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Research Article

A Review of Three Decades Using Agent-Based Modelling and Simulation in Marketing and Consumer Behavior

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Abstract

Agent-based modelling and simulation (ABMS) is one of the topics which has been extensively studied by researchers in the field of marketing and consumer behaviour. However, no such analysis has been conducted on using Agent-based modelling and simulation in marketing and consumer behaviour. An extensive bibliometric analysis, as well as a thorough visualization and science mapping, was carried out in this field from 1995 to 2022, in response to capturing recent ABMS development in this field. A total of 1210 documents from the WOS and Scopus databases were analyse d using bibliometrix R-Tool and VOS viewer. The results showed the 20 documents with the most citations were in the area of energy consumption (55%) and innovation diffusion behaviour (20%). The USA has the most publications in this field, with the production of 188 documents. The "EXPERT SYSTEMS WITH APPLICATIONS" is a productive journal publishing in this field. Generally, the major journals that publish research on the use of ABM in marketing and consumer behaviour are multidisciplinary or interdisciplinary. 6 clusters were identified based on the analysis of the most frequent keywords: Cluster 1 (multi-agent systems and consumer behaviour), Cluster 2 (agent-based simulation and SCM), Cluster 3 (ABM and energy consumption), Cluster 4 (AMB and innovation diffusion), Cluster 5 (complex system and Simulation) and Cluster 6 (ABM and TAM). Prediction is one of the goals that has attracted the most attention of ABMS researchers among many goals such as optimization, description, self-organization, and adaptability, and there are many recent works in this field. These results show that many topics that were of interest in the past, such as the ontology of ABMS, are no longer of much interest to researchers, and the attention of researchers has been directed toward issues such as the diffusion of innovation, energy consumption, and pricing in recent years. This topic can determine the appropriate approach for other researchers to research in this field.

Keywords: Agent-Based Modelling and Simulation, Marketing, Consumer Behavior, Science Mapping***. Fuzzy***

1. Introduction

Agent-based modelling is and simulation (ABMS) known as a modelling and simulation technique capable of modelling complex systems composed of interacting autonomous 'agents' (Segovia et al., 2022). Agents are autonomous decision-making units with diverse characteristics (heterogeneous) (Ringler et al., 2016). Agents interact with other agents, which affects their behavior, and have behaviors that are frequently described by simple rules. (Castro et al., 2020). Agents can learn, adapt, and reproduce (Rand & Rust, 2011). Agent-based models include rule-based agents that interact dynamically. The systems in which they interact can create complexity similar to that found in the real world. By modelling the agents individually, it is possible to observe all the effects of the diversity that exists between the agents in their attributes and behaviors, as this translates into the behavior of the system as a whole (North et al., 2010).

In this method, modelling is done at the level of the individual or small entities with the ability to make decisions, and according to the communication and interaction of these small entities, behaviors emerge at the level of the entire system (Gilbert, 2019). This system can be a society that consists of small entities or an industrial system that consists of other interconnected components (Gilbert, 2019).

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ABMS has been used in various fields such as recovery and purchase behavior (Roozmand et al., 2011), marketing (Rand & Rust, 2011; Rand & Stummer, 2021), finance and economics (Axtell & Farmer, 2022; Segovia et al., 2022; Zehra & Urooj, 2022), supply chine management (Rahman et al., 2021), and more. Features such as heterogeneity, bottom-up perspective, non-linearity, learning agent, and complex system approach, caused to ABMS has developed rapidly in management and business studies over the past two decades (Zehra & Urooj, 2022).

Agent-based modelling of marketing and consumer behavior is one of the topics which has been widely studied by researchers (Rand & Stummer, 2021). Consumers' behavior is known as a complex social system that consists of heterogonous entities with different decision-making capabilities that create macroeconomic society-level behavior as a result of inter-individual interactions (Roozmand et al., 2011).

In recent decades, to better understand this phenomenon, agent-based modelling, as a powerful analytical technique, has been widely used to model marketing and consumer behavior. Hence, as the applications of ABMS increase in this area of research, making a thorough review of this research area is important and necessary.

Although there are a few review articles on this topic (for example, (Gómez-Cruz et al., 2017; Kiesling et al., 2012; Negahban & Yilmaz, 2014; Rai & Henry, 2016; Rand &

Stummer, 2021; Zenobia et al., 2009; Zhang & Vorobeychik, 2019), these studies are used qualitative approaches. Unlike traditional qualitative reviews, there exist more relevant and modern quantitative techniques that can be used to conduct systematic literature analysis successfully. To the best of our knowledge, this aspect has not been examined by examined studies on agent-based modelling in marketing and consumer behavior. Hence, the current study conducts a comprehensive systematic review and bibliometric analysis to provide an overview of publication trends, productive articles, authors, journals, and countries. The bibliometric analysis review of research aims to extend the prior reviews by mapping the evolution of applications of ABMS in marketing and consumer behavior from 1995 to 2022. A thorough review of past studies in this area provides a roadmap for researchers interested in using this powerful analytical technique. As a result, the current study addresses these research gaps by answering five research questions (RQs):

RQ1. What is the growth trajectory and scientific publication trend in using ABMS in marketing and consumer behavior studies?

RQ2. What are the most productive journals, documents, authors, and countries in using ABMS in marketing and consumer behavior studies?

RQ3. What are the conceptual structures of using ABMS in marketing and consumer behavior studies?

RQ4. What are the emerging and promising topics in using ABMS in marketing and consumer behavior studies?

RQ5. What is the thematic map (Motor Themes, Developed and Isolated Themes, Emerging or Declining Themes, and General/Basic Themes) in using ABMS in marketing and consumer behavior studies in the periods studied?

2. Methodology

The synthesis of the results of previous studies is one of the most important methods of knowledge discovery (Zehra & Urooj, 2022). This study carried out a bibliometric analysis to analyze current research trends and discover emerging research topics in the field of using ABMS in marketing and consumer behavior studies. Bibliometric analysis is a systematic interdisciplinary approach that it uses mathematical and statistical methods to analyze scientific publications (Lamba et al., 2023). This method evaluates the most influential contributors of scientific research (e.g., authors, journals, documents, and countries) and visualizes the network among sources, authors, and keywords (Al Mamun et al., 2022). Also, this technique can explore the dynamics of the conceptual structure of a research field, and reveals the topics related to specific and foreseen emerging trends of a given file to provide rich information to readers (Jiang et al., 2019; Marcal et al., 2021; Niu et al., 2021).

Since Web of Science core collection (WOS) and Scopus database are complements and overlapping (Echchakoui, 2020), this study relies on the use of both databases to gather information on authors, journals, documents, and countries related to the use of ABMS in marketing and consumer behavior research. They are useful online scientific publication assistants that contain scholarly documents and research papers that it recommended by most bibliometric researchers having a wider coverage of scientific documents across all disciplines. To develop the analysis, the metadata of two databases (WOS and Scopus) was retrieved and merged by the use of bibliometrix R-Tool.

The search framework used in this review was informed by the "preferred reporting items for systematic reviews and meta-analysis" (PRISMA) guideline (Rethlefsen et al., 2021). Figure 1 shows four steps of this guideline such as identification, screening, eligibility, and inclusion.

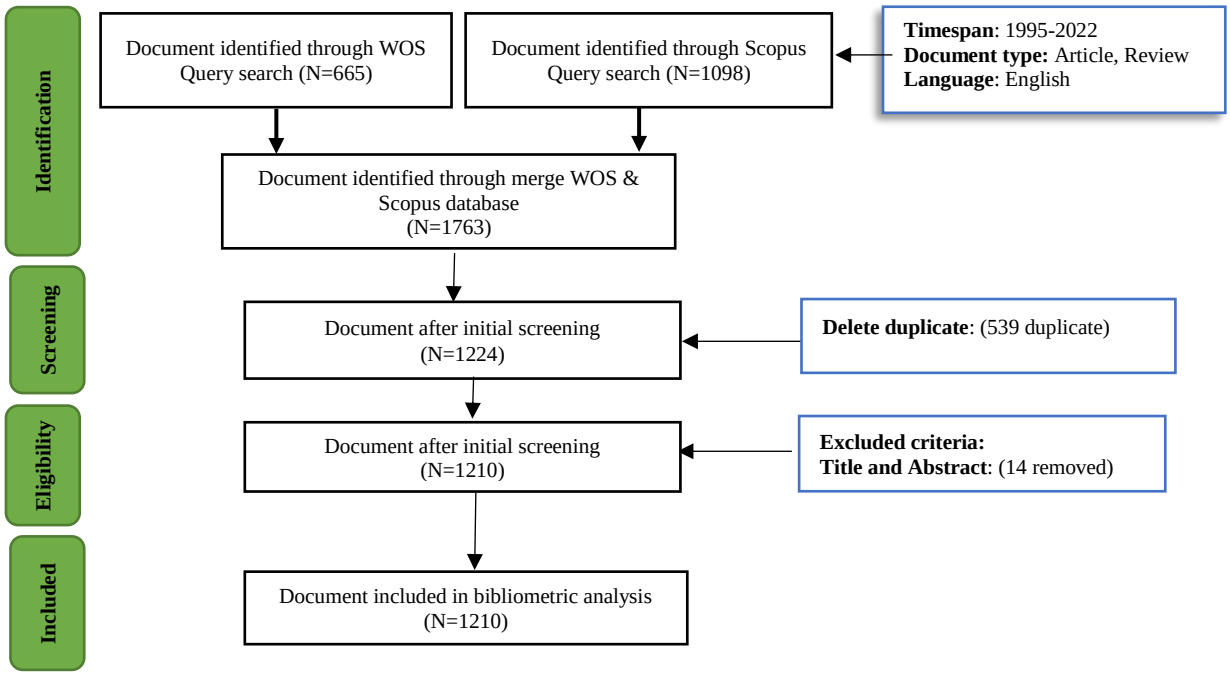


Fig. 1. PRISMA diagram outline using ABMS in marketing and consumer behavior studies search outcomes from the WOS and Scopus databases

In order to identify all publications in association with this field, a search string was created based on a preliminary assessment of prior literature. Hence, a suitable combination of keywords "Agent-Based Model*", "Multi-Agent System*", "Agent-Based Simulation*", "Multi-Agent model*", Marketing", "advert*", "purchase* behavior*", "Consumer* behavior*" and "Customer* behavior*" in TOPIC (title, abstract and keywords) used by employing conditional operators OR, AND & NOT.
The first phase of the work identified 665 and 1098 articles and reviews indexed in WOS and Scopus, from 1995 to the end of 2022 in English, respectively. The merged global database and after deleting duplicate items (539 documents duplicate) 1224 distinctive studies published were identified. Also, 14 studies were removed by title and abstract. Therefore, 1210 scientific documents (articles and reviews) are included in this study.
These analyze s were conducted using Bibliometrix, an RStudio package (Aria & Cuccurullo, 2017; Derviş, 2019; Moral-Muñoz et al., 2020), and enabled presenting the conceptual, social, and intellectual structures of the research field. Bibliometric networks are also built and visualized using the VOSviewer software. It is a free application for creating bibliometric networks (Van Eck & Waltman, 2010).

3. Results and Discussion

Two sections describe the findings. In the first section, a performance evaluation of the distribution of studies published over the years is done and then examined within the scope of other headings like author, journal, document, and country. In the second section. The main themes of using ABMS in marketing and consumer behavior literature are outlined as cluster analysis. This section also uses a thematic map (strategic diagram) to illustrate these themes and examine how the evaluation of various topics in this field changed over time.

3.1 Performance evaluation

The descriptive statistics were conducted to answer the RQ1: "What is the growth trajectory and scientific publication trend in using ABMS in marketing and consumer behavior studies?" by reviewing two databases (WOS & Scopus). The statistical summary of the studies is reported in Table 1.

Table 1
Statistical Summary

Description	Results
"Timespan"	1995-2022
"Sources (Journals, Books)"	613
"Documents (Article, Review)"	1210
"Annual Growth Rate %"	14.78
"Average citations per document"	20.33
"Authors"	2906
"Authors of single-authored documents"	108
"Single-authored documents"	118
"Co-Authors per document"	3.15
"International co-authorships %"	14.21

The total number of scientific documents (articles and reviews) that were published from 1995 through 2022, in English in WOS and Scopus is 1210. These documents received 20.33 citations on average. The higher average number of citations per document indicates that scholarly research on the use of ABMS in marketing and consumer behavior is expanding quickly.
The results also showed that 2906 unique authors have contributed to the use of ABMS in the marketing and consumer behavior field in this period including 108 documents as single-authored. In addition, less than 10 % of documents have one author (118 documents) on average, 3.15 authors contributed to complete each document. International co-authorship in this field is 14.21. Collaboration between two or more authors from different nations to complete a scientific article is referred to as international co-authorship. The yearly publication trend of the studies on using ABMS in marketing and consumer behavior from 1995 to 2022 is shown in Figure 2. The findings indicate that the annual growth rate is 14.78 % representing the increase of scientific documents in this field over time

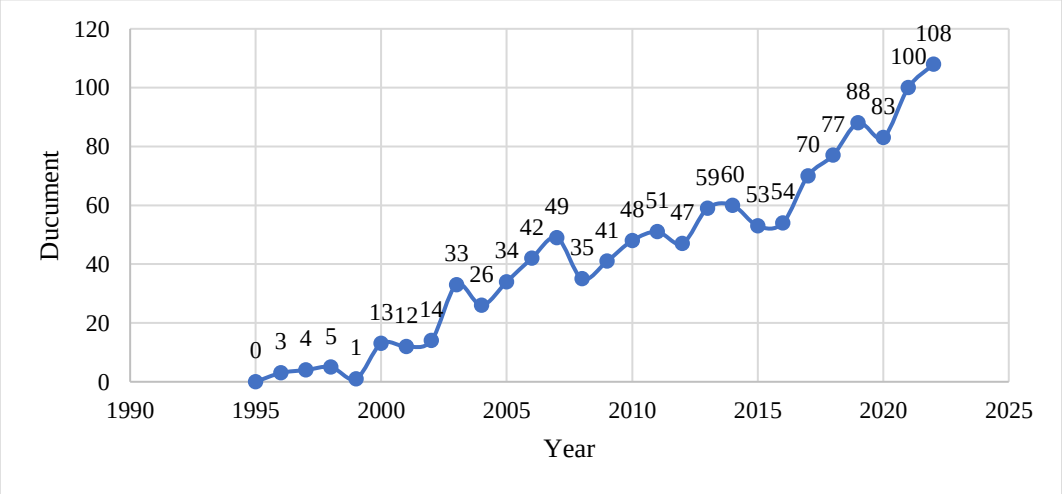


Fig. 2. Annual scientific production in using ABMS in marketing and consumer behavior studies (1995-2022)

To answer the RQ2- "What are the most productive journals, documents, authors, and countries in using ABMS in marketing and consumer behavior studies?"- The frequency distribution of authors, journals, documents, and countries productive in using ABMS in marketing and consumer behavior studies was extracted. Tables 2 to 5 show the performance of the top 20.

Table 2
Most Relevant Sources

Rank	Sources	N. Articles
1	EXPERT SYSTEMS WITH APPLICATIONS	30
2	IEEE ACCESS	20
3	JASSS-THE JOURNAL OF ARTIFICIAL SOCIETIES AND SOCIAL SIMULATION	19
4	PHYSICA A: STATISTICAL MECHANICS AND ITS APPLICATIONS	19
5	ENERGIES	18
6	DECISION SUPPORT SYSTEMS	17
7	ENERGY POLICY	17
8	PLOS ONE	16
9	EUROPEAN JOURNAL OF OPERATIONAL RESEARCH	15
10	INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH	15
11	TECHNOLOGICAL FORECASTING AND SOCIAL CHANGE	15
12	SUSTAINABILITY	14
13	INTERNATIONAL JOURNAL OF PRODUCTION ECONOMICS	12
14	JOURNAL OF CLEANER PRODUCTION	12
15	APPLIED ENERGY	10
16	JOURNAL OF BUSINESS RESEARCH	10
17	AUSTRALASIAN MARKETING JOURNAL	8
18	COMPLEXITY	8
19	IEEE TRANSACTIONS ON SMART GRID	8
20	INFORMATION SCIENCES	8

The results show that "EXPERT SYSTEMS WITH APPLICATIONS" had the highest contribution in this domain. Also, about a quarter of the documents in this field were published by the top 20 journals. In contrast, 426 journals (70% of journals) published just one article in this field.

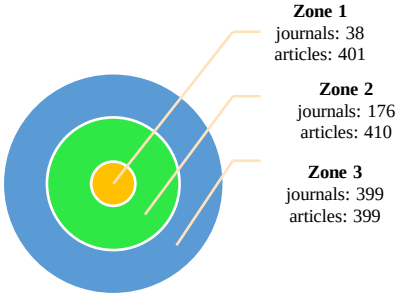


Fig. 3. source by Bradford Law Zones

Bradford's law-based source distribution frequency is depicted in Figure 3 showing three zones for each subject area. The journals that are most frequently cited in the related literature presented in Zone 1 are most likely to be of interest to discipline-specific researchers. About one-third of the documents in the core journals (the 38 journals) of the inter-collection are published. The Final third (Zone 3 or tail) is made up of a long tail of journals receiving few citations and are considered of marginal importance to the topic.

3.1.1. Journals Performance Evaluation

Table 2 shows the top 20 journals on the field of using ABMS in marketing and consumer behavior. The articles from this study were published in 613 distinct journals.

Although the major journals where the documents are published are significant and extremely fascinating for the analysis of a topic, a temporal component is also important to identify journals that have recently published content on the searched topic because the analyzed data often come from very long archival periods. It is shown in Figure 4 for the top 10 journals based on the number of publications. The results show that "EXPERT SYSTEMS WITH APPLICATIONS" is a significant contributor to the entire publications from 2001 to 2022.

3.1.2. Documents Performance Evaluation

In Table 3, a list of the most 20 cited articles of all time on using ABMS in marketing and consumer behavior is presented. The most influential articles are "Innovation diffusion and new product growth models: A critical review and research directions," published by PERES R in 2010 in INT J RES MARK, has received 35.07 total citations per year, and "The merit-order effect: A detailed analysis of the price effect of renewable electricity generation on spot market prices in Germany" published by SENSFUSS in 2008 in ENERG POLICY, has received 505 total citations.

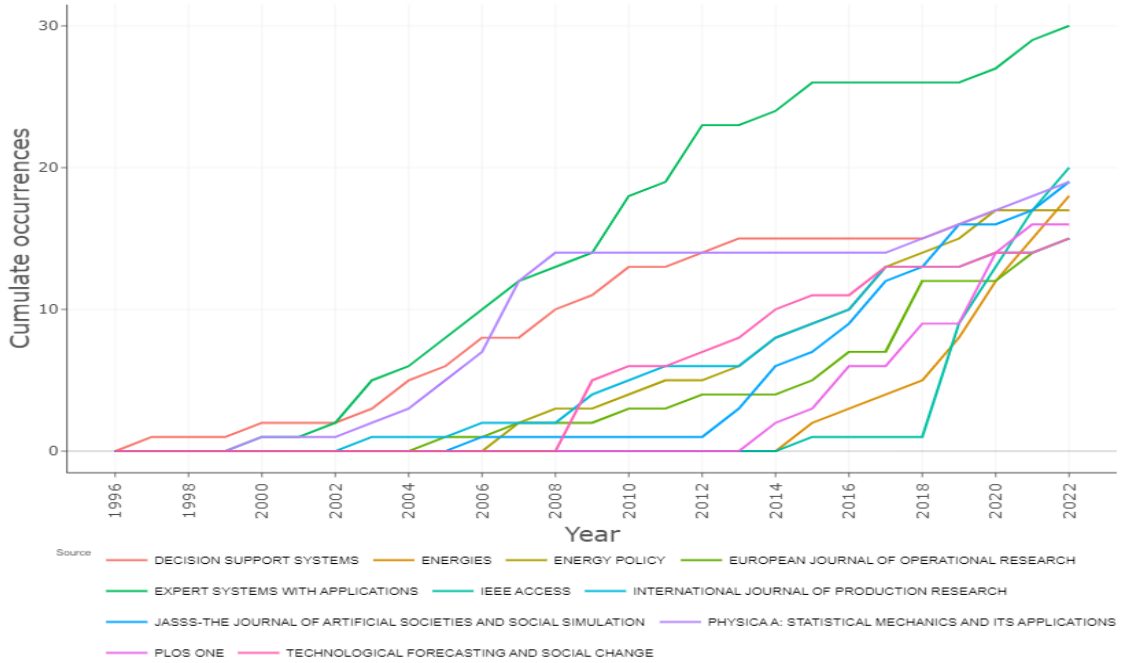


Fig. 4. Source Dynamics

Table 3
The Top 20 Documents

Rank	Paper	Title	Type document/Field
1	SENSFUSS F, 2008, ENERG POLICY	"The merit-order effect: A detailed analysis of the price effect of renewable electricity generation on spot market prices in Germany"	Ar/En
2	PERES R, 2010, INT J RES MARK	"Innovation diffusion and new product growth models: A critical review and research directions"	Re/ID
3	BERGER T, 2001, AGR ECON-BLACKWELL	"Agent-based spatial models applied to agriculture: a simulation tool for technology diffusion, resource use changes and policy analysis"	Ar/ID*
4	BUNN DW, 2000, PROC IEEE	"Forecasting loads and prices in competitive power markets"	Ar/En
5	KUMAR NUNNA HSVS, 2013, IEEE TRANS IND ELECTRON	"Multiagent-Based Distributed-Energy-Resource Management for Intelligent Microgrids"	Ar/En
6	AL-ALAWI BM, 2013, RENEW SUST ENERG REV	"Review of hybrid, plug-in hybrid, and electric vehicle market modelling Studies"	Re/En
7	KIESLING E, 2012, CENT EUR J OPER RES	"Agent-based simulation of innovation diffusion: a review"	Re/ID
8	RAND W, 2011, INT J RES MARK	"Agent-based modelling in marketing: Guidelines for rigor"	Ar/-
9	FARMER JD, 2005, PROC NATL ACAD SCI U S A	"The predictive power of zero intelligence in financial markets"	Ar/-
10	SIM KM, 2012, IEEE TRANS SERV COMPUT	"Agent-Based Cloud Computing"	Ar/-
11	PRAÇA I, 2003, IEEE INTELL SYST	"MASCEM: a multiagent system that simulates competitive electricity markets"	Re/En
12	EPPSTEIN MJ, 2011, ENERG POLICY	"An agent-based model to study market penetration of plug-in hybrid electric vehicles"	Ar/En
13	KRUPA JS, 2014, TRANSPORT RES A-POL	"Analysis of a consumer survey on plug-in hybrid electric vehicles"	Ar/En

Rank	Paper	Title	Type document/Field
14	SAFDARIAN A, 2014, IEEE TRANS IND INF	"A Distributed Algorithm for Managing Residential Demand Response in Smart Grids"	Ar/En
15	CASALÓ L, 2008, COMPUT HUM BEHAV	"The role of perceived usability, reputation, satisfaction and consumer familiarity on the website loyalty formation process"	Ar/-
16	SCHWARZ N, 2009, TECHNOL FORECAST SOC	"Agent-based modelling of the diffusion of environmental innovations — An empirical approach"	Ar/ID
17	ZHANG T, 2011, J PROD INNOVATION MANAGE	"A Study of the Diffusion of Alternative Fuel Vehicles: An Agent-Based Modelling Approach"	Ar/En
18	RAMACHANDRAN B, 2011, IEEE TRANS IND ELECTRON	"An Intelligent Auction Scheme for Smart Grid Market Using a Hybrid Immune Algorithm"	Ar/En
19	LIBAI B, 2013, J MARKETING RES	"Decomposing the Value of Word-of-Mouth Seeding Programs: Acceleration versus Expansion"	Ar/-
20	CAO J, 2005, FUTURE GENER COMPUT SYST	"Grid load balancing using intelligent agents"	Ar/En

*Ar: **Ar**ticle; Re: **Re**view; En: **En**ergy; ID: **I**nnovation **D**iffusion

The results showed that the top 20 cited articles were in the field of energy consumption (55%) and innovation diffusion behavior (20%). Also, in terms of the document type, 80% of them are articles and the rest of them are reviews.

3.1.3. Authors' Performance Evaluation

Table 4 lists the 20 most productive authors according to the number of documents indexed in WOS and Scopus. First and second place are, in order, WANG H and ZHANG J. (with 10), LI X and ZHANG Y (with 9). The following ranks are assigned to authors who have 8 publications or fewer.

Table 4
Most Productive Authors

Rank	Authors	Documents	Rank	Authors	Documents
1	WANG H	10	11	CHENG T	7
2	ZHANG J	10	12	LIU J	7
3	LI X	9	13	SAKAS D	7
4	ZHANG Y	9	14	STUMMER C	7
5	CHEN J	8	15	SZNAJD-WERON K	7
6	CHICA M	8	16	WANG J	7
7	DONG J	8	17	WANG L	7
8	WANG S	8	18	WERON R	7
9	CAO J	7	19	ZHANG Q	7
10	CHAPPIN E	7	20	BERGLUND E	6

Results are shown in Table 5 and demonstrate the authors' scientific productivity and application of Lotka's law to research related to using ABMS in marketing and consumer behavior. Lotka's law explains how frequently authors publish on any given subject (Nagaiah et al., 2021).

3.1.4. Country Performance and Country Collaboration Evaluation

Figure 5 and Table 6 show a distribution of published documents by country and collaboration between different countries on using ABMS in marketing and consumer behavior. According to them, the USA has the highest number of publications in this field, with the publishing of 188 documents, followed by CHINA with 180 documents and the UNITED KINGDOM with 91 documents. These three productive countries have published 38% of documents using ABMS in marketing and consumer behavior. In addition, SPAIN and UNITED KINGDOM with a 23.1% multiple-country publications (MCP) ratio have significant international collaboration.

More than 82% of authors on this subject only produce one piece of writing on occasion.

Table 5
Frequency of Publication by Authors (Lotka law)

Documents written	N. of Authors	Proportion of Authors (%)
1	2395	82.4
2	311	10.7
3	120	4.1
4	33	1.1
5	16	0.6
6	12	0.4
7	11	0.4
8	4	0.1
9	2	0.1
10	2	0.1

Table 6
Most Productive Countries

Rank	Country	Articles	Freq.	SCP	MCP (%)	MCP_Ratio (%)
1	USA	188	166	22	15.5	11.7
2	CHINA	180	154	26	14.9	14.4
3	UNITED KINGDOM	91	70	21	7.5	23.1
4	GERMANY	58	47	11	4.8	19
5	JAPAN	52	50	2	4.3	3.8
6	ITALY	41	35	6	3.4	14.6
7	SPAIN	39	30	9	3.2	23.1
8	AUSTRALIA	34	29	5	2.8	14.7
9	IRAN	34	27	7	2.8	20.6
10	NETHERLANDS	34	28	6	2.8	17.6
11	FRANCE	28	25	3	2.3	10.7
12	KOREA	28	24	4	2.3	14.3
13	CANADA	25	21	4	2.1	16
14	INDIA	24	20	4	2	16.7
15	POLAND	23	23	0	1.9	0
16	GREECE	18	16	2	1.5	11.1
17	PORTUGAL	18	16	2	1.5	11.1
18	BRAZIL	16	16	0	1.3	0
19	SWITZERLAND	16	13	3	1.3	18.8
20	AUSTRIA	11	10	1	0.9	9.1

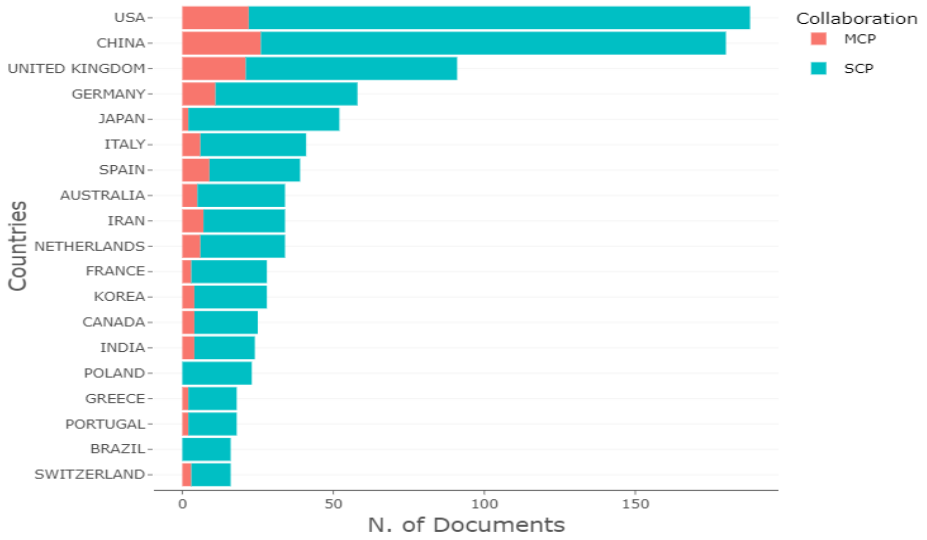


Fig. 5. Most Productive Countries and the Country Collaboration

Table 7
Country collaboration on using ABMS in marketing and consumer behavior literature around the world

Rank	From	To	Freq
1	USA	CHINA	12
2	AUSTRALIA	SPAIN	7
3	GERMANY	NETHERLANDS	7
4	CHINA	AUSTRALIA	6
5	UK	ITALY	6
6	USA	KOREA	6
7	USA	UK	6
8	CHINA	UK	5
9	ITALY	NETHERLANDS	5
10	UK	GERMANY	5

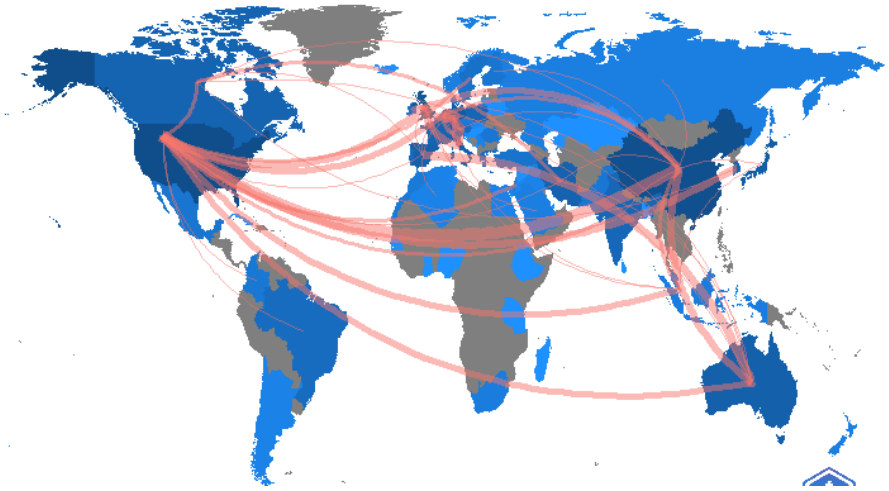


Fig. 6. The Country Collaboration Map

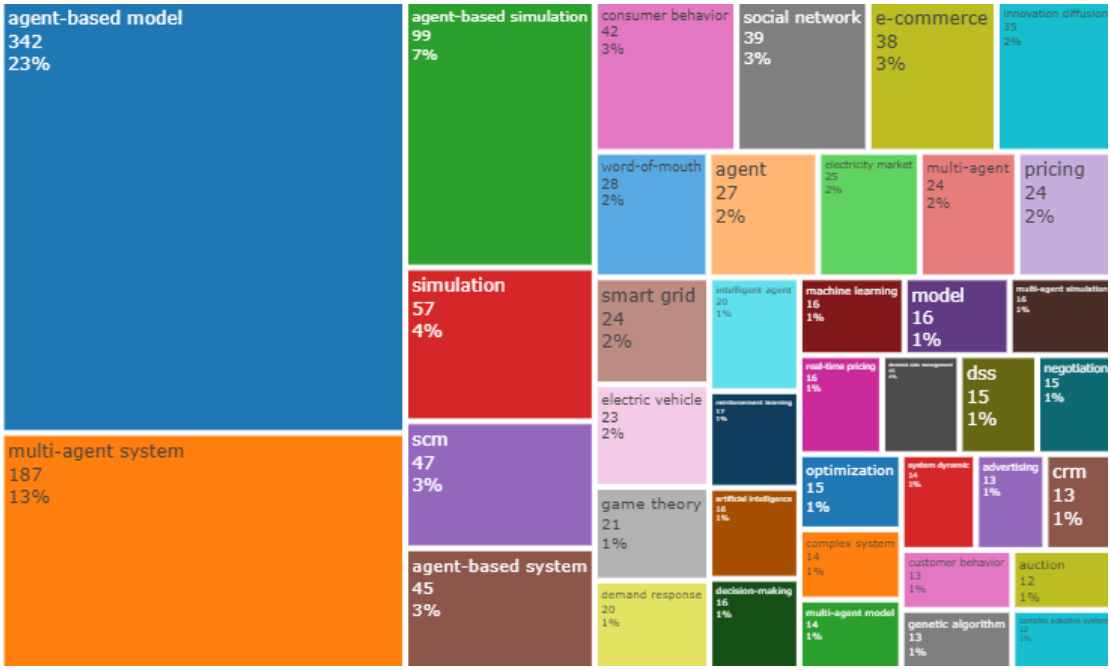
Figure 6, the country collaboration map, shows the collaboration path in the world. The color blue illustrates the presence of networks of study with other nations.
The findings indicate that the USA and CHINA (with 12 articles) have the most collaboration in publications on using ABMS in marketing and consumer behavior (Figure 7).

3.2. Conceptual Structure

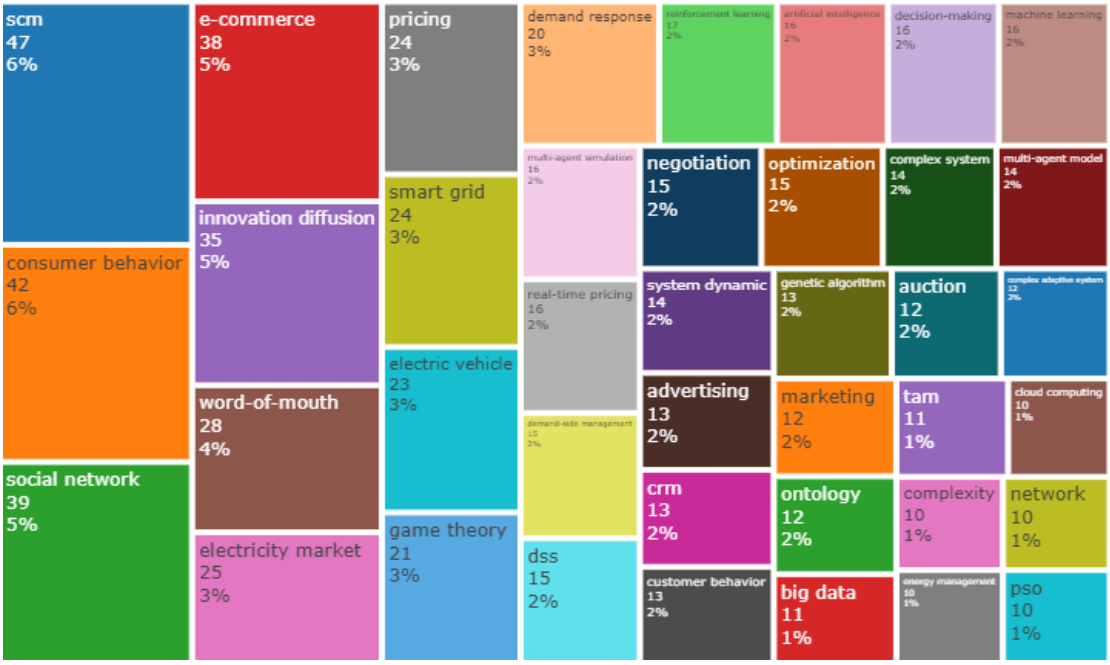
To identify key research topics in association with the use of ABMS in marketing and consumer behavior, the co-occurrences word analysis and visualization of the conceptual structure in a network of words during the timespan 1995-2022 was used. This analysis is necessary to determine interactions between the topics researched, trends in emerging topics, and identify interesting hotspots such as areas of research, development, and innovation.
Data cleaning is frequently required when a map is made using text or bibliographic data. This can be accomplished by using a thesaurus file. The thesaurus files can be used to combine various spellings of source titles, author and country names, or cited references when making a map based on bibliographic data. In the present research, for the analysis of the author's keywords related to the use of ABMS in marketing and consumer behavior researches, a thesaurus file was created as follows: to homogenize words in the singular and plural forms of words (e.g., 'customers' and 'customer'), whole words or phrases vs. Abbreviations/Acronym (e.g., ABM vs. 'agent-based model') or words in British vs. American English (e.g., "optimization" vs. "optimisation"). Then, keywords frequency and evolution, keywords cloud, keywords growth, thematic map (strategic diagram), and co-occurrence word network on using ABMS in marketing and consumer behavior were reported.

3.2.1. Frequency and Evolution of Words

The top 40 frequently occurring words from research on using ABMS in marketing and consumer behavior are represented in two plans represented in Figure 7: plan (a) includes whole 40 frequent keywords and plane (b) contains 40 frequent keywords regardless of the keywords associated with the ABMS method such as 'agent-based model', 'multi-agent system' and 'agent-based simulation', 'agent', 'agent-based system', 'simulation', 'agent' etc.



Plan (a)



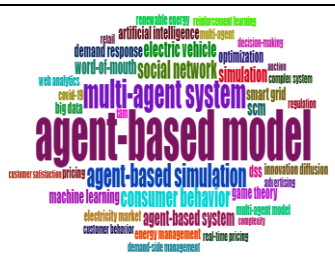
Plan (b)

Fig. 7. Words tree map (1995-2022)

As expected, these findings demonstrate that the frequent author's keywords used in all of the documents (plan (a)) are 'agent-based model' (23%), 'multi-based system' (13%), and 'agent-based simulation' (5%). Also, frequent author's keywords used in plan (b) are supply chain management (SCM) (6%), consumer behavior (6%), social network (5%), e-commerce (5%), and innovation diffusion (5%).

The topic's evolution is studied and plotted (in terms of trajectory along time) by dividing the period into various time slices (Table 8). According to the distribution of publications per year, three-time slices were established during the whole period: the first time slice includes 17 years (1995-2011), the second time slice 7 years (2012-2018), and the third slice 4 years (2019-2022).

Table 8
Occurrence and Evolution of Keywords

Time Slice	1995-2011		2012-2018		2019-2022	
	Documents=411 Sources=238 Authors=957		Documents=420 Sources=275 Authors=1069		Documents=379 Sources=239 Authors=1170	
Rank	**"Author's Keywords"**	**O***	**"Author's Keywords"**	**O**	**"Author's Keywords"**	**O**
1	multi-agent system	80	agent-based model	142	agent-based model	141
2	agent-based model	59	multi-agent system	58	multi-agent system	49
3	agent-based simulation	32	agent-based simulation	36	agent-based simulation	31
4	scm	24	Simulation	24	consumer behavior	22
5	e-commerce	23	innovation diffusion	20	social network	20
6	agent	19	smart grid	14	electric vehicle	15
7	agent-based system	19	social network	13	agent-based system	14
8	simulation	19	word-of-mouth	13	simulation	14
9	intelligent agent	16	agent-based system	12	scm	13
10	electricity market	14	consumer behavior	12	word-of-mouth	12
11	multi-agent	14	e-commerce	12	machine learning	11
12	crm	10	system dynamic	11	artificial intelligence	10
13	reinforcement learning	10	demand response	10	demand response	10
14	consumer behavior	8	Model	10	smart grid	10
15	innovation diffusion	8	Pricing	10	dss	9
16	negotiation	8	Scm	10	game theory	9
17	e-marketplace	7	multi-agent simulation	9	optimization	9
18	genetic algorithm	7	Agent	8	big data	8
19	ontology	7	customer behavior	8	electricity market	7
20	pricing	7	demand-side management	8	energy management	7
21	web-mining	7	electric vehicle	8	innovation diffusion	7
22	auction	6	real-time pricing	8	pricing	7
23	decision-making	6	cloud computing	7	covid-19	6
24	dss	6	complex adaptive system	7	multi-agent	6
25	econophysics	6	complex system	7	multi-agent model	6
26	semantic web	6	game theory	7	renewable energy	6
27	social network	6	agent-based modelling & simulation	6	tam	6
28	software agent	6	Diffusion	6	web analytics	6
29	artificial market	5	Sustainability	6	advertising	5
30	bounded rationality	5	energy market	5	customer behavior	5
Keywords Cloud						

O*: Occurrence

As expected, the most occurrence term, across the entire time slice, are 'agent-based model', 'multi-agent system', and 'agent-based simulation'. Regardless of the keywords associated with the ABMS method, similar to what happened in Plan (b), the analysis results of the most frequent keywords of three periods were as follows:

In the first period under review (1995-2011), most studies are about the ABMSs' paradigm and web analysis method, so words such as 'ontology' and 'bounded rationality' (concerning the paradigm) and 'web-mining' and 'semantic web' (concerning elementary applications ABMS) are in 30 frequent themes. These themes are not in the following periods. In the second period time, topics such as consumer behavior theory ('consumer behavior', 'demand response', 'pricing', 'customer behavior', 'demand-side management', and 'real-time pricing'), innovation diffusion ('innovation diffusion', 'social network', 'word-of-mouth', 'diffusion') and sustainability ('electric vehicle', 'sustainability', 'energy market') have emerged and become frequent. Also, the most significant and emergent topics in the third-time slice are 'big data, 'covid-19', and 'renewable energy'.

The top 10 keywords used most frequently in publications are depicted in Figure 8 as their annual growth. It demonstrates the significant and increasing growth of the keyword "agent-based model" and "multi-agent system". Nevertheless, although the frequency of the term "multi-agent system" was the most frequent term before 2016, after this, the term "agent-based model" significantly exceeds other terms.

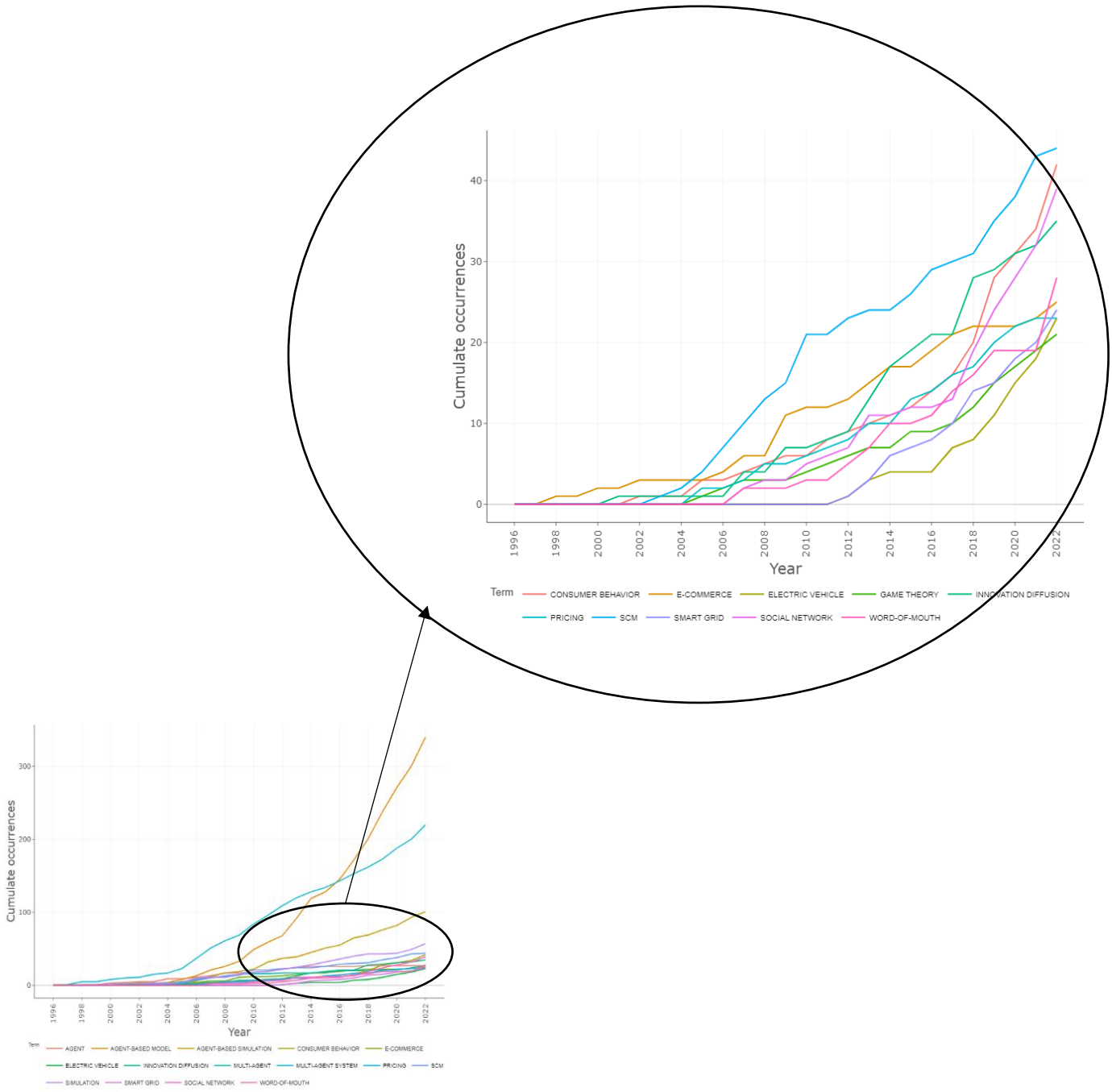


Fig. 8. Yearly Keyword Growth

The result of the word growth analysis shows that although The 'SCM' has a speedy growth in all periods, the terms 'consumer behavior' and 'social network' are increasingly correlated, simultaneously and in parallel in recent years. In other words, in this field, consumer behavior is mostly investigated in social networks. This could be explained by two reasons. First, the use of social networks has greatly expanded in recent years and most purchases and purchase interventions (such as pricing and advertising) happen in this area. Secondly, the simulation of consumer behavior in social networks, especially virtual networks, is more feasible due to access to more accurate data.

3.2.2. Thematic map (Strategic diagram)

A collection of interconnected networks or themes is obtained in the clustering process, which is then used to construct strategic diagrams. Therefore, each word network or theme in this context is described by two parameters (Concari et al., 2022; Rojas-Lamorena et al., 2022; Zhu & Zhang, 2020).

Centrality: It measures how closely a network interacts with other networks. The degree of external connections to other themes is measured by centrality. This value can be interpreted as a measure of a theme's significance in the growth of the entire research field under consideration.

Density: It measures the network's internal strength fortitude. The degree of internal connections between each keyword describing the research theme is measured by density. The development of the theme can be measured by this value

.

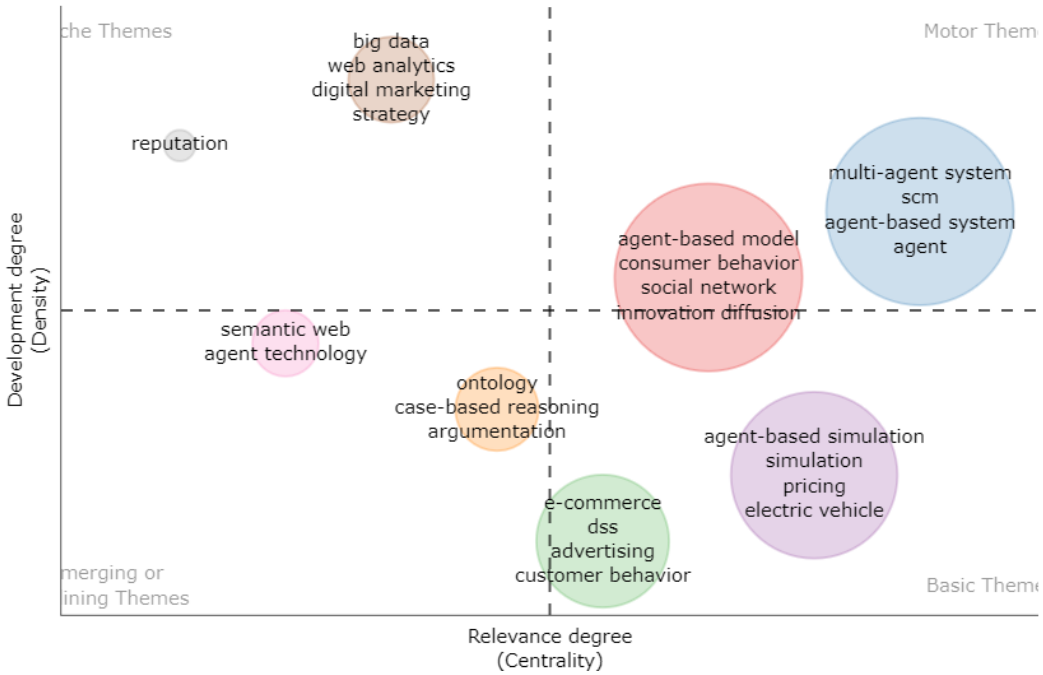


Fig. 9. Strategic diagrams of using ABMS in marketing and consumer behavior literature

A thematic map can be used to classify four types of themes (Figure 9) based on the quadrant in which they are located (Rojas-Lamorena et al., 2022):

Motor Themes: Themes in the upper-right quadrant are referred to as 'motor themes'. High centrality and density are what define them. They are therefore developed and important o the field of research. The 'motor themes' that have received the most attention in the literature are 'agent-based model', 'multi-agent system', 'consumer behavior', and 'SCM'.

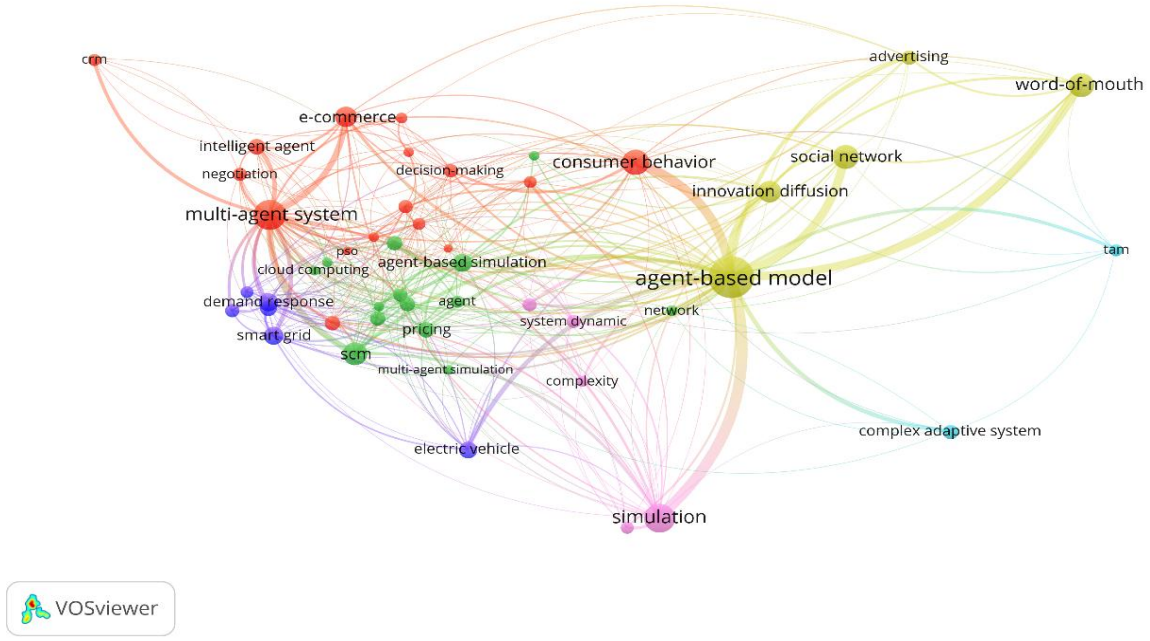
Developed and Isolated Themes: 'Developed and isolated' or 'niche themes' are terms used to describe the themes in the upper-left quadrant. Despite having well developed internal links (high density) but unimportant outward links, they are of very limited value for the field (low centrality). The field of using ABMS in marketing and consumer behavior has a niche theme called 'big data', 'web analytics', and 'reputation',

Emerging or Declining Themes: Emerging or declining themes are those in the lower-left quadrant. They are marginalized because they have low centrality and density. In the literature, "ontology" and "semantic web" are declining themes in this field.

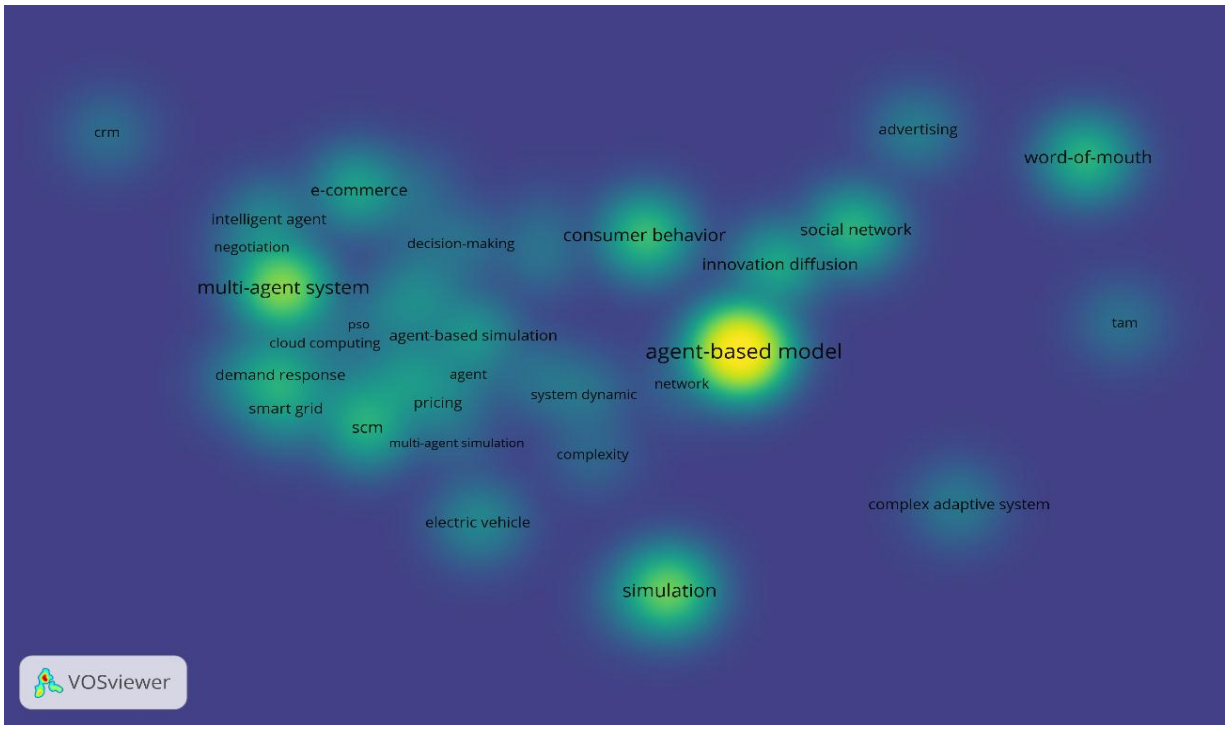
General/Basic Themes: The basic and transversal themes are those that are located in the lower-right quadrant. High centrality and low density are what define them. These topics are important for a research field and cross over into all the different subfields of the field's research. The Basic concepts in the field of using ABMS in marketing and consumer behavior are 'agent-based simulation' and 'e-commerce'.

3.2.3. Co-Words or Co-Occurrence Word Analysis

The co-word analysis is defined as the conceptual and thematic structure of a scientific domain by analyzing the co-occurrence of two terms (Callon et al., 1983). Co-occurrence can be quantified using concepts like mutual information or correlation. Co-word analysis is used to identify connections between topics in a research field and subsequently to trace the development of science (He, 1999). It is based on the frequency at which two words or phrases occur together. Co-word analysis is an effective tool that allows the relationships between keywords in a scientific field to be found, explained, and graphically represented (Donthu et al., 2021).



(a). Network visualization



(b). Density visualization

Fig. 10. the network and density visualization of co-word (48 keywords)

The network of co-word occurrence presents in Figure 10. The topics studied most frequently by scholars in this field cohere into 6 clusters. The area of the circle was determined by the occurrences of each keyword. Also, the cluster labels, different themes, Links/link strength, representatives' research (with Total Citation per Year), and core theoretical backgrounds are shown in Table 9.

Both the links attribute and the total link strength attribute are considered standard weight attributes.

The links attribute for co-word links between keywords shows how many times a given keyword appears in conjunction with other keywords. The total link strength attribute shows the overall strength of the co-word links between a given keyword and other keywords (Gholami et al., 2023). In the following, each cluster is explained:

Cluster 1 (multi-agent systems and consumer behavior): the first cluster has 16 themes. The main keywords represented in this cluster focus on consumer behavior theory (such as 'consumer behavior', 'e-commerce', 'negotiation', 'decision-making', 'customer behavior'. 'CRM' and 'DSS') and artificial intelligence (such as 'multi-agent system', 'intelligent agent', 'optimization', 'machine learning', 'artificial intelligence', 'big data', 'PSO'). The Core theoretical backgrounds in this cluster are consumer behavior & decision-making theory and artificial intelligence.

Cluster 2 (agent-based simulation and SCM): The main keywords that are represented in the second cluster, which has 14 themes, typically focus on "agent-based simulation" and "supply chain management theory". The main keyword in this cluster is 'SCM', 'agent-based simulation', and 'Pricing'. 'Game theory', 'reinforcement learning', 'cloud computing', and 'genetic algorithm' are widely used method that has been used for supply chain simulation along with the agent-based simulation. This cluster focuses on Supply chain management and game theory.

Cluster 3 (ABM and energy consumption): The third cluster is focused on the use of agent-based modelling for energy consumption prediction and management. The most frequent words in this cluster are 'smart grid', 'demand response', 'electric vehicle', 'real-time pricing', and 'energy management'.

Cluster 4 (AMB and innovation diffusion): The fourth cluster is focused on the application of agent-based modelling to innovation diffusion by word-of-mouth advertising in the social network context. The most frequent words in this cluster are 'agent-based model', 'word-of-mouth', 'social network', 'innovation diffusion', and 'advertising'.

Cluster 5 (complex system and Simulation): The fifth cluster is focused on the simulation and modelling of complex systems by system dynamics. This cluster was originally associated with keywords 'simulation', 'system dynamics', 'complex system', 'model', and 'complexity'.

Cluster 6 (ABM and TAM): The sixth cluster is focused on the process of technology acceptance. The most frequent words in this cluster are 'complex adaptive system', and 'TAM'.

Table 9
Clusters, themes, Links, link strength, representatives' research, and Core theoretical backgrounds

Cluster Label (N. of Themes)	**Themes**	**Links**	**link strength**	**Representatives' research (Total citation per Year)**	**Core theoretical backgrounds**
Cluster 1 (16 themes): multi-agent systems and consumer behavior	multi-agent system	38	982	(Antonopoulos et al., 2020) **(28.5)** (Deng et al., 2019) **(24.8)** (Sim, 2011) **(19.8)** (Rand & Rust, 2011) **(18.7)**	consumer behavior & decision-making theory artificial intelligence
	consumer behavior	24	532		
	e-commerce	17	289		
	intelligent agent	14	129		
	optimization	18	86		
	machine learning	16	65		
	negotiation	12	63		
	decision-making	15	63		
	artificial intelligence	18	60		
	customer behavior	9	58		
	CRM	6	54		
	big data	8	42		
	DSS	11	28		
	multi-agent	17	26		
	multi-agent model	14	17		
	PSO	12	15		
Cluster 2 (14 themes): agent-based simulation and SCM	SCM	22	376	(Al-Alawi & Bradley, 2013) **(26.7)** (Gholami et al., 2023) **(21.5)** (Eppstein et al., 2011) **(17.4)** (Shafiei et al., 2012) **(11.8)** (Yousefi et al., 2011) **(10.7)**	Supply chain management game theory
	agent-based simulation	24	188		
	Pricing	23	109		
	electricity market	14	94		
	agent-based system	22	89		
	game theory	18	88		
	reinforcement learning	14	64		
	Agent	16	51		
	Network	8	35		
	cloud computing	10	31		
	genetic algorithm	13	30		
	Auction	13	30		
	marketing	6	25		
	multi-agent simulation	9	23		
Cluster 3 (6 themes):	smart grid	16	180	(Sensfuß et al., 2008) **(31.6)** (Nunna & Doolla, 2012) **(30.8)**	energy management
	demand response	19	172		

Cluster Label (N. of Themes)	Themes	Links	link strength	Representatives' research (Total citation per Year)	Core theoretical backgrounds
ABM and energy consumption	electric vehicle	15	145	(Safdarian et al., 2014) **(19.5)** (Foruzan et al., 2018) **(19.4)**	
	real-time pricing	17	113		
	energy management	12	76		
	demand-side management	13	55		
Cluster 4 (5 themes): AMB and innovation diffusion	agent-based model	38	2788	(Peres et al., 2010) **(35.1)** (Kiesling et al., 2012) **(21.9)** (Berger, 2001) **(16.5)** (Farmer et al., 2005) **(12.7)** (Schwarz & Ernst, 2009) **(12.0)**	innovation diffusion theory
	word-of-mouth	11	436		
	social network	13	429		
	innovation diffusion	21	323		
	advertising	9	101		
Cluster 5 (5 themes): complex system and Simulation	simulation	26	788	(Elsawah et al., 2015) **(11.9)** (Kieckhäfer et al., 2017) **(9.3)** (Feng et al., 2012) **(9.0)** (Zhao et al., 2011) **(5.0)**	system dynamics complexity science
	system dynamics	13	74		
	complex system	15	66		
	model	9	59		
	complexity	12	39		
Cluster 6 (2 themes): ABM and TAM	complex adaptive system	7	87	(Krupa et al., 2014) **(19.5)** (Chang, 2010) **(5.9)** (Ding et al., 2019) **(5.6)** (Kanta & Zechman, 2014) **(5.5)**	Technology acceptance model
	TAM	7	61		

4. Conclusion

The main aim of the current research is to provide a quantitative (bibliometric analysis) and qualitative review (literature review) of the most relevant research on using ABMS in marketing and consumer behavior from 1995 until 2022. Also, this study provides insight into studies and the main topic in association with using ABMS in marketing and consumer behavior that have been studied in the last three decades.

A total of 1210 scientific documents (articles and reviews) was collected from the WOS and Scopus database. The trend is a sustainable growth of publications every year in this field, which shows that this topic is attracting more and more interest (annual growth rate of 14.78 %). The USA has the most publications in this field, with the production of 188 documents. Also, SPAIN and the UNITED KINGDOM with a 23.1% multiple-country publications (MCP) ratio had significant international collaboration. The EXPERT SYSTEMS WITH APPLICATIONS" is a productive journal publishing in this field. Generally, the major journals that publish research on the use of ABM in marketing and consumer behavior are multidisciplinary or interdisciplinary.

According to the analysis of the most frequent keywords was identified 6 clusters: Cluster 1 (multi-agent systems and consumer behavior), Cluster 2 (agent-based simulation and SCM), Cluster 3 (ABM and energy consumption), Cluster 4 (AMB and innovation diffusion), Cluster 5 (complex system and Simulation) and Cluster 6 (ABM and TAM).

The result of the word growth analysis shows that the words "ontology" and "semantic web" are declining themes in this field. Also, the most significant and emergent topics in recent years are 'big data, 'covid-19', and 'renewable energy'. Also, the most application of agent-based modelling in marketing and consumer behavior in two fields: (a) to forecast innovation diffusion in the social network context and (b) prediction energy consumption and pricing.

Prediction is one of the goals that has attracted the most attention of ABMS researchers among many goals such as optimization, description, self-organization, and adaptability, and there are many recent works in this field. These results show that many topics that were of interest in the past, such as the ontology of ABMS, are no longer of much interest to researchers, and the attention of researchers has been directed toward issues such as the diffusion of innovation, energy consumption, and pricing in recent years. This topic can determine the appropriate approach for other researchers to research in this field.

Declaration of interest statement

We have no conflicts of interest to disclose.

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