A Bibliometric Review of Agent-Based Models Application in Economics

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Abstract. *Agent-based modeling and simulation (ABMS) is a computational modeling technique that has been used in various fields of science with growing interest. In economics, ABMS has been used to model a wide range of systems, from financial markets to transportation systems. The goal of this paper is to explore the usage of agent-based modeling and simulation in economics, using bibliometric analysis techniques on data from Web of Science platform. The authors collected data on ABMS usage in economics for over five thousand papers from Clarivate Analytics Web of Science databases in terms of publishing frequency, journal bibliometric data, field of application and productivity by country for the period 2000-2022. Journals with highest productivity within this topic are The Journal of Artificial Societies and Social Simulation, Physica A-Statistical Mechanics and its Applications, and PLOS ONE.*

Keywords. agent-based, modeling, simulation, economics, bibliometric analysis.

1 Introduction

The sheer volume of data available today is staggering, leading to the rapid development of statistical learning techniques. These techniques can be used to describe phenomena, draw conclusions, and create decision-making models. In order to yield the most of the data, more sophisticated methods of data analysis, like machine learning and statistical learning, are increasingly employed. Machine learning models can be used in combination with agent-based models to gain insights into data. This combination is particularly powerful because it allows for the modeling of complex systems with large amounts of data. The use of machine learning models in combination with agent-based models has been applied in various fields such as finance, transportation, and healthcare (Zornić & Marković, 2022).

Agent-based models (ABM) are a type of computational model that simulate the behavior of complex systems by breaking them down into individual agents that interact with each other and their environment. Each agent is characterized by specific attributes and follows a set of rules that govern its behavior. Agents can be programmed to have different levels of autonomy and decision-making capabilities, which allows for the modeling of a wide range of systems, from simple to highly complex. Researchers are using ABMS to analyze policy and resource usage changes in agriculture (Berger, 2001), distributed energy resource management for intelligent microgrids (Kumar Nunna & Doolla, 2013), exploring the impact of shared autonomous vehicles on urban parking demand (Zhang et al., 2015), analyse telecommunication company churn (Zornić & Marković, 2022), etc.

In 2008, Jean-Philippe Bouchaud (Bouchaud, 2008) argued that the financial crisis demanded a change in attitude in economics and financial engineering, emphasizing data and plausible but not exact arguments over axioms that were taken as unquestionable. Farmer and Foley, also advocated for the need of agent-based modeling in economy (Farmer & Foley, 2009). In “The End of Theory: Financial Crises, the Failure of Economics, and the Sweep of Human Interaction” Rick Bookstaber outlines four issues of human experience that conventional economics is not equipped to adequately address (Bookstaber, 2017).

The first issue is computational irreducibility. Computational irreducibility is a concept in computer science that refers to the inability to reduce the behavior of some systems to a mathematical description that would provide a way to predict its future behavior without having to simulate and observe the system in action. This poses a challenge to economists who need to be able to predict the outcomes of economic systems using analytical methods.

The second issue is emergence. Emergence occurs when the collective result of individual actions is qualitatively different from the actions of each individual. This means that one cannot predict the outcome of the entire system based on the behavior of

its members, as the overall system has properties that its components do not have.

The third issue is non-ergodicity. Non-ergodicity is a concept in statistical mechanics where a single trajectory does not reflect an isolated system as a whole, and the past does not necessarily determine the future. This is in contrast to ergodic processes, which follow the same probabilities today as they did in the past and will in the future.

The fourth issue is radical uncertainty. Radical uncertainty is defined as a surprise outcome or event that cannot be put into a probability distribution because it is outside of what is expected to occur. It is distinguished from risk, which can be calculated, by the fact that it is impossible to know all the information needed to calculate the odds. Through ABMs, it is possible to determine properties and patterns that could not be predicted by observing the individual agents due to the complexity of their interactions. According to Wooldridge and Jennings (Wooldridge & Jennings, 1995), a computational agent is an entity that is independent, socially capable, reactive, and proactive in its interactions with the environment in order to meet its objectives.

Economists use simulation methods to study economic dynamics due to the challenges posed by computational irreducibility, emergence, non-ergodicity, and radical uncertainty. Agent-based modeling and simulation (ABMS) is a computational modeling technique that has been increasingly used in economics due to its ability to create detailed, realistic models of a system. ABMS allows researchers to explore the behavior of complex systems and understand their emergent properties.

Bibliometric analysis is a method of exploring research activities and findings through data from research publications. Multiple bibliometric studies regarding ABMS can be found in literature. Some of them are focused mostly on ABMS (Niazi & Hussain, 2011), and others are focused on ABMS usage in specific field, like modeling COVID-19 pandemic (Tang et al., 2022), marketing (Romero et al., 2023), organization management (Wu et al., 2023), construction (Khodabandelu & Park, 2021), and economics (Zehra & Urooj, 2022).

Although Zehra and Urooj (2022) already conducted the bibliometric analysis of agent-based modeling in economics, they used SCOPUS database and collected information about 1,568 documents. The goal of this paper is to explore the usage of agent-based modeling and simulation in economics, using bibliometric analysis techniques using the data from Web of Science platform.

After outlining the need for agent-based modeling and simulation in economics, the paper is organized as follows. A methodology used for data collection and analysis is presented in section 2. A bibliometric review of ABMS application in economics is presented in section 3, including journals and citation analyses, and research area and keywords trends analyses. Finally, conclusions and some visions for the future research are provided in section 4.

2 Methodology

Data is collected from the Web of Science platform (Clarivate Analytics, 2022) (all sources), using the following search configuration (Zornić et al., 2023):

(TS = (agent-based OR individual-based OR multi-agent OR multiagent OR ABM) AND TS = (model* OR simulat*))*
AND TS = (econom)*
Indexes = Web of Science Core Collection
Timespan = All years

Data is collected for 5,426 scientific papers. For the sake of analysis 5,347 papers published in period 2000-2022 were selected. Data contains information such as authors, titles, source titles, publication year, keywords, categories, times cited.

Data is analyzed using descriptive statistics and aggregated results are presented. Additionally, citation network analysis is conducted using Gephi software.

Gephi is an open-source software for network visualization and analysis. It is mainly used for visualizing, manipulating, and exploring networks and graphs from raw edge and node graph data. It uses a 3D render engine to display large graphs in real-time and to speed up the data exploration (Bastian et al., 2009).

3 ABMS and Economics in Literature

Bibliometric analysis geared towards a review of literature productivity and an observation of the trends in agent-based modeling and simulation application in economics is presented in this section of the paper.

Figure 1 presents the trend in number of papers published yearly, starting with 19 in 2000, rising to 466 in 2020, and dropping to 431 in 2022. Popularity of specific scientific domain is known to be based on its number of citations (Niazi & Hussain, 2011). This can be observed in Figure 2. It should be noted that number of citations in the last two years is expected to be lower, as those papers are just published.

We also identified most popular papers, based on number of citations: “Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change” is taking the first place with 891 citations (Kremen et al., 2007); “An economic approach to social capital” is in second place with 685 citations (Glaeser et al., 2002); “Review on modeling and simulation of interdependent critical infrastructure systems” is in the third place with 648 citations (Ouyang, 2014).

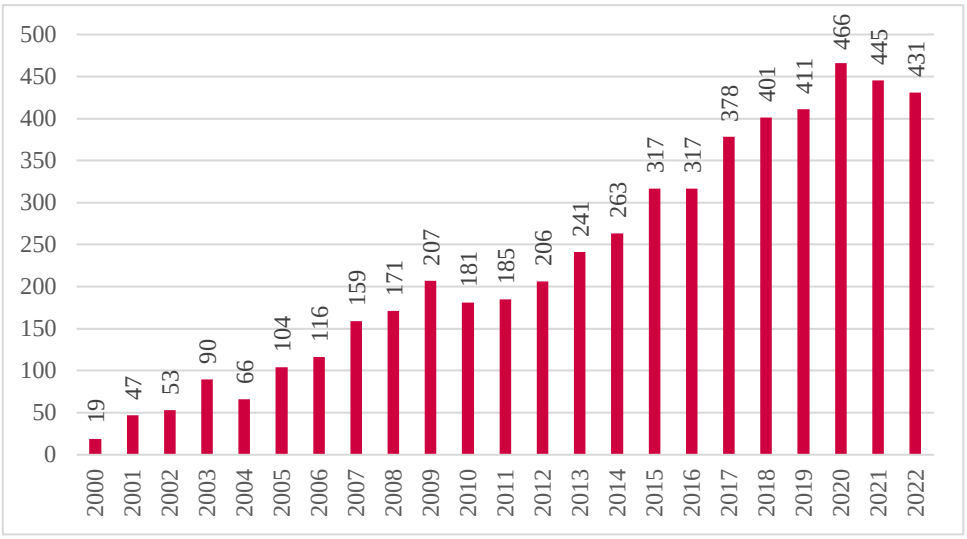

Figure 1. Papers published per year

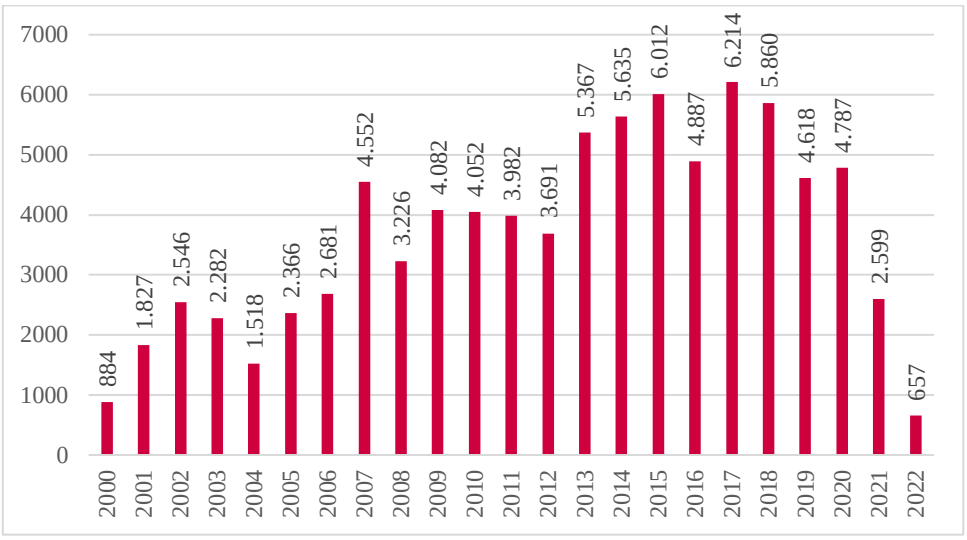

Figure 2. Number of citations per year

3.1 Journals and Citations Analyses

Those 5,347 papers are published in 2430 sources, including journals and conference proceedings. Table 1 presents 18 journals with at least 20 papers with ABMS and economics in topic.

The top contributor is *The Journal of Artificial Societies and Social Simulation* with 120 papers published, followed by *Physica A: Statistical Mechanics and its Applications* and *PLOS ONE*. Since its first issue in 1998, *Journal of Artificial Societies and Social Simulation* has been one of the leading references for readers interested in social simulation and the application of computer simulation in the social sciences (Marković & Zornić, 2016). In addition to journals that are expected to be on the list, journals specialized in Simulation and Modeling, and Economics (*Journal of Artificial Societies and Social Simulation, Journal of Economic Interaction and Coordination, Computational Economics, Journal of Economic Dynamics & Control, Journal of Evolutionary Economics, Journal of Economic Behavior & Organization*, etc.), there are journals specialized in other scientific fields, like: Ecology (*Ecological Modelling* and *Environmental Modelling & Software*), and other multidisciplinary jorunals. Table 1 also reports impact factor (IF), IF without journal self-citations, and percentage of change in IF after the self-citations have been excluded. Data about journals and IF is collected from Clarivate Analytics Journal Citation Reports (Clarivate Analytics, 2023). We can see that the journal with the highest IF is *Applied Energy* (11.20), while the journal with the highest decrease in IF after the self-citations were excluded is *Energies* (-21.88%). We can also see that all listed journals have IF higher than 1. The lowest IF has *Journal of Economic Interaction and Coordination* – 1.10, dropping to 0.90 when self-citations are excluded.

Table 1. Journals accounting for at least 30 papers with ABMS and economics in topic

Journal	Papers	Journal IF (2022)	IF Without Journal Self Cites (2022)	% IF Change Without Self Cites
JASSS-THE JOURNAL OF ARTIFICIAL SOCIETIES AND SOCIAL SIMULATION	120	4.20	3.80	-9.52%
PHYSICA A-STATISTICAL MECHANICS AND ITS APPLICATIONS	75	3.30	3.00	-9.09%
PLOS ONE	71	3.70	3.50	-5.41%
JOURNAL OF ECONOMIC INTERACTION AND COORDINATION	59	1.10	0.90	-18.18%
COMPUTATIONAL ECONOMICS	58	2.00	1.70	-15.00%
SUSTAINABILITY	54	3.90	3.10	-20.51%
JOURNAL OF ECONOMIC DYNAMICS & CONTROL	53	1.90	1.70	-10.53%
JOURNAL OF EVOLUTIONARY ECONOMICS	53	1.80	1.70	-5.56%
JOURNAL OF ECONOMIC BEHAVIOR & ORGANIZATION	51	2.20	2.00	-9.09%
JOURNAL OF CLEANER PRODUCTION	49	11.10	10.10	-9.01%
APPLIED ENERGY	46	11.20	10.00	-10.71%
ECOLOGICAL MODELLING	44	3.10	2.90	-6.45%
ENERGIES	43	3.20	2.50	-21.88%
ECOLOGICAL ECONOMICS	42	7.00	6.60	-5.71%
ENVIRONMENTAL MODELLING & SOFTWARE	41	4.90	4.50	-8.16%
IEEE ACCESS	34	3.90	3.60	-7.69%
JOURNAL OF STATISTICAL MECHANICS-THEORY AND EXPERIMENT	31	2.40	2.10	-12.50%
ENERGY POLICY	30	9.00	8.50	-5.56%

Additional analysis of citations is conducted using network visualization and exploration software Gephi (Bastian et al., 2009). Total citation count for the selected journals has been collected from the Clarivate Analytics Journal Citation Reports (Clarivate Analytics, 2023) for the period until 2022. The obtained results are displayed in **Error! Reference source not found.**, where node size is determined by the number of papers with ABMS and Economics in topic. For example, it is noticeable that *The Journal of Artificial Societies and Social Simulation, Physica A-Statistical Mechanics and Its Applications*, and *PLOS ONE* have the highest number of papers. The weight of the line is defined as the sum of percentages of citations acquired from the other observed journal. For example, *Ecological Economics* got 2572 citations from *Sustainability* and has 36,381 citations in total, which means *Ecological Economics* got 7.07% of citations from *Sustainability*. In the other direction, *Sustainability* got 43 citations from *Ecological Economics* and has 187,953 citations in total, which means *Sustainability* got 0.11% of citations from *Ecological Economics*.

The weight of line is determined by the sum of these percentages (7.07% + 0.11%). The size of the arrow is defined separately for each side in a similar manner. Similarly, we can analyze the remaining connections between journals.

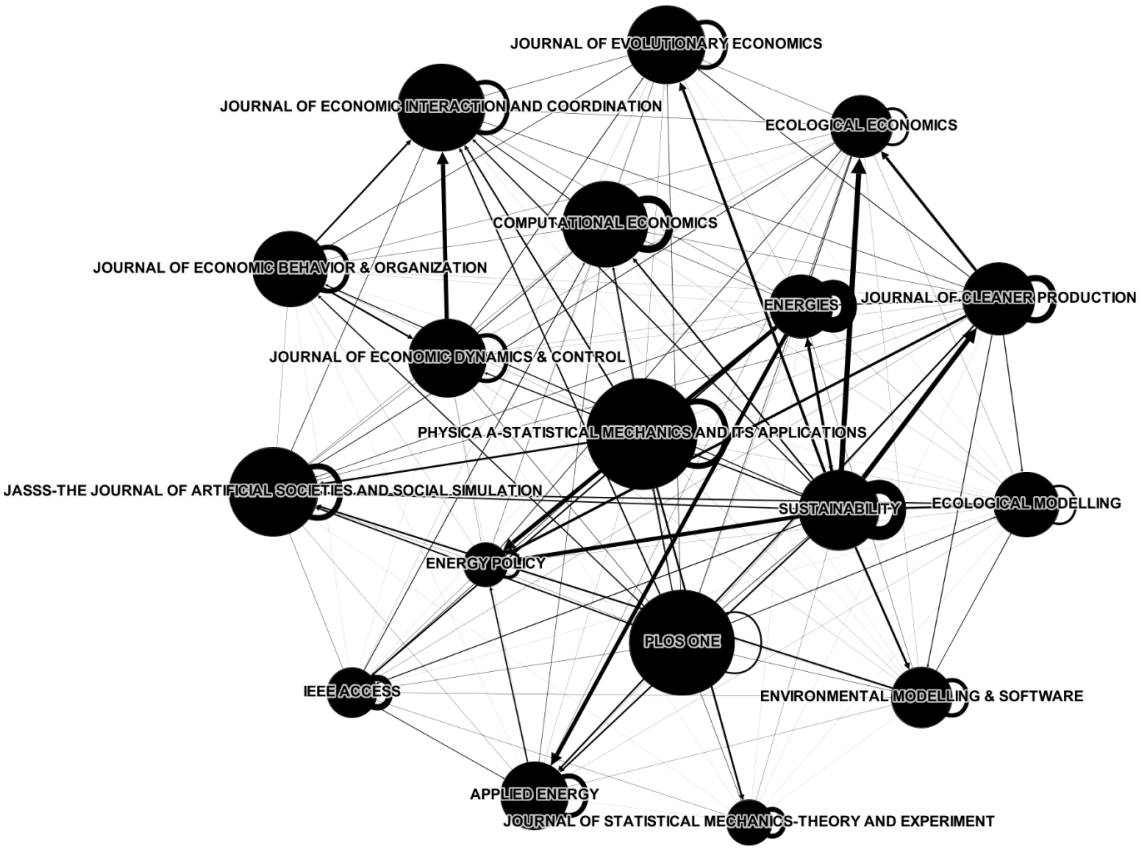

Figure 3. Network of citations among selected journals

3.2 Categories and Countries Analyses

Analyzing the categories in which ABMS are applied we can provide one more evidence that ABMS are used for modeling various economic problems. Data have been retrieved from Web of Science (Clarivate Analytics, 2022). Table 2 presents the most popular Web of Science categories for the papers with ABMS and economics in topic (with at least 100 papers). As expected, the first two are directly related to economics and ABMS. Engineering Electrical Electronic and Environmental Sciences are following, together with different categories of Computer Sciences.

Table 2. Most popular Web of Science categories for papers with ABMS and economics in topic

Web of Science Categories	Count
Economics	881
Computer Science Artificial Intelligence	693
Engineering Electrical Electronic	612
Environmental Sciences	475
Computer Science Interdisciplinary Applications	461
Computer Science Theory Methods	461
Computer Science Information Systems	429
Energy Fuels	343
Environmental Studies	309
Automation Control Systems	250
Operations Research Management Science	249
Mathematics Interdisciplinary Applications	246
Management	240
Ecology	227
Multidisciplinary Sciences	224
Green Sustainable Science Technology	216
Social Sciences Interdisciplinary	208
Engineering Environmental	158
Computer Science Software Engineering	148
Water Resources	146
Business	139
Telecommunications	130
Physics Multidisciplinary	129
Mathematics Applied	127
Engineering Industrial	115
Engineering Civil	110
Transportation Science Technology	107
Geography	106

We also analyzed the Web of Science KeyWords Plus (Table 3). KeyWords Plus is a feature in Clarivate databases that uses an algorithm to identify words or

phrases that frequently appear in the titles of an article's references, but not in the title of the article itself. Disregarding the expected ones (such as *model, dynamics, systems, simulation*, etc.), other keywords are describing the field of application (such as *Management, Economics, Market*, etc.).

Table 3. Most popular Web of Science KeyWords Plus for papers with ABMS and economics in topic

Web of Science Keywords Plus	Count
MODEL	498
DYNAMICS	348
MANAGEMENT	295
SYSTEMS	291
SIMULATION	281
BEHAVIOR	209
ECONOMICS	191
MODELS	189
IMPACT	177
OPTIMIZATION	172
GROWTH	143
EVOLUTION	135
DESIGN	125
SYSTEM	121
FRAMEWORK	118
MARKET	116
POLICY	113
CLIMATE-CHANGE	108
NETWORKS	108
RISK	106
DECISION-MAKING	105
LAND-USE	100

In Table 4 the most productive countries using ABMS in economics are observed (with at least 100 papers). USA and People's Republic China are leading the way accounting for over 40% of total papers published. Five European countries are following (England, Germany, Italy, France, Netherlands) with another 40% of total papers published. Here should be noted that one paper can be accounted for two or more countries (based on author affiliation).

Table 4. Countries with at least 50 papers with ABMS and economics in topic

Countries/Regions	Count
USA	1227
PEOPLES R CHINA	825
ENGLAND	527
GERMANY	500
ITALY	402
FRANCE	367
NETHERLANDS	296
AUSTRALIA	251
CANADA	212
SPAIN	192
JAPAN	180
RUSSIA	149
AUSTRIA	124
BRAZIL	122
SWITZERLAND	116
INDIA	95
PORTUGAL	89
SCOTLAND	83
SOUTH KOREA	82
SWEDEN	79
IRAN	74
TAIWAN	72
POLAND	71
DENMARK	66
CZECH REPUBLIC	65
SINGAPORE	61
BELGIUM	58
SOUTH AFRICA	50

4 Conclusion

In this paper, agent-based modeling and simulation application in economics is reviewed. The comprehensive bibliometric data has been collected and analyzed, including publishing trend, bibliometric analysis of most productive journals, research category, keywords and productivity by country. Bibliometric journal analysis includes IF, IF without journal self-citations, and citation network analysis.

This paper presents bibliometric analysis conducted using information from Web of Science platform about 5,347 scientific papers. Similar study can be found in literature, where authors presented bibliometric analysis of 1,568 documents from SCOPUS database.

We can conclude just at a glance that ABMS usage in economics is growing with the course of time, from 19 papers published in 2000, this number increased to 438 in 2022. Journals with highest productivity within this topic are The Journal of Artificial Societies and Social Simulation, Physica A-Statistical Mechanics and its Applictions, and PLOS ONE, while the most productive countries are USA, and People's Republic China, followed by European countries England, Germany, Italy, France, and Netherlands.

This paper presents a basis for the future research of most influential authors in the field of using agent-based modeling and simulation in economics, as well as systematic review of most influential papers.

References

Bastian, M., Heymann, S., & Jacomy, M. (2009). Gephi: An Open Source Software for Exploring and Manipulating Networks. Proceedings of the International AAAI Conference on Web and Social Media, 3(1), 361–362. https://doi.org/10.1609/icwsm.v3i1.13937

Berger, T. (2001). Agent-based spatial models applied to agriculture: a simulation tool for technology diffusion, resource use changes and policy analysis. Agricultural Economics, 25(2–3), 245–260. https://doi.org/10.1111/j.1574-0862.2001.tb00205.x

Bookstaber, R. (2017). The End of Theory: Financial Crises, the Failure of Economics, and the Sweep of Human Interaction. Princeton University Press.

Bouchaud, J.-P. (2008). Economics needs a scientific revolution. Nature, 455(7217), 1181–1181. https://doi.org/10.1038/4551181a

Clarivate Analytics. (2022). Web of Science. https://apps.webofknowledge.com

Clarivate Analytics. (2023, June 30). Journal Citation Reports.

Farmer, J. D., & Foley, D. (2009). The economy needs agent-based modelling. Nature, 460(7256), 685–686. https://doi.org/10.1038/460685a

Glaeser, E. L., Laibson, D., & Sacerdote, B. (2002). An Economic Approach to Social Capital. The Economic Journal, 112(483), F437–F458. https://doi.org/10.1111/1468-0297.00078

Khodabandelu, A., & Park, J. (2021). Agent-based modeling and simulation in construction. Automation in Construction, 131, 103882. https://doi.org/10.1016/j.autcon.2021.103882

Kremen, C., Williams, N. M., Aizen, M. A., Gemmill-Herren, B., LeBuhn, G., Minckley, R., Packer, L., Potts, S. G., Roulston, T., Steffan-Dewenter, I., Vázquez, D. P., Winfree, R., Adams, L., Crone, E. E., Greenleaf, S. S., Keitt, T. H., Klein, A.-M., Regetz, J., & Ricketts, T. H. (2007). Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change. Ecology Letters, 10(4), 299–314. https://doi.org/10.1111/j.1461-0248.2007.01018.x

Kumar Nunna, H. S. V. S., & Doolla, S. (2013). Multiagent-Based Distributed-Energy-Resource Management for Intelligent Microgrids. IEEE Transactions on Industrial Electronics, 60(4), 1678–1687. https://doi.org/10.1109/TIE.2012.2193857

Marković, A., & Zornić, N. (2016). Trends in the Application of Agent-Based Modeling and Simulation. Central European Conference on Information and Intelligent Systems, 65–70.

Niazi, M., & Hussain, A. (2011). Agent-based computing from multi-agent systems to agent-based models: a visual survey. Scientometrics, 89(2), 479–499. https://doi.org/10.1007/s11192-011-0468-9

Ouyang, M. (2014). Review on modeling and simulation of interdependent critical infrastructure systems. Reliability Engineering & System Safety, 121, 43–60. https://doi.org/10.1016/j.ress.2013.06.040

Romero, E., Chica, M., Damas, S., & Rand, W. (2023). Two decades of agent-based modeling in marketing: a bibliometric analysis. Progress in Artificial Intelligence. https://doi.org/10.1007/s13748-023-00303-y

Tang, J., Vinayavekhin, S., Weeramongkolkul, M., Suksanon, C., Pattarapremcharoen, K., Thiwathittayanuphap, S., & Leelawat, N. (2022). Agent-Based Simulation and Modeling of COVID-19 Pandemic: A Bibliometric Analysis. Journal of Disaster Research, 17(1), 93–102. https://doi.org/10.20965/jdr.2022.p0093

Wooldridge, M., & Jennings, N. R. (1995). Intelligent agents: theory and practice. The Knowledge Engineering Review, 10(02), 115–152. https://doi.org/10.1017/S0269888900008122

Wu, J., Ohya, T., & Sekiguchi, T. (2023). Applications of agent-based modeling and simulation in organization management: a quarter-century review through bibliometric mapping (1998–2022). Computational and Mathematical Organization Theory. https://doi.org/10.1007/s10588-023-09381-8

Zehra, A., & Urooj, A. (2022). A Bibliometric Analysis of the Developments and Research Frontiers of Agent-Based Modelling in Economics. Economies, 10(7), 171. https://doi.org/10.3390/economies10070171

Zhang, W., Guhathakurta, S., Fang, J., & Zhang, G. (2015). Exploring the impact of shared autonomous vehicles on urban parking demand: An agent-based simulation approach. Sustainable Cities and Society, 19, 34–45. https://doi.org/10.1016/j.scs.2015.07.006

Zornić, N., & Marković, A. (2022). A methodological framework for the integration of machine learning algorithms into agent-based simulation models. JUCS - Journal of Universal Computer Science, 28(5), 540–562. https://doi.org/10.3897/jucs.73924

Zornić, N., Marković, A., & Avramović, N. (2023). Agent-Based Models in Economics: A Review of Applications. Work in Progress Paper Presented at Challenges of Europe 2023 Conference.