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Agent-Based Modeling of Sustainable Behaviors

Springer

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Preface

Sustainability is a broad field, encompassing different aspects from technological, business, economic, environmental, and social sciences (among others), aiming at finding ways for humans to live more harmoniously with their environments, preferably without prejudicing the opportunities for humans in the future to do so. One of the most pressing issues at present is the potential of anthropogenic greenhouse gas emissions to increase global mean temperatures to a point where there are larger regions on Earth with unsuitable habitats for wildlife and/or poor-quality agricultural land. There are other issues around depletion of natural resources more generally (e.g., water, soil, biodiversity, phosphorus, and fuels), not to mention issues beyond purely environmental concerns, such as the provision of energy, jobs, growth, equality of opportunity, and ensuring human lifestyles themselves are psychologically enjoyable.

Sustainability is important because, by definition, our future depends on it. With a widespread perception that our lifestyles are currently unsustainable, finding ways to live more sustainably is critical to our future: we cannot maintain our quality of life as human beings, the diversity of life on Earth, or Earth's ecosystems unless we embrace it. It should be a priority in civil planning, environmental consultancy, agriculture, economics, corporate strategies, health assessment and planning, law, and politics. Understanding and striving for sustainability will pave the way for active and effective policies in environmental protection, while allowing for social and economical development.

Sustainability is complex because it can be perceived within different contexts, such as environmental, social, psychological, and economic [1]. These contexts could include the sustainability of economic sectors, ecosystems, countries, municipalities, neighborhoods, worker behavior patterns, transportation, private life patterns, and lifestyles. Fundamentally, sustainability is a problem involving humans making decisions. As such, studies of environmental sustainability issues can no longer ignore the human factor: there are now very few (if any) "pristine" ecosystems unaffected by human activity. Environmental sustainability is therefore a question bound by other issues influencing human behavior: such as prosperity, comfort, expectations, and governance.

The Industrial Revolution set a historical starting point for the connection between economic growth and environmental degradation, at least in terms of carbon emissions, which are observed to rise significantly from 1850 onward. Indeed, many of the global environmental problems we face today are associated with efforts to increase prosperity and improve the human condition (better healthcare, food security, shelter, and mobility), appearing with and to a large extent enabled by the Industrial Revolution. It was the beginning of major technological transitions from the use of hand tools to power tools and ultimately high technology enabling production on very large scales and robust economic development. However, we are now in the position that if we would like to maintain our lifestyles, we need to put technology, economy, and social sciences to work toward balancing human development and welfare and the needs of the environment, while also addressing the challenges posed to that balance of population growth and technological progress. If we are to develop a sustainable society, we must be willing to reexamine the conceptual foundation upon which our currently unsustainable society is built.

Traditional quantitative modeling of human behavior has, of necessity, relied on assumptions of human reasoning and access to information that those in the social sciences who study real humans have disputed. The supposed rift in the social sciences between qualitative and quantitative strands has led to skepticism about the ability of the social sciences to contribute meaningfully to studies in the natural sciences that are increasingly recognizing the need to include human behavior in the system. Once, calculus was all we had to model systems. However, the exponential growth of computational power over the past few decades has meant that it is now feasible to build simulations of social systems representing individual humans and their interactions with each other and their environment. These simulations need not rely on making assumptions for the sake of simplicity [2] or on studies of the conditions prevailing under equilibria that are never reached.

Interestingly, the simulation of human behaviors in computers has evolved separately from disillusioned economists experimenting with new ideas. Artificial intelligence (AI) has been preoccupied with this for several decades and, particularly in its early years, drew heavily on psychology for inspiration [3]. Many in the agent-based community now draw on, or are inspired by, AI architectures used to represent human decision-making and planning, not least of which include beliefs-desires-intentions [4–7], case-based reasoning [8–10], and other more general rule-based systems. That said, it is not uncommon to find agent-based modelers using simple heuristic rules or even utility maximization (though usually under conditions of limited information).

However human decision-making is simulated, developing the means by which we can explore scenarios under which people live more sustainably is arguably an urgent task, especially when more traditional approaches are simply not capable of addressing the social complexity of the transition. In particular, the concepts of "path dependence" in complex systems and "non-ergodicity" in dynamical systems mean that the doors to various visions of sustainable futures [11–14] could even now be being closed.

The purpose of this book is to gather together the latest work on simulating sustainable behaviors using agent-based modeling. Different applications of sustainability related with interesting areas as transportation, traffic management, and agricultural sustainability are also explored.

Programs that are effective in changing people's behaviors are to be promoted in order to make a graceful transition to a more sustainable future. Unfortunately, education and/or campaigns alone cannot be expected to change the individual behaviors, as various studies have already found [15–17]. Lack of knowledge and unsupportive attitudes are two possible barriers to adopting more sustainable behaviors and lifestyles, but there are also others to be accounted for, such as cultural practices, social interactions, and human feelings. In the chapter by Schaat et al., the authors describe two models for agent-based social simulations (ABSS), Consumat and SiMA-C, as a means of incorporating psychological and social factors in agent behavior. The authors examine work related to the use of ABSS in the study of sustainable behaviors. The chapter includes a review of Consumat as a tool for evaluating the influence of social policies on the adoption of sustainable behaviors. The chapter also includes a detailed explanation of the inner workings of SiMA-C and provides an example of its use in studying sustainable behaviors. Finally, it elaborates on the influence of psychological factors on decision-making in SiMA-C.

By contrast, the two chapters by Sánchez-Maroño et al. and Polhill et al. use decision trees as a supposedly transparent way to model the agents' decision-making in a project working with field researchers in environmental psychology. Their model, of everyday pro-environmental behavior in the workplace, is primarily aimed at demonstrating how data from appropriately designed questionnaires on sustainable behaviors can be used in a model to simulate the dynamics of norms. The first of the two chapters describes the processes used to derive the decision trees, comparing various methods and exploring the differences obtained. The work described in the second chapter not only suggests that different pro-environmental behaviors respond to different norms in different ways, it also argues that the topology of the social network has an effect on how norms work. The implications of this for traditional social science would be that reports of the effects of norms in a population under study should be accompanied with an account of the social network. For empirical agent-based modeling, it also means that social network topology is important data when constructing the model. The work demonstrates how agent-based modeling can collaborate with more traditional social sciences for the mutual benefit of both disciplines.

Household behavior is one of the most pertinent areas to study, as environmental pressure from households is projected to significantly increase by 2030 [18]. Better understanding of the relationships between policies implemented by governments and household decisions will improve guidance to policy makers on effective and efficient environmental policies, while addressing social concerns. One of the areas affected is waste management, as policies in this area have been successful in diverting increasing amounts of valuable materials from landfill, reducing associated environmental impacts. Despite this success, waste management is still anticipated to be a major challenge in the coming decade. Aside from various policy instruments, the literature on waste generation and recycling [19, 20] examines the role of sociodemographic, attitudinal, and contextual characteristics in households' decisions over waste management activities. Other issues still to be explored or expanded upon include whether there are interaction effects between policy variables and sociodemographic and attitudinal attributes; if there are such effects, it is important for policy makers to be aware of how and to what extent household and community characteristics can influence the success or failure of different policies. The chapter by Scalco et al. is devoted to the problem with waste. According to the authors, the increasing complexity of current non-recycled waste treatment makes waste prevention the most desirable outcome. In such a framework, recycling household waste becomes crucial, as it would both reduce waste and save resources. Household behavior is integral to the success of a recycling program. This chapter presents theoretical concepts related to recycling behaviors such as social norms and integrates them into a computational approach by formalizing, in this case, the theory of planned behavior. The resulting agent-based model is used to investigate the determinants of recycling behavior, focusing on the question of what is needed to encourage more of it.

The European Commission has launched a program for employment and social solidarity, aimed at contributing to the achievements of EU 2020 goals in employment, social affairs, and equal opportunities area [21]. Other countries, such as Japan or the USA, have similar programs to help employers find qualified applicants with disabilities, enforcing laws in the latter country by the Equal Employment Opportunity Commission [22]. There is an enormous employment gap between disabled population and nondisabled population that varies between 20 and 40 % in some countries, while is much larger, around as much as 80 %, in others. Thus, as disability benefit expenditures also tend to rise in the most developed economies, governments should converge toward activation policies that could ensure transitions to open labor markets that can promote people with disabilities. If disability policies are adequately designed, they can contribute to social inclusion and sustainable employment opportunities. The chapter presented by López Barriuso et al. introduces an innovative agent-based platform that uses 3D models of the environment to perform accurate simulations. This platform is specifically oriented toward facilitating the integration of people with disabilities in the workplace. The chapter is mainly focused on the description of the platform including specific sections about the locating infrastructure, the agent-based model and the environment. Two case studies are presented to demonstrate the technical and conceptual validity of the platform: one based on an environment of dependent people and the other dealing with an emergency situation.

The current transportation scenario leaves much room for improvement in several aspects regarding efficiency, safety, costs, and sustainability, as transportation accounts for approximately 25 % of total greenhouse gas emissions in the European Union. While emissions from other areas have been decreasing in general, those from transport continued to rise until 2008, when transport emissions started to decrease due to oil prices, increased efficiency of passenger cars, and slower growth in mobility. Despite this more recent decreasing, in 2012, transport emissions were still 20.5 % above 1990 levels and would need to fall by 67 % by 2050 in order to meet the 2011 Transport White Paper target reduction of 60 % compared to 1990. Among other measures, intelligent vehicles and traffic management is one development in personal transportation that is expected to make travel safer, more cost effective, and greener. Three chapters in this book describe research efforts in this area. The sustainability benefits of such systems could be significant, improving transportation safety, reducing traffic congestions, avoiding and reducing traffic accidents, increasing energy efficiency, and decreasing greenhouse gas emissions. The chapter by Jeffery Raphael et al. describes the application of ABM to optimizing traffic signal timings, by modeling critical elements such as vehicles and traffic control devices as autonomous agents. In this application, the MAS paradigm offers a flexible and inexpensive method for modeling the stochastic nature of the problem, allowing different models to be tested, which are then easier to maintain and scale in a real situation. Specifically, traffic control is modeled as a coordination problem, using actions to achieve coordination among traffic signal agents. One of the main characteristics of the proposed approach is that the authors propose an auction-based controller that does not need a vehicle agent. Experimental results under different traffic conditions demonstrate the interest of the proposal.

The chapter by Martin Schaefer et al. describes AgentDrive, a platform that supports development and testing of new coordination algorithms for intelligent vehicles in various levels of abstraction. As the platform is agent based, it allows the possibility of managing heterogeneous agents in any scenario. Besides a high-level description of the architecture of the platform, scalability properties are highlighted, as they are necessary for simulation of real traffic conditions. In addition, in this work, the platform is used for developing a lane-changing assistant technology, with experimental results enabling safer and swifter lane changing than the traditional non-coordinating approaches. The chapter by Francesco Barile et al. focuses on the problem of city parking and describes an automated system where software agents negotiate between the supply side and demand side of the parking allocation problem. A simulation of the automated negotiation system is presented, and notable aggregate social welfare benefits are found to be associated with its implementation. Understanding and managing the dynamics of parking is clearly an important issue for city managers in terms of allocating a scarce resource (parking places). Moreover, from a sustainability perspective, efficient allocation reduces emissions and air pollution, and also systems such as the one described here may have considerable utility in the design of future transportation systems which may incentivize, for example, car pools or shared ownership schemes.

In farming, new and more efficient farming methods will allow farms to consolidate, transforming the old models of ownership and exploitation to achieve gains in agricultural productivity and economic efficiency, with the help of government policies and technological tools. Although sustainable farming operations are site specific, individualistic, and dynamic, some general underlying characteristics of successful sustainable agricultural operations are beginning to emerge from diverse experiences. Using these characteristics, we can understand how to organize and manage sustainable farms. The chapter by Navarrete Gutiérrez et al. describes the application of a combined model, using agent-based model (ABM) and a life cycle assessment (LCA) to simulate the evolution of the agricultural system of the Grand Duchy of Luxembourg under different conditions given by policy-driven actions. On the one hand, the goal of the ABM is to represent the farmers via agents that take decisions about the crops that will be planted on their farms and the associated rotation schemes to be applied in order to maintain the health of the soil. The model provides as output the changes in land use arising from exogenous drivers, in terms of hectares of land planted with each crop. The ABM model is used to estimate the volume of agricultural commodities produced by the farmers at a given time under certain policy-driven scenarios. On the other hand, the LCA is employed to quantify the environmental impacts of these products across their whole life cycle. The LCA measures the environmental consequences, at a global scale, of different decisions made by farmers. This methodology can provide, as outputs, different levels of mid-point and end-point environmental assessments. These assessments could be a valuable tool to inform farmers on the potential impact of their activities.

The sector of energy production and management has become an important pillar for social and economic progress in modern societies. Recently, with the emergence and growth of smart grids, energy management systems have become more complex, but on the other hand, they provide a huge potential for the optimization of the energy consumed and produced. This allows the creation of new systems that boost sustainable energy management. The chapter by Lopes et al. presents the application of an agent-based software system to simulate the negotiating process of bilateral contracts between the main participants of the electricity markets (generating companies, retailers, etc.). Moreover, a risk-preference concession-making strategy was also included in the process. The agents, pursuing a predefined strategy, are able to prepare offers and counteroffers, according to different levels of risk attitude, in order to reach mutually beneficial agreements. Finally, the chapter presents a case study aiming to analyze the role of contracts for difference (CFD) as a financial tool to prevent price volatility.

On a similar topic, the chapter by Klaimi et al. presents an approach based on a multi-agent system and intelligent storage systems for energy management and control in smart grids, by balancing electric power supply and minimizing energy bill, while considering residential consumers' preferences and comfort levels. The aim of the system is to point to more responsible energy consumption while establishing lower contract prices. The proposal introduces in the smart grid four types of agents: the grid agent, the storage agent, the prosumer agent, and the consumption agent. They must control generation, load, and storage assets primarily from the outlook of power flows. Furthermore, the energy management system is split into two layers: the proactive layer and the reactive layer. The first one is responsible for the prediction of energy production and consumption. The second one is responsible for planning and negotiating consumption at shorter periods and helps to buy energy with a minimal cost. Finally, the approach has been evaluated in a simulated scenario using JADE.

As has been observed in other introductory materials to edited publications of applications of agent-based modeling to complex issues [23], the flexibility of the agent-based modeling approach in terms of the diversity of domains to which it can meaningfully be applied is ably demonstrated by the contributions to this book. One obvious observation, perhaps, is the lack of standardization in the approaches to developing the agent-based model. Though this, perhaps, is an inevitable consequence of applying agent-based models to such a diversity of fields, it is a matter that will need to be addressed if agent-based modeling is to become more established as a tool for analysis and development of robust policies aimed at transitioning societies to more sustainable futures. A key aspect of this is in building the means for the various stakeholders in a model to have confidence in the results it shows. Various chapters take a different approach to this, from the formalization of established social theory to the use of transparent, data-driven decision-making algorithms for the agents. However, in all agent-based models, a matter of notable significance is what might be termed their "ontological realism." The explicit representation of the important actors and processes in a system, without recourse to oversimplifying assumptions for the sake of analytical tractability, is an important strength of agent-based modeling. It is this that facilitates dialogue both with qualitative social scientists skeptical of traditional quantitative approaches and policy makers and stakeholders who are looking for hard facts and quantified uncertainty. In the field of sustainability research, such dialogue is essential in bringing about the sustainable future we all so desperately need.

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