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EVOLUTION OF TRIPLE AND QUADRUPLE HELIX MODEL TO QUINTUPLE HELIX MODEL: A BIBLIOMETRIC ANALYSIS

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Abstract

The Quintuple Helix Model, which emphasises the significance of integrating National Innovation Systems with environmental and social awareness, is a novel concept in the literature. The Quintuple Helix Model is an innovation model that was developed after the Triple Helix Model, which expresses the importance of establishing a synergetic relationship between the university-industry-goverment triangle, and the Quadruple Helix Model, which was developed by including the element of society. Every aspect of this helix is critical to providing a sustainable competitive advantage and to the economic development of countries. Furthermore, by creating strong links between environmental factors and creativity, this model has a close relationship with multidisciplinary analysis, problem solving, and decision making abilities. The purpose of this research is to provide a knowledge of the topic by examining the process from the formation of the Quintuple Helix Model through its development, and then to analyse studies on this model using the bibliometric analysis approach.

Keywords: Innovation, Triple Helix Model, Quadruple Helix Model, Quintuple Helix Model, Bibliometric Analysis

ÜÇLÜ VE DÖRTLÜ SARMAL MODELİN BEŞLİ SARMAL MODELE EVRİLMESİ: BİR BİBLİYOMETRİK ANALİZ

Öz

Ulusal İnovasyon Sistemlerinin çevresel ve toplumsal farkındalıkla bütünleştirilmesinin önemini vurgulayan Beşli Sarmal Model, literatürde yeni bir kavramdır. Beşli Sarmal Model, üniversite-sanayi-devlet üçgeni arasında sinerjik bir ilişki kurmanın önemini ifade eden Üçlü Sarmal Model ve bu modele toplum unsurunun dahil edilmesiyle geliştirilen Dörtlü Sarmal Modelin ardından geliştirilen bir inovasyon modeli

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olmaktadır. Bu sarmalın her yönü, sürdürülebilir rekabet avantajı sağlamak ve ülkelerin ekonomik kalkınması açısından kritik öneme sahiptir. Ayrıca bu model, çevresel faktörler ve yaratıcılık arasında derin bağlantılar kurarak, disiplinler arası analiz, problem çözme ve karar verme becerileriyle de yakın bir ilişki içerisinde olmaktadır. Bu araştırmanın amacı, Beşli Sarmal Modelin oluşumdan geliştirilmesine kadar geçen süreci inceleyerek, konuya ilişkin bilgi sağlamak ve daha sonra bu model üzerine yapılan çalışmaları bibliyometrik analiz yöntemiyle analiz etmektir.

Anahtar Kelimeler: İnovasyon, Üçlü Sarmal Model, Dörtlü Sarmal Model, Beşli Sarmal Model, Bibliyometrik Analiz

1. Introduction

The world's resources are being exhausted at an increasing rate, and ecological catastrophes are sounding warning bells that threaten human survival. These shifts are driving people to seek a solution. Today, when the winds of change are so strong, it is critical to develop social consciousness and an understanding of social responsibility. In light of this predicament, Hawken stated that "*it is necessary to carry out activities that will increase the quality of human welfare and that business promises to make money in a fading world will be meaningless*." (Önel, 2021). Businesses should aim to change the world's direction by including social and environmental considerations into their mission and vision, as well as the goal of profit.

The increased societal awareness caused by environmental crises reshapes the building blocks of competition for firms on both a national and global scale (Bartoloni et al., 2022). Throughout this transformation, knowledge and innovation emerge as the most fundamental principles for organizations seeking to survive and thrive in the blue oceans by establishing a sustainable competitive advantage. Knowledge and innovation are attempting to create a shared answer to the expanding environmental concerns in a world that is interconnected in terms of technology, socioeconomics, and culture by leading the entire transformation process (Carayannis & Campbell, 2010).

It has been discovered that the synergistic interplay formed by knowledge, innovation, and the environment has a favourable effect on the welfare levels of countries (Carayannis & Campbell, 2010). Innovation, which accounts for a substantial portion of a country's development level, is the key that unlocks the door to long-term economic progress (Lindberg, Danilda, & Torstensson, 2012). National Innovation Systems (NIS) are being built in countries in response to the need for innovation, and it is hoped that these systems would enable sustainable economic and social development within the framework of university-industry-goverment cooperation.

The Triple Helix Model (Triple HM) defines university-industry-goverment cooperation to adhere to the norms of transparency and equality between these three actors in high contact. This interaction aims to boost knowledge creation and use capacity, as well as to take innovation efforts to the next level in order to gain a competitive edge and cope with any economic crises (Etzkowitz & Leydesdorff, 2000; Galvao et al., 2019). As the relevance of the society dimension grew over time, it was integrated in the helix, and the Quadruple Helix Model (Quadruple HM) developed. The relevance of environmental elements has increased with the increase in social awareness, and by adding the environmental dimension to the helix, the Quintuple Helix Model (Quintuple HM) occurs (Carayannis & Campbell, 2009).

The Quintuple HM is a new model that has been studied in the worldwide literature in recent years. The amount of studies on this model in our country is almost non-existent. This concept strives to promote sustainable development by achieving synergy between the environment and society through economy, knowledge, and innovation. To achieve this development, active interaction between the university, industry, goverment, society, and environment is required. (Carayannis & Campbell, 2021).

This innovation approach, which is closely related to concepts like sustainability (Kholiavko et al., 2021; Carayannis & Campbell, 2010; Durán-Romero et al., 2020), design thinking (Bartoloni et al., 2022; Bustard et al., 2022), society 5.0 (Bartoloni et al., 2022; Carayannis et al., 2021) and creativity (Harwiki & Malet, 2020; Keskin & Ovalı, 2022; Carayannis & Campbell, 2015), plays an essential role in making the world a more livable place. These relationships make it easier to maintain nature and attain sustainability for nations.

The goal of this study is to introduce this innovation model, in which NIS and environmental and social awareness are interwoven, to our literature. Within the scope of our research, we will conduct a literature review on the triple, quadruple, and quintuple helix, followed by bibliometric analysis of the quintuple helix.

2. Literature Review

Creating value is critical for organizations to acquire a long-term competitive advantage. Along with technological developments, organizations must become more innovative, productive, and dynamic, and they require the existence of new and superior values in order to survive and obtain a lasting competitive edge. Innovation is one of the most powerful tools on the front lines of organizations in this era of disruptive developments (Visnjic et al., 2016).

The concept of innovation, originating from the Latin word "innovare," literally means to accomplish something new (Flynn et al., 2003). In its most basic form, innovation is defined as "*the effective commercialization of a novel concept*" (Dziallas & Blind, 2019). Another definition of innovation is "*adaptability to new developments for the organization in response to the environment*" (Knight, 1967; Ganzer et al., 2017). Activities carried out in the context of innovation improve living circumstances, enhance production and employment rates, contribute to economic growth, create stability, and gain a durable competitive edge (Neely & Hii, 1998; Işık & Keskin, 2013; Olavarrieta & Villena, 2014).

Innovation, an essential component of business, is as crucial as it is complex. From the initial to the last stage, innovation efforts have a powerful effect (Ganzer et al., 2017). The capacity to think creatively is critical in tackling these complicated and demanding innovation processes. It contributes significantly to the development of effective and efficient solutions by addressing challenges in depth as a result of brainstorming (Bartoloni et al., 2022).

Every process inside innovation requires knowledge management (Hoarau & Kline, 2014; Varis & Littunen, 2010). Nonaka (1994) defines knowledge as *"the power to make effective and rational decisions and to take the right actions at the right time."* Creating, changing, and reshaping knowledge is critical to the emergence of innovations (Quintane et al., 2011). It is critical to lay the groundwork for innovation by leveraging the integration of knowledge and technology (Dudin et al., 2015).

The NIS idea emphasises the need for all necessary parts to interact in order to develop, use, disseminate, and provide economic gain from new knowledge and technology inside national borders (Godin, 2009; Arranz et al., 2020). The building blocks of NIS are high engagement between the players who will carry out the innovation and effective sharing of knowledge and technology among the actors throughout the entire process (Afonso et al., 2012; Maruccia et al., 2020). Although the NIS is widely used in the literature with theoretically similar phrases, the results of its implementation by countries are diverse (Fagerberg et al., 2009; Gregersen & Johnson, 1997).

It has been found that this system, which plays an active part in all processes from innovation generation to commercialization, contributes significantly to countries' economic development and national competitiveness (Sarpong et al., 2017). NIS comprise research and development systems, education systems, and cultural systems within the framework of interactions between university-industry-goverment players (Afzal et al., 2018; Chung, 2002).

Knowledge, technology, and the economy are three critical components in the context of NIS. It is critical to secure the supremacy of these factors, which are viewed as essential demands in countries' innovation efforts, within their own boundaries and to analyse their interactions with one another (Chung, 2002). The Triple HM was developed as a consequence of research on the NIS, emphasising the importance of the interaction between university-industry-goverment (Yoda & Kuwashima, 2020; Afzal et al., 2018).

2.1.Triple Helix Model

Innovation activities that result from the combination of knowledge and technology play an essential role in a country's economic progress (Schartinger, Schibany, & Gassler, 2001). Increased research and development activities, in conjunction with the knowledge-based economic model, shape the innovation system (Leydesdorff, 2010). With this formed innovation system, the notion of the NIS evolved in the late 1980s, with the goal of comprehensively investigating the countries' university-industry-goverment systems and their interactions with their environs (Godin, 2009). Together with the NIS, it lays the groundwork for the development of the Triple HM by highlighting the importance of achieving synergy among the actors within national borders (Etzkowitz, 2003).

The Triple HM is a structure in which actors interact intensely and synergy is created. The actors have a balanced relationship in which borders are removed and integration is dominant (Etzkowitz & Leydesdorff, 2000). According to Dzisah and Etzkowitz (2008), the interactions in the Triple HM are similar to the blood flow that creates dynamism in our circulatory system via the arteries. Just as blood flow is required for our bodies to function, interaction between universities, governments, and industries is required to carry out innovation activities. The Triple HM is critical in developing knowledge-based societies and boosting country welfare levels (Sarpong et al., 2017).

As the value of knowledge grows, the goverment and industry actors must benefit more from the university actor's power in the implementation of innovation activities (Etzkowitz & Carvalho de Mello, 2004). Universities' knowledge production and development of qualified personnel capable of processing knowledge are critical in the development of innovation activities (Fini et al., 2011; Etzkowitz, 2003). By employing qualified personnel, the industry actor will be able to process knowledge, transform it into an output, and make breakthroughs for its commercialization (Herliana, 2015). The need for the goverment actor to support innovation activities by establishing a system with legal, political, and even economic power

emphasises the importance of close collaboration between these three actors (Etzkowitz et al., 2000; Dzisah & Etzkowitz, 2008; Feola et al., 2019).

As a result of globalization and technical advancements, the existence of Triple HM is required to attain long-term competitive advantage (Safiullin et al., 2014). The structures of connections built within the framework of this model should be predominantly knowledge-based (Arranz et al., 2020). Furthermore, in addition to their traditional roles, each actor should be able to create chances and prevent deviations that may develop in order to give a sustained competitive advantage by supporting the roles of other actors in the helix. The industrial actor, for example, must be able to conduct research and carry out elements such as personnel training. The state actor must be able to establish units capable of developing creative ideas in the formulation or implementation of innovative activities. The university actor, on the other hand, should be allowed to take initiative and conduct out innovative activities inside its own structure (Etzkowitz, 2003).

The university actor's role in capitalising knowledge is critical. The Triple HM transforms the university actor into a dynamic structure that adapts to changing environmental conditions and revises its strategies on a regular basis. Furthermore, as a result of its interactions with other helix actors, it has greater access to financial resources, can access new knowledge and technologies, and can play an active role in knowledge use by acquiring industry skills (Schartinger, Schibania, & Gassler, 2001). Each actor should be able to create opportunities for long-term competitive advantage by supporting the roles of other actors in the helix as well as their traditional roles, and to prevent any deviations from occurring (Etzkowitz, 2003).

When considering the Triple HM criticisms, it is thought to be a difficult model to understand theoretically (Shinn, 1999). The direct impact of dynamic environmental factors on the innovation process complicates the Triple HM explanation (Razak & White, 2015).

As a result of the changes and advances that have occurred, we have reached a period in which the aspirations and requirements of society are becoming increasingly important. To keep up with these changes and developments, the Quadruple HM was developed by including the element of society in addition to the university-industry-goverment actors (Afonso et al., 2012).

2.2.Quadruple Helix Model

The Quadruple HM is a model that promotes innovation development by focusing on innovation users. In response to societal demands, it also involves society in the innovation

process in order to increase the spread of knowledge creation and sharing. This helix's fourth dimension, which includes end users and stakeholders, is actively involved in innovation activities (Bartoloni et al., 2022). In addition to economic factors such as competition and productivity, meeting social and social needs and increasing social welfare are among the primary goals of the society dimension (Morawska-Jancelewicz, 2022).

The social dimension, on the one hand, facilitates the exchange of traditions and values within the context of culture, which helps societies build relationships and mutual understanding. On the other hand, it allows societies to receive knowledge through the media (Barcellos-Paula et al., 2021). Still, within the context of cultures and values, this dimension impacts each NIS differently (Lindberg et al., 2012).

This fourth helix dimension, which intellectually contributes to the innovation process, plays an important role in shaping innovation activities in accordance with university-industry-goverment interactions (Carayannis & Rakhmatullin, 2014). Initiatives to meet societal demands for higher quality products, services, or processes enable the growth of innovation activities (Afonso et al., 2012). The media plays an important role in understanding societal demands and needs, as well as in disseminating knowledge (Bartoloni et al., 2022; Carayannis et al., 2018).

The Quadruple HM was used to develop the Mode 3 concept, which aims for long-term development, includes intellectual capital supported by financial and social structures, and is in close interaction with knowledge and innovation elements (Carayannis, 2018). Before explaining the notion of Mode 3, the concepts of Mode 1 and Mode 2 in conjunction with the Triple HM will be briefly explained.

Mode 1, also known as the Traditional Knowledge Production System, relates to knowledge production in the university environment. This linear model represents the step-by-step transmission of knowledge from basic research in universities to the implementation of experimental breakthroughs in companies (Carayannis & Rakhmatullin, 2014). Knowledge is viewed as a component that contributes to the economy in this linear model (Carayannis & Campbell, 2019; Carayannis & Campbell, 2021).

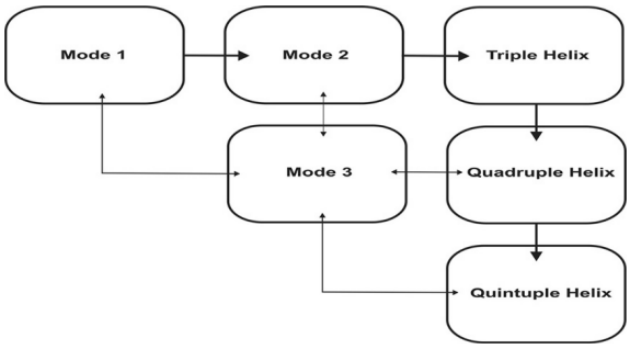
Mode 2 is a model with no linear structure. This model tries to popularize knowledge generation, which is a problem-solving component in the context of specific applications. This model, which connects university and industrial actors, also deals with linked scientific and technology issues. Within the framework of this model, there is a strong integration of the parts

across the entire process, from knowledge creation to knowledge use (Carayannis & Rakhmatullin, 2014).

The concept of Mode 3, which aims at sustainable development, includes intellectual capital supported by financial and social structure, and is in close interaction with knowledge and innovation elements, has been developed within the framework of the Quadruple HM (Carayannis, 2018). Mode 3 is an innovation model that allows for the coexistence and development of various knowledge and innovation structures (Carayannis et al., 2018). During the innovation process, it is desired to search for the most effective method by incorporating elements of different structures in interaction at the same time (Carayannis & Campbell, 2021).

The Mode 3 model and the Quadruple HM established by Carayannis and Campbell are expressed as a glocal knowledge production system that demonstrates the existence of intensive interaction between all elements on a local, regional, and even global scale (Carayannis & Rakhmatullin, 2014). It is the goal of the innovation system to generate a synergy that enhances the economy, society, and democracy by fostering an effective, efficient, and logical interaction between all actors from top to bottom (Carayannis & Campbell, 2012; Keskin & Ovalı, 2022). Figure 1 depicts the progression of this model, which is effective in knowledge generation.

Figure 1. The Evolution of the Models of Knowledge Creation



Source: Carayannis, E. G., Barth, T. D., & Campbell, D. F. (2012). The quintuple helix innovation model: Global warming as a challenge and driver for innovation. *Journal of Innovation and Entrepreneurship*, 1(1), 4.

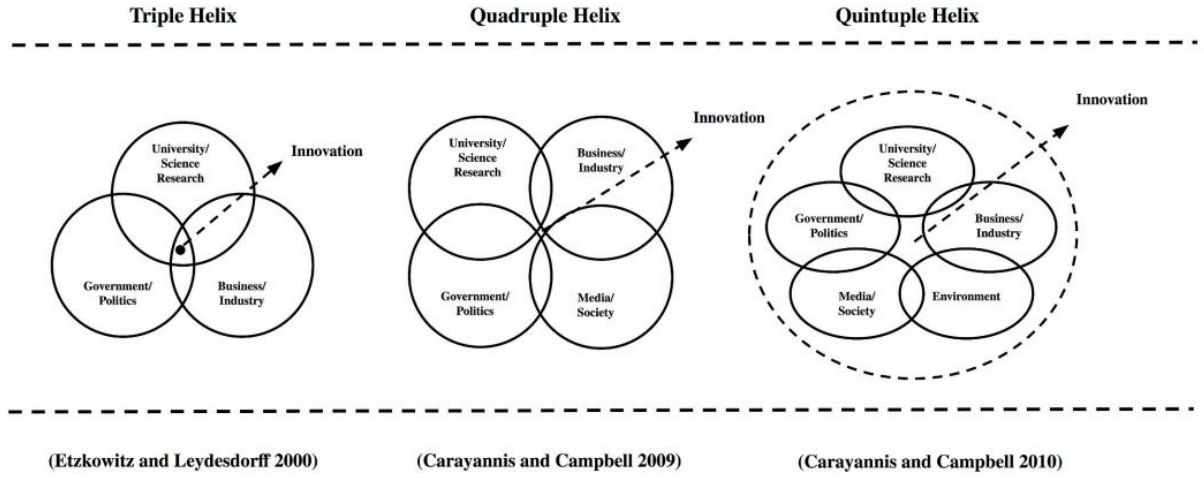
This model emphasises the importance of interdisciplinarity while also emphasising the importance of sustainable development and social ecology (Carayannis & Campbell, 2019). Another concept that emerged as a result of this model is knowledge democracy. According to knowledge democracy, all actors contribute to the development of society and economy by being in a dynamic relationship at every stage of knowledge development processes (Carayannis, Campbell, & Grigoroudis, 2022).

As environmental issues become more prevalent, there is a growing awareness of green practises. This awareness has resulted in an increasing trend towards corporate social responsibility projects and social innovations, and in response to this trend, the Quintuple HM was developed by incorporating the environmental helix into the innovation model (Morawska-Jancelewicz, 2022).

2.3.Quintuple Helix Model

The extraordinary increase in global warming, seasonal fluctuations due to climate change, the increase in carbon footprint, the decrease in energy resources, and the risky position of biodiversity direct the activities that must be done in order for humanity to survive. These changes resulted in the development of the Quintuple HM, which addresses the role of the environment in the creation and application of knowledge and innovation (Provenzano, Arnone, & Seminara, 2016; Carayannis & Campbell, 2010; Galvao et al., 2019; Carayannis, Cherepovitsyn, & Ilinova, 2017). Along with the environmental dimension, it is observed that the interaction and solidarity between all dimensions increases, providing more opportunities for the development of innovative activities (Bartoloni et al., 2022).

Figure 2. The Evolution of Triple, Quadruple, and Quintuple Helix Innovation Ecosystem Models



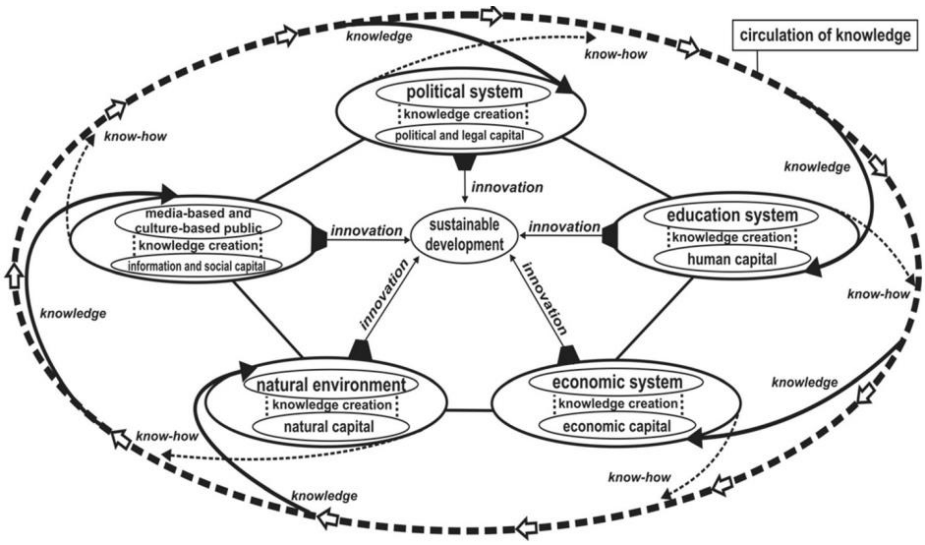
Source: Bartoloni, S., Calò, E., Marinelli, L., Pascucci, F., Dezi, L., Carayannis, E., Revel, G. M., & Gregori, G. L. (2022). Towards designing society 5.0 solutions: The new quintuple helix-design thinking approach to technology. *Technovation*, 113, 102413.

One of the most important elements of this model is the concept of "social ecology," which expresses the relationship between society and nature. This notion emphasises the importance of the interplay between social relations and nature, and it also asserts that these relationships lead innovation activities (Carayannis, Campbell, & Grigoroudis, 2022). Figure 2 depicts the significance of actor interaction within the context of the Triple, Quadruple, and Quintuple HM. These relationships are centred on innovation activities.

This innovation approach has a win-win mentality, aiming to achieve synergy between society and the environment through economy, knowledge, and innovation (Carayannis, & Campbell, 2021). It is desired to ensure sustainability in innovative activities by using green practises that preserve the environment, even in tiny increments, in accordance with their view that starting is the first step towards victory (Carayannis, & Campbell, 2019).

The Quintuple HM is a cumulative model that ensures continuous knowledge flow between its subsystems in order to maintain sustainable development (Carayannis, Barth, & Campbell, 2012). Through knowledge and know-how, innovation activities are the outcome of continual knowledge and cooperation between subsystems. The helix's five structures allow knowledge to flow in a continuous interaction (Liyanage & Netswera, 2021). The Quintuple HM, as shown in Figure 3, is a cumulative model in which knowledge flows continuously between its subsystems to promote sustainable development (Carayannis et al., 2012). Innovation occurs as a result of constant contact and cooperation among subsystems via knowledge and know-how. These five structures assure the continuous flow of knowledge (Liyanage & Netswera, 2021).

Figure 3. The Quintuple HM and Its Function



Source: Carayannis, E. G., Barth, T. D., & Campbell, D. F. (2012). The quintuple helix innovation model: Global warming as a challenge and driver for innovation. *Journal of Innovation and Entrepreneurship*, 1(1), 7.

The Quintuple HM and the design thinking process appear to have a comparable relationship. The integration of the design thinking approach with each actor of the Quintuple HM enables for more efficient innovation activities (Bartoloni et al., 2022).

The Quintuple HM is closely related to the notion of Society 5.0, which includes an environmental factor. Both of these concepts agree on the importance of using knowledge to

protect nature and ensure sustainability. It aims to use technological advancements to produce effective, efficient, rational, and sustainable society, economies, and environments (Carayannis, & Campbell, 2022).

3. Methodology

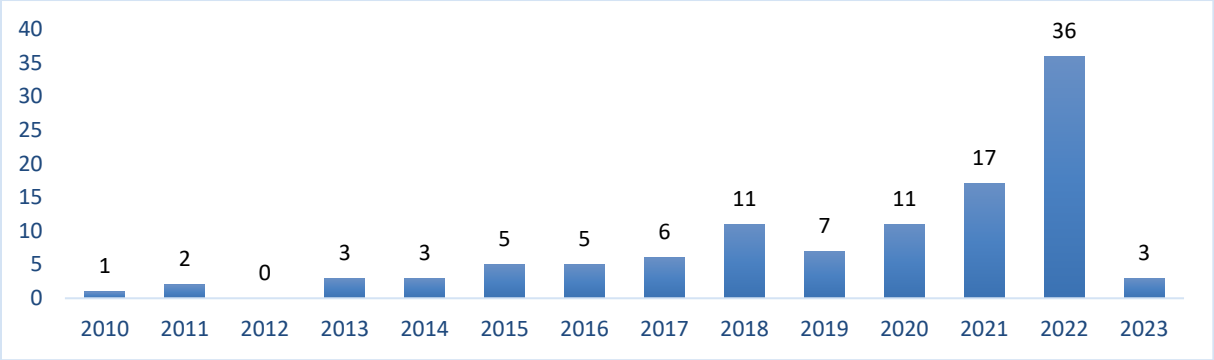
The Quintuple HM is a novel innovation model that has gained popularity in recent years. Because it is a new model, the number of research conducted is quite limited. The goal of this study is to add to the literature by thoroughly describing the Quintuple HM from its creation to its evolution. Following that, it is desired to establish a thorough literature pool on the issue and to measure the depth of the subject using the bibliometric analysis approach.

Bibliometric analysis is a way of analysing and evaluating data such as study topics, researchers, and the relationships between researchers, the relationships between citations, and the terms used in the research linked to the research topic (Artsın, 2020). Web of Science and Scopus databases are commonly employed in bibliometric analysis approaches due to their dependability as sources (Muritala et al., 2020). The fact that the number and relevancy of knowledge regarding the Quintuple HM in the Scopus database are both higher helps us decide to employ the Scopus database within the scope of our research. On February 1, 2023, the terms "quintuple helix" and "model" were scanned at the same time to gain access to studies on the Quintuple HM. As a consequence, 110 studies were obtained, and these studies formed the basis of our research's study. The acquired data is analysed using the programme VosViewer 1.6.19, which supports mapping methods. This programme analyses and presents data using visualisation and mapping methods by utilising network data (Demirel, 2022). This is one of the research that does not require the approval of an ethics committee.

4. Data Analysis

The distribution of studies on the Quintuple HM over the years is described first in the analytical section of our research. Figure 4 depicts the number of research conducted on this relatively new model over the years. According to the data, the first study on the issue was conducted in 2010. While no studies were conducted in 2012, the most studies were conducted in 2022, with 36 studies. Over time, the number of studies conducted has increased. The fact that three studies were conducted in January 2023, combined with the expectation that the same amount of work will be completed in other months of the same year, leads us to believe that the number of studies conducted in 2023 will be at least equal to the number of studies conducted in 2022.

Figure 4. Distribution of Studies Carried Out by Years



When we look at the researchers who have done the most research on the Quintuple HM, Carayannis comes out on top with 16 studies, Campbell comes in second with 9 studies, and Barth and Grigoroudis come in third with 4 studies. Table 1 shows the ranking of the total link strength of the studies based on the authors, with Carayannis having the highest link strength. Carayannis, who also has the most studies (16), is also seen to have the most citations and, by a large margin, the highest total link strength. It is observed that Campbell, who follows Carayannis, is far ahead of other researchers in second place. Campbell obtained 815 citations and 5939 total link strenght with a total of 9 studies. Following Carayannis and Campbell, Grigoroudis has four studies with a total of 2503 link strenght and 235 citations. Although Liyanage and Duran-Romero have fewer studies, the total link strength of their studies is found to be greater than that of Barth's studies.

Table 1. Ten Researchers with the Highest Link Strength in Quintuple HM Studies

Author	Research	Citation	Total Link Strenght
Carayannis, E.G.	16	1025	7979
Campbell, D.F.J.	9	815	5939
Grigoroudis, E.	4	235	2503
Liyanage, S.I.H.	3	7	1654
Duran-Romero, G.	2	62	1478
Barth, T.D.	4	29	1420
Stamati, D.	2	212	1414
Cai, Y.	3	22	1252
Del Vecchio, P.	2	18	1206
Passiante, G.	2	18	1206

Figure 5 depicts the linkage relationships between researchers of studies on the Quintuple HM. Carayannis and Campbell have a very intense relationship, it is observed. In addition to their intense bond, it is observed that these two researchers, who direct the literature, have a relationship with all other researchers. As a result of their significant contributions to

literature, it is clear that the work they accomplished together played a significant impact in securing the first two positions. Within the context of these relationships, it is revealed that, while Carayannis and Campbell had an intense relationship with Barth in 2016, this intensity has shifted in recent years to Bartoloni and Marinelli. Given this result, the idea that Bartoloni and Marinelli, who have an intense relationship with these two pioneers of the Quintuple HM, will increase the possibility of announcing their work within the scope of this model to the masses and finding a place for themselves in the top ranks in the coming years. In recent years, it has been anticipated that the contributions of researchers such as Liyanage and Cai to the literature, who have acquired high citation and link strenght with their works, will expand exponentially in the coming years.

Figure 5. Link Map of Researcher Relationships in the Scope of Quintuple HM Studies

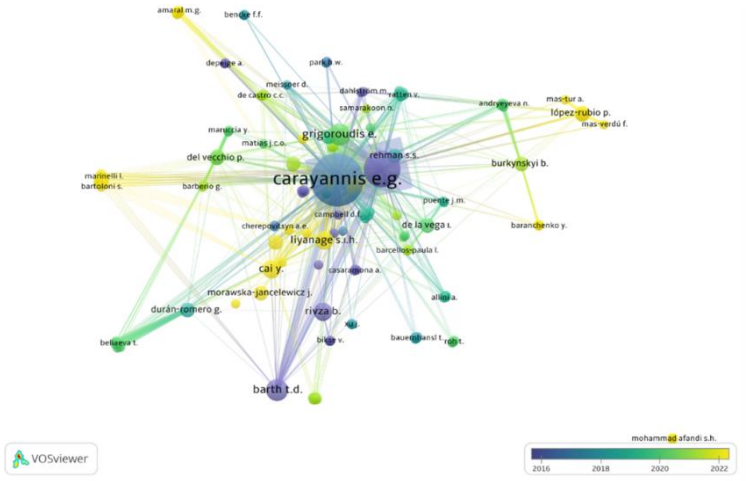


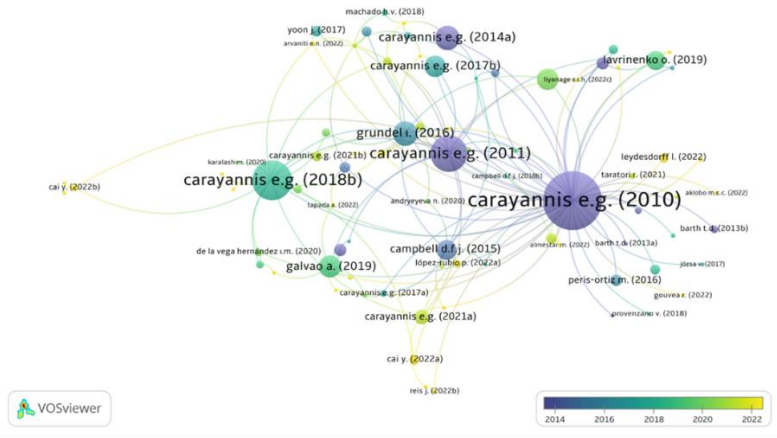
Table 2 lists the ten most cited research on the Quintuple HM and the names Carayannis and Campbell appear frequently. Carayannis and Campbell are acknowledged as pioneers in the most prominent studies on the Quintuple HM. The first study in the literature on the issue, by Carayannis and Campbell, is the most cited. This study can be described as a guidance in the development of the Quintuple HM. The contributions of these two researchers, whose names are invariably found in the first two lines of the literature on this model, to this innovation model are undeniably valuable. From the beginning of this model to its evolution over time, we can say that these two researchers have conducted effective studies almost every year. The only study that did not include Carayannis and Campbell among the top five most cited was conducted in 2016 by Grundel and Dahlström. These most-cited studies were conducted in 2020 and earlier. Although the citation numbers of the most cited studies are not very high because it is a new concept, there is no question that studies on this concept have increased at an exceptional pace in recent years and the number of citations will climb dramatically.

Table 2. The Top Ten Studies in Citations in the Scope of Quintuple HM Studies

Author	Research	Citation
Carayannis & Campbell, 2010	Triple Helix, Quadruple Helix and Quintuple Helix and How Do Knowledge, Innovation and the Environment Relate To Each Other? A Proposed Framework for a Transdisciplinary Analysis of Sustainable Development and Social Ecology	406
Carayannis et al., 2018	The Ecosystem as Helix: An Exploratory Theory-Building Study of Regional Co-opetitive Entrepreneurial Ecosystems as Quadruple/Quintuple Helix Innovation Models	185
Carayannis & Campbell, 2011	Open Innovation Diplomacy and a 21st Century Fractal Research, Education, and Innovation (FREIE) Ecosystem: Building on the Quadruple and Quintuple Helix Innovation Concepts and the "Mode 3" Knowledge Production System	158
Grundel & Dahlström, 2016	A Quadruple and Quintuple Helix Approach to Regional Innovation Systems in the Transformation to a Forestry-Based Bioeconomy	72
Carayannis & Campbell, 2014	Developed Democracies Versus Emerging Autocracies: Arts, Democracy and Innovation in Quadruple Helix Innovation Systems	72
Galvao et al., 2019	Triple Helix and Its Evolution: A Systematic Literature Review	61
Costa & Matias, 2020	Open Innovation 4.0 as an Enhancer of Sustainable Innovation Ecosystems	57
Durán-Romero et al., 2020	Bridging the Gap Between Circular Economy and Climate Change Mitigation Policies through Eco-Innovations and Quintuple Helix Model	56
Carayannis et al., 2017	Sustainable Development of the Russian Arctic Zone Energy Shelf: The Role of the Quintuple Innovation Helix Model	56
Carayannis et al., 2015	Quadruple Helix Structures of Quality of Democracy in Innovation Systems: The USA, OECD Countries and EU Member Countries in Global Comparison	50

Figure 6 depicts a link map of the relationships between all of the studies undertaken in the context of our research. The names that make up the linking map's centre points are unmistakably the same: Carayannis and Campbell. The impact of the citations indicated in the previous paragraph on the literature can be seen more clearly in this link map. The first three most cited articles, which include Carayannis and Campbell, have a dense network of relationships in the centre of the link map. The number of links and the magnitude of the impact of the first study on this topic, created by Carayannis and Campbell, clearly demonstrate its contribution to the literature. However, when the impacts of the links of the studies put up by these two researchers by years are examined, it is discovered that the studies that shape the literature in general are based on 2018 and earlier. Although these two researchers continue to do outstanding research, it is clear that other researchers have begun to have a voice in the literature with their studies as the 2020s progress.

Figure 6. Link Map Showing the Relationships Between Quintuple HM Studies



When we examine the evaluation of the research in Table 3 by country, we can conclude that, thanks to Carayannis' efforts, America has 18 studies, 1032 citations, and 6501 total link strength. With 14 studies, 916 citations, and 5462 total link strength, Campbell undoubtedly contributes the most to Austria's second-place finish. Following Austria is Spain, which has nearly the same number of studies but far fewer citations and total link strength. Following Spain is Greece, which outperforms Italy in terms of citations and total link strength despite having done less work. While 7 research in Greece have 292 citations and 2177 total link strenght, 9 studies in Italy have 47 citations and 2118 total link strength. Grigoroudis' highly cited and link strength studies, completed in collaboration with Carayannis and Campbell, are viewed as the most important factor in Greece passing Italy. Although the number of citations for the 7 studies conducted in Brazil is much lower than the number of citations for the 8 studies conducted in Portugal, the total link strength is higher.

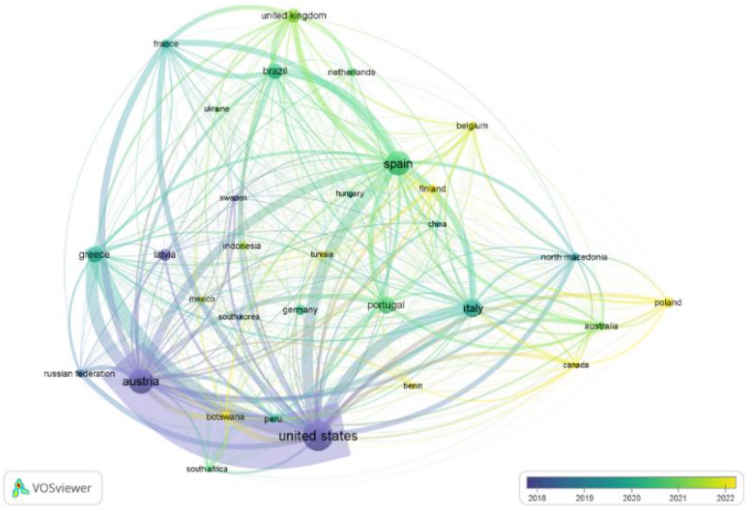
Table 3. Evaluating Studies on the Quintuple HM Based on Country

Country	Research	Citation	Total Link Strength
USA	18	1032	6501
Austria	14	916	5462
Spain	13	120	3481
Greece	7	292	2177
Italy	9	47	2118
Brazil	7	68	1707
Portugal	8	140	1639
France	3	61	1559
UK	6	80	1525
Northern Macedonia	3	7	1260

When examining the studies by country, the countries in which at least two studies were conducted were discussed. Figure 7 shows a link map of these countries' relations, which clearly shows that America and Austria have a close relationship. As previously stated, the most significant influence of this situation arises from the fact that Carayannis and Campbell collaborated on the studies that had the most impact on the literature. Aside from the link between these two countries, it has been discovered that they have strong links with Italy, Spain, Greece, and Brazil. However, interactions between these countries, both within themselves and with America and Austria, appear to be in the 2020s. The links between countries appear to have changed over time. It is observed that studies carried out in nations such as Poland, Canada, Botswana, Belgium, and Finland have begun to gain importance as of 2022. While interactions were limited to two or three countries in 2018 and before, it is now seen that they

have roughly doubled or tripled in the 2020s, and their diversity has increased significantly in recent years.

Figure 7. Link Map of the Quintuple HM Studies' Country-Based Relationships



When we examine the keywords used in the studies, we find 66 common words with a frequency of at least two. The Quintuple HM, the subject of our research, is the most frequently used keyword with various word combinations. Following the "five helix," the most commonly used keywords are "sustainable development" and "sustainability." In addition to the first study in the literature by Carayannis and Campbell, many studies have been found that touch on the relationship between the Quintuple HM and sustainability (Carayannis & Campbell, 2010; Kholiavko et al., 2021; Carayannis et al., 2012; Durán-Romero et al., 2020; Barcellos-Paula et al., 2021). The Quintuple HM and sustainability have a strong relationship. Because these efforts must be sustainable in order to maintain the effective continuity of environmental factors and to connect with innovation activities (Carayannis & Campbell, 2010; König et al., 2021; Durán-Romero et al., 2020). Following these notions are "innovation," "Quadruple HM," and "Triple HM," which are useful in the development and growth of the Quintuple HM. It can be seen that the concept of "social innovation," which emphasises the importance of green practises, is frequently used in relation to the environmental helix of the Quintuple HM (Morawska-Jancelewicz, 2021; Carayannis et al., 2019). Furthermore, we can argue that the great number of studies on social innovation and the Quadruple HM contributed significantly to the development of the Quintuple HM (Carayannis et al., 2019; Bellandi et al., 2021; Nordberg et al., 2020; García-González & Ramírez-Montoya, 2019).

Figure 8. Link Map of Keywords Used in Quintuple HM Research

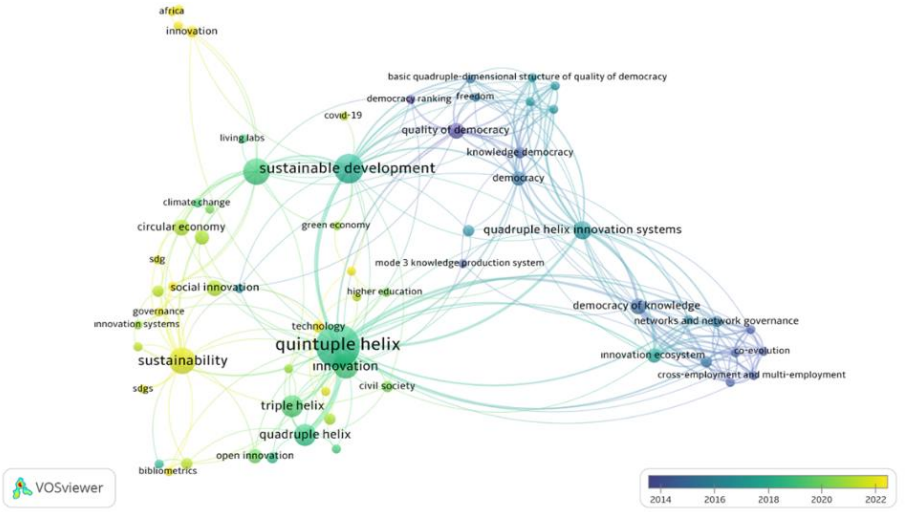
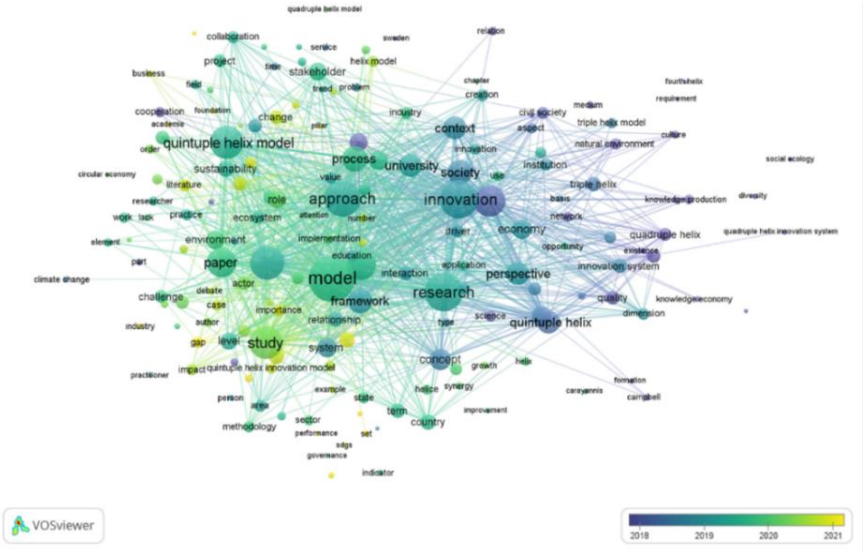


Figure 8 shows the link map of the keywords used. It is discovered that the most frequently used keywords, quintuple helix and sustainable development, have a very dense link network. It is observed that about 2018, there was a strong relation between these two notions and their triple and quadruple helix. When we look at the preferred keywords by year, we can see that the studies conducted in the early years of the Quintuple HM were focused on the concept of Knowledge Democracy, which is one of the most popular concepts of the Quadruple HM (Carayannis et al., 2012). Yet, over time, environmental changes and the needs that result from these changes have caused this intensity to shift towards green practises and sustainability (Carayannis et al., 2019; Duran-Romero et al., 2020; Liyanage & Netswera, 2021; Kholiavko et al., 2021; Quacoe et al., 2023). This link map clearly shows the Quintuple HM close relationship with the Triple and Quadruple HM, which is the main subject of our research.

Figure 9. Link Map of the Most Commonly Used Words in Quintuple HM Research



The concept of "model" appears to be the most frequently used word in studies on the Quintuple HM. In addition to the concept of "model," the concepts of "Quintuple HM" and "quintuple helix" are frequently used in studies. Given that our topic is an innovation model, it's not surprising that the word "innovation" appears frequently. It has been observed that technical terms are frequently used in the studies. “Model”, “research”, “approach”, “development”, “process” and “study” are the most often used technical terms. Figure 9 illustrates a link map of the most frequently used words in studies on the Quintuple HM. It is discovered that there is a strong interaction between the commonly used words. It is clear that the first four most frequently used words, "model," "innovation," "research," and "approach," are the leading actors in this dense interaction network. However, it is seen that the frequency of use of these four most commonly used words is primarily around 2020. According to the years of use of words, the concepts of "triple helix" and "quadruple helix" are frequently used in studies conducted in 2018. However, the fact that these two notions were not employed extensively in the following years can be attributed to the concept of the Quintuple HM beginning to grow in the literature. The frequent usage of the words "environment", "ecosystem", and "sustainability" demonstrates the priority placed on the environmental factor of the Quintuple HM (Carayannis et al., 2021).

5. Conclusion, Limitations and Recommendation

The formation and development stages of the Quintuple HM are examined from a conceptual perspective in all aspects in the first stage of this study. The growing number of ecological issues, as well as the fact that living conditions are becoming increasingly difficult, have necessitated the pursuit of smart, sustainable, and inclusive solutions in innovative activities (Carayannis et al., 2021). In light of this requirement, it is clear that the development of the Quintuple HM has begun to gain popularity in the literature (Carayannis et al., 2012). Although it is a new concept, the second part of our research includes a bibliometric analysis of the studies in the literature on this rapidly developing innovation model. The evolution of the Quintuple HM over time is revealed within the scope of this analysis, along with the mapping method.

The Quintuple HM, which places people at the centre of innovation activities, emphasises developments that will improve society's welfare, ensure social and environmental responsibilities, and ensure sustainability (Bartoloni et al., 2022). It is stated that with the provision of sustainability, improvements and developments are experienced in knowledge and innovation activities, green practises, social responsibility activities, cultural formations, and

economic conditions (Yun & Liu, 2019). To ensure sustainability, all actors of the helix must act in an integrated and systematic manner. The cumulative increase in knowledge and know-how among all Quintuple HM actors is effective in establishing sustainability. It is hoped that achieving sustainability will result in a greener and more social world (Carayannis et al., 2012; Liyanage & Netswera, 2022).

One of the most important ways to promote sustainable development is to use design thinking to build knowledge, know-how, and innovative activities. All actors must collaborate within the framework of the Quintuple HM in order to create knowledge societies through design thinking (Carayannis et al., 2012; Bustard et al., 2022).

Creativity is a fundamental component of both innovation and sustainability. Activities that lack innovation are nothing more than repetition. It is required for the creation of new knowledge and the execution of innovative actions. Increases in creativity play a significant part in ensuring sustainability by enhancing innovation activities. (Keskin & Ovalı, 2022). Living standards in nations will rise as sustainability improves, resulting in a more livable, fair, free, and green world.

The needs are changing quickly in this age, where dynamism is felt so strongly. With the formation of the Triple HM and the increasing importance of the elements of society and the environment, the Quadruple and Quintuple HM were realised in response to the needs. It will not be surprising to see new helix models added in the future. As a result, the N-tuple Helices Model was created (Park, 2014). This concept, which allows for the addition of new dimensions to the helix, also demonstrates the power of dynamism (Zhou & Etzkowitz, 2021; Leydesdorff, 2012). Changes in the climate and living situations together with natural disasters, force us to come up with new ideas. We must find solutions to the changes and adapt to new circumstances. Over time, further helices will be added as a result of the changes that have occurred, and new ideas pertaining to these helices will develop.

Ethical aspects of the research

In this study, all the rules specified in the "Directive on Scientific Research and Publication Ethics of Higher Education Institutions" were followed. None of the actions specified under the second part of the Directive, "Actions Contrary to Scientific Research and Publication Ethics", have been carried out.

I declare that this research is one of the researches that do not require ethics committee permission.

Declaration of conflict of interest

I declare that there are no financial or other material conflicts of interest in this study that may affect the results or interpretations.

Author contribution rate

All stages of the study were equally designed and prepared by the authors.

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