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COFFEE INNOVATION: GLOBAL TRENDS AND FUTURE PERSPECTIVES

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ABSTRACT

Coffee is the second most consumed beverage in the world, as well as one of the most valuable commodities, providing a livelihood for 25 million farmers in the tropics. The aim of this research was to analyze recent trends in coffee innovation. The documents for this review were extracted from the Scopus database in two separate searches. The first search registered 365 documents on coffee innovations between 1977 and April 2022, and the second flagged 138 documents on the life cycle analysis (LCA) of coffee, which was the primary innovation identified. Bibliometric methodologies in VOSviewer and the RStudio *bibliometrix* package were used for data processing. The results showed a growing number of articles on coffee innovations since 2010, with research focused on the areas of business, management, and accounting (14.1 %); environmental sciences (11.9 %); and agricultural and biological sciences (11.8 %). In terms of document production by country, the most prominent were the United States, Brazil, and the United Kingdom. The findings also revealed that the initial focus of coffee innovations was on issues related to dissemination, the human factor, and marketing. Since 2016, innovation trends have focused on sustainability evaluated through life cycle analysis originating mainly in producing countries as a response to climate change to ensure food security under a sustainable development approach.

Keywords: bibliometric analysis, sustainable development, climate change, food security.

INTRODUCTION

Coffee is one of the most traded commodities worldwide and provides a livelihood for millions of small-scale producers in tropical areas. Global coffee consumption during the 2021–2022 production cycle increased 4.2 %, or 175.6 million 60-kg bags (ICO, 2023). Due to its origin as an understory shrub in the mountains of East Africa with stable microclimates, coffee is vulnerable to climate variations. In countries such as Ecuador and Mexico, coffee farming has experienced a decline in yield due to limited

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access to production system technologies for small-scale farmers (Duicela-Guambi *et al*., 2018) and the high incidence of pests and diseases (Pham *et al*., 2019). Given these challenges and the need to meet the growing demand for high-quality coffee, innovations have emerged throughout the coffee value chain.

Innovation is defined as the implementation of a new product, good, or service, or the improvement of a process or method, whether commercial or organizational (Nandal *et al*., 2020). Innovation occurs as long as the people or organizations involved make a long-term commitment to increasing efficiency, competitiveness, and resilience to the problems they face (Kangogo *et al*., 2020). Innovation is fostered when farmers adopt new agricultural products or processes, or when an exchange of knowledge allows for the development of new ideas or technological processes that generate economic, social, and environmental benefits (Cofré-Bravo *et al*., 2019). When talking about innovation, a connection with improved processes can be inferred, which are not always product-related (Fernandez-Stark and Gereffi, 2019).

Although there are numerous studies on coffee, few use bibliometric methods. This type of analysis can help inform the scientific community of the trends and dynamism inherent in the research topic under consideration. In the case of coffee, scientific production and collaboration related to certification have been mapped (Cabrera *et al*., 2020). In addition, over the last five years, sustainability in the sector has received significant attention in bibliometric research, including the use of technologies in precision coffee farming to strengthen the sector's competitiveness through operational efficiency (Santana *et al*., 2021). The incorporation of technology in coffee cultivation has also been assessed with the use of remotely piloted aircraft systems (drones) to obtain timely and efficient aerial images (Bento *et al*., 2023). Another study reported scientific data on the effect of caffeine on the general public and athletes resulting from coffee consumption (Contreras-Barraza *et al*., 2021).

Bibliometric analyses on coffee using other approaches, such as the circular bioeconomy based on the use of organic residues (Ranjbari *et al*., 2022), have boomed in the last 10 years. However, similar studies addressing trends in coffee innovations and covering aspects such as publication trajectories, country productivity, areas of knowledge, the most prolific journals and authors, the most relevant documents, the science map, the evolution of the topics addressed in publications, and cutting-edge topics are lacking. The main objective of this study was to address this gap by reviewing and reporting on trends in coffee innovation, covering the aforementioned aspects.

MATERIALS AND METHODS

Data collection

Analysis was conducted to examine the existing literature on innovations in coffee, to describe emerging trends in articles and journals, and to identify the most prolific authors and countries (Donthu *et al*., 2021). The study was carried out in two stages using searches in the Scopus database (Elsevier), recognized for its high quality and peer review.

In the first stage, the search criteria used the keywords "innovation" and "coffee" in the title, abstract, or keywords. Keywords in British English were standardized to American English, and plural words were changed into singular (Verma and Gustafsson, 2020). This resulted in a total of 365 documents generated between 1977 and April 22, 2022, when the search was conducted. These included: 216 articles, 57 conferences, 37 book chapters, 32 reviews, 10 conference reviews, six books, four notes, two short surveys, and one editorial.

All available documents were considered to obtain a broader overview of the development and evolution of innovation in the coffee sector. Data eligibility included all subject areas and languages used in the documents –mainly English (89.6 %), and a mix of French, German, Korean, Portuguese, Chinese, Russian, Slovak, and Spanish-.

Data analysis

The VOSviewer software version 1.6.20 was used to map the science and visualize the domain formed by the network of co-occurrences of coffee innovation keywords. The results are presented in network, overlay, and density cluster visualizations, which allow researchers to broaden their understanding of emerging research topics and the nature of the research, define the scope, or avoid bias in the source selection process (van Eck and Waltman, 2010). To generate the clusters, the association (S_{ij}) between elements i and j is estimated based on the distance between the nodes according to the following formula:

$$S_{ij} = \frac{C_{ij}}{W_i W_j}$$

where C_{ij} represents the number of occurrences of elements i, j, W_i, and W_j, the sum of the occurrences of elements i and j, or the sum of occurrences of pairs of these elements.

The scientific productivity of the authors was quantified based on Lotka's Law, which provides a platform for studying the variation between the actual and expected productivity patterns of authors in a subject area during a specific period (Tran and Aytac, 2021). This model establishes that the number of authors, A_n, who publish n research papers on a topic is inversely proportional to the square of n, according to the following formula:

$$A_n = \frac{A_1}{n^2}$$

where A_n is the number of publications corresponding to a given number of authors. A_1 represents the number of publications with a single author, and n^2 corresponds to the number of authors to be calculated using the exponential growth law squared.

Life cycle analysis

The first stage of analysis of publications showed that most innovations focused on sustainability as described in life cycle analyses (LCA). Therefore, another search was conducted to obtain more information on LCA as an element of innovation in coffee. To analyze the performance of publications on the LCA thematic map for coffee, documents were also collected from the Scopus search engine, using the keywords "life cycle analysis", "life cycle assessment", and "coffee" (TITLE-ABS-KEY). On this occasion, 138 documents were detected, spanning January 1996 to March 6, 2023. To illustrate the topics addressed in the various publications related to LCA, the *biblioshiny* library from the RStudio *bibliometrix* package was used, which allowed for network, data reduction, and correspondence analysis (Derviş, 2019).

RESULTS AND DISCUSSION

Publication timeline

The analysis of the evolution of publications on innovation in coffee yielded 21 documents during the period from 1977 to 1997, which suggested a lack of interest in the subject during this period. Around 2010, the topic of coffee innovation began to appear ever more frequently in publications, a trend that has continued to the present day (coefficient of determination $R^2 = 0.81$).

Country productivity

Research on coffee innovations was produced in more than 70 countries, with the 10 most prolific being the United States, Brazil, the United Kingdom, Indonesia, the Netherlands, Germany, Colombia, France, Italy, and Mexico, representing both the main consumers and the main producers of coffee worldwide, and accounting for 67.4 % of total publications, with the United States having the highest number of contributions with 14 %. In addition, the results revealed that the contribution of Indonesia, a coffee-producing country, has increased in recent years.

In coffee-importing countries (the United States, the United Kingdom, the Netherlands, Germany, France, and Italy), research has focused on the last two segments of the value chain (consumption and waste disposal). In contrast, LCA of coffee producing countries (Brazil, Indonesia, Colombia, and Mexico) address environmental issues and concerns.

Areas of knowledge, journals, and the most prolific authors

Analysis of the available scientific literature on innovations in coffee showed they are spread across six main areas of knowledge: business, management, and accounting

(14.1 %); agricultural and biological sciences (11.8 %); environmental sciences (11.9 %); engineering (8.2 %); economics, econometrics, and finance (7.3 %); and computer science (5.6 %). Documents were published in a total of 287 journals, of which the most prominent, with the highest number of publications related to innovations in coffee, were Earth and Environmental Science (4.1 %), Sustainability (2.2 %), Journal of Cleaner Production (1.4 %), ACM International Conference Proceeding Series (1.4 %), and Journal of Physics (1.4 %).

Most authors publish a small number of papers on a specific research topic. A small number of authors comprised the most prolific group, accounting for most of the available literature. The results of this research showed that 95 % of authors generated only one paper out of the total number of publications on coffee innovations, while 4 % wrote two, 0.41 % wrote three, and only 0.41 % wrote four or more publications. The main authors who published collectively were Drs. Bertrand, Etienne, Georget, and Montagnon.

Relevant documents

The most influential documents on coffee innovations, identified according to their impact on the academic community, received a total of 3920 citations, with an average of 17 citations per article (Table 1).

Table 1. The ten most cited articles on coffee innovations produced between 1977 and April 22, 2022.

Article	Description of the innovation	Citations	Average[1]
Campos-Vega *et al*. (2015), Trends in Food Science and Technology	Potential use of coffee residues, generated at any stage of the process, as functional ingredients in the food industry.	288	28.80
Notarnicola *et al*. (2017), Journal of Cleaner Production	The implementation of life cycle analysis (LCA) to assess and improve the environmental impacts of coffee production, identifying critical points and proposing solutions to reduce emissions and resource consumption.	241	30.13
Chua and Banerjee (2013), Journal of Knowledge Management	The use of social media to transform customers from passive recipients to active contributors of innovation, allowing them to propose and evaluate ideas for new products and services.	176	14.67

Table 1. Continuation

Article	Description of the innovation	Citations	Average[1]
Monaci and Palmisano (2004), Analytical and Bioanalytical Chemistry	The development of analytical methods for the detection of ochratoxin A in food, emphasizing biosensors, test strips, and molecularly imprinted polymers as alternatives to conventional chromatographic techniques.	153	7.29
Flood (2010), Food Security	The start-up Global Plant Clinic (GPC) takes a radical approach by offering plant health services to farmers, improving early detection of pests and diseases through plant health clinics run by "plant doctors" in rural areas.	116	7.73
Bray *et al*. (2002), Society and Natural Resources	The production of certified organic coffee in Mexico is driven by institutional transformation, organizational changes, and accumulated social capital among smallholder farmers.	108	4.70
Tscharntke *et al*. (2015), Conservation Letters	Linking existing certification mechanisms with landscape-scale ecosystem service management and conservation approaches for biodiversity conservation.	98	9.80
Matzler *et al*. (2013), Journal of Business Strategy	A capsule system design that combines high quality and convenience, creating an exclusive and premium experience for consumers.	97	8.08
Fuzi (2015), Regional Studies, Regional Science	Coworking spaces to promote creative interaction, facilitating entrepreneurship through support and adequate infrastructure.	85	8.50
Blackburn *et al*. (2008), Communications of the ACM	A new set of benchmarks and methodologies for assessing Java applications, using real applications and metrics to address the limitations of traditional benchmarks.	83	4.88

[1]Average number of citations per year.

Map of science

The construction of the keyword co-occurrence network revealed that, out of 2889 keywords, 33 met the minimum threshold of six co-occurrences. These were used to visualize the co-occurrence networks (Figure 1) between the concepts grouped into four clusters. A marketing cluster emphasized the importance of physical, chemical,

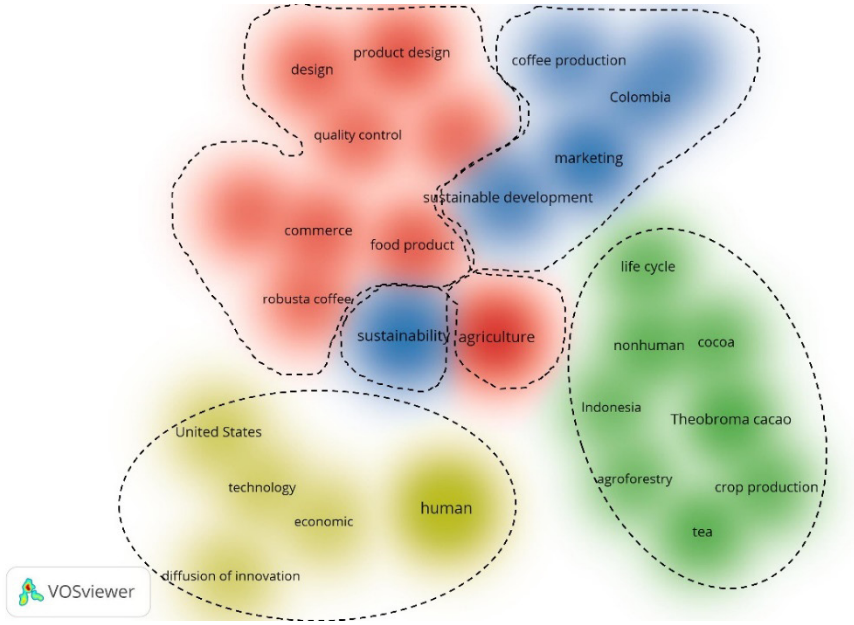

Figure 1. Keyword co-occurrence network of coffee innovation research, showing four thematic clusters (red: marketing and quality analysis; green: environmental sustainability; blue: social innovations; yellow: technology transfer.

and sensory analyses to guarantee the quality and traceability of coffee as elements for higher customer acceptance in an increasingly educated market, where not only quality is valued but also particular aspects associated with varieties and species, such as *Robusta* or *Arabica*. Another aspect that stood out in this cluster was the added value in product design, commercial aspects, and the way coffee is grown in various systems, with the use of technological innovations such as robots in the cultivation phase.

A second environment cluster brought together issues related to reducing greenhouse gases (GHG) based on an LCA in both coffee-producing and coffee-consuming countries. In the case of Indonesia, alternatives were considered to increase farmer income through the adoption of new commercial crops such as cocoa. In addition, innovations were oriented toward the production of coffee with protected origin designation and farmers' response to incentives derived from payments for environmental services.

A third cluster focused on social innovations based on collaboration between different actors in the coffee production chain, showed that educational resources have been used to develop entrepreneurial skills to promote economic development. One of the innovative strategies for adding value to coffee was the emergence of specialty coffee, targeting a specific market segment where consumers value flavor and aroma attributes. In addition, there are co-products from residues generated during coffee processing.

The final cluster was focused on technology transfer, and revealed that the United States has the greatest impact in this area, with research focused on the valorization of coffee spent grounds, commercialization, the nutritional compounds contained in the beverage, and the health benefits of coffee consumption. Likewise, technology has been used as a means to increase coffee production and consumption. In addition, the impact of the dissemination of innovations through mass media on the generation of economic benefits has been evaluated.

Trends in the topics covered in publications

From the publication of the first article on the subject of innovations in coffee until 2010, research focused on topics related to the promotion of innovations, specifically in the agroforestry area; afterwards, the topics addressed by academics were marketing and technology. Over time, the fields of research expanded to include themes related to economic factors and agricultural products, focusing on quality control and product design, such as blockchain, which emerged to meet the needs of a demanding market that makes use of technology. This allowed inclusive business models to be generated to ensure traceability, which results in greater confidence for end consumers of coffee (Miatton and Amado, 2020).

The thematic evolution was represented using colors on a plasma scale (Figure 2), ranging from purple to yellow. This visualization allows for easy identification of trends

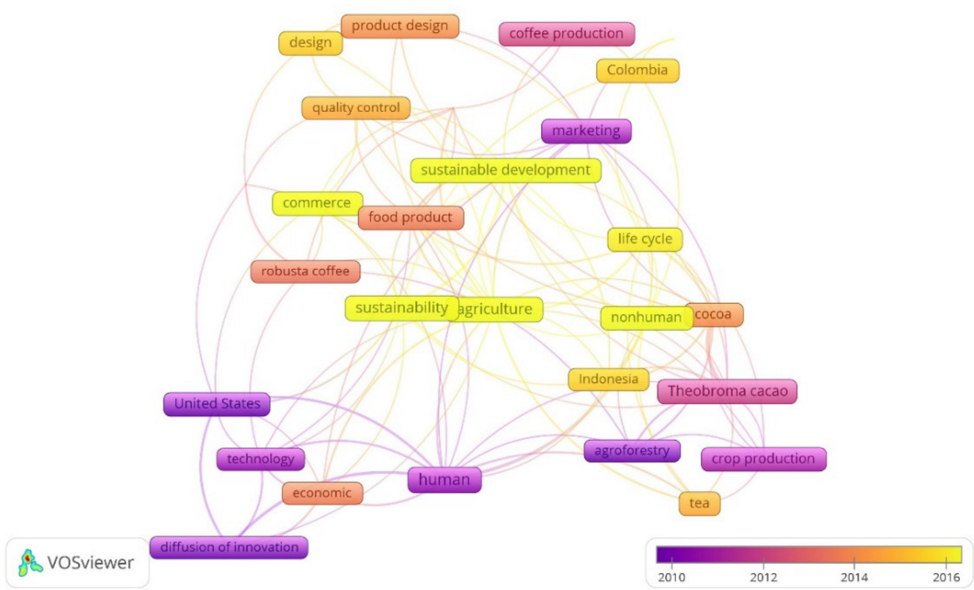

Figure 2. Keyword co-occurrence network of innovations in coffee by evolution of topics of interest, highlighting shifts in research focus over time. Older terms are represented in purple tones, while more recent terms appear in yellow.

and changes in research over time. Since 2016, authors have focused on sustainability, assessing the environmental impact at different stages of the coffee value chain, with the exporting stage being where the most GHG emissions (70 %) are released into the atmosphere (Nab and Maslin, 2020). For this reason, it is not surprising that research trends promote ventures with a focus on sustainable development to ensure food security, in accordance with the 2030 Agenda for Sustainable Development.

The evolution of the topics developed in different research projects related to innovations in coffee allowed the identification of innovations adopted by producers, whether to control weeds or manage plantations with varieties derived from Timor hybrids, due to their lower susceptibility to pests and diseases such as *Hemileia vastatrix* (Bertrand *et al.*, 2011). This also includes the adaptation of strategies to mitigate climate change with agroforestry systems (Camara *et al.*, 2012). Another example of studies related to environmental conservation is the transition process of the coffee value chain in pursuit of sustainability and the innovations this entails (González-Pérez and Gutiérrez-Viana, 2012).

The trend in recent years has focused on issues that facilitate technological development without neglecting economic, social, and environmental aspects, through the creation of new businesses. The European Union assessed the environmental impact of the consumption of products such as coffee, identifying through a life cycle analysis that the cultivation phase has the greatest impact and that farmers who use protected designation of origin have a higher level of technology adoption (Yamoah *et al.*, 2020). These trends set the stage for research on the adoption of innovations in coffee farming. Another cutting-edge issue is sustainability which, in producing countries such as Costa Rica, has been analyzed for GHG reduction through the carbon neutrality certification process, based on an LCA assessment (Birkenberg *et al.*, 2021). Therefore, to protect the environment, innovations have been developed for the production of clean energy, generated through the alternative use of by-products such as coffee husks (Rajesh Banu *et al.*, 2020).

Commerce has also been a topic of interest for the scientific community since 2016. Consumer tastes and preferences represent a more knowledgeable and environmentally conscious market. Guiné *et al.* (2020) reviewed the factors influencing new product development in the food sector, emphasizing that consumer behavior and willingness to pay a premium for a higher quality coffee are decisive elements for product success. Agricultural practices, particularly the use of fertilizers and other chemical inputs, are significant sources of GHG emissions, mainly carbon dioxide and nitrous oxide. Consequently, LCA has become a widely applied methodological tool, often combined with analyses of the carbon footprint, to evaluate the climate change impacts throughout the different stages of the coffee value chain.

Cutting-edge topics

The search conducted for LCA in coffee revealed that the distribution of documents was as follows: scientific articles (76 %), conferences (12.3 %), review articles (3.6 %), and book chapters (2.9 %), while the remaining percentage included other types of documents. The countries with the most research on LCA in coffee are Italy, the United States, Colombia, the United Kingdom, Brazil, Spain, Germany, France, and Switzerland. Among all the research thematic areas, the main ones were environmental sciences (26.4 %), engineering (14.5 %), energy (12.9 %), agricultural and biological sciences (6.9 %), business, management, and accounting (6.6 %). The leading journals for publishing in this field are the International Journal of Life Cycle Assessment and the Journal of Cleaner Production.

The first document on LCA and coffee was published in 1996 in CIRP Annals Manufacturing Technology, entitled "Design for Disassembly and the Environment," which analyzed the environmental impacts of manufacturing a small coffee maker (Harjula *et al*., 1996). The most influential document was written by Notarnicola *et al*. (2017) from the University of Bari in Italy, in which they evaluated the environmental impacts of various products, including coffee consumed in the European Union. Considering that there are various coffee production systems and that one or more systems prevail in each producing country, it is recommended that the LCA be carried out by system and by country, in order to have a clearer picture of the environmental impact of coffee production.

The scope of an LCA can cover the entire coffee value chain (from cradle to grave) or certain segments (from cradle to door, door to door, or door to grave), considering only the activities that take place in each of the stages included in the assessment (Figure 3). For this reason, the carbon footprint metric is used for the calculation, considering the total GHG emissions to produce 1 kg of cherry, parchment, or green coffee, with the processing method as the functional unit (Figure 3). LCA studies in consumer countries have focused on the valorization of residues (Kookos, 2018), concentrating on the spent coffee grounds generated by the soluble industry and on residues from coffee consumed at home and in coffee shops, as well as its potential uses through recycling, recovery of compounds, or energy recovery (Mata *et al.*, 2018).

Figure 3. Greenhouse gas (GHG) emission sources across all the segments of the coffee value chain, from production to consumption, based on life cycle assessment (LCA) boundaries and functional units.

Another way to capitalize on information related to environmental impact is via certification labels, which allow small and medium-sized enterprises to gain credibility and access to global markets through the European Union's product category rule, while also enabling promotional strategies for the domestic market (Rocha and

Caldeira-Pires, 2019). Consumers require reliable and easy-to-understand information, therefore technical units are proposed within the LCA to help them make decisions when choosing an environmentally friendly product (Vizzoto *et al.*, 2021). Carbon Neutrality is one of the certifications that provide this type of information, using the environmental indicator known as the carbon footprint (Birkenberg and Birner, 2018). The topics covered in publications related to the LCA of coffee have evolved to include issues that are currently relevant, such as the use of coffee by-products, GHG emissions, and their environmental impact (Figure 4). In coffee-producing countries such as Indonesia and Colombia, research conducted using LCA methodology has focused on technology transfer, certification at different steps in the production chain, profitability, and economic benefits. These efforts promote the development of topics such as the quantification of different environmental footprints at critical points, which helps to improve the efficiency of processes and identify ways to grow, process, and commercialize coffee with minimal environmental impact, for example, through product design with environmentally friendly packaging.

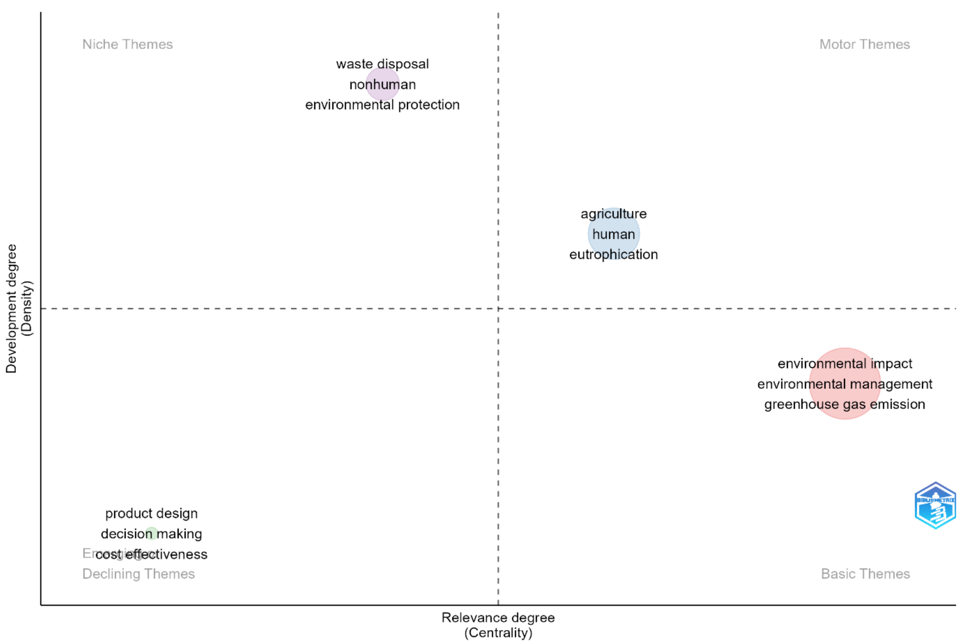

Figure 4. Thematic map of life cycle assessment (LCA) research in coffee, highlighting emerging environmental and sustainability topics across the value chain. The labels in grey indicate the names of the quadrants (types of themes), while the terms in black correspond to the most representative keywords of each cluster identified in the analysis.

CONCLUSIONS

This study provides an understanding of the evolution of the topics addressed in the various research studies on coffee innovation. In addition, the literature searches conducted revealed the growth potential of sustainable innovations focused on ensuring food security, reducing environmental impact, and making better use of resources and co-products. Since 2016, life cycle assessment (LCA) has gained prominence as a key methodological tool, positioning it as a valuable framework for guiding future research in the sector. In coffee-importing countries, research has focused on the last two steps in the value chain (consumption and end use). Coffee LCA ranked first among producing countries due to environmental concerns and the development of studies that help to solve environmental problems.

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