Multiagent Climate Change Research

Blue Sky Ideas Track

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ABSTRACT

We call for attention to *climate change* research as a domain of application for *multiagent technologies*. The multiagent nature of climate change challenges and successful application of multiagent methods in decentralized power grid systems, market organization, and industrial engineering, could improve our ability to address decarbonization (climate change mitigation) and to deal with some unavoidable consequences of global warming (climate change adaptation). We review major challenges to which the community of multiagent systems can contribute, highlight open research problems and argue for the application of multiagent models and solution concepts in a variety of issues related to this global challenge.

KEYWORDS

Innovative Agents and Multiagent Applications, Agents for Climate Change, Emerging Applications of Agent-Based Systems, Multiagent Research for Global Challenges.

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1 INTRODUCTION

The overwhelming scientific consensus is that: *Earth's climate is warming and humans are the primary cause* [3, 20, 60]. Scientifically understood beyond any doubt, human-induced climate change from greenhouse gas emissions will modify the planet's physical systems in ways that will adversely impact our weather, how we grow food, the availability of fresh water and our ability to protect coastal regions. As a consequence, we urgently need to find ways to mitigate it and to adapt our life-style, our manufacturing processes, our economic systems and the operation of our cities. It is not a doomed situation but will be if we fail to deliver decarbonization globally within the coming decades. Following Pinker [66], we see the opportunity for applying available reasoning tools—in this case, from the Multiagent Systems (MAS) research—in the solutions needed and envisage a more enlightened future if we did so.

For such a socio-politically relevant issue, we suggest avoiding fast-thinking approaches/algorithms (in the sense of [37]) and instead apply rigorous and verifiable multiagent methods, engineering techniques, and coordination mechanisms, to address some of the problems in climate change. Challenges related to Climate Change (CC) mitigation and adaptation—by means of changing the decision processes—are multiagent in nature. In most CC challenges we deal with multiple competing actors/stakeholders, scarcity of resources, and coordination and cooperation problems. This motivates the use of techniques that are agent-based (not merely factor-based or event-based), which are able to capture social and behavioral aspects of (collective) decisions.[1]

While the sub-field of agent-based modeling/simulation[2] has contributed to this topic, it is an overlooked and under-represented application area in the rest of the MAS research community.[3] Mitigating climate change and adapting to it goes beyond *modeling*

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[1] We highlight that our focus is not on the ecological dimensions of the debate but on what the MAS community is capable of addressing.

[2] To clarify the setting for readers outside the agent research community, Agent Based Modeling (ABM) [30] has focus on gaining insight and explanation about the behavior of a (mostly real-life) phenomenon/system by means of computer simulation. As an umbrella field, multiagent systems research [34, 89] is concerned with questions on design, development, and coordination of systems that consist of various natural and/or artificial entities: including (among others) multiagent coordination models; multiagent engineering and problem-solving techniques; knowledge representation and reasoning frameworks; and strategic and game-theoretical solution concepts.

[3] According to ACM Digital Library (https://dlnext.acm.org/), from 6034 papers published in the proceedings of AAMAS from 1997 to 2019, we merely see 29 full papers, extended abstracts, and demonstrations (i.e., 0.48 %) that explicitly relate to *climate change* or *global warming*. This include the use of keywords that authors may use to refer to climate change and global warming in any part of the text. Our query was: *"climate change" OR "global warming" OR "climate action" OR "climate emergency" OR "environmental emergency" OR "environmental crisis" OR "ecological crisis" OR "climate challenge" OR "environmental challenge" OR "ecological challenge"*. These papers are from 20 authors and co-authors combined (0.24 % out of 8051 AAMAS authors).

scenarios and in addition requires *design*, *coordination*, and *governance* methods to foster social-ecological resilience and enable sustainable socio-technical transitions. As highlighted by Naomi Oreskes—in a reflection on the history of climate change research—"*climate change research overemphasized the importance of models and modeling*" [61].

We argue that, due to behavioral aspects, decision making with the aim to improve efficiencies (as a standard goal in optimization and operations research) is intrinsically different from, and hence inapt for, supporting decisions in view of disastrous events or existential risks. Moreover, we agree with [36, 62] that application of *purely* data-driven techniques are misleading.

In response, this work is the first attempt to articulate CC challenges to which the MAS community can contribute and is a starting point for establishing a research agenda for *Multiagent Climate Change (MACC)* research.

2 MACC RESEARCH

We focus on two main dimensions of the climate change research: Climate Change *Mitigation* and *Adaptation*.[4] For both dimensions, we briefly discuss current practices, elaborate on challenges and open research problems, and present a way forward by sketching multiagent methods that we see well-suited to investigating the problems.

2.1 Agents for Climate Change Mitigation

In principle, seeing the high possibility of disastrous environmental changes as result of humankind's interaction with the environment, a natural immediate response would be to *change how we act* to *mitigate* further damages. Examples include the way we consume resources (e.g., food types and the production of food and/or energy) and what we emit to the environment (e.g., as a result of transport, production processes, and burning of fossil fuels). In a nutshell, the focus of Climate Change (CC) mitigation research is on evaluating the effectiveness of potential forms of behavior change, their feasibility, and consequences [21, 25, 26, 92]. In this vein, we see three main challenges for which the community of multiagent systems has viable solution concepts and argue that although these problems are well-studied, the integration of multiagent techniques leads to capturing unaddressed dimensions.

Challenge 1 (Socio-Behavioral Pricing Schemes: Macroeconomic Coordination and Behavior Change). *The need for verifiable system-level (carbon) pricing schemes that are fair and stable in view of the behavioral and social aspects of climate change.*

Although carbon pricing is among one of the first policies aimed to mitigate emissions, investigating their effectiveness and ensuring their reliability remain open problems. One can argue that dismissing the social and behavioral aspects of climate change results in unrealistic assumptions (e.g., that firms are purely driven by short-term financial gains) and accordingly ineffective, or even counter-effective, pricing schemes. Reviewing recent trends and the state of the art on carbon pricing as a CC mitigation method [15, 41, 84], we see conceptual models (that are mostly unverifiable), factor-based techniques (that dismiss the agency of involved decision makers and the potential for emergence behaviors in their models), the rise of (model-free) data-driven techniques, and the absence of multiagent techniques and verifiable formal methods. We follow Pearl [62, 63] and argue that reasoning about interventions and their effectiveness needs sophisticated formal models. Moreover, if the main aim of pricing schemes is to nudge the behavior of macroeconomic entities (e.g., industrial firms) towards the environmentally friendly supply of resources or/and production technologies, the integration of social aspects is crucial. This is not simply to apply behavioral game theory but the integration of a range of social aspects (e.g., to capture trust and reputation). Introducing such aspects calls for tailoring multiagent social notions for the context of climate change (e.g., by building on formalizations in [16, 71]). This in turn enables developing systematically verifiable socio-behavioral (carbon) pricing tools.

Challenge 2 (Sustainable Incentivization: Microeconomic Coordination and Behavior Change). *The need for methods to analyse the reliability and effectiveness of incentive engineering techniques that aim to nudge the behavior of micro-level stakeholders towards a spectrum of sustainable behaviors.*

Focusing on micro-level entities and expecting that consumers opt for costly environmentally-friendly practices and products, is an unrealistic assumption. A natural response is to allocate incentives *in a reasonable and verifiable way* to nudge the collective choice and the change of behavior over time (e.g., in energy/food consumption and choice of transportation modes). This is related to macro-level pricing schemes, and raises distinct problems. For instance, currently we have products that are produced in a sustainable manner (so we can say the macro-level coordination was successful) but they may require subsidies to become attractive to consumers. While we see the application of methods from operations research and economic theory to this problem [45, 75, 88, 96], we suggest a line of scientific research to capture the agency of stakeholders and their propensity to follow social norms. To this end, one main avenue would be to employ norm-aware coordination mechanisms [8, 13] for incentive engineering. Such methods are effective in other contexts (e.g., in business administration and natural resource management) and are expressive-enough for specifying desirable properties in the context of climate change.

Challenge 3 (Climate Liability Determination/Sharing Methods). *The need for automatized methods for liability evaluation and responsibility sharing in the context of climate change litigation.*

In various judiciary cases related to climate change and environmental damage [64, 76], we observe *responsibility gaps* and

[4]We see three dimensions to the Climate Change (CC) research: CC science, CC mitigation, and CC adaptation. In this work, we build on the results of CC science [39, 79] and assume that undesirable changes in the climate are a result of humankind's interventions and the use of environmentally-unfriendly technologies or decision making techniques. In response, we focus on what can be done—by highlighting the potentials of multiagent methods and technologies—to mitigate further damages and to adapt to unavoidable consequences. In principle, seeing CC scenarios as counterfactuals (as remote possibilities), the CC science is focused on improving our knowledge by relating what we know about actualities and what may happen (an epistemic problem). To compliment this, the focus of MACC research is on developing multiagent representation, reasoning, intervention, and decision support tools for analyzing and influencing eventualities based on our knowledge about actualities (a semantic problem). We deem that neither of the two suffice to address the climate change challenges while the combination (of CC science and MACC) is a permissible machination in our reasoning and solution-finding artillery.

variations of the *problem of many hands*.[5] If you take the example of recent (energy corporation) court cases where responsibility is shared among oil and natural resources corporations, individuals and governing entities who are responsible for the occurrence of undesirable outcomes, determining who is to blame—and more importantly *to what extent*—requires rigorous methods. Such methods are expected to capture strategic, epistemic and temporal subtleties of the problem. We argue that the complexity of such problems calls for automated methods to support judiciary decisions. Building on [18, 87], we see the potential for application and tailoring of multiagent responsibility reasoning techniques. Agent-oriented causal responsibility ascription [18], moral notions of responsibility [10], and strategic responsibility reasoning [93] could formally address challenges in responsibility reasoning and have the potential to capture various dimensions of climate change litigation cases.

2.2 Agents for Climate Change Adaptation

For decades, much climate change research was focused on mitigation [92]. However, to deal with now unavoidable consequences, adaptation strategies and decision support tools are necessary. Thus, in this section, we look at CC adaptation [1, 2, 54] and highlight open research avenues and challenges. These are not necessary capturing *all* the challenges in the field of CC adaptation but are mainly focused on the class of challenges to which the community of AAMAS can contribute by providing solution concepts.

Challenge 4 (Adaptive Financial Measures and Insurance Mechanisms). *The need for dynamic economic systems and multiagent organizational models to enable reorganization in response to radical changes.*

Observing the occurrence of radical changes in the climate (and seeing predictions that high-impact events will increase in frequency and magnitude), it is questionable whether *“all loss and damage from climate change can be covered”* by insurance [44, 48]. Recent studies show that (potential) costs can not be fully covered by insurance companies, and that climate change may result in situations where insurance companies avoid covering the most vulnerable areas (e.g., in the case of flood insurance, river-bank residential/industrial buildings). To avoid such outcomes, reorganization of final measures and insurance mechanisms is necessary. For such a purpose, the body of work on *multiagent organizational frameworks*, principles for *self-organizing institutions*, and methods for *adaptive re-organization* [4, 57, 67, 80] have promising potential. In particular, they can provide computational organizational models in the context of CC insurance and a formal basis for evaluating and improving the reliability and adaptability of financial and insurance mechanisms [82, 83].

Challenge 5 (Transitional Business Models for Circular Economy). *The need for business models to foster the transition from a linear towards a circular economy.*

In contrast to traditional linear-economic models (to take resources, produce and discharge the waste), the concept of the circular economy is focused on reusable resources among industrial firms [17, 40]. Due to the non-commodity nature of such resources (e.g., waste energy and material), price-based techniques are effective neither for initiation nor for operation of such relations. (A similar situation on inapplicability of price-based techniques can be observed in kidney-matching, for example [29, 72].) Thus, realizing such a form of collaboration requires tailored operations-oriented methods for identifying potential matches, evaluating them to generate mutually beneficial instances, implementing cost-sharing schemes in bilateral contracts and decentralized governance of the established relations.[6] We observe, in real-life practices (e.g., see successful cases in the SHAREBOX project [77]), that if firms apply systematically verified decision support tools for making decisions in various phases of industrial symbiosis, the practice is not only a sustainable choice but also a profitable one. In other words, they can evaluate collaborative potentials in a systematic manner. Therefore, we see the potential to build on the line of research on *multiagent industrial symbiosis systems* [94, 95] to support the decision processes for implementing the transition towards a circular economy.

Challenge 6 (Climate Change Policy-Effectiveness Analysis and Conflict-Free Rules). *The need for methods to analyze the effectiveness of policies and develop conflict-free rules.*

To ensure adaptability with CC—in urban, rural, and industrial areas—Agent-Based Modeling (ABM) and simulation techniques are among the most well-established techniques in the CC literature [33]. Despite early attempts in which agents’ decision rules were merely based on economic theories (and sometimes in conflict with the reality of CC scenarios), there is an ongoing trend to inform ABM rules using participatory techniques such as fuzzy cognitive maps and serious games [50, 51, 78]. However, as [6] discusses, this may lead to modeling dilemmas for which novel multi-modal knowledge aggregation and representation tools are required. In particular, to analyze the effectiveness of CC policies, we lack methods able to represent various forms of qualitative and quantitative knowledge as well as reasoning tools to highlight the class of conflict-free ABM rules. For the former, we see that multiagent logic-based knowledge representation models [7, 91] are appropriate and expressive-enough to be tailored for integrating qualitative and quantitative forms of knowledge in CC scenarios. And to address conflict-freeness, integration of methods from multiagent argumentation theory is viable [24, 43, 69].

3 CONCLUDING REMARKS

We introduce MACC research as an interdisciplinary field to foster the application of various multiagent methodologies for climate change mitigation and adaptation (see Figure 1). We would like to highlight differences in the so called *“methodology readiness”* of MAS techniques for addressing CC challenges, e.g., to address Challenge 3–6, MAS techniques have a higher readiness/maturity to be applied in the context of CC (in comparison to those in Challenge 1 and 2). This motivates more work, but not in a serial way (i.e., to build theories, wait for their maturity and then apply them to

[5] This problem refers to cases where a group is responsible for a state of affairs but it is not straightforward to determine the extent of responsibility of each member [22, 47].

[6] Reducing the material and energy footprint of firms is directly linked to sustainability gains and fits their business model with respect to Corporate Social Responsibility (CSR) goals [35]. But the question is: will it result in a sufficient cost reduction to compensate the opportunity costs that firms may face to focus on industrial symbiosis?

Figure 1: Multiagent Climate Change Research (Methodological Subdisciplines and Related Work).

CC). We argue that contextualization should be embedded from the beginning for both micro and macro level coordination techniques (in Challenges 1 and 2).

The next steps are to develop a roadmap for MACC research where we clarify its relations with neighbouring disciplines—e.g., with environmental economics [81, 85], AI for sustainable development [12, 27], and work relating to societal well-being and potential existential risks [9, 31, 38]—and focus on concrete CC problems in which multiagent technologies are applicable.

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