

Confronting Current Crises and Critical Challenges of Climate Change

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ABSTRACT

Climate change heightens global warming and brings about impending risks for both human society and natural systems. Climate change is the greatest threat modern humans have ever faced. Pollutant discharges involve the global atmosphere and result in the challenge of global warming that must be solved before it results in irreversible damage. Current common threats of crises need common actions among all of us: every continent, every country, every community, and every common citizen. The earlier an action, the larger its impact. This review article scrutinizes the newest developments in this paramount important research area and provides directions for future research.

KEYWORDS

Air Pollution, Circular Economy (CE), Citizen Actions, Climate Change, Ecological Engineering, Global Warming, Greenhouse Gas (GHG), Negative Emission Technology, Renewable Energy

INTRODUCTION

There are two serious and intertwined global environmental issues that affect human health: climate change and air pollution. Climate change can compound air pollution via climate penalty. Appropriate climate policy can reduce air pollution and provide co-benefits for human health and the economy. However, natural variability complicates the effects of climate policy on air pollution and its associated health impacts. A major cause of climate change is greenhouse gas (GHG) emissions, including carbon dioxide, nitrous oxide, and methane, as they pile up in the atmosphere due to economic activity and reradiate the sun's energy (Castle & Hendry, 2022). Numerous unexpected and irreversible ecosystem impacts lead to natural calamities such as extreme weather events (heat waves, hurricanes, cyclones, tornados, tsunamis, floods, droughts), wildfires, mass migration, crop failure, food and water security, biodiversity loss, coastal erosion, shrinking of glaciers, rising sea-level, thawing of permafrost, ocean acidification, increases in vector-borne diseases, altitudinal and poleward shifts of animal and plant ranges, and political crises (Mandal et al., 2021).

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The United Nations issued a glaring warning on climate change on August 9, 2021, with a call for urgent and speedy large-scale action on cutting emissions. The Intergovernmental Panel on Climate Change's (IPCC) report put the blame indisputably on human activity and U.N. Secretary-General António Guterres said the findings were a "code red for humanity." Some changes are already locked in, with Greenland's land-ice sheet expected to keep melting, leading to rising sea levels. Heat waves that occurred once in 50 years are now happening every 10 years. Currently, the Dixie Fire in California is now the second-largest wildfire in the state's history and could take weeks to contain. And the harshest heat wave in 30 years is leading to damaging wildfires across Greece and Italy.

According to Hanberry (2022), the threshold of a tipping point is around the 36 °C maximum monthly temperature. However, most land areas on the earth will surpass this threshold on the fossil-fueled pathway, maybe 70 years from now. Given the current pathway, the author's analysis indicated that most land areas may tip beyond a maximum monthly temperature of 36 °C by 2081–2100 or be deferred until the early 2100s at best. Swift decarbonization using existing technologies is crucial to alter the trajectory from the maximum monthly temperature threshold, which will inflict ecological and socio-economic costs of climate damage.

As a result of human actions and the associated energy consumption, especially in the last century, the world has faced serious environmental problems, particularly carbon dioxide (CO₂) emissions (Sterin and Lavrov, 2020). Environmental sustainability is an increasingly important dimension in both business and political decision-making. Efficient environmental policy, regulation, and management critically depend on reliable information (Kuusmanen and Zhou, 2021). Research in the field of environmental sustainability has shifted from a country's perspective to a global perspective (Sarkodie, 2018). United Nations, in their sustainable development goals (SDGs), focused on creating human and industrial capacity, improving education, and reducing the impact of climate change and environmental changes (Answer et al., 2021).

Climate change presents such an immense threat to us and the need to reduce the pace of warming is so pressing. There is an urgent need to investigate the issue of climate change from different perspectives as they provide the academic and practice communities with the needed knowledge to understand the issue holistically. Policymakers in various economic and social fields are encouraged to coordinate their policies to balance achieving prosperity for their communities with the environmental implications of those policies (Alotaibi and Alajlan, 2021).

The timeframe set under the United Nations Framework Convention on Climate Change (UNFCCC) is to become net zero (the state in which greenhouse gases going into the atmosphere are balanced by removal from the atmosphere) by 2050 (United Nations, 2022). Meeting that target could help stave off the starkest predictions of a climate disaster — extreme weather, toxic air, uninhabitable regions, and conflicts over resources like food and water. It could lead to a rosier future, with clean energy that powers vehicles, homes, and businesses as well as new industries and more jobs.

RESEARCH METHODOLOGY

Content Analysis has been applied in a variety of topical contexts over the years. Technological advances and prolific application in mass communication and personal communication have renewed the attractiveness of research in Quantitative Content Analysis recently. Social media and mobile devices have attracted more and more users. Content Analysis of textual big data faces new challenges. It is considered a quantitative method because it can be used to identify the statistical frequency of thematic or rhetorical patterns (Boettger and Palmer, 2010).

As Salem et al. (2022) indicate, content analysis is a research method that provides a systematic and objective means to make valid inferences from verbal, visual, or written data in order to describe and quantify specific phenomena. Also, it is a widely used qualitative research technique to explore group, individual, societal, or institutional attention (Hsieh and Shannon, 2005; Downe-Wamboldt, 1992; Weber, 1990).

Having conducted Content Analysis, we went through a systematic literature search by checking some related databases and indexes, such as Web of Science, Scopus, SCI, EI, ScienceDirect, ABI/INFORM Collection, ProQuest Central, Computing Database, Business Source Complete, Academic Search Premier, Project Muse, JSTOR, Google Scholar, etc. In line with Duriau, Reger, and Pfarrer (2007), “Content Analysis is a class of research methods at the intersection of the qualitative and quantitative traditions. It is promising for rigorous exploration of many important but difficult-to-study issues of interest to organizational researchers in areas as diverse as business policy and strategy, managerial and organizational cognition, organizational behavior, human resources, social-issues management, technology and innovation management, international management, and organizational theory.”

After first searching based on keywords and phrases, we used the authors’ names from the relevant studies identified in the initial searches and searched the databases again. Additionally, the reference sections of the studies identified in the initial screening were thoroughly examined, along with relevant literature reviews. Affinity Diagramming has been conducted. Related facts need to be organized into distinct clusters consistent with affinity diagramming. There are a few synonyms, such as collaborative sorting, mapping, snowballing, etc. Affinity Diagramming is a very simple but powerful technique for grouping and understanding information. Affinity Diagramming provides a good way to identify and analyze issues. There are several variations of the technique.

RESEARCH MODELS

Along the lines of Rasul et al. (2022), modeling is the cutting-edge approach to studying climate change. Right after WWII, predominantly in the USA, by the end of the 1960s, representatives were being presented with the model’s findings, which strongly supported the concept that the persistent intensification in GHG emissions caused by human activities has completely changed the overall impact of global climate. With the passage of time, more advancement in modeling was observed; first of all, conceptual models were formed; those were replaced by analog models and then energy balance models were introduced by researchers.

OPTIMIZATION

The Min-Max Robust Optimization Method

Renewable energy integration can reduce emissions and other environmental impacts significantly. Where the required data or parameters of the problem are uncertain, Min-Max Robust Optimization can come to the rescue. Its objective is to minimize the maximum value of the loss function that measures the deviation of the solution from all constraints. Prabatha et al. (2021) use this method to develop a decision model considering uncertainty. Their evaluation time is significantly reduced compared to the other methods, such as linear optimization, Taguchi Orthogonal Array method, and Monte Carlo simulation. Robust optimization is better at handling both scenario and data uncertainties, which affect energy planning problems in the real world. The rescued computational power and time requirements indicate that this method is more suitable for decision support tools developed for industrial applications. The findings indicate that robust optimization can be used to develop an uncertainty-based decision model. Although the presence of uncertainties can change the optimal configuration of a planned energy system, the assessment method itself does not significantly impact the outcomes.

The Two-Box Energy Balance Model (EBM)

This model provides a constructive framework for understanding the complex interactions between different components (the fast box and the slow box – either quickly or slowly exchangeable energy stores) of an energy system, and for making predictions about the impact of changes in one component on the overall energy balance. Soldatenko & Yusupov (2021) propose considering geoengineering

problems within the optimization framework by applying methods of the optimal control theory. This approach allows one to obtain a geoengineering scenario by rigorously solving the optimal control problem for a given performance index (objective function). This model is linear and does not describe the climate system dynamics. Even though the heuristic technique is not guaranteed to be optimal and rational, this approach is sufficient for obtaining good enough solutions in the case when finding an optimal solution is unbearable.

Arc Parameterization Method (APM)

In the arc parameterization method, a curve is symbolized as a function of a single parameter, habitually referred to as the “arc length parameter”. The parameter varies along the curve and can be used to specify points on the curve in an unceasing and smooth manner. Semmler et al. (2022) establish that their multi-phase model incorporating climate, fiscal and financial policies is superior to single-phase models. The arc parameterization method (APM), a new algorithm, extends the model to multiple regimes, operationalized through a three-phase policy environment. The first policy regime is expressed by a limited set of policy tools. Green bonds (i.e. climate-focused financing) are introduced in the second regime. Finally, green bonds are repaid with a new tax. This is an extended integrated assessment model (IAM) that optimizes climate financing policies over multiple phases of discrete policy action. The model is solved by discretizing the optimal control problem and applying large-scale optimization techniques.

Decarbonization Pathways

Decarbonization pathways denote the strategies and actions that can be taken to reduce the amount of carbon dioxide (CO₂) and other greenhouse gases (GHGs) emitted into the atmosphere. Having integrated political-organizational and techno-economic considerations, Zhu et al. (2022) analyze decarbonization pathways for the United States. Three portfolios of granular policies that target greenhouse gas emissions reductions in the electricity, transportation, and buildings sectors are constructed due to their feasibility under different federal political contexts. After that, the authors implement sectoral policy portfolios in the US-TIMES model and compare them to a business-as-usual (BAU) scenario and an 80% system-wide decarbonization scenario that uses stylized emissions constraints to produce the least-cost decarbonization pathway. Their findings show that greater political alignment enables electrification to play a more significant role as a central component of decarbonization. Their results indicate that none of the corresponding sectoral policy portfolios is sufficient to reduce system-wide GHG emissions by 80% by 2050. New technologies and policies will be needed for major emissions sources, such as industrial production, air travel, heavy-duty vehicles, aviation, and natural gas use in buildings.

A Nonlinear Mathematical Model

Mathematical modeling is a well-known technique to describe natural phenomena both analytically and numerically. A nonlinear mathematical model can make more accurate predictions about the behavior of real-world systems because it allows for more complex relationships that cannot be represented by a linear mathematical model. Mandal et al. (2021) propose a four-compartmental non-linear mathematical model to illustrate the potential impacts of excess emissions of GHGs on climate change and the corresponding harmful effects on living beings near coastal areas. The authors performed the positivity test and boundedness analysis to conform to the existence of the non-negative dynamics. Also, they applied the next-generation matrix method both at co-existing and human-free equilibrium points in conduction stability analysis. The authors noticed that if the situation is continued, the concentration of GHGs in the environment and the atmospheric temperature will reach such a position in just only 50 years later in which all the lives, as well as the earth’s environment, will become unstable.

SIMULATIONS

A Simulation-Based Multistage Optimization

Simulation-based multistage optimization is a powerful tool for solving complex optimization problems that involve a complex system or process. Computer simulation needs to model the research system first and then use optimization algorithms to explore the best inputs or decisions that lead to the preferred outcome. Almost 40 percent of the total energy worldwide is used by the building sector, which comes from non-renewable sources and contributes up to 30% of annual greenhouse gas emissions globally. One of the most effective ways of reducing global energy consumption and greenhouse gas emissions is retrofitting existing buildings. Aram et al. (2022) investigate whether a particular energy-optimized design under the present climate conditions would respond effectively to future climate change. This can help designers make a better decision on an optimal model, which can remain optimal over the years based on climate change. The authors apply the non-dominated sorting genetic algorithm (NSGA-II) to minimize the cooling and heating load, as well as consider investment costs for present and future weather files, using the jEPlus tool. Finally, the best set of retrofit measures is identified with the TOPSIS method.

Distributive Justice

Jafino et al. (2021) propose eleven requirements for IAMs in order to allow for justice evaluation. The requirements are structured based on the XLRM framework and derived from ethical imperatives rooted in intra-generational (between people in the same generation) and intergenerational (between different generations) justice. In addition, by using IAMs in a multi-temporal fashion, modelers and planners can observe the expected impacts on future generations. Incorporating uncertainties in human values and behavioral systems with a higher granularity should be explored. Also, another reason for caution is the plausible adverse impacts of quantification and over-trust in numbers. If decision-makers are fully outsourced to number-based analysis, information on who wins and who loses could be misused and/or abused.

Public Transport

Kashifi et al. (2022) investigate the effect of transit leverage on vehicle kilometers of travel, energy consumption, and greenhouse gas emissions for seven major Saudi Arabia cities with at least half a million population. The authors found that if the annual average per capita mileage of public transport can be increased by one-fifth of the current per capita mileage, energy consumption and carbon dioxide emissions from road transport can be reduced to half of the existing values. Also, the author studies the effect of variations of three input variables (vehicle occupancy, average trip length, and average daily trips) on vehicle kilometers of travel, energy consumption, and CO₂ emissions via Monte Carlo Simulation.

Regional Climate Model (RCM)

RCM can be used to analyze future climate change scenarios and evaluate the potential impacts on specific regions. Under the influence of a strong, moderate, and no mitigation Representative Concentration Pathway (RCP2.6, RCP4.5, and RCP8.5) and covering the historical period 1970–2005 and the future period 2006–2100, Georgoulas et al. (2022) present an updated assessment of projected climate change over Greece. They focus on near-surface temperature, precipitation, and related heat (Hot Days and Tropical Nights), cold (Frost Days), and drought (Consecutive Dry Days) climate indices. The authors conduct 11 high-resolution EURO-CORDEX regional climate model (RCM) simulations and assess the statistical robustness of climate change signals.

Lakes and Reservoirs

Empirical evidence reveals that lakes and reservoirs are warming across the globe. The largest international effort to project future water temperature, thermal structure, and ice phenology of lakes at local and global scales and paves the way for future simulations of the impacts of climate change on water quality and

biogeochemistry in lakes is the ISIMIP Lake Sector. Golub et al. (2022) describe a simulation protocol developed by the Lake Sector of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) for simulating climate change impacts on lakes using an ensemble of lake models and climate change scenarios.

Land System Modular Model (LSMM)

With modular and hierarchical structures, LSMM models the interactions between physical, biological, and human systems in order to understand the changes that take place in landscapes and ecosystems. Maire et al. (2022) present an approach to better understand adaptation and/or the interaction between adaptation and mitigation in the land use and food system. The new combination of multiple models in the LSMM can simulate climate change adaptation and mitigation strategies and the impacts on the global food system and socio-economic development over long-term predictions. LSMM takes into account the impacts of changes in climate (i.e. temperature, precipitation, atmospheric greenhouse gas concentrations) and land management on crop yields with its implications for land allocation, food security, and trade. This new coupled model integrates, over a fine spatial scale, the interactions between commodities consumption, land use management, vegetation, and climate into a worldwide dynamic economic system.

SYSTEMATIC ANALYSIS

Systematic Development

The Earth system is inherently linked with the human system. Franzke et al. (2022) consider interactions and feedback between them at different spatial and temporal scales, specifically those that enable decision-making to reduce the likelihood of crossing local or global tipping points. In Earth system science tipping points largely have a negative connotation, indicating a change that will negatively impact on society and ecosystems. Sustainable and adaptive governance approaches include mitigation, adaptation, the building of social networks, disaster management, and conflict resolution. To meet the temperature limit of 1.5 °C or 2 °C t, an anticipative policy framework will be necessary to avoid perilous pathways, which allows for a systemic transformation toward self-organized stabilization. Early warning systems can build on measuring sensitivity, including criteria for instability, thresholds for transitions, factors of criticality, and control mechanisms to facilitate transformation across tipping points.

Energy-Economy-Environment (E3) Models

Energy-Economy-Environment (E3) models feature prominently in energy policy and climate mitigation planning. However, these models have a mixed track record when assessed retrospectively and exhibit biases that can make them counterproductive for prescriptive policy during the transition. Sgouridis et al. (2022) claim that it is preferable to develop a vision of the desired future energy system instead of relying on techno-economic solutions based on simple objectives (such as lower carbon emissions) in times of energy transition. The authors support this argument through reasoned inference supported by historical examples. A critical appraisal of E3 modeling exercises highlights the biases, structural or implicit, favoring existing energy system modalities. As a result, if E3 models are uncritically used to formulate long-term energy policy, there is the risk of unintended or deliberate performativity preventing a radical transition.

The Closed-Loop Control Problem

The closed-loop control problem refers to the design and implementation of a control system that continuously monitors, updates, and adjusts a system in real time via a feedback loop to maintain desired behavior or conditions. In order to account for nonlinear behavior and feedback from a global carbon monitoring system, Sierra et al. (2021) theorize it as a network congestion problem. As opposed to *scenarios*, the goal of closed-loop control is to develop *rules* for continuously steering the global

carbon-climate system away from dangerous climate change. There is fortunately a tremendous amount of work in defining policy and economic instruments for mitigation and adaptation to climate change. The problem of steering Earth's carbon-climate system to the desired state can be posed as a closed-loop control problem that continuously adapts action according to measurements and uncertainty in the dynamic behavior of the system. This representation takes advantage of the compartmental structure of the global carbon system, which imposes specific mathematical restrictions on the system of equations that lead to particular properties such as dynamic stability. In particular, CO₂ levels in the atmosphere can be effectively controlled using concepts and tools from congestion control of networks.

Citizen Actions

Facing complex issues such as climate change and its effects on public health requires the participation of various actors. The research tool citizen science is one way for people to get involved. Over and done with it, citizens work together with scientists to find solutions to problems in their regions. From a participatory work with citizens, Álvarez-Miño & Montoya (2022) design a taxonomy proposal, which can expedite citizen and community action in suggesting research ideas. Stakeholders can use it to systematically classify and code initial questions and answers on public health and climate change issues. The development of this taxonomy integrates the global agenda of Sustainable Development Goals (SDG) in such a way that citizens not only help their communities but also, the direct fulfillment of SDGs such as Climate Action (SDG 13), indirectly impacting other SDGs. The systematic classification and coding of citizens' contributions worldwide will contribute to the large-scale organized collection of information to be analyzed in proposing better responses to reduce the impacts of climate change on health.

Life Cycle Assessment (LCA)

LCA assesses the total environmental impact of a product over its entire life cycle, from raw material origin to production, utilization, and disposal. BRANDÃO (2022) formulates an integrated environmental and economic assessment of the global consequences of changing current land use in the UK with different land-use strategies for food, feed, fuel, timber, and carbon sink. A systematic life cycle assessment (LCA) is used for the environmental assessment and a parallel economic assessment is integrated with LCA for the characterization of the main land-use strategies in the UK. The results indicate that changing land use and management on current cropland generally does not bring improvement in all three criteria of mitigating climate and impacts on ecosystem service and biodiversity while creating additional economic value. Expanding cropland onto set-aside and permanent grassland is more beneficial when crops are used for fuel or for carbon sink. Spreading out set-aside grassland is largely undesirable if by arable cropping, but desirable by energy and forestry crops.

ECOSYSTEM STUDIES

Ecological Network Analysis (ENA)

As an interdisciplinary field, ENA creates network models to represent the relationships and interactions between different components of an ecosystem. Integrative and spatialized tools for studying the effects of a wide variety of ecosystem drivers are needed to implement ecosystem-based management and marine spatial planning. Noguees et al. (2022) develop a tool for analyzing the direct and indirect effects of anthropic activities on the structure and functioning of coastal and marine ecosystems. Using innovative modeling techniques, the authors ran a spatially explicit model to perform ecological network analysis (ENA) of the effects of climate change (CC), of an offshore wind farm (OWF) and of multiple fishing scenarios on the Bay of Seine (eastern part of the English Channel) ecosystem. ENA indices described the effects of those different drivers in a holistic and spatial way. The spatial analysis of ecosystem properties revealed local and global patterns of modifications attributed to CC, while the OWF resulted in localized changes in the ecosystem. This ability of ENA indicators to detect human-induced changes

in ecosystem functioning at various spatial scales allows for a more integrative view of the effects of human activities on ecosystems. ENA indices could be used to link both local and global ecosystem changes, for a more cross-scale approach to ecosystem management.

Whole-Ecosystem Functioning

It is all the time more apparent that climate sustainability depends not only on societal actions and responses but also on ecosystem functioning and responses. That is, climate-change policies must involve not only preparing for a future with weather anomalies but also actively minimizing climate hazards and risks by conserving and managing ecosystems and their essential supporting and regulating ecosystem services. Hessen & Vandvik (2022) summarize general climate–nature feedback processes relating to carbon and water cycling on a broad global scale. The authors make a case that a key instrument for both climate-change policies is to play on the climate buffering and regulative abilities of a well-functioning natural ecosystem. This will empower shared benefits to nature, climate, and human well-being. To meet the global climate and natural crises, decision-makers must capitalize on the importance of nature for buffering climate-change effects, combat short-term perspectives and the discounting of future costs, and maintain or even make stronger whole-ecosystem functioning at the landscape level.

Integrated Modelling Tools

In face of global changes, projecting and mapping biodiversity changes are of critical importance to supporting the management and conservation measures of marine ecosystems. The current models neglect intra- and inter-specific interactions and thereby can lead to biased projections of changes in biodiversity distribution. To evaluate the influence of trophic interactions on projections of species richness and assemblage composition under climate change scenarios, Moullec et al. (2022) compare biodiversity projections derived from an ensemble of different SDMs to projections derived from a hybrid model coupling SDMs and a multispecies trophic model in the Mediterranean Sea. Their results show that accounting for trophic interactions modifies projections of future biodiversity in the Mediterranean Sea. The authors justify the development of integrated modeling tools that can mechanistically consider multiple biotic and abiotic drivers to improve projections of future marine biodiversity.

Ecological Engineering

Combining knowledge from different fields, ecological engineering designs and maintains ecosystems that provide desired ecological services while enhancing human well-being. Along the lines of Hadary et al. (2022), ecological engineering is an evolving discipline with the aim of building more resilient and safer coastal and marine structures for people and nature, while maximizing ecosystems, social, and economic benefits. Oceans form 71% of the earth's surface and more than 50% of the world's population lives in coastal areas, resulting in coastal hardening. Urban and industrial waterfronts replace natural habitats and cannot provide appropriate ecosystem services. Consequently, coastal infrastructures lose environmental value. Floating offshore structures will add substantial amounts of hard surfaces to the marine environment that will inevitably be colonized by marine life. Planners must take concrete action toward reducing the ecological footprint of future floating structures. Innovative floating urban marine environments must be carefully created to generate productive multifunctional structures that are teeming with life.

BEHAVIOURAL INTERVENTIONS

Carbon Labeling Systems

Carbon labeling systems can enlighten individual and organizational choices, which potentially diminish the carbon footprints of goods and services. Taufique et al. (2022) review the ways labeling is conceptualized and operationalized and the available evidence on effectiveness. The authors found that current literature focuses mainly on how labeling affects retail consumer behavior, but much less on how labeling affects the

behavior of the producers, transportation companies, and retailers despite preliminary research suggesting that the effects on corporate behavior may be substantial even without strong consumer responses. The authors consider key challenges for carbon labeling systems related to standard setting, data collection and use, and label design. Also, the authors summarize the available knowledge, identify key research questions and identify steps toward achieving the promise of carbon labeling.

Socioeconomic Foundations & Specific Geographies

Yang et al. (2022) use ESS Round 8 data from 23 European countries to examine whether climate change skepticism and concern, pro-environmental personal norms, and a willingness to engage in energy-saving behavior exhibit regional differences and their explanations. The authors find that climate change skepticism and concern do exhibit urban-rural differences, where living in a country village is associated with greater climate skepticism and lower concern compared to living in a big city. Also, higher climate change concerns and pro-environmental norms are associated with living in a region with constant population growth. The results underscore that climate change mitigation is not an equivalent project either spatially or within certain socioeconomic strata. Consequently, their results suggest that when reworking climate change and environmental policies in the EU, policymakers should be aware of the needs of socioeconomic disadvantaged and spatial marginalization populations.

Climate Smart Cities

Thioye (2022) describes key categories of mature climate change mitigation solutions that can be promptly implemented by cities. Cities' governments can play a prominent role as climate actors. They are in an irreplaceable position that entitles them to conduct a broad range of possible climate actions, such as facilitating emission avoidance by fostering a change in the consumption behavior of their citizens leading to the displacement of carbon-intensive products; Enabling GHG emission reduction by the citizens in their jurisdiction; and Reducing the emission related to the infrastructures they build and operate. The first category of climate action is the most transformative. Cities, through a city action plan, are well-equipped to mobilize this potential by mainstreaming disruptive climate action into city development action. The authors propose a reformed green bond framework to support climate action by cities with digital technologies and discuss its benefits.

INTERDISCIPLINARY MODELS

A Socio-Psychological Analysis

A socio-psychological analysis systematically examines social and psychological factors that influence human behavior and attitudes. Rishi (2022) examines and evaluates climate change and sustainability communication from a transdisciplinary perspective integrating communication models and concepts from the disciplines of sociology, philosophy, psychology, and political science. Furthermore, it draws examples from diverse fields of understanding and proposes its application as a management tool. With the COVID-19 pandemic and associated loss to individual incomes as well as global economies, the inconsistencies and inequalities in information access are further widened in developing countries, and the 'digital divide' expands the gap further between the 'front-runners' and 'back-seaters' of climate change and sustainability communication. It warrants assuming responsibility on the part of individuals, institutions as well as governance systems worldwide to redesign their platforms with each other and the natural environment.

Resource Efficiency–Climate Change (RECC)

Pauliuk et al. (2021) perceive that at the society and policy level, it is necessary to know the total financial gains and costs of material efficiency to be able to compare it to the gains and costs of other impact mitigation strategies such as supply-side measures like a shift to hydrogen as an energy carrier

or end-of-pipe solutions, like carbon capture technologies. The authors present the resource efficiency–climate change (RECC) mitigation framework, which is the first comprehensive operationalization of the link between services, products, materials, material cycles, energy use and supply, and emissions in an industrial ecology model framework. To facilitate the integration of knowledge and to enable different assessment tools to work together efficiently, the RECC framework is modular and made available under a permissive open-source license. RECC provides scenario results for the life cycle impacts of ambitious service–material decoupling concurrent with energy system decarbonization, giving detailed insights on the RECC mitigation nexus to policy-makers worldwide.

Circular Economy (CE)

In a circular economy, resources are used, reused, and redeveloped in a closed loop, rather than being extracted, used, and abandoned as waste. In order to enhance the current response to the global climate crisis, Romero-Perdomo et al. (2022) propose the circular economy (CE) as a potentially significant facilitator. The author examines the scientific literature on the research between climate change and CE adopting a knowledge mapping approach. Having based on a total of 789 peer-reviewed publications extracted from Scopus, they found that research on climate change and CE is continually on the rise and interdisciplinary in nature. Europe outstandingly leads scientific research. Keyword evolution shows that CE has been influenced by more lines of research than climate change. However, there are knowledge gaps in the integration of the social dimension, the promotion of climate change adaptation, and the association of sustainable development goals (SDG).

STOCHASTIC MODELS

A Stochastic Mathematical Programming Approach

The goal of stochastic programming is to find the optimal decisions that minimize the expected value of the objective function, taking into account the unpredictability of the inputs. To slow down climate change and improve energy security, the Taiwanese government proposed the “Greenhouse Gas Emission and Management Act” in 2015 which provides a green bond that can only invest in renewable energy, green building, pollution control, and clean transportation in recent years. Having evaluated the optimal bioenergy development patterns considering the potential shifts in water use equilibria, Kung & Wu (2021) develop integrated stochastic programming with a recourse model to evaluate the potential impact of water competition across sectors on agricultural practices and subsequent bioenergy development. The theoretical framework developed by this study offers an approach for analyzing the influences of changes in production inputs in different stages, especially when the upstream sectors are competing intensely for such inputs.

Stochastic Demographic Model

Stochastic demographic models are used to study various aspects of population dynamics, which are based on mathematical models of demographic processes, such as the cohort-component method, the life table method, and the Markov chain method. Caselles & Sanz (2021) designed a stochastic demographic model, involving demographic and quality of life variables worldwide. Demographic variables are determined by birth and death rates, as well as by the variation between the total world population and births and deaths. A global demographic model does not consider migratory movements. The authors use two indices, including the Human Development Index (HDI) and the environmental energetic contamination index, to represent the quality of life. A genetic algorithm has been applied to optimize the amount and share of main energy consumptions (coal, oil, gas, nuclear energy, and renewable energies), forest area, as well as the average birth rate in the world, in order to conserve the global present population and mean temperature. The evolution of other variables (like unemployment, carbon dioxide production, gross capital formation, water cycle, etc.) is obtained as collateral information.

Artificial Neural Networks

Physics-Informed Neural Networks (PINNs)

In PINNs, the neural network is trained to approximate the solution of the partial differential equations (PDEs), rather than being trained on a set of data points. The functions and influences of the oceans on climate change need to be deeply analyzed because the carbon pump of the world's oceans plays a vital role in the biosphere and climate of the earth. deWolff et al. (2021) study the behavior of physics-informed neural networks (PINNs) concerning the wave, shallow water, and advection-diffusion equations. The authors solve partial differential equations related to ocean modeling and note that the added loss term for the deviation to the physical law inhibits the network from training and generalizing well to unseen data, despite using various activation functions, which may be attributed to the large amount of training data used. However, it is yet unclear how neural networks can learn the complexities of (second) derivatives as present in PDEs, as well as the influence of the amount of training data.

eXplainable Artificial Intelligence (XAI)

XAI creates AI systems that can be transparent and interpretable in their decision-making processes. Chakraborty et al. (2021) present a novel data-driven XAI model to predict long-term building energy consumption (EC) under the new 21st-century climate change shared socioeconomic pathways scenarios (SSPs) and analyze the impacts of climate change on the cooling EC. The authors also explained the fundamental reason behind the predicted increase in the EC using their XAI model in which they employed a tree-based ensemble model called XGBoost integrated with game theory-based SHAP. The integrated XAI model boosted the interpretability of the XGBoost model by determining the influence of the predictors for accurate prediction of the target and investigating the interactions and dependencies amongst the predictor variables with the target variable EC. The XAI results divulged that the incremental EC under all SSPs will increase exponentially after 2050 when socioeconomic pathways deviate from the sustainable green energy path or current trends.

There is a noteworthy amount of additional research. For instance, Al Shawabkeh, Alhawari, & Al-Kharabsheh (2022) tested the impact of knowledge management (KM) processes, organizational capabilities (OC), and mediating KM mechanisms and KM technologies toward the smart organization (SO) using structural equation modeling. Alim & Abdulrahman (2022) investigated effective employers and community engagement with Content Analysis. Singh & Jain (2022) conduct exploratory research using NVivo to explore business continuity; Dawra, Chand, & Aggarwal (2022) investigated the achievement of organizational sustainability through structural equation modeling. Lemon & McLeod (2022) discovered that if change can be designed and managed through a socio-technical framework, future expansion, and intended improvements can be smoother and more effective. Shanmugam et al. (2022) use reinforcement learning (RL) where the agent learns the behavior of the node and isolates the malicious nodes to improve the network performance. Redjati et al. (2022) developed a novel Deep Learning Model for the detection of endangered water-bird species. The knowledge of these birds allows one to acquire crucial information on the state of health of considered environments. Ibitomi & Iyamu (2022) examined the factors that influence the selection, deployment, and evaluation of IT solutions.

FUTURE RESEARCH

Carbon Capture and Utilization (CCU)

Corresponding to Desport & Selosse (2022), carbon capture and utilization (CCU) technologies are of interest for both mitigating emissions and generating revenues. Rather than considering CO₂ as a waste or a pollutant, CCU treats it as an opportunity that could support promises not only for producing clean fuels in the future but also for producing valuable chemicals, not harmful plastics and building materials, etc. In order to develop this technology, an assessment of CCU potentials and performances needs to be thoroughly examined, not only through TEA (techno-economic analysis) and LCA (life

cycle assessment) studies but also by employing energy models due to their ability to integrate several components of an overall energy system. The authors argue that CCU needs to be modeled at all possible capture sites and for all CO₂ utilization processes, including biogenic and atmospheric CO₂. Moreover, CCU should be further explored at the global level. Deeper research to produce LCA and TEA studies on the range of options available for CO₂ utilization is both challenging and promising.

Negative Emission Technology

Panepinto et al. (2021) conduct an analysis of the climate change mitigation phenomena. Specifically, the authors focus on the leading negative emissions technologies (NETs) or the technologies able to absorb the CO₂ present in the atmosphere. For instance, companies can use new technologies and renewable energies, making older equipment more energy efficient, or in the meantime change management practices or consumer behavior. The mitigation technologies are able to reduce or absorb the GHG and particularly the concentration of CO₂ in the atmosphere. The NETs are technologies able to captivate the CO₂ in the upper troposphere and lower stratosphere. It is clear that these technologies can play an important role in achieving the objectives of the Paris Agreement atmosphere. Additionally, the microalgae massive cultivation for CO₂ bio-fixation, an emergent NET, has been analyzed. Regardless, concerning the use of microalgae for CO₂ bio-fixing, more work is required, as the bio-fixation efficiency is strictly related to the microalgae growth rate, and to obtain a valid technology many difficult aspects still need to be solved. Along these lines, it will be in the cards to reduce energy demand, investment, and operating costs.

Automated Text Analysis

Automated text analysis can automatically analyze and extract meaningful information from text data through sentiment analysis, topic modeling, named entity recognition, and text classification, among others. Ulibarri & Han (2022) apply qualitative content analysis to assess the integration of climate change into Environmental Impact Statements (EISs) in the United States. Environmental impact assessment (EIA) is a globally-used tool to form the environmental and social sustainability of infrastructure systems. In order to protect and improve the nation's environmental security, the National Environmental Policy Act (NEPA) requires federal agencies to consider the potential social and environmental impacts of their decisions, like other EIA regulations. A shift in the planning, design, and operations of infrastructure is entailed in addressing climate change. Lessening GHG emissions will involve decarbonizing energy, water, transportation, and other infrastructures. Expected changes in precipitation, sea level, heat and cold spells, and natural hazards like hurricanes and wildfires will impinge on the long-term elasticity of many infrastructure projects. The authors make out that future research can utilize automated text analysis and natural language processing to build a larger sample size and allow a quantitative understanding of when and why we see differences in climate integration.

More Distant Horizon Scanning

Human-caused activity is changing Earth's climate and ecosystems in ways that are potentially hazardous and troublesome to humans. GHG concentrations in the atmosphere continue to upsurge, making certain that these changes will be felt for centuries beyond 2100, the current benchmark for most projections. As a result, assessing the effects of past, current, and potential future emissions to only 2100 is short-sighted. To highlight the need for more distant horizon scanning, Lyon et al. (2022) model climate change to 2500 under a suite of emission scenarios and quantify associated projections of crop viability and heat stress. Their projections past 2100 indicate that without rapid and significant reductions in greenhouse gas emissions, large areas of the Earth will change in ways that reduce their capacity to support large-scale human occupation. As a result, the authors argue that projections of climate and its effects on human well-being and associated governance and policy must be framed beyond 2100. These longer-term projections are critical to preparing the way for a serene and livable Earth in the coming decades and centuries.

CONCLUSION

Nowadays, global climate change is an acute and unprecedented reality, but not a fiction or an overreaction anymore. Its consequences, due to our carbon-intensive lifestyles, are damaging human beings' health, depriving our wealth, and threatening our societies. We are witnessing and/or suffering from extreme weather events, storms, heat waves, droughts, wildfires, extreme rain or flooding, and environmental degradation. Some species are facing potential extermination, which is increasingly common. How much worse they get will be affected by how uncompromisingly the entire world acts to decelerate climate change now and continue later. Certainly, early and immediate actions can have a larger impact, yet future actions will be needed also. Increasing clean energy investment can radically decrease GHG. In order to achieve resource-saving and environment-friendly development, energy conservation and emission reduction measures should be forcefully implemented.

The Paris Agreement announces that climate change should be confined to well below 2°C above pre-industrial levels, with 1.5 °C as a target. We also face both domestic and international new challenges: the Ukraine war has held back the fight against climate change as countries come together on finding fossil fuels to make up for lost Russian oil. The Supreme Court has made it tougher for the US to battle the damages of climate change. We need to look for creative ways to ward off the horizon of catastrophe. By implementing a collective tactic, each common citizen can make a difference. From ourselves to family members to friends, we all need to take the issue seriously and educate ourselves on our ecological footprints - the most commonly used metric of the environmental impacts of human resource use.

The field of climate change research is constantly advancing, and it is crucial that we stay informed of the latest advancements. Keeping up with the latest developments can potentially enhance the scope and depth of our analysis. There are not enough walks referring to talks. Why not walk talks? There are too many conflicting issues and arguments, which can become involved more or less in politics, especially at the local level, where many climate policies are supported. Current common threatening crises need common actions among all of us: every continent, every country, every community, and every common citizen. We need both mitigation strategies that diminish or preclude GHG emissions and adaptation strategies, which facilitate adjustments in natural or human systems to moderate negative or take advantage of some constructive impacts due to climate change. Working together through social media, we can change what politicians and policies they support, achieving a bright and sustainable future.

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