Human Simulation and Sustainability: Ontological, Epistemological, and Ethical Reflections

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Abstract: This article begins with a brief outline of recent advances in the application of computer modeling to sustainability research, identifying important gaps in coverage and associated limits in methodological capability, particularly in regard to taking account of the tangled human factors that are often impediments to a sustainable future. It then describes some of the ways in which a new transdisciplinary approach within "human simulation" can contribute to the further development of sustainability modeling, more effectively addressing such human factors through its emphasis on stakeholder, policy professional, and subject matter expert participation, and its focus on constructing more realistic cognitive architectures and artificial societies. Finally, the article offers philosophical reflections on some of the ontological, epistemological, and ethical issues raised at the intersection of sustainability research and social simulation, considered in light of the importance of human factors, including values and worldviews, in the modeling process. Based on this philosophical analysis, we encourage more explicit conversations about the value of naturalism and secularism in finding and facilitating effective and ethical strategies for sustainable development.

Keywords: computer modeling; human simulation; social simulation; sustainability; development studies; assemblage theory; ontology; epistemology; ethics

1. Introduction

This Special Issue highlights the potential of computational modeling and simulation (M&S) to contribute to research on human–environment interactions. Studying the intricate, multi-dimensional, and nonlinear dynamics that characterize these interactions requires powerful analytic and synthetic tools suited to understanding complex adaptive systems. This article explores some of the challenges and opportunities involved in the computational modeling of sustainability from the perspective of "human simulation," a new transdisciplinary and collaborative approach to M&S, and offers some reflections on philosophical issues surrounding the task of finding and facilitating more ethical, effective, and efficient modes of adaptation and sustainable development in our increasingly pluralistic, globalizing, and ecologically fragile environment.

In the next section, we describe some recent advances in sustainability modeling that use M&S techniques. Here, we are using the term sustainability in a broad sense, inclusive of the wide range of themes and tasks identified in the United Nations' Sustainable Development Goals [1]. Problems related to sustainability may be explored from the perspective of ecological, climate, biological, economic, cultural, or social systems. Here, we explore ways in which M&S can help provide answers to questions about the reciprocal causal relationships between human behaviors and the natural systems within which they are entangled at all these levels. These methodological tools have been growing rapidly

in popularity in the social sciences more broadly [2–4], but their potential relevance for disciplines such as development studies, which are increasingly organized around issues of sustainability [5], has not yet been fully appreciated. In particular, we identify gaps in coverage and associated limits in methodological capability in regard to taking account of human (all too human) factors, biases, and tendencies that are often impediments to a sustainable future. The third section introduces "human simulation," a collaborative approach to M&S that engages subject-matter experts, policy professionals, and stakeholders at all stages of the model construction process (including design, implementation, and dissemination of results). With its explicit inclusion of insights from cognitive science, moral psychology, and a rich variety of human sciences, human simulation opens up new vistas for sustainability research, especially through its use of multi-agent artificial intelligence modeling techniques, which are better capable of incorporating human factors relevant for navigating toward a sustainable future into their computational architectures. The fourth section identifies and discusses some of the key ontological, epistemological, and ethical topics that are raised at the intersection of human simulation and sustainability research, focusing on the values and worldviews that tend to advance or impede sustainability. In this connection, we show how approaching sustainability research through human simulation highlights the positive potential of naturalistic explanations and secularistic strategies in our shared struggle to adapt in the Anthropocene—that is, the current geological age, during which human activity has become a dominant influence on the environment.

2. Advances in Sustainability Modeling

In the broadest sense, all research on sustainability involves modeling—the construction and testing of coordinated concepts and theories that aim to make sense of what is happening (or may happen) in complex social systems. Nobel prize winner Elinor Ostrom, for example, developed an influential theoretical model of the conditions for the sustainability of socio-ecological systems (SESs), in which she put a heavy focus on the complexity and heterogeneity of such systems [6]. Such theoretical models are obviously useful, but in this context, we are interested specifically in computational models based on the formalization of theories such that they can be implemented in computer programs. In fact, Ostrom herself worked with computer scientists to explore the usefulness of agent-based models for analyzing the robustness of SESs [7,8].

There are pragmatic reasons for emphasizing the value of such models for sustainability research. Computational models are uniquely able to express the dynamics of complex adaptive systems, including the behaviors and interactions of agents within the simulated time and space of a virtual ecological environment. Multidisciplinary research teams have developed social simulations aimed at addressing a wide range of societal challenges that affect the sustainability of human groups, including the COVID-19 pandemic [9,10] and the integration of economically, ethnically, and ideologically diverse populations [11]. In this context, we focus on the application of M&S to more classical themes in sustainable development.

Given the potential of M&S approaches, it is not surprising that they were applied relatively early in their development to the task of understanding the conditions under which human societies would remain sustainable in the face of major climate change. The (in)famous Club of Rome system-dynamics models in the 1960s [12], for example, illustrated the limitations as well as the opportunities involved in modeling sustainable futures. Over the decades, the accuracy, explanatory power, and insight-generating capacity of computational models of climate change have increased rapidly [13], as have the diversity of approaches to modeling human–environment interactions that address the growing challenges of the Anthropocene [14–17]. The importance of linking models of human behavior and models of climate has been poignantly brought home by a recent article showing the significant extent to which including social processes (such as shifts in the perception of risk) can alter projections in climate change modeling [18].

This suggests the need for renewed attention to the task of developing models that incorporate the complexity and mutuality of human–environment interactions as we explore the challenges and

opportunities for transitioning toward more sustainable societies. In fact, M&S has been increasingly used in recent years to study sustainability transitions at a variety of scales from one (relatively) stable socio-ecological equilibrium to another. For example, M&S has been employed to study the importance of local communities and the role of local leaders in encouraging or discouraging low-carbon energy transitions [19], and the importance of broader, collaborative, multi-level adaptive strategies for managing regional and international sustainability transitions [20]. Other models have been able to simulate some of the major historical shifts in human civilizational forms, such as the transition from hunter-gathering to sedentary agriculture [21], the transition from pre-Axial to Axial Age civilizations across the globe during the first millennium BCE [22], and the ongoing modern transition from cultures in which supernatural beliefs play a dominant role in maintaining social cohesion to more naturalistic and secular cultures [23].

The academic community is increasingly realizing the potential of agent-based models (ABMs) in particular as a consolidated "bottom-up" multidisciplinary approach for studying the emergence of collective responses to climate change policies and related issues by taking into account both "adaptive behavior and heterogeneity of the system's components" [24] (p. 17). One of the distinctive features of ABMs is the capacity for linking the micro-, meso-, and macro-level factors at work in complex adaptive systems. Appropriately verified and validated ABMs can shed light both on the conditions under which and the causal mechanisms by which social (and other) macro-phenomena emerge from micro-level behaviors and meso-level network interactions. This ability to "grow" social phenomena within artificial societies has led some scholars to refer to such methods as generative social science [25]. Although it is still not uncommon to find system dynamics modeling techniques used to study the sustainability of such systems [26,27], ABMs seem to be gaining ground as the computational methodology of choice especially when the primary purpose of the model is to inform policy discussions in a way that takes human behavior into account.

ABMs have been utilized for research on a wide variety of issues related to the sustainability of social systems, including the way in which: cultures arise, develop, and evolve through time [28], norms emerge and shift within populations [29], cooperation is maintained and enhanced within pluralistic contexts [30], diverse agents impact land-use and land-cover change [31], and different values interact with the treatment of and public attitudes toward refugees [32]. The influential MedLand model links an ABM to a landscape evolution model in order to provide a platform for "experimental socioecology," i.e., a platform for studying the interactions among social and biophysical processes in order to inform decision-making strategies for land-use related to issues such as farming and herding [33,34]. Multi-agent models have also been developed to study other probabilistic causal processes in coupled human and natural systems (CHANS), including how interactions between climate, built environment, and human societies could lead to permafrost thawing in Boreal and Arctic regions, thereby greatly impacting human migratory movements [35]; and how interactions between human decisions and natural systems could lead to the long-term sustainability of forest ecosystems in areas such as north-central Texas [36]. Given the potential of ABM techniques to shed light on the reciprocal relations between human behavior and ecological change, it is not surprising that calls for their use in research on the sustainability of economic systems are increasing [37,38].

A recent state-of-the-art survey of methodologies and models for studying SESs summarized the achievements of the field and articulated persistent challenges, such as the need to represent human decision-making more accurately in light of knowledge from social psychology [39]. Other scholars have called for more precise and formal ontologies in SES models that pay more attention to the pivotal role that human actors play in such systems, which is often underrepresented in SES modeling [40]. One recently proposed framework calls for comparing ways in which different behavioral theories (e.g., rational actor, bounded rationality) impact SES outcomes. This opens up the possibility for "sensitivity analysis of human behavior within a natural resource management context [;] such an analysis enables assessing the robustness of the performance of policy options to different assumptions of human behavior" [41] (p. 33); see also [42]. Understanding such human factors requires special attention to

insights from biological and cultural evolution into the ways in which humans have adapted (and might adapt) to changes in their environment [43]. This is why several of the leading scholars in the application of ABMs to sustainability issues have attempted to develop models with agents who are capable of adapting to (simulated) climate change challenges [44,45] and called for even more behaviorally realistic agent architectures [46].

Most SES models that have explicitly tackled challenges related to sustainability have focused on particular regions and specific policy intervention options such as pastoralist conflict in eastern Africa [47,48], decision-making related to a watershed in Kansas [49], and sustainable practices for grassland consumption in Mongolia [50]. ABMs have also been used to evaluate policies for promoting "climate clubs" oriented toward facilitating cooperation among institutions and states in response to the challenges of the Anthropocene [16,51–53]. Social simulation techniques are increasingly applied in the study of sustainability transitions such as shifts toward low-carbon energy [19,54]. For reviews of other uses of ABMs to address issues related to human adaptation and sustainability, see [17,24,55,56].

This growing interest among sustainability researchers and policy stakeholders in using ABMs and other computational modeling techniques to identify "plausible and desirable futures in the Anthropocene" [57] is obviously good news. Such tools are being used to pursue an "experimental socioecology" that can enhance diverse decision-making strategies in cooperative processes such as land-use [33], to optimize cooperation and information exchange [58], and to facilitate the construction of "future safe and just operating spaces" for human societies [26]. Scholars in this sub-field of M&S are quite aware of the limitations in the use of ABMs to study the sustainability of CHANS or SESs, especially challenges related to verification and validation, but are striving to improve the state of the art [39].

3. The "Human Simulation" Approach

This brief review of the literature documents growing interest in the use of M&S methodologies to address concerns related to our capacity to attain and maintain sustainable human–environment interactions. However, it also suggests that those who engage in this endeavor are faced with at least two major challenges. First, as we have seen, many scholars in this field are acutely aware of the difficulty (and the importance) of constructing more cognitively and sociologically realistic simulated agents and artificial societies in order to take account of the human factors that are important in moving our civilizations toward a sustainable future. Computer modelers have been working on this for decades and several models with relatively psychologically plausible and behaviorally realistic agent architectures have recently been developed for simulating human decision-making in complex environments [41,59,60]. Simulation results from one such "socio-climate" model designed to chart optimal pathways to climate change mitigation suggest that the most efficient route to a reduced peak temperature anomaly is to focus first on increasing social learning (better informing the population about climate change) prior to reducing mitigation costs [61]. However, as the authors of that model acknowledge, their approach assumed homogeneous agents in a socially unstructured artificial society, and they point out the need for new models that involve heterogeneous agents nested in hierarchically complex social structures.

Second, despite extensive efforts in recent decades to engage policy professionals, public stakeholders, change agents, and subject matter experts in the process of model design, simulation implementation, and interpretation of results, there is a broad consensus among computational social scientists that we need to invest more energy into improving our strategies for (and practices in) participatory modeling [27,62–66], including the modeling of CHANS [67,68]. This challenge grows ever more salient as the ethical implications of the development and use of artificial intelligence for human life and social order increasingly become a part of public policy discourse. This is not merely a matter of training simulation engineers to be more sensitive and better able to engage and elicit wisdom from stakeholders, though that will certainly help. It is also about paying attention to the limitations of overly abstract sustainability simulations that seem irrelevant to stakeholders who spend every

day thinking about the complexity of human responses to societal instability in the face of ecological change. In other words, it is about registering within simulation models the very human factors that experts know are crucially important in determining whether or not positive change occurs in our struggle to forge a sustainable future.

The approach outlined and illustrated in *Human Simulation: Perspectives, Insights, and Applications* [69] is intended as a response to these (and related) challenges. The introduction to that volume articulates a transdisciplinary approach that is committed to involving scholars from the humanities and the social sciences, along with subject matter experts, policy professionals, and other stakeholder change-agents in the process of constructing computational simulations that address pressing societal challenges. Human simulation strives to incorporate vital human factors into agent architectures and the artificial societies they inhabit in order to account more adequately for the cognitive and cultural complexity of our species within its models, as well as for the role of actual humans in the ethical production and use of computational models. The overarching vision for the participatory approach in human simulation is depicted in Figure 1.

Figure 1. Components of the human simulation participatory approach.

All of these components are oriented toward understanding and solving societal problems (e.g., cultural integration, religious conflict, pandemics, economic exploitation). The top circle is data, indicating the seriousness with which the human-simulation approach takes the need for empirical validation when modeling for explanatory or forecasting purposes. The upper-right circle represents the wealth of resources that M&S methodologies can bring to the task. The lower-right circle indicates the vital role of subject matter experts (SMEs), including from relevant disciplines in the social sciences and the humanities (even philosophers, as we will see below). The lower-left circle points to the critical role of policy professionals in informing research and translating its results into effective change at the policy level. Finally, the upper-left circle expresses the importance of rigorous engagement with stakeholders and change agents who may not be directly involved in public policy but can create the conditions for sustainable development from the bottom-up. All five components of this approach to problem-solving are crucial within human simulation.

The *Human Simulation* volume offers several methodological chapters as well as substantive examples of collaborative social simulation involving a wide array of disciplines, including the development of more cognitively and sociologically realistic computational models designed to study human phenomena such as cultural integration, ritual participation, religious systems, and empathic cooperation. They also show that not all five components (the outer circles in Figure 1) are equally important in every application of the approach since their relevance depends on the problem and the audience to which a model is directed. Typically, however, the pressing problems associated with modeling sustainability require attention to all five components.

The human-simulation approach has also guided the development of several earlier models that incorporate human values or worldviews and are relevant for studying sustainability. We have found that multi-agent artificial intelligence (MAAI) models, which incorporate more psychologically realistic and socially networked simulated agents than traditional ABMs [70], are particularly useful when factors related to human cognition and culture play a significant role in the target phenomenon. For example, one MAAI model simulated the causal relationship between mortality salience and religiosity within an artificial society whose networked agents had cognitive architectures informed by the literature on terror management theory, and who were confronted by environmental threats (including contagion and natural hazards) to which humans have evolved to react with anxiety [71]. A later model, which incorporated additional variables within the artificial society, further informing the agent architectures with social identity theory and identity fusion theory, was able to simulate the conditions under which—and the mechanisms by which—mutually escalating conflict between religious groups tends to increase (or decrease) in a population [72]. Another MAAI model that utilized the human-simulation approach was able to simulate the expansion of secularism in the populations of 22 countries. Utilizing more psychologically realistic simulated agents in social networks, it was able to "grow" macro-level secularization in artificial societies from micro-level agent behaviors and interactions [73].

All of these models were constructed through extended collaboration among the various kinds of experts described above, following a particular procedure (depicted in Figure 2).
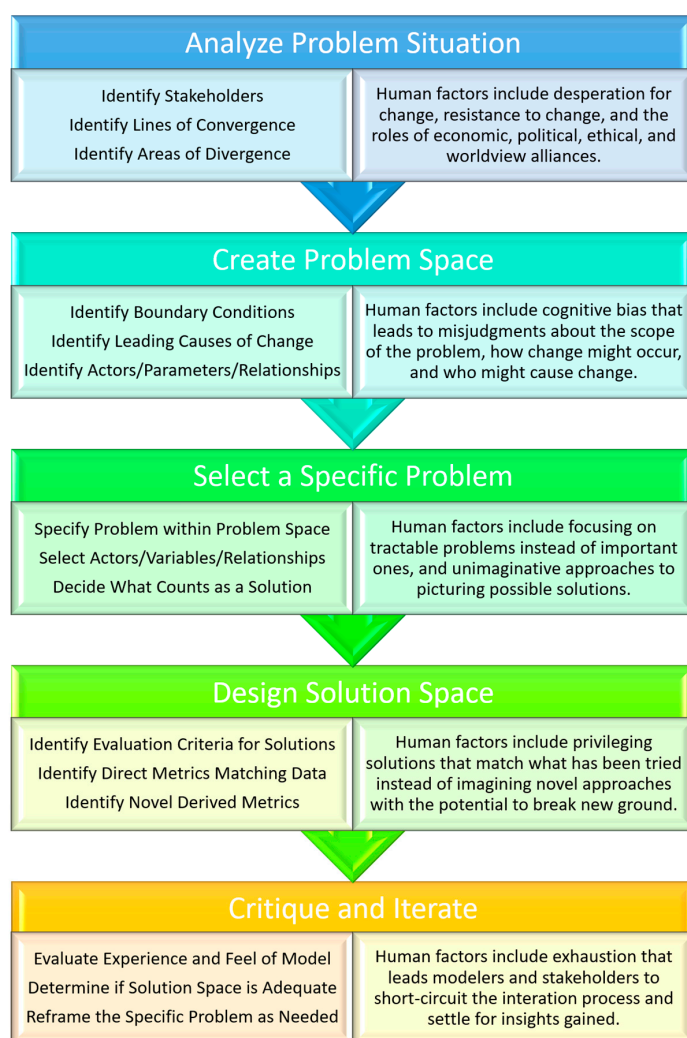

Figure 2. Navigation of insight space in the human-simulation approach.

This procedure involves the navigation of a conceptual and computational model's "insight space," which comprehends both its problem space and its solution space (see [69] for further details). Under each of the steps in Figure 2, key tasks are listed on the left, and examples of human factors that need to be considered are described on the right. Note that these examples of human factors are relevant not only in the insight space of the model but also in the workflow of the modeling team. The human-simulation methodology calls for managing human factors in the modeling *process* with every bit as much energy and creativity as it seeks to incorporate human factors into simulated agent minds and artificial societies.

Ideally, the types of expertise represented in the outer circles of Figure 1 will be included in the key processes related to the design and implementation of models, as well as the dissemination of their results. This makes sense not only because the SMEs, policy professionals, stakeholders, and change agents have the knowledge necessary to help the simulation engineers construct more realistic simulated agents and social networks but also because their participation helps to ensure that the problem and solution spaces are as relevant as possible for addressing real-world societal challenges. The human-simulation approach requires sensitivity and openness on the part of all collaborators, and this sort of experimentation with transdisciplinary teams continues to lead to new insights for participatory modeling [74,75].

4. Ontological, Epistemological, and Ethical Reflections

The human-simulation approach also takes seriously the ontological, epistemological, and ethical issues associated with the process of model development and deployment [69] (p. 11). Many sustainability researchers and M&S practitioners may find this sort of philosophical discussion unfamiliar or even irrelevant. However, we argue that, because human values and worldviews do in fact impact behavior in profound ways, it is worthwhile engaging in philosophical reflection on these issues as part of the process of applying the human-simulation approach to sustainability modeling and informing the discovery of more effective socio-ecological adaptive strategies for transitioning toward sustainable human societies in our current pluralistic and ecologically fragile environment.

One can think of a person's *ontology* as his or her inventory list of existing entities and relationships. Assumptions about what belongs on this list may be more or less implicit, but they shape one's understanding and anticipation of potential causal interactions in the world. Computer modeling forces us to make these assumptions explicit, that is, to articulate the ontologies of the artificial societies we construct [40]. Some scholars in sustainability studies have expressed concern about the relative lack of attention traditionally given in the field to ontology, a lacuna increasingly filled by growing attention to and application of social scientific theories such as "assemblage theory", which make explicit claims about what really exists [76–78]. Assemblage thinking has recently been applied, for example, to the analysis of policies related to promoting sustainability in urban and rural areas [79–81] and to the study of aquaculture and agriculture sustainability [82–84]. Some scholars have even applied the concept of assemblage to the process of sustainability policy formulation and implementation, using phrases such as "response assemblages" [76,85] or "adaptation assemblages" [86,87] to refer to the way in which humans attempt to engage and alter the socio-ecological systems in which they live.

M&S methodologies provide sustainability researchers with tools that encourage and enable a more robust articulation of the ontological (including causal) assumptions that are shaping their hypotheses and predictions. By forcing the breakdown of complex causal processes into component parts, human simulation naturally surfaces assumptions latent within politico-economic practices and renders them subject to more rigorous discussion and critique. Other modelers can substitute alternative assumptions, which could potentially lead to very different outcomes in complex social systems. The formalization of theories of sustainability in computational architectures provides what we might call *artificial ontologies* that can then be tested and validated in relation to empirical data in the real world. The credibility of these ontologies (including the causal relations implemented in the model) depends on the extent to which simulation experiments can generate or "grow" the relevant

macro-level social "wholes" from the local interaction of *micro*-level "parts." We have argued elsewhere that the successful development of MAAI and other simulation technologies lends plausibility to a form of metaphysical *naturalism* involving what philosophers call "weak emergence" (for a fuller statement of this aspect of the argument, see [88]).

Insofar as social simulation through computer modeling can actually generate wholes (e.g., more or less sustainable artificial societies) with emergent properties, tendencies, and capacities that arise solely from the interaction of parts (e.g., physical resources, individual humans), it strengthens the claim that the mechanisms of morphogenesis that explain the causal forces at work in socio-ecological systems are wholly *naturalistic*. The possible implications of these developments for the articulation of a fully immanent metaphysics have been spelled out elsewhere [89,90]. Our point here is that if something goes wrong with the simulation, simulation engineers do not hypothesize a ghost in the machine; rather, they check the code, review the data, and run new simulations. Similarly, in sustainability research, scholars *qua* scholars do not include hypotheses about supernatural entities (such as sea gods, Jesus, or Allah) as potentially responsible for climate events such as hurricanes or tsunamis. In other words, sustainability scholars typically exhibit methodological naturalism: a preference for academic arguments that optimize the use of theories, hypotheses, methods, evidence, and interpretations that do not appeal to supernatural agents. Their causal explanations are only populated with "natural" entities or processes susceptible to empirical analysis such as geological forces, biological organisms, electricity, or climate change.

The success of M&S lends credence to such naturalistic explanations of emergent phenomena. Manuel DeLanda, one of the most well-known developers of "assemblage theory" as well as a computer modeler [91,92], argues that computer simulations "are partly responsible for the restoration of the legitimacy of the concept of emergence [in science and philosophy] because they can stage interactions between virtual entities from which properties, tendencies, and capacities *actually emerge*. Since this emergence is *reproducible* in many computers, it can be probed and studied by different scientists as if it were a laboratory phenomenon. In other words, *simulations* can play the role of laboratory experiments in the study of emergence complementing the role of mathematics in deciphering the structure of possibility spaces. Furthermore, *philosophy* can be the mechanism through which these insights can be synthesized into an emergent *materialist* world view that finally does justice to the creative powers of matter and energy" [92] (p. 6), emphases added.

For DeLanda, assemblage theory is not only explicitly tied to metaphysical naturalism [93] but also to epistemological insights linked to computer modeling and simulation [92]. We can think of a person's *epistemology* as his or her assumptions, again more or less implicit, about what counts as knowledge and how to acquire it. As is the case in all scientific disciplines in the contemporary academy, sustainability researchers and computer modelers are usually methodologically *secularistic* as well as methodologically naturalistic. By methodologically secularistic, we mean that they (as scholars) have a preference for academic practices that optimize the use of scholarly strategies that are not tied to the idiosyncratic interests of a religious coalition. This includes not making appeals to supernatural authorities to defend their knowledge claims. Most scientists assume (while doing science) not only that the ontological components and explanatory causes in their theories are naturalistic but also that the best way to acquire knowledge is through scientific methods that are not dependent on supernatural revelation or the religious authorities of any specific ingroup. While not all scientists live up to this ideal, the secular academy generally values arguments based on evidence that is accessible to any research group across cultures, and not only to those who believe in the supernatural revelation of a particular religious coalition. At least in part, this valuation is based on the fact that methodological secularism has funded the most productive and progressive research programs in science.

The processes by which M&S practitioners clarify, calibrate, verify, and validate the scientific knowledge, hypotheses, and theories formalized within their computational architectures through simulation experiments render their methodological secularism more explicit. What we might call the *artificial epistemologies* built into explanatory computer models are also tested and validated in

relation to empirical data in the real world. Given the complexity of socio-ecological systems and the diversity of challenges related to achieving the UN Sustainability Development Goals (SDGs), we agree with the call by Sonetti et al. for a "transdisciplinary epistemology" that includes insights from the humanities as well as the natural and social sciences within sustainability research [94]. As we noted in Section 3, commitment to such an epistemology is at the heart of the human-simulation approach. However, Sonetti et al. also briefly allude to the papal encyclical *Laudato Si*, which they argue promotes an attitude of humility rather than domination and sets up "a sort of democracy of all God's creatures" [94] (p. 11). They do not point out that this encyclical is based on unfalsifiable assumptions about disembodied supernatural entities, knowledge of which can only be allegedly acquired and authorized by imaginatively engaging in the causally opaque rituals led by authorized officers of a particular religious ingroup. While allusions to supernatural authorities might feel inspiring to members of some religious coalitions, it is hard to see what epistemological relevance they have for the increasingly urgent task of finding efficient strategies for adapting to the Anthropocene and pursuing the SDGs here and now. At best, they can engender the support of religious-coalition members for sustainability initiatives articulated and tested within the scientific domain.

However, accommodating supernaturalist epistemologies within the scientific discourse about sustainability could be problematic for other reasons. Empirical research from a wide array of disciplines that contribute to the bio-cultural study of religion has shown that cognitive and coalitional biases related to supernatural worldviews *interfere* with sustainability movements, even when their proponents intend to help, by promoting superstitious beliefs and segregative behaviors that exacerbate rather than ameliorate the deleterious psychological and socio-economic conditions and can promote intellectual obstruction and moral paralysis in the face of globally relevant societal challenges such as climate change [95–103]. Supernatural beliefs and the ritual behaviors associated with them likely played a crucial role in helping humans survive in early ancestral environments, but today they have become maladaptive. Attempting to debunk claims about the existence or causal relevance of supernatural agents is not likely the best strategy here, not only because such claims cannot be definitively disproven (only rendered less plausible) but also because such attempts typically activate confirmation biases and other forms of motivated reasoning that only makes things worse. These are some of the all-too-human factors that impede change and need to be incorporated into computational simulations. As social psychologists and policy-oriented climate scientists are discovering, prebunking strategies that attempt to inoculate individuals against misinformation and superstitious reasoning are more likely to succeed [104].

Thinking about ontology and epistemology may be fun (for philosophers at least), but what ought we to *do* about all this? This brings us to the importance of ethical reflection before, during, and after the process of developing computer models and experiments in human simulation. We can describe a person's *ethics* as his or her assumptions, more or less explicitly articulated, about what (if any) moral dispositions or behaviors are normative or commendable. Sustainable adaptation to the challenges of the Anthropocene, as well as success in achieving the SDGs, will require the widescale emergence of norms and behaviors that promote global sustainability, many of which do not come naturally to most members of our species. We humans are not "rational actors" who calmly calculate utility functions. On the contrary, our moral reasoning is surreptitiously shaped by cognitive and coalitional biases that all too easily activate superstitious inferences, ingroup preferences, and other biases of the sort that promote resistance to naturalistic scientific explanations of (and secularistic policies for responding to) sustainability crises. This is why it is important to incorporate insights from the sciences of bio-cultural evolution about our phylogenetically inherited moral equipment into the ethical (and metaethical) frameworks that guide reflections around the design and implementation of, as well as the dissemination of results from, human-simulation modeling [105].

As the potential (and actual) impact of artificial intelligence (AI) on human life becomes increasingly clear, computer modelers, philosophers, and others are highlighting the importance of discussions about *artificial ethics*. The approach to human simulation described above is heavily invested in

these debates. In fact, the focus on MAAI modeling and other social simulation techniques can help bring a distinctive focus on artificial *social* ethics into the conversation [106]. By constructing and validating "digital twins" of real-world societies, populated by simulated agents and groups with divergent and changing norms, *multi-agent* AI can provide tools for testing hypotheses about the impact of policy proposals and environmental changes on human social behavior. In fact, whether or not one accounts for the actual divergent norms within the pluralistic cultures one is attempting to model has a significant effect on the outcomes of social simulation experiments [107]. This is why the human-simulation approach puts so much attention on minding morality, that is, on incorporating variables such as shared norms and divergent worldviews into the computational architectures of artificial societies [11,108].

Ethical reflection on the application of human simulation to sustainability research is tied to the issues related to naturalism and secularism discussed above. We illustrate this briefly with reference to Rumy Hasan's transdisciplinary analysis of *Religion and Development in the Global South* [109]. As Hasan notes, "adherence to religious doctrines is necessarily in tension with cognitive thinking . . . Criticism, curiosity, critiquing, hypothesizing, theorizing, experimentation and the search for evidence all appear to be suppressed or discouraged" (p. 198). The capacities and skills of contemporary human populations are linked to the presence (or absence) of naturalistic education about the actual (non-supernatural) causal mechanisms at work in the world. Hasan concludes that high levels of religious beliefs in the Global South suppress the capacities and skills needed for sustainable development and exacerbate conflict, a claim that is widely supported in the relevant literature [110–113].

The extent to which our ontological, epistemological, and ethical reflections have explicitly highlighted the value of methodological naturalism and secularism in sustainability research, and explicitly criticized the obstructive effects of "religion," may come as a surprise. The goal here has not been to provide a comprehensive philosophical argument designed to compel scholars to take a more aggressive public posture against supernaturalist worldviews and the unsustainable parochial behaviors they promote, though it should be obvious that we think doing so might be a condition for finding and implementing more effective adaptation strategies in the Anthropocene. We have confined ourselves here to the more limited claim that there are at least some good reasons to include philosophical reflection about issues such as metaphysical naturalism and secularism as part of broader conversations among computer modelers, sustainability researchers, and the wider public.

5. Conclusions

We began this article by sketching some recent developments within the application of computer modeling to sustainability research, noting the pressing need to take better account of human factors. We went on to describe some of the ways in which the "human simulation" approach can contribute to the further advancement of sustainability modeling, especially through its emphasis on stakeholder, policy professional, and subject matter expert participation and its focus on constructing more realistic cognitive architectures, both of which help to facilitate the incorporation of human factors (such as values and worldviews) into the modeling process. Finally, we offered some philosophical reflections on the ontological, epistemological, and ethical issues raised at the intersection of sustainability research and computer simulation. We stressed the importance of having more explicit conversations about the relevance of metaphysical naturalism and secularism in finding and facilitating effective and efficient strategies for sustainable development.

Like all methodologies, computational tools and techniques have their limitations. However, we have attempted to show some of the reasons for hoping that the application of human simulation within sustainability research will continue to be increasingly useful for the purpose of analyzing and forecasting changes in socio-ecological systems as we attempt to respond to the challenges of the Anthropocene.

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