a philosophy of social and economic change [51]. Bloch wrote extensively about utopia as an aspirational possible future in his book series "The Principle of Hope" [52]. Utopian thought assumes, as Bloch and Bhaskar do, that the future is open alternative pathways can be realized. Bloch believed in framing a utopian vision of the future in the process of social change. In the context of climate change science and science in general, Bhaskar advocates using an elaborated utopian vision grounded in today to detail possible futures to encourage change. The interesting aspect here is, in Bhaskar's words to "make out a persuasive case for change," which implies an audience/consumer. At the time Bhaskar wrote this, the global ecological crisis of climate change was proceeding apace and predominantly unchecked, as it continues until now. In his 2016 work, Bhaskar is clear that the role of CU goes beyond the crisis of climate change, noting that CU is crucial to "effect[ing] a *transition* to the good society" [39]. In summary, the stated purpose of CU, echoing Ernst Bloch, is social change.

> Quote 3: Traditional leftist critiques of utopianism have actualistically failed to notice that what is, is only one possible world and that it, moreover, always presupposes the possibility of other worlds. Radical intellectuals need to show in detail how alternative futures can be coherently grounded in the deep structures of what already exists, of what people already know and have. Without this exercise, they will not be able to make out a persuasive case for change. [1]

A 2019 article by Archer "Critical Realism and Concrete Utopias," compares and contrasts Bloch's use of CU with Bhaskar's CU proposal. She concludes that Bloch's and Bhaskar's versions of CU "shared the assumption that utopianism is indispensable to postulating a different state of affairs from the actually existing one, but also that it does so in way that conveys hope for an alternative future" [50] Bhaskar's CR and CU specifically for "understanding complex open-systemic phenomena such as climate change" [1] is an intriguing proposition for modeling.

5. Research design, methods, and data

This section describes the theoretical framework and detailed research design and method applied to the dataset. The theoretical framework is Organizational Sensemaking [53] and Organizational Storytelling [54]. These theories are applied because they guide research of a distinct community of people engaged in a social activity, working in a collective that assigns meaning to their work. This theoretical perspective is appropriate for this analysis because, as highlighted in the brief history of the SSPs in Section 2:

- The community of researchers co-creating and using the SSPs have a shared identity as climate change researchers although they represent different disciplines;
- Are organised into a research community with shared concepts and methods; and
- A small but influential group of climate researchers communicated with each other to develop and diffuse the SSPs and share knowledge, norms, and values.

The process of developing and using the SSPs is adopting an organizational story and placing oneself as a researcher within it i.e., Sensemaking. Communication is critical to Sensemaking, using discussion and written text to organize a social group to act in a certain way [53]. The way to act is coordinated and "consensually constructed" [55]. The dataset represents the main vehicle of public communication for the researchers that created the SSPs to the community of SSP users.

Research design and method

There are several schools of thought regarding the research design and methods of a qualitative analytical framework. For example, a fundamental question, about which there exists disagreement in the literature, is whether or not a qualitative analysis should set a research hypothesis and use coding to test it as in Phenomenology / Hermeneutics, or generate theory solely from the data as in Grounded Theory. The present analytical framework takes a phenomenological approach whereby a working hypothesis is developed recursively through examining the data using analytical induction. Then, the

hypothesis is investigated by analysing relevant data with coding to verify or controvert it. The analysis' coding was repeatedly fine-tuned to ensure it was focused on CR and not generic philosophy of science. This is an established qualitative analytical framework [56, 57]. The recursive nature of the inquire means that often "…data collection, hypothesis construction, and theory building are not three separate things but are interwoven with one another" [58]. The hypothesis of this article is set out in the introduction—that the SSPs are compatible with CR and can be described as an expression of CU. The hypothesis was tested and refined using a Structured Thematic Qualitative Content Analysis (STQCA).

A STQCA is well suited to the objective of this analysis, to identify, extract, and describe the ontological, epistemological and methodological intent of the SSPs in the data. Also, a STQCA is concept-driven and suitable for testing hypotheses. Mayring (2000 and 2004) and Schreier (2012) establish that the theoretical basis of Qualitative Content Analysis (QCA) began in the early 1900s with publications in the 1950s, for example Kracauer's "The Challenge of Qualitative Analysis" published in 1952 [59,60]. Essentially, a phenomenon such as the SSPs is a "lived experience" that can be understood through its participants' narratives. It is possible to discern meaning through an examination of relevant narrative data about the participants' experience of the phenomenon. Meaning may be associated with, but is not limited to, the frequency of certain text in the dataset. The meanings inferred from the data cannot be observed directly as in quantitative research. This is a limitation of the approach. The researcher must interpret meaning using data coding as a tool. "Qualitative content analysis is a method for systematically describing and conceptualizing the meaning of qualitative data. This is done by classifying parts of the material as instances of the categories of a coding frame." [59]. As meaning is inferred rather than observed explicitly, QCA research may be criticized as subjective, biased, and unscientific. These criticisms are addressed by following a rigorous process to ensure credibility and believability.

The scientific rigor of a qualitative analysis is shown by its clarity, reliability, and validity of the process in order to demonstrate that findings are robust. Nevertheless, all qualitative content analysis of text is open to the criticism that the public written word may not reflect the private views of its authors. The present analysis followed the process recommended by Schreier (2012) and Braun and Clarke (2006) with due care to reliability (clear to others) and validity (coding captures important material in the dataset). The aim of describing the steps in this analysis is to assure the reader that the author has taken due care to ensure the integrity of the research process. The data was analysed on hard copies by hand and electronically coded with the ATLAS.ti qualitative data analysis software (Version 7.5.1 - release date September 2014). The following steps were carried out.

- The data was collected and read multiple times in order to become familiar with the data and generate ideas about the analysis [61]. The research questions became increasingly clear as a result of re-reading the text. A concept-driven or theoretical thematic analysis was selected based on a preliminary observation of patterns in the text.
- The first rounds of coding applied general philosophy of science and CR keywords and concepts in a relatively unstructured way. Although there was a nascent concept in mind, the first rounds followed an open-coding strategy, creating new codes as relevant text was encountered, that fit the topic of philosophy of science. Examples of the early stage coding were general terms: assumptions, causal relationship, critical realism, deduction, epistemology, interpretative, methodological, methodology, normative, ontological, philosophy, positivist, realist, scientific credibility, transparency, and uncertainty. Successive rounds of coding included more terms associated with CR with specific CR definitions: agent, Bhaskar, demi-regularity, emergence, mechanism, Lawson, open system, and Sayer. This process created codes for subcategories, helped to reduce the data and refine the research hypothesis.
- The codes were then grouped into thematic code families that indicated a broader level of meaning. Code family terms included Critical Realism Buzzwords, Uncertainty/Certainty, People / Actors / Agents, Interdisciplinarity / Transdisciplinarity, Statistics / Regression, Structures and Conditions, and Timeframes. At this stage, the code families made sense of the data by categorizing passages, but the categories were too broad and overlapping. The lack of clarity at the early stages of coding detracted from the reliability of the analysis because the coding structure was able to extract general philosophy of science meanings but was not focused enough on CR to test the CR hypothesis adequately. A fresh reading of the data and review of the existing coding confirmed the need to revise the coding to explicitly test the hypothesis.
- The final thematic categories are individual key tenets of CR extracted from the literature. These tenets are recognizable to anyone familiar with the CR literature. Although they are developed from the subcategories identified in the current SSP-related dataset, they could be applied to any another dataset identify CR. It is reliable for this study or others. The code book codes are components of CR that do not stand alone but are part and parcel of the constellation of concepts that is CR and CU. Other scholarly works apply similar CR criteria when analysing a discipline such as economics [43], ecological economics [62], and future studies [41]. The final coding process is an instrument to extract only the CR relevant or counter CR text, which means it is valid for its intended purpose and credible inferences. The revised coding was tested on a subset of the data and determined to be reliable and valid. Subsequently, the entire dataset was coded using the final coding as it appears in the Code Book in the Appendix Table A. The findings are based only on the presence of concepts in the text, but how those concepts are used. Inferring meaning is the researcher's task.

Dataset

The dataset is comprised of thirty-three published peer-reviewed journal articles written by the designers of the SSPs. This research refers to these articles as the "SSP foundation papers." Primarily, the papers were published between 2010 and 2016 in peer-reviewed scientific journals. The ICONICS group used two journal issues to introduce the SSP concept to the world. Today, the ICONICS website lists the collections of papers on its website as "Special Issues." The "Special Issue on the Framework for the Development of New Socioeconomic Scenarios for Climate Change Research" is the journal Climatic Change, Volume 122, Issue 3, 2014. This special issue contains thirteen foundation papers. They were published online in 2013 and 2014. The second collection is the "Special Issue of Global Environmental Change Journal on the Quantification of Shared Socioeconomic Pathways." The journal Global Environmental Change, Volume 42, includes sixteen papers that specify the SSP narratives and quantify key assumptions. The papers were published online in 2014, 2015, and 2016. In addition, this research includes four additional articles that are frequently cited as part of the history of the SSPs. Collectively, this set of thirty-three articles (the SSP foundation papers) are the dataset for this analysis. The documents are grouped into three categories for the analysis: Foundation Doc Not Special Issue; Special Issue 2014; and Special Issue 2016. Table C of the Appendix lists the papers organized by category.

In summary, the research design, carefully applied method, and selection of relevant data ensure that the analysis is rigorous and its findings robust. The final iteratively developed coding scheme honed in on CR and CU, rather than ambiguous philosophy of science text. The possible overlap of CR concepts was accounted for and is discussed in the results. The final coding would be reliable for similar analyses with other data sets (replicable). In addition, instances of text that were counter to CR were coded and are reported in a separate section of the results. The detailed methodology and the presentation of the findings

allows the reader to judge the author's inferences from the data. The Appendix provides the Code Book and additional data to the reader. The dataset analysed is representative of the SSPs and the experiences of a specific community (foundation paper's authors). This Structured Thematic QCA allowed for hypothesis testing in accordance with well-established scientific qualitative analysis practice.

The findings are based solely on the analysis of the text present in the dataset. Additionally, personal communications with several of the foundation paper's authors occurred at a conference in 2019 and in meetings during this study. For example, in one personal communication with an author, the finding that the SSPs function as a methodology rather than a method was confirmed. A future study, could use formal interviews or a workshop to elicit first-person histories of the foundation papers' authors.

6. Main findings and discussion

This section explains the findings based on interpreting passages from the dataset that illustrate the key themes in the Code Book. The interpretation of key themes in the dataset takes note of co-occurrences of themes in the coded text, which can reveal a coherent CR theme made of several individual elements. In some cases, the prevalence of a theme in a majority of papers in the dataset means that the theme is a shared understanding that reflects an organizational story. When an organizational story is consistently communicated to SSP users, it is relevant according to organizational theories of Sensemaking [55]. The results are organized logically by the following questions: 1) Are the SSPs a methodology or a method? 2) Did the SSP community define its philosophy? 3) If so, how and where is the argument documented? 4) If no direct statements of the philosophy are found, is the hypothesis that the SSPs are consistent with CR inferable from the text? 5) If the SSPs are consistent with CR, is the hypothesis that they are Bhaskarian CU inferable from the text?

6.1. SSPs are a methodology

There are many, often interwoven, definitions of method and methodology in the literature. For this work, a distinction is made between "methods," defined as tools and techniques for carrying out research (experiments, interviews, specific analyses, etc.). (Aligica, 2005; Mingers, 2001; Olsen & Morgan, 2005; Sousa, 2010) and "methodology," defined as "a combination of techniques, the practices we conform to when we apply them, and our interpretation of what we are doing when we do so" (Olsen & Morgan, 2005).

The foundation papers are explicit but not consistent on the key theme of methodology or method. Although the majority of texts refer to the SSPs as a framework or tool, in which case they would be a method, this paper argues that they are in fact a methodology. The SSPs are a compilation of methods. Considered together, these methods form the practices of the SSPs. The foundation papers make clear statements about how climate change research should be done. The SSPs have established internal rules, for example with the matrix architecture [63]. Thereby legitimating certain combinations of socioeconomic and environmental futures but not others. Further, the scenarios embed expert judgement in the quantitative projections at a level of detail that no individual researcher could achieve. Finally, several foundation papers do recognize that the SSPS have "methodological purpose," "a methodological basis and process," and provide a "methodological (hypothetical / counterfactual) purpose." As a methodology, the SSPs become the carrier of specific ontologies and epistemologies that are revealed in the discourse of the foundation papers.

6.2. Explicit philosophy of the SSPs

The analysis did not find any explicit statements of the SSPs' underlying philosophy in the dataset. The foundation papers contained no in-depth discussion pondering the ontological, or epistemological nature of the SSPs. In fact, the term "philosophy" is used little and it is never used to refer to the SSPs directly. Also, no explicit statements using the terms "ontology" or "epistemology" or their derivations are present in the data. It seems that the authors of the foundation papers zoned in on designing and testing the methods of the SSPs rather than its general philosophy. Interestingly, in doing so, they repeatedly place value on the key CR theme of interdisciplinarity, which is both an ontological and epistemological concept [39]. Bhaskar notes that real world problems of open complex socioeconomic environmental systems that scientists are attempting to explain are not limited to one discipline; therefore focusing on the techniques of one discipline limits understanding [39]. The value the foundation paper authors place on interdisciplinarity is revealed by the emphatic terms they employ such as "key aim," "the focus should be on," and "appear necessary". Each of the foundation papers mention that the methods of the SSPs *should* be designed to meet the needs of an interdisciplinary group of researchers. They also note that the SSPs are meant to bridge the integrated assessment and impact, adaptation and vulnerability communities. In addition, several of the papers label *communication* between disciplines as a positive and valuable outcome. The commitment to interdisciplinarity is echoed in many of the Special Issue papers. Several authors explain that interdisciplinarity in the SSPs has a methodological role, helping to better address uncertainty, increase understanding, and build a "foundation for international credibility and acceptance" [33]. "Acceptance" brings the analysis again to the purpose of science as discussed in Section 3. The audience is decision-makers, agents that can guide policy. Bhaskar too directly links interdisciplinary science to policy. He states, "The practical goal is an integrated policy response to an integrated problem" [39]. Interdisciplinarity is the one clearly stated and detailed "philosophical" mandate in the data. Interdisciplinarity is also an essential CR perspective; however, it is not limited to or indicative of CR alone. Although no expose' on the SSPs' philosophy of science exists in the dataset, several publications pose ontological and epistemological questions.

6.3. Implicit philosophy of the SSPs: is it CR?

The analysis examined if the key themes of CR Ontology and CR Epistemology are discernable in the dataset. This section draws upon the explanation of CR's key principles as summarized in Section 3.1.

The key theme of CR Ontology in the dataset was investigated first by reviewing text that reflects the objective reality concept (intransitive knowledge); the real world exists independent of human knowledge (transitive knowledge). The "epistemic fallacy" is defining the real as limited to human knowledge. Language that pinpoints the existence of the real world being distinctly different from human knowledge or pinpoints fallibility because it is "beyond current knowledge" is of interest. This type of language makes clear that the author is not repeating the common epistemic fallacy. Climate change science is an interesting field for exploring objective reality because, presumably, the existence of anthropogenic climate change began with industrialization- long before human knowledge of it. For example a passage from a Foundation Doc Not in Special Issue, poses a telling question, "How can one project impacts of a change of temperature without an understanding of how impacted systems change with changes in temperature?" [28]. This quote crystalizes comparable questions that are found in the text to illustrate that the authors recognize that real processes are ongoing (transitive), that are not understood (intransitive). There are several dialogues in the texts that indicate that the authors perceive the real world as a complex open system or systems. About half of the dataset included text relevant to open vs. closed systems positions. The author finds that the texts demonstrate that the underlying ontology of the SSPs is that the real world is an open system of objects and processes distinct from human knowledge of them.

The concept of actualization as part of the CR stratified ontology is

particularly relevant for the SSPs. Several fundamental features of the SSPs focus on actualization of real agents and mechanisms that could behave in multiple ways depending on conditions. First, the overall structure of the SSPs' challenge space is similar to CR actualization. Consider that the socioeconomic factors are aligned according to narratives about the "capacity to mitigate greenhouse gas emissions, and the vulnerability and capacity to adapt to climate change" [63]. This framework depends on the innate powers of real mechanisms to actualize (e.g., scalar "ability to" or "inability to" X in response to X). Further, climate change vulnerability, risk and resilience are all defined as a systems' "adaptive capacity" to changes in temperature or weather. The ontology of the SSPs separates the existence of a thing from its activation. Naturally, scientists discuss potential causal mechanisms and this topic is included in more than two thirds of the papers in the dataset. Often, indicators for mechanisms and their effects / events follow on from the discussion of potential mechanisms, in many cases these co-occur. As one would expect, the foundation papers hotly debate to what extent climate change impacts can be measured now and in the future. For example, the statement, "The projections are not predictions, and should be interpreted with sufficient caution. Differences between SSPs are for example more robust than individual projections, and average growth rates are more robust than specific GDP and income levels" shows a dialog with users [33]. Texts deliberating mechanisms and indicators are placed within CR ontology's empirical domain. The analysis concludes that the real domain, the actual domain, and the empirical domain are recognized in the SSP's ontology.

Emergence is essential to delineating a critical realist ontology from other philosophies. As mentioned in Section 3, with a stratified ontology, the new and unexpected can emerge at every ontological domain. The foundation papers are quite explicit about their struggle to build emergence into their work. Nearly half of the foundation papers grapple with this issue. In this respect, one document is particularly rich data for this analysis. Ebi et al. (2014) provides an account and history of how the conceptual framework of the SSPs were developed. The paper recalls that the members of the consortium sought "surprise" scenarios. The paper states that the core group of SSP designers wanted to include "tipping points and wild cards to capture the unlikely, but not impossible" [24]. This text indicates that an in-depth conversation about emergence took place within the core group at the early stages of the process, when communal and consensual concepts were agreed. Organizational Sensemaking theorizes that this type of change process proceeds and galvanizes new actions [53,55]. This analysis shows that emergence is a core concept of the SSPs.

In summary, the key theme of CR Ontology is in evidence throughout the dataset. The data was evaluated and the meanings of the text interpreted by the researcher. This exploration of the data reveals that the SSPs are built on a CR Ontology characterized by a realist, open-systemic stratified ontology with emergent properties.

The key theme of CR Epistemology in this analysis focuses on how knowledge is understood and used in the foundation papers. The four components are:

1 Interpretation of research results as a necessary analytical step in contrast to simply reporting research results;
2 Consideration of what can be known (shown by science);
3 The framing of demi-regularities; and
4 Transdisciplinary /interdisciplinary goals. Although epistemic, interdisciplinarity is clarified above under explicit philosophical statements in the dataset and is not repeated here.

Based on its open-system ontology, CR frames research outcomes as knowledge that requires human interpretation to be meaningful. For CR, the bottom-line question for evaluating the efficacy of social science is explanatory power. Explanatory power must be determined by interpretation not only event regularities. The statements recommending or documenting interpretation are pervasive in the dataset. A foundation paper estimating economic growth projections for the SSPs is interesting because it cautions against drawing narrow conclusions from a stream of results and notes the relative greater explanatory power of comparing the results horizontally as interpretations of the qualitative narratives [33]. The relevant text, in red, is shown in context here. This document and passage is rich data for this analysis because of its strong potential to influence the users of the SSPs who employ the very projections that are the subject of the passage in their own analyses.

The foundation papers indirectly pose the broad epistemological question "What can we know?" sparingly or not at all. However, this research identified relevant explanatory data for this key CR concept in the dataset. The analysis finds that in general the researchers frame epistemological considerations of what can be known or shown by science as "uncertainties" rather than "knowledge claims," as is common in philosophy of science discourse. The reason is the shared identity of the SSP authors' as climate change researchers of the IPCC. The IPCC defines knowledge claims as uncertainties [64]. The IPCC's core definition of uncertainty is skewed toward labeling imperfect knowledge. The possibility that something is unknowable is merely added at the end "the degree to which a value or relationship is unknown. Uncertainty can result from lack of information or from disagreement about what is known *or even knowable* [emphasis added]" [64]. As a result, when the texts refers to "knowledge" and "knowing" to express the authors' views on the state of climate change science it is remarkable. The author perceives these uses as motivated by a desire to persuade the audience of the importance of the statements. In addition, passages about the past failures of science to predict or adequately explain climate change tend to use strong wording. One of the Foundation Doc Not in Special Issue paper uses the term "painful fact that neither scientists nor policymakers have a clear picture" to express dismay at the deep lack of knowledge in the field" [5]. The foundation papers' authors definitely considered what can be known (or shown by science) when framing the SSPs, although specific cases are framed using the uncertainty terminology of the IPCC.

Demi-regularities, sometimes referred to as demi-regs, are empirical observations of regular events over a certain period. CR analyses may make use of demi-regularities without jeopardizing their epistemological foundations because demi-regs are not universal laws but recognition of measurable empirical events resulting from causal mechanisms over a defined time period. Two SSP foundation papers apply demi-regs in economic analyses in the form of "stylized facts" [65,66]. Downward traces the history of demi-regs from the discipline of economics to CR and back again to economics [67]. Economist Nicholas Kaldor popularized the use of stylized facts in economics [68]. According to Downward, in the 1990s, critical realist writer Tony Lawson, adapted Kaldor's "stylized facts" into demi-regs in Lawson's book "Economics and Reality" [49,67]. One of the two papers explains the choice of stylized facts as follows, "The effect of education on labor productivity, a robust empirical stylized fact at the microeconomic level, justifies such an approach" [66]. The stylized facts concept and their use in the SSPs are not an attempt to reproduce a closed social system with clockwork rules, but an attempt to improve the explanatory power of economic models in the sense of CR interpretation.

To review, the epistemological meanings found in the dataset are colored by the traditions of the disciplines or associations of the authors (i.e., economists and IPCC climate change researchers). Nonetheless, the key epistemological themes of CR, interpretation, the forms and limits of knowledge; demi-regularities; and transdisiciplinarity / interdisciplinarity are found in the dataset. The overall conclusion is that the epistemological foundation of the SSPs aligns with CR.

6.4. Complex causality: workings of climate change in the SSPs

Complex causation is the lynchpin of CR. As discussed in Section 3, CR ontology and CR epistemology culminate in the CR model of

complex causality for any complex socioeconomic and environmental phenomena. The main elements of complex causation, structures, mechanisms, conditions and events are explained in Section 3. The coding of the analysis of the text for complex causality followed two logics, coding main elements and creating a picture of how climate change phenomena are characterized in the SSP foundation papers. First, the text was coded for the main elements of complex causation as noted in Table 4. Second, the causal mechanisms of climate change described in the text were evaluated. The analysis explored how the foundation documents described causation, linearly with repeated instances of experiences in closed systems or otherwise. Language that highlights complexity, feedback loops, and non-linear relationships in climate change processes express complex causality. Passages that declare that temporal and spatial conditions affect the outcomes of causal mechanisms are of particular interest. CR holds that outcomes of the same causal mechanisms may vary depending upon existing structures in a given year, e.g. a legal ban on nuclear powered electricity, or spatial characteristics e.g., an urban community. Third, instances where codes appeared together were reviewed to find text that articulated several elements of complex causation together as one thought. This step is vital to the analysis because the integration of multiple elements in one text indicates that the authors understand causal processes of climate change in the same way as CR proposes. Fig. 2 provides examples from the foundation papers that align with the components of CR causation as explained by Sayer (2000). Additional passages that express complex causality are in the Appendix .

6.5. CR counterarguments

Counterarguments to CR represented in the text are a key theme of the analysis. The dataset was read for instances of text that are contrary to the CR hypothesis. The clearly counter CR meanings were found in several documents but limited to three main topics, metrics and indicators, scenario quantification and internal consistency. The first two topics are about quantitatively capturing key features of causation. The metrics and indicators discussions in the dataset often describe a given indicator or indicators as linearly dependent on known, measurable variables. The scenario quantification discussions in the dataset often describe quantitative models that assume a linear function, for example income projections. It is a misconception that CR eschews quantitative methods. Not so. CR does not rule out quantitative modeling in general or in climate change science. Several critical realist theorists including Naess, in his chapter “Disciplinary tunnel vision” on climate change in [1] and Sayer in his text “A critique of urban modeling” [69] discuss quantitative modeling details. They conclude that the researchers’ understanding of causality between variables that excludes and assumes away open complex systems is problematic, not quantitative modeling itself. Their goal is that models, to the extent possible, reflect the real world as the researchers see it, triangulated with observations, and the results of models be interpreted rather than reported [69,70]. Sarah Cornell's chapter about climate change modeling, “Brokering physical and social sciences” [71] points out that the understanding of what a model is meant to achieve, prediction or projection, is relevant to the philosophy behind the model and the interpretation of the model results. She urges climate modelers to simplify the causal relationships in their models, and communicate these for outside evaluation and interpretation [71]. As discussed, using stylized facts is not anti-CR. The concern is modeling an essentially closed system of linear relationships without a broader understanding. The third topic is internal consistency. Several texts expressed the desire to create “internal consistency”. In the texts, internal consistency is often juxtaposed with the desire to capture uncertainties. This indicates that the authors see these two as trade-offs. The author perceives that this is a counterargument to CR, to the extent that pursuing internal consistency is “closing down” the ability for scientists to recognize and theorize about events that may not be measurable in the model. The main conclusion is that how modeling is perceived and carried out is dependent on the broader perspective of the modelers. Therefore, it is imperative for the SSP modelers to openly discuss their perspectives on quantitative representations of climate change's causal mechanisms.

6.6. Concrete utopianism

The key theme of CU is indicated foremost by the articulated belief that the future is open. CR ontology, as discussed in Section 3, explains why many alternative futures are possible, some “better” and some “worse.” The basic design of the SSPs, scenarios for plausible futures built on existing observations, understanding of climate change causality including data, is unequivocally CU. Perhaps unintendedly, the SSPs have grasped that CR ontology is “a fruitful starting point for studying possible futures”[41]. Patomäki, who is a political scientist writing on future studies, states “[S]cenarios must be based on systematic scientific analysis of various possible causal sequences of events, episodes and processes produced by actors, understood as

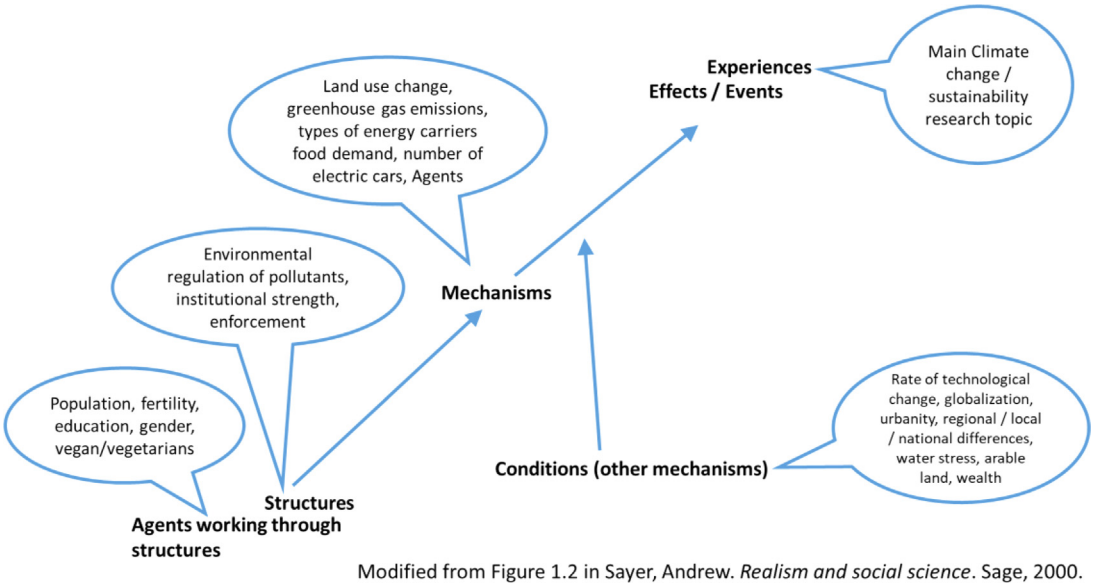

Fig. 2. Author's diagram of Complex Causation of Climate Change in the SSPs based on Sayer (2000).

embodied and collective self-organised systems, in open and complex systems" [41]. This description tracks quite well to the SSPs as clarified in this article. However, producing future scenarios alone does not make the SSPs CU. CU includes two considerations. The first consideration is that alternate futures are possible. The second consideration is normatively framing a *preferred* future(s). The SSPs' basic design achieves both considerations.

The choice of which futures to represent with scenarios is a decision point in the process of building any scenarios. Defining which futures are "plausible" based on best professional judgement of the designers is a normative exercise. It is not an objective act and is open to interpretation and challenge. For example, one could argue that SSP1, "Sustainability" is unlikely rather than probable, given that not even one government has made a binding commitment to halt or even limit overall consumption of natural resources. Can one "predict" degrowth or even lower consumption from past history and current trends? No. Yet, by representing SSP1 in the range of futures in the SSPs, a preferred future enters the scientific and policy discourse. From a CU perspective, SSP1 is plausible and real because it is *realizable*. The scenarios in the SSPs are real because they represent the states that could be brought about by recognized, albeit non-actualized mechanisms. The detailed descriptions of the features of the SSPs narratives in Section 2 are examples of the two considerations of CU explained here. Additional quotes from the foundation papers appear in the Appendix. In conclusion, the analysis identified several excerpts in the dataset that establish that the overall intent of the SSPs echoes Bhaskar's CU.

To consolidate the answers to the research questions and summarize, the Findings Section of this article provides thick descriptions of the thoughts, intentions, and even emotions of the foundation paper authors to discern their meaning and discover the philosophy of the SSPs. To briefly restate the findings, and succinctly answer the research questions of this analysis: 1) The SSPs are a methodology. 2) The SSP community did not define an overt philosophy other than interdisciplinarity. 3) The foundation papers proved to be a source of rich data for the epistemological and ontological viewpoints; however, no statements were "labeled" as such. 4) The hypothesis that the SSPs are consistent with CR is inferable from the foundation papers. 5) Finally, it may be concluded that the SSPs are an expression of CU.

The author notes that Bhaskar did not formulate CU as an abstract concept. With CR as an ontology and CU as an emancipatory strategy, he hoped to inspire "the good society." Anthropocentric environmental crises are a strong focus of his good society ideas. "Nature is not apart from us, we are a part of it. The destruction of nature is not only murder, but suicide, and must be treated as such." [39]

7. Conclusion

This analysis is the first study of the philosophical underpinning of the new SSPs methodology. The author conducted a structured thematic QCA of the dataset of papers published between 2010 and 2016 by the designers of the SSPs. Collectively, these papers serve as a "Handbook of the SSPs" to guide climate change research. It concludes that the SSPs are consistent with critical realism's concrete utopianism. This conclusion is based on the implicit meanings attributed to an abundance of texts in the dataset that demonstrate CR ontology, CR epistemology, and CU. The analysis concludes that the SSPs are a significant methodology.

The SSPs represent a break from previous climate change modeling that was in large part technocratic, applying simple GDP and population trends. The SSPs are the first large-scale attempt in climate modeling to better account for socioeconomic aspects. Better accounting for socioeconomic aspects and social change in models is a movement and an ongoing debate. IAMs' first explained that the current course of the global economy results in dangerous global climate changes [14]. Over time, IAMs were modified to provide potential solutions to policymakers for meeting climate targets. The range of solutions largely followed the types of data in the models, remaining technocratic and quantifiable [14,15,72]. The emergence of negative emission technologies in modeling-derived solutions has been repeatedly called out as an example of this phenomenon [19,21]. As explained herein, the criticality of social science research is now recognized by the IAM community's development of the SSPs.

Social science research is necessary as a source of potential solutions and may define the necessary pre-conditions for solutions to climate change [73,74]. These solutions will focus on the social and political factors guiding people to move towards sustainable consumption and production behaviors and infrastructures [73]. However, social science research funding on climate change mitigation is very low [75]. The suitability of IAMs, which remain largely technocratic, is under scrutiny [14,72]. How can the IAM community, which has enormous impact on policy, catch up? A December 2019 paper "Societal Transformations in Models for Energy and Climate Policy: The Ambitious Next Step" (2019) recommends mapping assumptions and identifying quantifiable stylized facts that can be included in existing models and developing new modifications and new models. Steps to enhance the interdisciplinarity and usefulness of climate models to craft solutions towards a sustainable low-carbon economy is a laudable initiative that needs acceleration - and it corresponds with a CU approach.

The context of this paper is the current debates about the utility of IAMs and moves to expand the social science scope of climate models. Given this setting, this paper encourages the SSP and IAM community to also examine the SSP's ontological and epistemological commitments. This paper argues that the SSPs philosophy reflects a metatheory of social science. Perhaps a shared metatheory can be used to build better solution-oriented interdisciplinary research with modelers and non-modelers from the social sciences? Knowing the SSPs' philosophy has the potential to improve the discourse on the challenges of integrating with or bridging to social science disciplines such as transitions researchers that have debated ontological position for years. [76]

If CR is the philosophical home of the SSPs and CU is the purpose of modeling, then the research agenda could change. First, the philosophy of the SSPs could be communicated to its users in future versions of the foundation papers in order to avoid further ambiguity. Second, CR is inclusive of many quantitative and qualitative methods that could be used to implement the SSPs in addition to IAMs. How to expand the "menu" to include explicitly CR methods into the practice of the SSPs is an open research question. Third, modelers could use the emancipatory tenets of CU as a foundation for broadening the scope of their work beyond the climate change crisis to include societal transformation towards human flourishing, as Bhaskar encouraged. The foremost question for the SSP community from a CU perspective is "How can climate science be aspirational rather than reactionary?"

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

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References

[1] R. Bhaskar, 1. Contexts of Interdisciplinarity: interdisciplinarity and climate change, in: R. Bhaskar, C. Frank, K.G. Hoyer, P. Næss, J. Parker (Eds.), Interdisciplinarity and Climate change: Transforming Knowledge and Practice for Our Global Future (Ontological Explorations), Routlidge, USA and Canada, 2010, pp. 1–24.

[2] J.P. Bruce, H.-s. Yi, E.F. Haites, Climate Change 1995: Economic and Social Dimensions of Climate change: Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel On Climate Change, Cambridge University Press1996.

[3] B.C. O'Neill, E. Kriegler, K.L. Ebi, E. Kemp-Benedict, K. Riahi, D.S. Rothman, B.J. van Ruijven, D.P. van Vuuren, J. Birkmann, K. Kok, M. Levy, W. Solecki, The roads ahead: narratives for shared socioeconomic pathways describing world futures in the 21st century, Glob. Environ. Change 42 (2017) 169–180.

[4] D.P. Van Vuuren, J. Edmonds, M. Kainuma, K. Riahi, A. Thomson, K. Hibbard, G.C. Hurtt, T. Kram, V. Krey, J.-.F. Lamarque, The representative concentration pathways: an overview, Clim. Change 109 (1–2) (2011) 5.

[5] E. Kriegler, J. Edmonds, S. Hallegatte, K.L. Ebi, T. Kram, K. Riahi, H. Winkler, D.P. Van Vuuren, A new scenario framework for climate change research: the concept of shared climate policy assumptions, Clim. Change 122 (3) (2014) 401–414.

[6] R.H. Moss, J.A. Edmonds, K.A. Hibbard, M.R. Manning, S.K. Rose, D.P. van Vuuren, T.R. Carter, S. Emori, M. Kainuma, T. Kram, G.A. Meehl, J.F.B. Mitchell, N. Nakicenovic, K. Riahi, S.J. Smith, R.J. Stouffer, A.M. Thomson, J.P. Weyant, T.J. Wilbanks, The next generation of scenarios for climate change research and assessment, Nature 463 (7282) (2010) 747–756.

[7] F.J. Sousa, Chapter 9 Metatheories in research: positivism, postmodernism, and Critical realism, Organizational Culture, Business-to-Business Relationships, and Interfirm Networks, Emerald Group Publishing Limited, 2010, pp. 455–503.

[8] S. Esbjörn-Hargens, An ontology of climate change, J. Integr. Theory Practice 5 (1) (2010) 143–174.

[9] W.S. Parker, Understanding pluralism in climate modeling, Found. Sci. 11 (4) (2006) 349–368.

[10] B.L. Murphy, From interdisciplinary to inter-epistemological approaches: confronting the challenges of integrated climate change research, Can. Geogr. 55 (4) (2011) 490–509.

[11] A.C. Petersen, Philosophy of climate science, Bullet. Am. Meteorol. Soc. 81 (2) (2000) 265–272.

[12] R.A. Rosen, E. Guenther, The economics of mitigating climate change: what can we know? Technol. Forecast Soc. Change 91 (2015) 93–106.

[13] K. Anderson, Climate change going beyond dangerous–brutal numbers and tenuous hope, Dev. Dialogue 61 (1) (2012) 16–40.

[14] K. Anderson, J. Jewell, Debating the bedrock of climate-change mitigation scenarios, Nature Publish. Group (2019).

[15] J.C.H. Miguel, The technopolitics of climate change: climate models, geopolitics, and governmentality, História, Ciências, Saúde-Manguinhos 24 (4) (2017) 1–19.

[16] M. Mahony, M.J.M. Hulme, Modelling and the nation: institutionalising climate prediction in the UK, 1988–92, Minerva 54 (4) (2016) 445–470.

[17] W. McDowall, F.W. Geels, Ten challenges for computer models in transitions research: commentary on Holtz et al. Environ. Innov. Soc. Trans. 22 (2017) 41–49.

[18] M. Hulme, Reducing the future to climate: a story of climate determinism and reductionism, Osiris 26 (1) (2011) 245–266.

[19] O. Geden, G.P. Peters, V. Scott, Targeting carbon dioxide removal in the European Union, Clim. Policy 19 (4) (2019) 487–494.

[20] M.J. Vink, A. Dewulf, C. Termeer, The role of knowledge and power in climate change adaptation governance: a systematic literature review, Ecol. Soc. 18 (4) (2013).

[21] M. Heymann, A. Dahan Dalmedico, Epistemology and politics in Earth system modeling: historical perspectives, J. Adv. Model. Earth Syst. 11 (5) (2019) 1139–1152.

[22] P.N. Edwards, History of climate modeling, Wiley Interdis. Rev. 2 (1) (2011) 128–139.

[23] Edited by, N. Nakicenovic, R. Swart, Special report on emissions scenarios, in: Nebojsa Nakicenovic, Robert Swart (Eds.), Special Report on Emissions Scenarios, Cambridge University Press, Cambridge, UK, 2000, p. 612 Edited byISBN 0521804930July 2000. 1.

[24] K.L. Ebi, S. Hallegatte, T. Kram, N.W. Arnell, T.R. Carter, J. Edmonds, E. Kriegler, R. Mathur, B.C. O'Neill, K. Riahi, A new scenario framework for climate change research: background, process, and future directions, Clim. Change 122 (3) (2014) 363–372.

[25] I.C.O.N.I.C.c.a.S, ICONICS, Mission, 2019, https://depts.washington.edu/iconics/ Accessed May 30, 2019 2019.

[26] N. Arnell, T. Kram, T. Carter, K. Ebi, J. Edmonds, S. Hallegatte, E. Kriegler, R. Mathur, B. O'Neill, K. Riahi, A Framework for a New Generation of Socioeconomic Scenarios for Climate Change Impact, Adaptation, Vulnerability and Mitigation Research, Working Paper CIRED - Centre International de Recherche sur l'Environnement et le Développement CIRED - Centre International de Recherche sur l'Environnement et le Développement, 2014 Working Paper.

[27] D.P. van Vuuren, K. Riahi, R. Moss, J. Edmonds, A. Thomson, N. Nakicenovic, T. Kram, F. Berkhout, R. Swart, A. Janetos, S.K. Rose, N. Arnell, A proposal for a new scenario framework to support research and assessment in different climate research communities, Glob. Environ. Change 22 (1) (2012) 21–35.

[28] E. Kriegler, B.C. O'Neill, S. Hallegatte, T. Kram, R.J. Lempert, R.H. Moss, T. Wilbanks, The need for and use of socio-economic scenarios for climate change analysis: a new approach based on shared socio-economic pathways, Glob. Environ. Change 22 (4) (2012) 807–822.

[29] K. Riahi, D.P. van Vuuren, E. Kriegler, J. Edmonds, B.C. O'Neill, S. Fujimori, N. Bauer, K. Calvin, R. Dellink, O. Fricko, W. Lutz, A. Popp, J.C. Cuaresma, S. Kc, M. Leimbach, L. Jiang, T. Kram, S. Rao, J. Emmerling, K. Ebi, T. Hasegawa, P. Havlik, F. Humpenöder, L.A. Da Silva, S. Smith, E. Stehfest, V. Bosetti, J. Eom, D. Gernaat, T. Masui, J. Rogelj, J. Strefler, L. Drouet, V. Krey, G. Luderer, M. Harmsen, K. Takahashi, L. Baumstark, J.C. Doelman, M. Kainuma, Z. Klimont, G. Marangoni, H. Lotze-Campen, M. Obersteiner, A. Tabeau, M. Tavoni, The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: an overview, Glob. Environ. Change 42 (2017) 153–168.

[30] B.C. O'Neill, E. Kriegler, K.L. Ebi, E. Kemp-Benedict, K. Riahi, D.S. Rothman, B.J. van Ruijven, D.P. van Vuuren, J. Birkmann, K. Kok, The roads ahead: narratives for shared socioeconomic pathways describing world futures in the 21st century, Glob. Environ. Change (2015).

[31] D.P. van Vuuren, K. Riahi, K. Calvin, R. Dellink, J. Emmerling, S. Fujimori, K. Samir, E. Kriegler, B. O'Neill, The Shared Socio-economic Pathways: trajectories for human development and global environmental change, Glob. Environ. Change 42 (2017) 148–152.

[32] S. KC, W. Lutz, The human core of the shared socioeconomic pathways: population scenarios by age, sex and level of education for all countries to 2100, Glob. Environ. Change (2014).

[33] R. Dellink, J. Chateau, E. Lanzi, B. Magné, Long-term economic growth projections in the shared socioeconomic pathways, Glob. Environ. Change (2015).

[34] L. Jiang, B.C. O'Neill, Global urbanization projections for the shared socioeconomic pathways, Glob. Environ. Change (2015).

[35] A. Dahan, Putting the earth system in a numerical box? The evolution from climate modeling toward global change, Stud. History Philos. Sci. 41 (3) (2010) 282–292.

[36] W. Steffen, K. Richardson, J. Rockström, S.E. Cornell, I. Fetzer, E.M. Bennett, R. Biggs, S.R. Carpenter, W. De Vries, C.A. de Wit, Planetary boundaries: guiding human development on a changing planet, Science 347 (6223) (2015) 1259855.

[37] M. Hartwig, Dictionary of Critical Realism, Routledge, 2015.

[38] R. Bhaskar, A Realist Theory of Science, Routledge, 2013.

[39] R. Bhaskar, Enlightened Common Sense: The Philosophy of Critical Realism, Routledge, 2016.

[40] R. Bhaskar, Plato etc.: Problems of Philosophy and Their Resolution, Routledge, 2009.

[41] H. Patomäki, Realist ontology for futures studies, J. Critic. Realism 5 (1) (2006) 1–31.

[42] P. Næss, Prediction, regressions and critical realism, J. Critic. Realism 3 (1) (2004) 133–164.

[43] J. Morgan, Critical realism as a social ontology for economics, Handbook Res. Methods Appl. Heterodox Econ. (2014).

[44] D.E. Wynn Jr, C.K. Williams, Critical Realm-Based Explanatory Case Study Research in Information Systems, ICIS Proceedings, 2008, p. 202.

[45] A. Sayer, Realism and Social Science, Sage, 2000.

[46] A. Collier, Critical realism: an introduction to Roy Bhaskar's philosophy, (1994).

[47] J. Jäger, L. Horn, J. Becker, Critical international political economy and method, The Palgrave Handbook of Critical International Political Economy, Springer, 2016, pp. 101–118.

[48] M. Archer, R. Bhaskar, A. Collier, T. Lawson, A. Norrie, Critical realism: Essential readings, Routledge, 2013.

[49] T. Lawson, Economics and Reality, Routledge, 2006.

[50] M.S. Archer, Critical realism and concrete utopias, J.Critic. Realism (2019) 1–19.

[51] W. Hudson, The Marxist Philosophy of Ernst Bloch, Springer, 1982.

[52] E. Bloch, The Principle of Hope: Volume Two, Basil Blackwell, 1986.

[53] K.E. Weick, K.M. Sutcliffe, D. Obstfeld, Organizing and the process of sensemaking, Org. Sci. 16 (4) (2005) 409–421.

[54] D.M. Boje, Storytelling Organizations, Sage, 2008.

[55] J.R. Taylor, E.J. Van Every, The Emergent Organization: Communication as its Site and Surface, Routledge, 1999.

[56] S. Hesse-Biber, P. Dupuis, T.S. Kinder, Hyperresearch: a computer program for the analysis of qualitative data with an emphasis on hypothesis testing and multimedia analysis, Qual. Sociol. 14 (4) (1991) 289–306.

[57] D. Silverman, Interpreting Qualitative Data: A Guide to the Principles of Qualitative Research, Sage, Los Angeles, 2011.

[58] D. Silverman, Doing Qualitative research: A practical Handbook, SAGE, 2005.

[59] M. Schreier, Qualitative Content Analysis in Practice, Sage Publications, 2012.

[60] P. Mayring, Qualitative Inhaltsanalyse [28 Absätze], Forum (2000) 2.

[61] V. Braun, V. Clarke, Using thematic analysis in psychology, Qual. Res. Psychol. 3 (2) (2006) 77–101.

[62] A. Puller, T. Smith, A critical and realist approach to ecological economics, Routledge Handbook of Ecological Economics, Routledge, 2017, pp. 17–26.

[63] D.P. Van Vuuren, E. Kriegler, B.C. O'Neill, K.L. Ebi, K. Riahi, T.R. Carter, J. Edmonds, S. Hallegatte, T. Kram, R.J.C.C. Mathur, A new scenario framework for climate change research: scenario matrix architecture, Clim. Change 122 (3) (2014) 373–386.

[64] C.B. Field, V. Barros, T.F. Stocker, Q. Dahe, D.J. Docken, K. Ebi, M.D. Mastrandrea, K. Mach, G.K. Plattner, S.K. Allen, M. Tignor, P.M.e. Midgley, Glossary of terms. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change adaptation: Special Report of the Intergovernmental Panel On Climate Change, Cambridge University Press, New York, NY, 2012.

[65] J.C. Cuaresma, Income projections for climate change research: a framework based on human capital dynamics, Glob. Environ. Change 42 (2015) 226–236.

[66] M. Leimbach, E. Kriegler, N. Roming, J. Schwanitz, Future growth patterns of world regions–A GDP scenario approach, Glob. Environ. Change 42 (2017) 215–225.

[67] P. Downward, Applied Economics and the Critical Realist Critique, Routledge, 2005.
[68] N. Kaldor, Capital Accumulation and Economic growth, The theory of Capital, Springer, 1961, pp. 177–222.
[69] R.A. Sayer, A critique of urban modelling: from regional science to urban and regional political economy, Prog. Plann. 6 (1976) 187–254.
[70] P. Næss, 4. The dangerous climate of disciplinary tunnel vision, in: R. Bhaskar, C. Frank, K.G. Hoyer, P. Næss, J. Parker (Eds.), Interdisciplinarity and Climate change: Transforming Knowledge and Practice for Our Global Future (Ontological Explorations), Routledge, USA and Canada, 2010, pp. 54–84.
[71] S. Cornell, R. Bhaskar, C. Frank, K.G. Hoyer, P. Næss, J. Parker, 7. Climate Change Brokering interdisciplinarity across the physical and social sciences, Interdisciplinarity and Climate change: Transforming Knowledge and Practice for Our Global Future (Ontological Explorations), Routledge, USA and Canada, 2010, pp. 116–131.
[72] E. Trutnevyte, L.F. Hirt, N. Bauer, A. Cherp, A. Hawkes, O.Y. Edelenbosch, S. Pedde, D.P. van Vuuren, Societal transformations in models for energy and climate policy: the ambitious next step, One Earth 1 (4) (2019) 423–433.
[73] J. Köhler, F. Geels, F. Kern, E. Onsongo, A. Wieczorek, A Research Agenda For the Sustainability Transitions Research Network, Sustainability Transitions Research Network (STRN), Sustainable Consumption Institute, University of Manchester, Manchester, UK, 2017.
[74] G.J. Foster, K. Dobernig, K. Gruszka, K. Schanes, E.M.L. de Schutter, Chapter 5. Sustainable Consumption, Production, S. Lutter, F. Luks, S. Stagl (Eds.), 2018.
[75] I. Overland, B.K. Sovacool, S. Science, The misallocation of climate research funding, Energy Res. Soc. Sci. 62 (2020) 101349.
[76] F.W. Geels, Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective, Res. Policy 39 (4) (2010) 495–510.