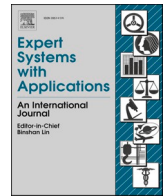




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Analytic network process in economics, finance and management: Contingency factors, current trends and further research

Hannia Gonzalez-Urango ^{a,b,*}, Enrique Mu ^c, Anna Ujwary-Gil ^d, Anna Florek-Paszowska ^e

^a INGENIO, Universitat Politècnica de València, CSIC, Edificio 8E, Cam. de Vera, 46022 Valencia, Spain

^b Latin American Studies Association (LASA), 4338 Bigelow Blvd, Pittsburgh, PA 15213, USA

^c Carlow University, 3333 Fifth Ave, Pittsburgh, PA 15213, USA

^d Institute of Economics, Polish Academy of Sciences, Laboratory of Process and Network Analysis, Nowy Swiat 72, Warsaw 00-330, Poland

^e CENTRUM Católica Graduate Business School, Pontificia Universidad Católica del Perú. Jirón Daniel Alomía Robles 125–129, Urbanización Los Álamos de Monterrico, Santiago de Surco 15023, Lima, Peru

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ABSTRACT

This study explores the recent use of the Analytic Network Process (ANP) in the decision process in the areas of economics, finance and management to identify common contingency factors, current trends, representative studies and directions for further research applications in the target areas. A systematic literature review of 434 ANP studies for a 10-year period (2012–2021) within the Scopus database was conducted using the keyword “Analytic Network Process” in articles indexed in the following two categories: (1) Business, Management and Accounting, and (2) Economics, Econometrics and Finance. Further analysis using a citation-based graph and contingency analysis approaches was performed to identify usage trends. Our findings indicate that the most common ANP applications are with sustainable supply chain management and business evaluation frameworks. There is also a trend of applications engaging stakeholders in the decision-making process. Finally, it was found that the ANP is most commonly used as part of a multicriteria multi-method (a method followed by others) or integrated decision-making (hybridization of methods) approach rather than alone. The most common use (>80%) of the ANP is as part of a multi-method or integrated method with other tools such as DEMATEL, which suggests these approaches, in particular integrated ones (>50%), are becoming the preferred method of analysis to simplify the ANP process. From a practical point of view, it was found that the ANP is particularly utilized in sustainable projects to facilitate the participation of various stakeholders. This is the first focused review of the use of the ANP in the areas of economics, finance and management with an emphasis on its application as well as its contingent factors. Also, representative studies have been highlighted in each area. Traditional reviews have not delved deeply into the areas and contingent factors that this study explores.

1. Introduction

The Analytic Network Process (ANP) is a decision-making analysis methodology that addresses decisions in which the decision elements (called nodes), such as criteria and alternatives, are interrelated (dependence and feedback) (Saaty, 1996). The ANP constitutes a generalization of the widely used Analytic Hierarchy Process (AHP), in which the decision elements only have a hierarchical relationship arranged as the goal, criteria and alternatives (Saaty, 1980).

Contingency theory states that managerial activity, such as decision-making, must take into account situational factors (Hatch, 1997; Mu & Stern, 2018). MCDM methods have been developed to assist in a key

managerial activity, decision-making, which according to the contingency approach must take into account situational factors that may affect the decision-making process outcomes. MCDM methods differ in their adequacy and ability to incorporate and address these contingent factors. Not all decision-making methods can adequately support all decision types and situations; for this reason, when exploring the use of the ANP in MCDM analysis, contingency factors should be considered (Mu & Cooper, 2022). Two kinds of contingencies are usually considered for decision-making purposes. These contingencies are content and context. Both of these contingencies are considered to influence the choices, expected benefits, and processes (such as decision analysis methodology) to be applied (Bell, Bromley, & Bryson, 1998).

* Corresponding author at: INGENIO, Universitat Politècnica de València, CSIC, Edificio 8E, Camí de Vera s/n, 46022 Valencia, Spain.
E-mail address: hkgonzal@upvnet.upv.es (H. Gonzalez-Urango).

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In terms of content, strategic decisions tend to be less structured, have inter-dependent criteria, and less defined alternatives, etc. For this reason, and given the importance of strategic decision-making in the three areas (economics, finance and management) targeted in the present study, the extent of the use of the ANP based on the decision content (strategic vs. non-strategic) will also be explored.

Context identifies the environment in which a decision is made. Contextual external factors play an important role in strategic and public decision-making. For example, in the public sector, the broader context requires consultation or even participatory decision-making with the stakeholders involved. One key difference between public and private sector management is that the former requires a great deal of transparency and interaction with a large number of stakeholders whose actions may play a decisive role in the adoption and public acceptance of proposed actions (Bryson, 2004). A stakeholder is defined as any group or individual who can affect the achievement of or is affected by the achievement of the organization's objectives (Freeman, Harrison, Wicks, Parmar, & De Colle, 2010). Again, not all decision-making methods are equally suitable for the described task. Some may be very difficult to understand by an untrained participant or even challenging to participate in without some technical training. Other methods, such as the ANP, facilitate stakeholders' participation by limiting their cognitive efforts to answering pairwise comparison questions in terms of criteria importance or outcome preferences. In any case, and given that MCDM methods differ drastically in their ability to facilitate public decision-making needs, it is essential to assess the extent of use of the ANP with respect to public and private decision-making.

Another contextual factor to consider is the decision-making process itself. There is a wider recognition that the manner in which the decision analysis is conducted will strongly impact the decision's validity. The proposed decision analysis must be in accordance with accepted best practices for the particular decision (e.g., benefit/cost/risk analysis for financial investment decisions; transparency for public administration decisions). Given that using a single method may not provide all the decision analysis needs for all the different situations, some researchers combine different multicriteria decision-making methods in the decision analysis process. This can be done by using one method for the structuring phase or the first stage of the analysis and a different method for the second stage. For example, some studies use interpretive structure modeling (ISM) or decision making trial and evaluation laboratory (DEMATEL) to analyze the interrelationships among the decision model elements prior to using the ANP for the proper decision analysis (Meena & Thakkar, 2014). Another more recent approach consists of combining MCDM methods to create a hybrid method, such as Fuzzy AHP/ANP or a more recent DEMATEL-ANP integration proposal with the intended purpose of obtaining an ad-hoc hybrid method of decision analysis for the specific decision context (Kadoić, Divjak, & Begičević Redep, 2019; Kahraman, Çebi, Onar, & Öztayşi, 2022).

In summary, to properly address and increase the use of the ANP in the areas of economics, finance and management, this study will explore the extent of its use in these areas; the contingency factors such as decision content (strategic vs. non-strategic), decision sector (public vs. private) and methodological approaches (single, mixed or integrated methods); and finally, the usage trends in the selected three areas of study.

Based on the above discussion, the proposed research questions (RQ) are:

RQ1: To what extent is the ANP used in the areas of economics, finance and management?

RQ2: What are the contingency factors of the use of the ANP in economics, finance and management?

The above discussion provides the context of the present study that will focus on the use of the ANP in the areas of economics, finance and management. The ANP will be used because it constitutes the most

complete generalization of the AHP and is particularly suitable for the complexity and interrelated nature of the three proposed areas of study.

The rest of this paper is organized as follows. In Section 2, the theoretical background is presented. The review methodology is described in Section 3, and comprises the study design, data collection steps, and analysis of the contingency variables. The analysis of the results for the RQs are given in Section 4. Then, the main results and a model framework for the use of the ANP in economics, finance and management are discussed in Section 5. Finally, Section 6 presents the main conclusions.

2. Theoretical background

It is not possible to discuss the Analytic Network Process (ANP) without discussing its predecessor, the Analytic Hierarchy Process (AHP). Ever since the development of the AHP by Saaty (1980), this method has caught the imagination of decision makers worldwide. For the first time, there was a method that could facilitate the participation of key stakeholders who, even without understanding the mathematical underpinnings of the method, could certainly express their preferences by simply answering questions related to the pairwise comparison of decision criteria or alternatives. The AHP was initially diffused in the academic literature (Saaty, 1988), where it had to be reviewed by the academic community prior to becoming practically useful in Fortune 500 companies (Bauer, Collar, Tang, Wind, & Houston, 1992) and then worldwide (Vaidya & Kumar, 2006). Today it is the most widely used decision-making method worldwide and there is vast literature, beyond Saaty's original work, that addresses the fundamentals of the method aimed at an audience of practitioners (Brunelli, 2015; Mu & Pereyra-Rojas, 2018).

While the AHP allows many decision situations to be addressed, its use in more complex situations where there may be a strong interaction between different elements of the hierarchy, either at the same level of the hierarchy or at different levels violates AHP axioms of lack of interrelationship among peer elements (interdependency) or the presence of feedback from the alternatives (Saaty, 2010); therefore, a new approach was needed. This problem was solved by Saaty (1996) with the proposal of a generalized approach to the well-known AHP method. In this approach, called the Analytic Network Process (ANP), the decision model in its more generic form is constituted by a network composed of connecting nodes (criteria and alternatives) grouped in clusters. In this situation, a decision hierarchy constitutes a special case of the network model. For this reason, the ANP constitutes a generalization of the AHP method. The reader is referred to the original sources or additional literature for a complete treatment of the subject (Ishizaka & Nemery, 2013; Mu & Pereyra-Rojas; 2018; Saaty, 1980; Saaty 1996).

In the AHP, the decision is modeled as a hierarchy where the top decision element is the goal, followed by the decision criteria and at the lowest level, the alternatives. The criteria are compared pairwise with respect to the goal to derive their relative importance. The alternatives are compared pairwise to derive their relative importance with respect to each criterion. Finally, through a synthesis process, the overall priorities of the alternatives are calculated. In the AHP, it is assumed that the alternatives depend on (affect) the criteria, which in turn depend on the goal. This dependence is unidirectional (the opposite direction would constitute feedback). Furthermore, at any given level of the hierarchy, the elements are not interdependent.

However, complex decisions may involve dependence within and between elements of the decision. The ANP was developed to address this interdependence and feedback among the decision model elements (e.g., criteria, alternatives), leading to a better modeling of the complexity through networks (Saaty & Kulakowski, 2016). Since these interdependencies can occur between any of the model elements (called nodes in the ANP), the model is no longer a hierarchy but a network (see Kalantari et al., 2021; Miller et al., 2021; Ujwary-Gil & Potoczek, 2020). In the ANP, clusters replace the hierarchy levels and each cluster

contains elements (Ishizaka & Nemery, 2013).

The ANP had a rather slow start after it was first introduced due to the complexity of the calculations necessary for its implementation; however, the development of the Super Decisions software by the Creative Decision Foundation contributed to its growing use (<https://www.superdecisions.com/>). Its use has started to increase during the past ten years based on the various ANP literature reviews conducted during that period (Chen et al., 2019; Kheybari et al., 2020; Sipahi & Timor, 2010). The current ANP literature reviews tend to focus on the general use of the method and are extremely broad (including all sorts of applications) or are part of even broader studies (for example, as part of a MCDM methods literature review). To date, there no focused studies of ANP applications in economics, finance and management exist that could help researchers and practitioners in these areas understand where the ANP is most widely used and where it should be applied in the future. This is the gap in the literature that the present study intends to fill. However, there is also a greater gap present in the larger MCDM literature that this study aims to fill which is the exploration of the contingency factors in which ANP decision-making is used.

In summary, the ANP is a methodology that allows complex decisions to be modeled as networks that include dependence and feedback among the decision elements grouped in clusters. The above discussion provides the theoretical foundation to understand the ANP methodology and its great potential to address problems in the areas of

economics, finance and management.

3. Methodology

For this study, a three-stage methodology consisting of: (1) a literature survey; (2) an analysis and synthesis; and (3) a reporting of results was conducted (Fig. 1). The methodology was designed based on previous reviews (Denyer & Tranfield, 2009; Xiao & Watson, 2019).

Stage 1 involved the design of the survey process and the definition of the initial search criteria. First, Scopus was selected as the most suitable database for the literature search since it has the largest collection of abstracts and citations of peer-reviewed literature. Due to its wide coverage of academic literature, we considered it the most reliable, relevant and up-to-date research database. The first search item used was the term “Analytic Network Process” in the category “Article title, Abstract, Keywords”. In order to focus on the most advanced developments and trends rather than historical ones, the selected time period was 2012–2021. The search was also limited to articles written in English for practical purposes and consistent with the fact that most published academic literature is in this language. This first search resulted in a list of 1,543 articles. However, this list included many areas other than economics, finance and management. To ensure that the selected articles would only be within the three areas of this study, two Scopus subject areas were selected. These areas were Business,

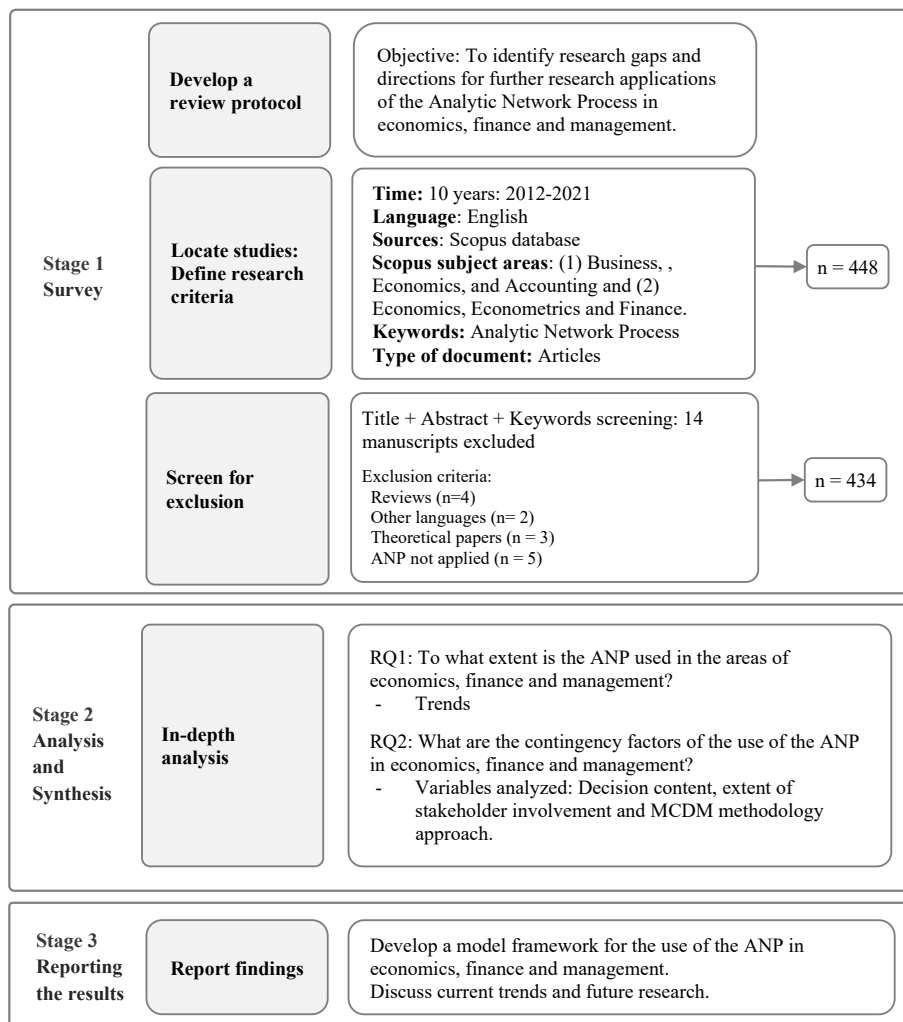


Fig. 1. Methodology of the systematic literature review process.

Management and Accounting; and Economics, Econometrics and Finance and this search returned 448 articles. Within the 448 results, four were reviews, two were in languages other than English, three were theoretical rather than empirical applications, and five only referenced the ANP. This screening process resulted in 434 articles to be reviewed. The appendix provides a more detailed list of the articles selected.

During Stage 2, an in-depth analysis process was conducted to answer each of the two proposed research questions. To answer RQ1: *To what extent is the ANP used in the areas of economics, finance and management?*, the main trends in the application of the ANP were identified based on the analysis of the references cited by the 434 articles and with the assistance of the *Tree of Science* analysis tool (Robledo, Osorio, & López, 2014; Valencia-Hernández, Robledo, Pinilla, Duque-Méndez, & Olivar-Tost, 2020). This web-based tool applies graph theory based on the analysis of citation networks, where the 434 articles were evaluated according to network indicators including indegree, intermediation and outdegree. This analysis allowed the articles to be viewed as a large network that combined the different interactions among the studies and made it possible to identify different perspectives or trends in the application of the ANP. While the method suggested clusters of papers, the researchers still needed to analyze the titles, abstracts and keywords of the clustered papers in detail to identify their commonality and identify trends.

To answer RQ2: *What are the contingency factors of the use of the ANP in economics, finance and management?*, three contingent factors (also called variables), widely used in the literature, were used. The first factor is related to the decision content reported (strategic, non-strategic); the second factor is related to the extent of stakeholder involvement (public or private); and the last factor refers to the MCDM methodology approach, the ANP (single, multi, or integrated method). Variables were identified from a detailed analysis of each article's title and abstract. During this review process two additional articles were eliminated because they were duplicates.

To identify the contingency variables in the surveyed papers, the researchers analyzed the titles, abstracts and keywords using the following definitions.

Decision content: *Strategic Decisions* (SDs) are defined as strategic choices that have long-term consequences due to the resources required and precedents set. SDs are followed by operational decisions and actions for implementation. This definition is chosen because it also involves decisions made by top and middle managers rather than just top organizational leaders (Nutt & Wilson, 2010). The operationalization will be based on the scale, risk and long-term significance characteristic of the strategic decisions (Papadakis & Barwise, 1998).

Extent of stakeholder involvement: One key distinction between public and private sector management is that the former requires a great deal of transparency and interaction with a large number of stakeholders, many of whom are quite vocal and organized, and whose actions will play a decisive role in the adoption and public acceptance of the proposed actions (Bryson, 2004). For the purpose of the present study, we will consider *Public Decisions* as not just those made by public organizations, i.e. government entities, but also decisions that will have an impact on the public; that is, involve a large number of stakeholders. *Private Decisions* are made in the context of an organization or sector that operates in a competitive market and do not fall within the scope of the previously defined public sector decisions.

MCDM methodology approach: Decision analysis, in the context of the present study, can be conducted using only the ANP (*Single Method*), or the ANP combined with other techniques in a two-step approach, either as the first step or a follow-up method (*Multi-Method*). Other techniques can be combined with the ANP in order to modify the method of implementation of the ANP resulting in a hybrid approach to decision analysis (*Integrated or Hybrid Methodology*).

Finally, in stage 3 the results were analyzed and current trends and future research were discussed. A model framework for the use of ANP in economics, finance and management was also developed. In this

framework, representative studies were highlighted for each area.

4. Results

The literature search returned a total of 434 studies published between 2012 and 2021. The years 2018 and 2020 had the highest number of publications (Fig. 2). The journals with the highest number of publications are the *Journal of Cleaner Production and Technological and Economic Development of Economy* (see Table 1).

4.1. RQ1. To what extent is the ANP used in the areas of economics, finance and management?

The analysis allowed the identification of some trends and novelties in the application of the ANP as shown in Fig. 3. A detailed discussion of these findings follows next.

The analysis allowed the identification of some trends in the application of the ANP. First, the model focuses on sustainability (Zhang, 2016) and supply chain management. The use of the ANP in supplier/vendor selection (Bhadani, Shankar, & Rao, 2016) and supply chain design (Wu & Barnes, 2016) is also highlighted. The following three studies were the most cited: an integrated decision making trial and evaluation laboratory technique (DEMATEL)-ANP approach for selecting renewable energy resources in Turkey (Büyükoçkan & Güleriyüz, 2016); the assessment of green supply chain practices in the Ghanaian mining industry (Kusi-Sarpong, Sarkis, & Wang, 2016), and a supplier selection in the electronic supply chain (Rajesh & Ravi, 2015).

The next trend that became apparent was the development of models in business contexts applied to strategic design (Fouladgar, Yazdani-Chamzini, Zavadskas, & Haji Moini, 2012; Lee & Lee, 2012; Chang, Pu, & Hsieh, 2014; Medel-González, Salomon, & García-Ávila, 2015; De Felice & Petrillo, 2015). These studies highlight the use of the ANP in combination with the Balance Score Card (Tjader, May, Shang, Vargas, & Gao, 2014; Hu, Wen, & Yan, 2015; Varmazyar, Dehghanbaghi, & Afkhami, 2016). The most cited work in this area is a green supply chain performance measurement framework using a fuzzy ANP-based balanced scorecard (Bhattacharya et al., 2014).

The final identified trend was studies with a large number of stakeholders involved (Rydval, Bartoška, & Brožová, 2014; Horng, Liu, Chou, Yin, & Tsai, 2014) and applied to marketing (Liu, Tzeng, & Lee, 2013; Lin, Yeh, & Hsu, 2014; Liu & Chou, 2016), mainly focusing on product and service design (Horng, Chou, Liu, & Tsai, 2013; Liu, Tzeng, Lee, & Lee, 2013). The most cited study in this group developed an integrated DEMATEL-ANP-VIKOR model that focused on assessing and improving strategies to reduce the gaps in customer satisfaction in e-stores (Chiu, Tzeng, & Li, 2013).

In addition to the above trends, the analysis also allowed the identification of some studies that stand out for the novelty of their proposed methodology. Two of the studies proposed an integrated DEMATEL-ANP, called DANP, to decide on an appropriate interactive trade strategy (Wang, 2012) and to prioritize types of infrastructure (Huang, Liou, & Chuang, 2014). Both stand out as some of the first DANP applications and also because of the type of problem to which they were applied. In addition, Wang et al. (2013) proposed an integrated fuzzy Delphi method (FDM), interpretive structural modeling (ISM), and ANP with benefits, opportunities, costs, and risks (BOCR) approach for project selection for district revitalization and regeneration. The novelty of this application is the integration of different approaches to propose a new perspective.

Finally, a tabulation of the ten most cited articles during the 10-year study period was conducted. Six of the ten most cited ANP articles focused on sustainable applications (papers 1, 2, 3, 5, 6, & 8 in Table 2) and most (except for paper 3) focused on supply chain management, which reinforces our finding of sustainability and supply chain management as a very important trend. Also, with the exception of paper 10, all the other studies are either multi-method or integrated approaches

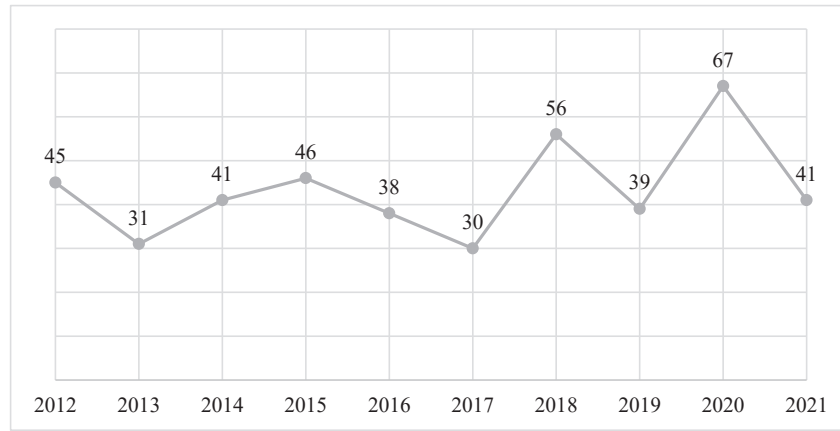


Fig. 2. Publication frequency by year.

Table 1
Journals with the most ANP publications.

Journals	Publications
<i>Journal of Cleaner Production</i>	39
<i>Technological and Economic Development of Economy</i>	14
<i>Journal of Business Economics and Management</i>	10
<i>Journal of Multi-Criteria Decision Analysis</i>	10
<i>Journal of Modelling in Management</i>	10
<i>International Journal of Production Economics</i>	10
<i>International Journal of Production Research</i>	9
<i>Production Planning and Control</i>	8
<i>Journal of Civil Engineering and Management</i>	7
<i>Benchmarking</i>	7

using the ANP and other methods such as DEMATEL and ANP, fuzzy DEMATEL-ANP or even DANP combined with VIKOR. This is consistent with the finding that 80.7% (from Table 4) of the studies from the period of study used multi-method decision-making approaches.

4.2. RQ2. What are the contingency factors of the use of the ANP in economics, finance and management?

The analysis of the selected variables to understand the contingency factors of ANP applications in economics, finance and management allowed us to confirm and complement some of the findings as shown in

Fig. 4. A detailed discussion of these findings follows next.

Regarding the type of decisions reported (Table 3), we primarily found decision models oriented toward non-strategic decisions (82%). These decisions were characterized by being operational for implementation purposes and evaluative with the aim of measuring performances. The decision models studied were also oriented toward the private context (89%), in other words, designed for a project, organization or sector whose main objective is to remain in the market and be more efficient.

Strategic decisions, which represented 18% of the studied cases, are mostly made in the private context. These include the evaluation and selection of strategies in marketing (Dahooie, Mohammadi, Meidutė-Kavaliauskienė, & Binkytė-Velienė, 2021; Chang, Hsu, & Swanson, 2021; Chou, Horng, Liu, & Lin, 2021), maintenance (Jamali, Feylizadeh, & Liu, 2021; Kurian, et al., 2020; Pourjavad, Shirouyehzad, & Shahin, 2020; Aghaee, Aghaee, Fathi, Shoa'bin, & Sobhani, 2020), manufacturing (Ocampo, Clark, Chiu, & Tan, 2020), logistics (Gu, Wang, Dai, Wei, & Chiang, 2021; Rajesh, 2020) infrastructure (Lin, Zhao, et al., 2021; Huynh, Pham, & Le-Hoai, 2021), and the design of business competitive strategies (Munim, Sornn-Friese, & Dushenko, 2020; Chang, 2020) among others. An interesting aspect was that most of the models were oriented toward sustainability.

Among the so-called public strategic decisions oriented toward a broader/wider group of stakeholders, models related to land use planning (Lin, Chen, Trac, & Wu, 2021; Dragoi, 2018; Liu, Tzeng, Lee, et al.,

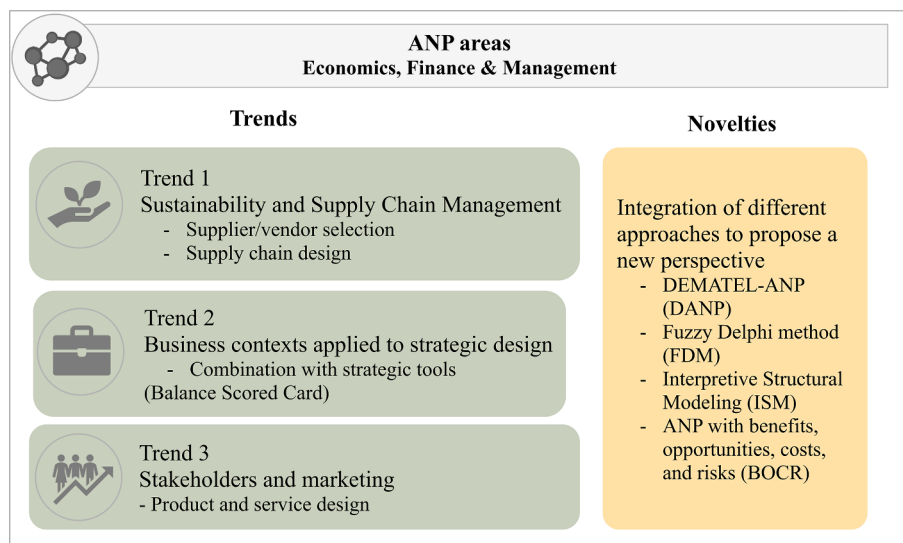


Fig. 3. ANP trends and novelties in the areas of economics, finance and management.

Table 2
Most cited papers.

No	Author - Year	Title
1	(Hashemi, Karimi, & Tavana, 2015)	An integrated green supplier selection approach with analytic network process and improved Grey relational analysis
2	(Rajesh & Ravi, 2015)	Supplier selection in resilient supply chains: A grey relational analysis approach
3	(Büyüközkan & Gülleryüz, 2016)	An integrated DEMATEL-ANP approach for renewable energy resources selection in Turkey
4	(Chiu et al., 2013)	A new hybrid MCDM model combining DANP with VIKOR to improve e-store business
5	(Cabral, Grilo, & Cruz-Machado, 2012)	A decision-making model for Lean, Agile, Resilient and Green supply chain management
6	(Bhattacharya et al., 2014)	Green supply chain performance measurement using fuzzy ANP-based balanced scorecard: A collaborative decision-making approach
7	(Liu, Tzeng, & Lee, 2012)	Improving tourism policy implementation - The use of hybrid MCDM models
8	(Hsu, Wang, & Tzeng, 2012)	The best vendor selection for conducting the recycled material based on a hybrid MCDM model combining DANP with VIKOR
9	(Kiani Mavi & Standing, 2018)	Critical success factors of sustainable project management in construction: A fuzzy DEMATEL-ANP approach
10	(Van Horenbeek & Pintelon, 2014)	Development of a maintenance performance measurement framework-using the analytic network process (ANP) for maintenance performance indicator selection

Table 3
Type of decision.

	Public	Private	Total	
Strategic	18	60	78	18.1%
Non-Strategic	30	322	352	81.9%
Total	48	382	430	
	11.2%	88.8%		

Table 4
Type of methodology.

Multi-Method	96	22.3%
Integrated	251	58.4%
Single Method (ANP)	83	19.3%
	430	

2013) and the development of public policy (Sayyadi & Awasthi, 2018; Mavi, Gheibdoust, & Khanfar, 2020; Šimelytė, Peleckis, & Korsakienė, 2014; Liu et al., 2012) stand out. To a lesser extent, they are oriented toward macroeconomic decisions (Zams et al., 2020; Wang, 2012) and management of resources such as water (Arasteh & Farjami, 2021). In

these studies, sustainability-oriented models were predominant.

The non-strategic decision models found in the private sector are mainly aimed at the identification of drivers or barriers for the implementation of plans or actions (Raut et al., 2021; Shiue, Liu, & Li, 2021; Nimawat & Gidwani, 2021), the definition of evaluation frameworks (Zhang et al., 2021; Tsai & Chen, 2021; Nabeeh, Abdel-Basset, & Soliman, 2021), knowledge management (Ada, Ilic, & Sagnak, 2021; Amoozad Mahdiraji, Beheshti, Jafari-Sadeghi, & Garcia-Perez, 2021; Fanati Rashidi, 2020), location (Ocampo, Himang, Kumar, & Brezocnik, 2019; Rahimi, Ashournejad, Moore, & Ghorbani, 2020; Anand, Kodali, & Dhanekula, 2012), waste management (Tsai et al., 2021; Thakur & Ramesh, 2017), risk management (Akcay, 2021; Sharma, Sharma, & Singh, 2021; Silva, de Oliveira, Leite, & Marins, 2021), supply chain management (Uzuner & Geyikçi, 2021; Wan, Liu, Du, & Du, 2021), production or manufacturing (Bayhan, Demirkesen, Zhang, & Tezel, 2021; Lin, Wang, et al., 2021; Lee, Chen, & Kang, 2020), resource allocation (Kaur & Kaushik, 2021; Xu, Ren, Dong, & Yang, 2020; Atta Mills, Baafi, Amowine, & Zeng, 2020), supplier/vendor selection (Tirkolaee, Mardani, Dashtian, Soltani, & Weber, 2020; Valipour Parkouhi & Safaei Ghadikolaei, 2017), technology evaluation (Yeo et al., 2020; Shen, Lin, & Tzeng, 2012), and quality (Hsieh & Chuang, 2020; Gedela, Mohan, & Prasad, 2018) among others.

At the public level, the models were more diverse and were similarly orientated as at the private level, but oriented toward a broader group of stakeholders. For example, the models at the public level were oriented toward the development of infrastructure (Liu, Wang, Fowler, & Ji, 2021; Omrani, Safaei, Paydar, & Nikzad, 2020; Cabral et al., 2012), technology evaluation (Fetanat, Mofid, Mehrannia, & Shafipour, 2019; Noorollahi, Fadai, & Ghodsipour, 2018; Giner-Santonja, Aragonés-Beltrán, & Niclós-Ferragut, 2012), the importance of driver factors (Iskin, Daim, Kayakutlu, & Altuntas, 2012), the development of management indicators (Zhang & Zhang, 2020; Tavana, Zandi, & Katehakis, 2013; Horng, Hu, Teng, & Lin, 2012; Lee, 2012) and primarily land management (Ferretti & Pomarico, 2013; Wang et al., 2013).

The use of the ANP in combination with other techniques was also analyzed (Table 4). The ANP as the only decision tool was used in 19% of the studies. Also, it was found that in 22% of the studies the ANP was combined with other techniques using the hybrid methodologies approach that include other techniques to better capture or analyze information. Some of the techniques found to be used in the hybrid methodologies approach were the AHP (Nimawat & Gidwani, 2021; Hornická & Brožová, 2013), spatial analysis tools (Oppio et al., 2015; Ferretti, Bottero, & Mondini, 2015; Ferretti & Pomarico, 2013), Delphi (Zhang & Zhang, 2020; Zams et al., 2020), system dynamics (Sayyadi & Awasthi, 2018; Kumar & Thakkar, 2017), SWOT (Geç, Kabak, Özceylan, & Çetinkaya, 2018), BOCR (Jaafari et al., 2015; Šimelytė, Peleckis, & Korsakienė, 2014) and interpretive structural modeling (Dahooie et al., 2021; Chang et al., 2021; Wang et al., 2013).

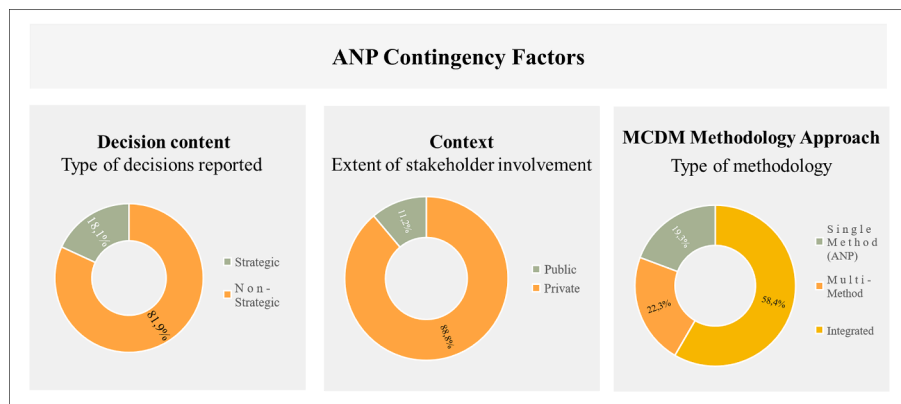


Fig. 4. Contingency factors of the use of the ANP in economics, finance and management.

However, the trend that stands out the most is the integration of the ANP with other methodologies that modify its implementation. The DEMATEL technique (Raut et al., 2021; Lin, Zhao, et al., 2021; Mili, 2017) and the fuzzy theory (Tekez & Taşdeviren, 2020; Sagnak, Ada, Kazancoglu, & Mishra, 2020; Azizi, Rahimi, Ray, Faezipour, & Ziaie, 2016) are the most commonly integrated methods, followed by TOPSIS (Davodabadi, Daneshian, Saati, & Razavyan, 2021; Thakur & Ramesh, 2017), VIKOR (Girubha, Vinodh, & Kek, 2016), Weighted Linear Combination (Lin et al., 2021), simple additive weighting method (Wudhikarn, 2021; Yasmin, Tatoglu, Kilic, Zaim, & Delen, 2020), and grey relational analysis (Ocampo et al., 2020; Ou, 2016), among others. The integrated use of the ANP with other techniques, although it has been a fairly common practice, has intensified during recent years.

In general, the use of the ANP in the areas of economics, finance and management is characterized by integration with other techniques, application to operational decisions in the private sector in the short term and involvement of a few stakeholders.

5. Discussion and further research

This study has shown that there is a trend toward using the ANP as a decision-making methodology in sustainable applications in supply chain management. This trend should continue and increase given the growing importance of sustainability on a global level and also because the current pandemic has highlighted the importance of effective supply chain management. An interesting example of the use of the ANP in economics and finance is provided by Zams et al. (2020). They argued that if a central bank decides to develop a central bank digital currency (CBDC), the design should conform to the country's characteristics and consumer needs. To evaluate the most suitable CBDC design, they developed an ANP model and used expert opinions from 18 economic experts representing the different participating economic agents and concluded that the most appropriate digital currency design was a cash-like CBDC design, since it could enhance financial inclusion and reduce shadow banking in Indonesia.

Another important trend is the use of the ANP for the development of business evaluation frameworks applied to strategic design and performance assessment. The most representative paper within this category is Bhattacharya et al. (2014) who developed a green supply chain (GSC) performance measurement framework using an intra-organizational collaborative decision-making (CDM) approach. This approach assisted the firm in identifying further requirements of the collaborative data across the supply chain and information about customers and markets. In general, business applications in the areas of marketing and product service and design require an increasing number of stakeholders involved in the decision-making process, which constitutes another of the growing trends found in this study. Another interesting example of the use of the ANP in business management is Horenbeek and Pintelon (2014)'s development of a maintenance performance measurement (MPM) framework for maintenance performance indicator selection. The ANP-based methodology addresses what the authors considered the two major flaws of the available MPM frameworks (at the time) by considering all organizational levels (i.e., strategic, tactical and operational) of corporate as well as operational maintenance objectives to define management performance indicators (MPI). The development of the MPM system and the ANP model aligns the maintenance objectives on all management levels with the relevant MPI used.

In terms of contingency variables, the ANP is more widely used in operational-oriented private applications than in public ones. However, this may simply reflect the fact that these are the most common decision-making situations in organizations. In effect, strategic decisions are less common in organizations than operational decisions. It would be interesting to know how the use of the ANP in strategic decisions compares to other MCDM methodologies, but this is outside the scope of the present study. In addition, public decisions, involving a large number of stakeholders are complex in methodological terms and, for this reason,

may not be very prevalent. Still, the growing movement toward open data and processes may increase the interest in participatory decision-making in decisions that have a broad impact on the public. The flexibility of the ANP as evidenced by its ability to be combined with other methods, many of them used for strategic decision making (SWOT, BOCR, Balanced scorecard, etc.) suggests that the identified trend of the use of the ANP in strategic organizational design and performance will continue to increase. In fact, an important finding of the present study is that a large number of studies use a multi-method approach (>80%); furthermore, more than half of the studies use integrated methods; that is, a combination of the ANP with other methods to produce hybrid decision-making approaches. Methods such as Fuzzy theory, DEMATEL, TOPSIS, VIKOR and Grey relational analysis are increasingly used in combination with the ANP. Hashemi et al. (2015), which is the most cited paper from 2012 to 2021 (Table 2), is a representative example of most of our findings in the present study. This study used both economic and environmental criteria to develop a comprehensive green supplier model. The ANP was used to address the interdependencies among the criteria and a modified Grey relational analysis was used to address the uncertainties inherent in supplier selection decisions. This study exemplifies the trends found in the current survey which are the increasing use of the ANP in sustainable supply chain applications usually as part of a multi-method decision-making approach.

From the literature review, it is also possible to develop a model framework for the use of the ANP in the different areas studied in the present article and provide some representative studies (mostly selected based on their high number of citations) from the identified literature, as will be discussed next.

ANP Use in Economics. It is possible to address the use of the ANP in the field of economics based on our findings in the current study. Table 5 provides some of the findings about the use of ANP in economics.

ANP Use in Finance. Finance, and more specifically corporate finance, can be defined as the management of cash in a firm; however, it can be more precisely described as the practice of the following five key functions: financing, financial management, capital budgeting, risk management and corporate governance (Graham, Adam, & Gunasingham, 2020). The ANP can be used to support these functions as shown in Table 6.

Table 6 shows that the first four functions (financing, financial management, risk management and investment) can be addressed through the use of the ANP in what constitutes a portfolio optimization taking into account benefits, costs, opportunities and risks while the corporate governance function constitutes an ANP strategic decision-making application.

ANP Use in Management. While there have been several discussions about the functions of management; in general, the most commonly used list of functions is that of Koontz and O'Donnell (1959), as discussed by Shinde (2018) and others, and consist of planning, organizing, staffing, directing and controlling. The ANP is widely used to support these management functions as shown in Table 7.

The results of the study also suggest some avenues for further research in the use of the ANP under the theoretical umbrella of decision-making contingent factors, as used in the present study. First, given the growing use of the ANP in sustainability studies which usually require stakeholder engagement, it is important to develop a decision-making protocol for the use of the ANP in a way that optimizes stakeholder's engagement and participation in decision-making in general. To date, each study has followed an ad-hoc process, with little consideration of the lessons learned from other studies, leading to redundant and inefficient results. Some tentative research has been done in this area but it is still incipient. For example, Gonzalez-Urango et al. (2021) explored the extent of stakeholder's engagement in sustainable territorial and urban development decision-making studies and proposed a basic set of variables to consider including stakeholder identification, prioritization, inclusion of stakeholders' perspectives in the decision model and extent of participation in the decision-making process. These

Table 5
ANP Use in Economics.

Function/ Purpose	Description	ANP use and representative studies
Policy Analysis	Consists of the examination and evaluation of available options to address various economic, social or other public issues (Encyclopedia Britannica, 2023)	Cost benefit analysis is one of the most common forms of policy analysis and has been widely implemented using ANP Benefits/Cost analysis. Another important advantage of the ANP is the possibility of including stakeholders and their perspectives in the policy analysis. The current study found several exemplary works in this area (Liu, Tzeng, & Lee, 2012; Catron, Stainback, Dwivedi, & Lhotka, 2013; Šimelytė, Peleckis, & Korsakienė, 2014)
Investment Evaluation	Consists of determining how an investment is likely to perform and its suitability for a particular investor (Investopedia, 2023)	Analysts use past performance as well as other criteria such as return on investment, risk level and others to evaluate potential investments. The ANP is suitable for this type of analysis and several examples were found in the current literature review (Wu, Wang, Ji, Song, & Ke, 2019; Gharanfoli & Valmohammadi, 2019; Büyükoçkan & Güleriyüz, 2016)
Development Economics	Consists of the structural transformation of an economy to produce economic growth or the potential for sustained well-being of the society (Khan, 2019)	The ANP can be used to evaluate the benefits and costs of different possible avenues for economic development (Jaafari, Najafi, & García-Melón, 2015; Fanati Rashidi, 2020; Kusi-Sarpong, Sarkis, & Wang, 2016)

Source: Authors.

studies are also embedded in the broader efforts to improve ANP research best practices (Mu, Cooper, & Peasley, 2020).

Second, while the use of the ANP as a business performance evaluation framework is widely spread, the development of these frameworks are rarely embedded in the widely known literature for the development of composite indicators available such as [Freundenberg \(2003\)](#). This omission may raise concerns about the overall validity of the evaluation framework. For example, one important consideration in the development of social indicators is the aggregation of the indicators used for each category or variable. While indicators may have been collected for each variable, it is necessary to determine whether the indicators converge toward a single variable and can therefore be aggregated ([León & Mu, 2021](#)). [Greco et al. \(2019\)](#) reviewed the issues surrounding composite indicators' weighting, aggregation, and robustness and identified and compared many participatory methods for this purpose. However, only a few studies have addressed modeling ANP evaluation frameworks within the methodological context of the development of social composite indicators ([Mu, Florek-Paszowska, & Pereyra-Rojas, 2022](#)).

Third, while the ANP has been used in finance in many different ways, some untapped application areas could still be explored in the future. One area may be the optimization of investment portfolios by assessing many criteria, such as risk, return, liquidity, and diversification. The ANP can also consider asset interdependencies and determine the most efficient allocation of funds to achieve the desired portfolio mix. Another area of application of the ANP is sustainable finance, by evaluating multiple criteria such as environmental impact, social responsibility, and financial performance. The ANP can also identify the most effective strategies for integrating sustainability into investment

Table 6
ANP Use in Finance.

Function	Description	ANP use and representative studies
Financing	Involves raising capital to support a firm's operations and more importantly to determine the proper mix of debt and security to optimize.	The ANP can be used to evaluate the different possible criteria such as risk, return, liquidity and diversification. Representative examples of these applications were found in the literature review (Büyükoçkan, Güleriyüz, & Karpak, 2017; Rahiminezhad Galankashi, Mokhtab Rafiei, & Ghezlbash, 2020)
Financial Management	Consists of managing a firm's cash flow as efficiently as possible.	Decisions such as what suppliers to pay, based on specific criteria, can be made based on ANP modeling. Some exemplary works are listed in the present study (Hashemi, Karimi, & Tavana, 2015 ; Lin, 2012 ; Rajesh & Ravi, 2015)
Investment	Requires evaluating the best projects in which to invest the company funds.	The ANP can be used to evaluate the different investment options using criteria such as profitability, market size and others; the ANP can help make informed decisions (García-Melón, Poveda-Bautista, & Del Valle, 2015 ; Jeng & Huang, 2015)
Risk Management	Comprises identifying, measuring and managing a firm's exposure to all types of risks.	The ANP can be used to evaluate not only the risks associated with investments but other potential risks a firm may be exposed to (Chemweno, Pintelon, Van Horenbeek, & Muchiri, 2015 ; Valipour et al., 2015 ; Fazli, Kiani Mavi, & Vosooghidizaji, 2015)
Corporate Governance	Consists of developing enterprise-wide structures and incentives that encourage managers to behave ethically while maximizing benefits for shareholders.	It is necessary to make decisions between different possible structures and incentives and the ANP allows the consideration of not only tangible criteria, such as alignment with a firm's strategy, but also intangible criteria such as ethical considerations. Interactions such as moral hazard situations can also be modeled. Good examples of this function can be found in the present study (Hsu, Lee, & Chao, 2013 ; Poplawska, Labib, & Reed, 2017 ; Liu, Shiue, Chen, & Huang, 2018)

Source: Authors, functions and their definitions adapted from [Graham et al. \(2020\)](#).

decisions and financial operations.

Finally, the increasing use of multi-methods, in particular integrated methods, also offers a clear avenue for future research. How valid are the integrated methods? Given that many different MCDM methods exist, the possible number of combinations is extremely high. Also, what should the criteria be to decide the combination of any of these methods? For the integrated methods, how useful and valid are they? A recent DEMATEL-ANP integrated approach proposed by [Kadoić et al. \(2019\)](#) to simplify the use and analysis of the ANP was tested by [Schulze-González et al. \(2021\)](#) who found that the values of the priorities and the ranks obtained with this new proposal were very similar to the results obtained with the ANP, suggesting that while the proposed integration drastically decreased the number and complexity of questions, it was

Table 7
ANP Use in Management.

Function	Description	ANP use and representative studies
Planning	Consists of determining a future course of action to move a firm from where it is to where it should be (goals) as well as how to make that happen.	The ANP is used in these cases to evaluate and decide from among the different possible courses of action. This application falls within the field of strategic decision making. Several relevant studies were found in the current literature review (Tjader, May, Shang, Vargas, & Gao, 2014; Cabral, Grilo, & Cruz-Machado, 2012; Greco, Cricelli, & Grimaldi, 2013)
Organizing	Process of efficiently using a firm's physical, financial and human resources to obtain desired results.	This function has been typically associated with operations management which involves evaluation, selection and optimization (Chiu, Tzeng, & Li, 2013; Hsu, Wang, & Tzeng, 2012; Orji, Kusi-Sarpong, Huang, & Vazquez-Brust, 2020)
Staffing	Consists of the proper recruitment, training, compensation and performance evaluation of personnel. The aim is to ensure that the right person is in the right position in a firm.	Since its inception, the ANP and its predecessor the AHP, have been used for personnel selection and performance evaluation (Kanat & Atilgan, 2014; Upadhayay & Vrat, 2016; Ada, Ilic, & Sagnak, 2021)
Directing	Encompasses supervision, motivation, leadership, and communication.	While the ANP can be used to evaluate any directing decision, this function constitutes mainly the inter-personal function of management (Kiani Mavi & Standing, 2018; He, Luo, Hu, & Chan, 2015; Tavakoli, Shirouyehzad, & Dabestani, 2016)
Controlling	Consists of measuring organizational accomplishments against the standards and goals previously set to identify deviations and opportunities to correct course.	The ANP has been used in the development of composite indicators to assess the extent of completion of different activities or the extent of the presence of desired organizational features. The current study found several exemplary works in this area (Bhattacharya et al., 2014; Van Horenbeek & Pintelon, 2014; Büyükoçkan & Çifçi, 2012)

Source: Authors, functions and descriptions adapted from Shinde (2018).

also mathematically equivalent in terms of the ANP results. This kind of study with integrated methods is still very incipient and needs to be increased.

6. Conclusion

The application of the Analytic Network Process (ANP) has been extensively used in the areas of economics, finance and management, with a significant focus on sustainability, supply chain management, and stakeholder involvement in decision-making. The ANP has proven to be an effective method as part of a multi-method decision analysis approach. The top six journals with over 10 ANP publications mainly focus on these target areas of study, accounting for approximately 40% of the publications. The formalization of ANP evaluation frameworks, the assessment and recommendation of ANP multi-methods, and the development of best practices for ANP research is likely to be the focus of future research.

The ANP could also be integrated with the latest technologies such as

Big Data, Machine Learning (ML), and Artificial Intelligence (AI) to automate decision-making processes in the areas of economy and management. By integrating the ANP with ML and AI, governments and organizations can streamline their decision-making processes, optimize resource allocation, and achieve their goals more effectively. However, integrating the ANP models with these technologies presents challenges that require further research.

Moreover, the ANP could be applied in emerging fields such as the circular economy and social entrepreneurship, as well as other fields of management, including healthcare and public administration, to enhance decision-making and resource allocation.

In conclusion, the application of the ANP in economics, finance and management has shown significant potential to improve decision-making, enhance resource allocation, and contribute to sustainability. Further research and development of ANP methodologies and their integration with emerging technologies will provide greater insight and improve the efficiency and effectiveness of decision-making in these areas.

CRedit authorship contribution statement

Hannia Gonzalez-Urango: Methodology, Investigation, Data curation, Writing – original draft, Writing – review & editing. **Enrique Mu:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Anna Ujwary-Gil:** Conceptualization, Writing – review & editing, Supervision. **Anna Florek-Paszowska:** Project administration, Visualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The code (and data) in this article has been certified as Reproducible by Code Ocean and is available at: <https://doi.org/10.24433/CO.9922938.v1> and at Zenodo Repository Website: <https://doi.org/10.5281/zenodo.7711628>.

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