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Technological and Innovative Structure and Capabilities of Türkiye's Automotive Industrial Sector: An Exploratory Study

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Abstract

The automotive sector ranks as the 4th largest contributor to the global economy, accounting for approximately 5% of the world's Gross Domestic Product (GDP). Additionally, employment in the automotive industry generates a fivefold multiplier effect on job creation in other sectors. This study focuses on the sustainable science, technology, and innovation indicators relevant to Türkiye's automotive industry, which holds the 7th position in terms of its contribution to the country's GDP. Drawing on previous research and 33 years of data that reflect the state of Türkiye's automotive sector, as well as its science and technology landscape, this research identifies 10 key indicators that influence the sector's technological development and innovation capacity. To analyze the similarities and differences among these indicators, a hierarchical cluster analysis (HCA) method was initially employed. Subsequently, a non-hierarchical cluster analysis (NHCA) was conducted to validate the HCA findings. Additionally, multidimensional scaling (MDS) was utilized to assess the similarities and distances among the economic, science, and technology indicators. The formation of 2 clusters was later verified through correlation analysis and factor analysis. The research findings indicate that the R&D and science-related parameters in Türkiye operate in a cohesive manner as anticipated. The percentage changes in the production of automobiles, commercial vehicles, and total domestic output show similar trends, forming a distinct group. In contrast, the indicators for high-technology exports and automotive exports are influenced by different dynamics, displaying separate and unique patterns. Based on these results, the study concludes with recommendations for sector-specific improvement initiatives.

Keywords: Correlation analysis; Factor analysis; Hierarchical cluster analysis (HCA); Multidimensional scaling (MDS); Non-hierarchical cluster analysis (NHCA); Science, Technology and innovation indicators; Türkiye's automotive

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1. Introduction

Automobiles account for a significant share of global output and trade [53]. Since the birth of the first ever vehicle powered by gasoline by Carl Benz back in 1886, automotive industry has been a major contributor to industrial and economic development [35]. Countries like China, the United States of America (the USA), Japan, Germany, South Korea, India, etc. which have command over the automotive industry and significant share in global automotive markets are also leading global economies [47, 53].

The automotive industry interacts with many sectors and while it is the buyer of sectors such as iron-steel, petrochemical, plastics; it supplies on the other hand vehicles to sectors such as agriculture, tourism, and construction [38]. It has a high multiplier effect and benefit on economic growth due to its strong forward and backward links with other sectors [54]. Due to continuous technological progress, especially like digital transformation and artificial intelligence (AI), the automotive sector around the globe is undergoing massive change [32]. Furthermore, in this highly competitive world, countries are trying to explore ways for the sustainability of the automotive sector [34] via exploring new materials [29] and material matrix [5]. This is only possible if a country explores the evolution process of its automotive industry and its position in global competition [28] and also calculates the impact of ever-changing technologies on their automotive sector [32].

On the other hand, the automotive sector is characterized by high Research and Development (R&D) expenditure compared to other sectors. For example, the share of the automotive sector in total R&D expenditures is more than 10% in developed countries such as Germany, Japan, S. Korea, and Italy, and in developing countries like Romania, Türkiye, and Mexico. The automotive sector's share in total R&D expenditure is as shown in Figure 1. below by selected countries according to Organization for Economic Cooperation and Development (OECD) reports.

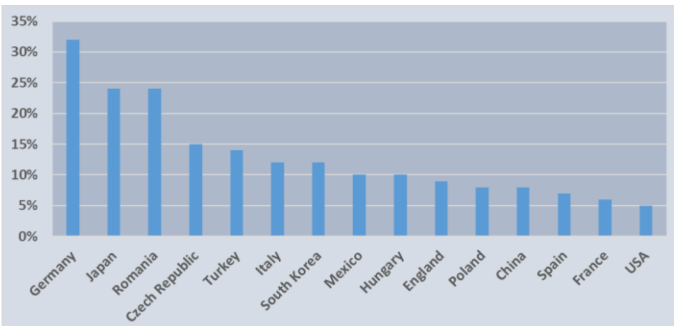

Fig. 1. Automotive sector share in R&D expenditures by countries (OECD, 2017)

In Türkiye, the automotive sector is the 7th major contributor to the country's GDP. Türkiye ranks 13th in global automotive producers [1]. TEMSA, Otokar and BMC are among the global automotive players in terms of production of busses, trucks and vans [15].

This study aims to analyze Türkiye′s automotive industry in terms of science, technology, and innovation indicators for its sustainability and to determine the similarities and distances between the specified indicator variables. In this way, it will be possible to shed light on the strategic planning of the automotive industry by observing how science, technology, and innovation indicator variables are grouped or separated relative to each other in the context of Türkiye's automotive industry.

1.1. A Brief History of Türkiye's Automotive Industry

The first ever automotive industrial unit was Türkiye's aircraft, automobile and engine limited company named as Tayyare Otomobil Türk Anonim Şirketi, (TOMTAŞ) which was established in 1925. They have even started production, however due to 1930 "*Great Depression*" production could not continue [50]. Türkiye started automotive production again in the 1950s and the first production started in 1954 by Türkiye Willys Overland Ltd. company producing jeeps and pickup trucks for the army. A year later, the truck factory of Türk Otomotiv Endüstrisi A.Ş. (TOE) and later the truck factories of OTOSAN and Çiftçiler A.Ş. were established [43].

The success of the assembly plants established in the late 1960s and 1970s to reach sufficient capacity and locality rate had played a very important role in the development of Türkiye's automotive sector. The first bus production facility in Türkiye was established in 1963 by İstanbul Otobüs Karoseri Sanayi A.Ş. to assemble Magirus buses [43].

The first Türkiye's car was produced in 1961 at State Railways Factory (TÜLOMSAŞ) in Eskişehir. However, the cars named Devrim were limited to only 4 prototypes.

The first successful mass production was carried out in 1966 with the OTOSAN Anadol car. Later, in 1968 TOFAŞ company and in 1969 OYAK Renault company were established both in Bursa, and these two companies started their production in 1971 [16].

With the introduction of Assembly Industry Instruction (Montaj Sanayii Talimatı) in 1964 (Official Gazette, 29 September 1964) by the government, it was aimed to reduce the dependence on imports in production. Accordingly, in order to reach a certain number of domestic productions, the protection rates in imports were kept high, with the increase in domestic contribution rates, the list of prohibited items was expanded, and the foreign exchange allocation provided to companies was reduced.

TOFAŞ started to manufacture Murat 124 model in 1971 under Italian Fiat license. OYAK launched its first model as the Renault 12 in 1971 with the French Renault license. Due to the policies continuing until the 1980s, the automotive industry operated within a structure consisting of many companies in the domestic market. In addition, an increase was observed also in the sub-industry production [43].

With the liberal economic policies adopted, it was aimed that Türkiye would become a country to produce at economic scales by using modern technology and had international competitive power in terms of price and quality [41]. However, due to the predetermined protection policies, very little product diversity has occurred in the domestic market throughout time and to remedy this, protection rates have been drastically reduced since the late 1980s.

In 1985, FORD OTOSAN company started to produce the Taurus model and OYAK Renault company started to produce the Renault 9 model [6]. Türkiye's first hatchback model Renault 11 was released in 1987, and the first diesel engine was fitted to Anadol Pickup. In 1989, Renault 12 series was converted to Toros model, and its production continued until 2000 [7].

The 1990s were the years when Japanese brands made themselves more visible in Türkiye [27]. The first domestic production started with Toyota company in 1994 and Honda company in 1997. Automotive production increased in Türkiye from 1990 to 1993 [45]; a decrease was observed in the following years and the production level in 1993 could not be reached until 2003.

Following Serçe, Şahin, Kartal and Doğan models as bird series; Tempra, Tipo, Marea, Bravo, Uno and later Palio, Siena and Palio Weekend models were launched by TOFAŞ company in the 1990s. Similarly, OYAK Renault company responded by launching models such as Broadway, Europa, Clio and Megane in the 1990s. On the other hand, Honda from 1992, Toyota from 1994 and Hyundai from 1997 took their place in the Türkiye's automotive industry by launching different models [42]. Türkiye's automotive production figures are as given in Figure 2. based on 33 years of data mainly from the Automotive Manufacturers Association (OSD) of Türkiye.

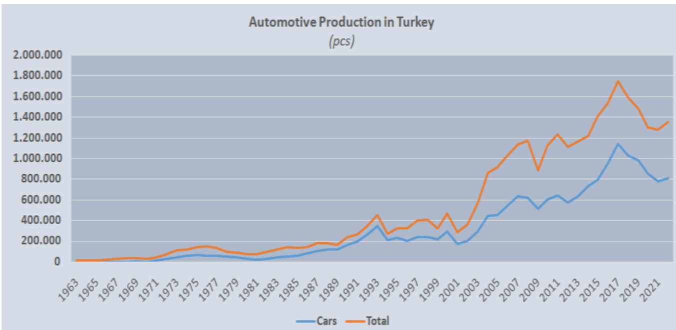

Fig. 2. Total automotive and car productions in Türkiye between 1963-2022 (Authors)

The concepts of Quality Control (QC), Integrated Factory (IF) and Total Quality Management (TQM) came to the fore in Türkiye’s automotive industry in 1990s and were used extensively by all enterprises in the sector [8].

Especially after the 2000s the concepts of Lean Production and Lean Management have been put into practice for the optimal use of available resources and increasing efficiency.

As can be seen from Figure 2., starting especially after 2003, there was a continuous increase in automotive production quantities until 2017. However, parallel to the shrinkage in the world after 2017, it seems that there is a significant decrease in the automotive production volume in Türkiye.

In 2009, Türkiye's first 4×4 domestic jeep Türkar was produced. In 2010, Fiat Doblo and in 2015 Fiat Egea production started. Egea has managed to become the best-selling car in Türkiye for 5 years following its production.

On 27 December 2019, the new domestic fully electric car brand Türkiye'nin Otomobili Girişim Grubu (TOGG) was introduced to the world market [22]. Design and factory-building activities were started by the state-supported consortium and mass production started in the first quarter of 2023 with T10X SUV model.

1.2. Current Situation of Türkiye’s Automotive Industry

The Turkish automotive industry has experienced significant growth and transformation in recent years, establishing itself as one of the key sectors in the national economy. As of 2023, Türkiye ranks among the top 10 automotive manufacturers in Europe, specializing in both passenger and commercial vehicles [40]. Notably, the sector has embraced sustainability, with major manufacturers investing in electric and hybrid vehicle production, driven by both domestic demand and global environmental standards [38].

One of the major achievements of the Turkish automotive sector is the ongoing development of indigenous electric vehicles, with brands such as TOGG (Türkiye's Automobile Joint Venture Group) leading the way in innovation [36]. The launch of the first domestically manufactured electric SUV in 2022 exemplified Türkiye's commitment to advancing its automotive capabilities and reducing reliance on imports. Additionally, the industry has adopted advanced technologies such as Industry 4.0, significantly enhancing manufacturing efficiency and productivity [18].

Despite these advancements, the sector faces several challenges. One of the foremost issues is the need for further investment in R&D to keep pace with global technological trends and improve competitiveness [2]. Additionally, geopolitical tensions and supply chain disruptions have posed risks to production stability, particularly regarding the availability of raw materials and components required for electric vehicle production [20]. Furthermore, the transition to electric vehicles requires substantial infrastructure development, including charging stations and support services, to encourage consumer adoption.

While Türkiye's automotive industry has made notable strides and achieved significant milestones, it must navigate ongoing challenges to sustain growth and innovation in a rapidly changing global landscape.

1.2.1. Production

Automotive production in Türkiye increased by 8.6% in 2023 compared to the previous year (Figure 2.) and amounted to 1,468,393 units. As seen in Table 1. on the other hand, Türkiye ranked 13th among the top 20 countries in total automotive production.

Table 1. World automotive production by countries, 2023 (Wikipedia)

#	Countries	World Automotive Production (2023)
1	China	30,160,966
2	United States	10,611,555
3	Japan	8,997,440
4	India	5,851,507
5	South Korea	4,244,000
6	Germany	4,109,371
7	Mexico	4,002,047
8	Spain	2,451,221
9	Brazil	2,324,838
10	Thailand	1,841,663
11	Canada	1,553,026
12	France	1,505,076
13	Türkiye	1,468,393
14	Czech Republic	1,404,501
15	Indonesia	1,395,717
16	Iran	1,188,471
17	Slovakia	1,080,000
18	United Kingdom	1,025,474
19	Italy	880,085
20	Malaysia	774,600

1.2.2. Domestic market

As can be seen from Figure 3. automotive local sales increased by 7% to 827.147 units in 2022 based on data from OSD [40].

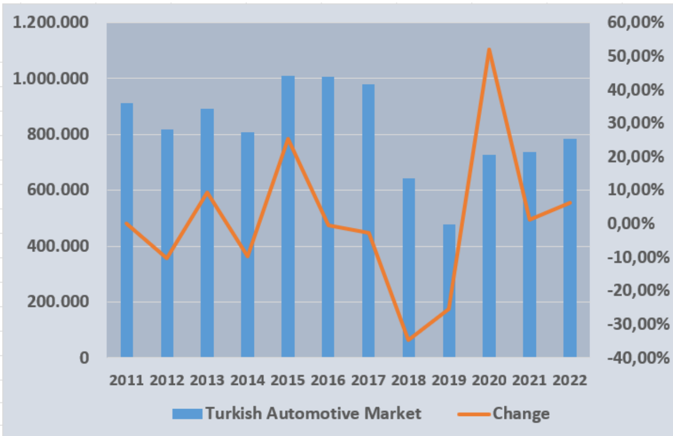

Fig. 3. Türkiye's automotive market, 2011-2022 (Authors)

As can be seen from Table 2. Türkiye ranked 18th in the top 20 countries in sales statistics with a local sales figure of 736.47 units in 2021.

Table 2. World Light Vehicle Market by Country including passenger cars, pickup trucks and light commercial vehicles, 2021 (FIAT Group)

#	Countries	**World Light Vehicle Market (2021)** *(passenger cars, pickup trucks and light commercial vehicles)*
1	China	26,275,000
2	United States	15,043,129
3	Japan	4,388,263
4	India	3,517,630
5	Germany	2,880,999
6	France	2,087,390
7	United Kingdom	2,002,631
8	Brazil	1,975,182
9	South Korea	1,693,634
10	Canada	1,667,866
11	Russia	1,666,545
12	Italy	1,641,157
13	Mexico	1,014,478
14	Spain	1,006,947
15	Australia	1,003,703
16	Iran	925,000
17	Indonesia	813,278
18	Türkiye	736,547
19	Thailand	728,466
20	Saudi Arabia	528,031

2. Concept and Literature Survey

Science and technology (S&T) play a very important role in development and economic growth in both developed and developing countries. Endogenous Theory [31] suggests that technological development depends on R&D, manufacturing activity, human capital and public policies. National Innovation System (NIS) is on the other hand a modern term that specifically refers to the interactions between technical and institutional innovative development and naturally has a significant impact on the innovation and technology performance of countries. The concept of the NIS was first introduced by Lundvall BA. [33] and then by Freeman & Soete [21] pioneers of evolutionary economics, and subsequently developed by other researchers. Petrenko & Grechanyk [44] state that the NIS includes all aspects of the institutional and economic structure that have an impact on learning. According to them, the NIS is a network of public and private sector organizations, whose activities and interactions initiate, modify, import, and disseminate new technology. The efficiency and dynamism of this network determine the speed of innovation of enterprises and the level of economic success obtained from innovation. Furthermore, they define the NIS as a multitude of international or national interactions between various institutions interested in S&T as well as innovation, technology diffusion, and higher education. Considering that such growth dynamics differ from country to country, it is stated that it is also important to understand the interactions between such institutions to analyze the growth dynamics of S&T.

Studies on NIS focus especially on information flow, and the analysis aims to increase performance in knowledge-based economies [49]. Knowledge, which exists both in the knowledge of people and the technological infrastructure of institutions and enterprises, has always been of central importance for economic development, but its importance is understood more recently. As seen from the increasing need for qualified personnel and the growth and developments in high technology industries, economic activities started to be more information-based nowadays. It is accepted by all today that investments in R&D, education and innovative working approaches are extremely important for economic growth and development. Therefore, NIS's have also emerged because of the attention and value given to the economic role of knowledge and sustainable growth [12].

In this respect, it is essential to determine and define the indicators of science, technology and innovation. S&T input and output indicators have been already determined for OECD member countries as given in Table 3. and Table 4. respectively [11].

Table 3. S&T Input indicators of OECD members [11]

Input *(Resources)* Indicators	
Financial Resources	Human Resources
R&D Expenditures as % of GDP	Number of R&D Emplo yees

Table 4. S&T Output (Performance) indicators of OECD members [11]

Output *(Performance)* Indicators		
Economic	Technological	Scientific
Exports of high-t ech products as % of total exports	Patents and Pate nt applications	Scientific and t echnical journal a rticles

Technological development is generally divided into two as input (resources) and output (performance) indicators [37]. Input indicators are divided into financial and human resources. As an indicator of financial input, the percentage of R&D expenditures in GDP is the most important indicator commonly used to evaluate and compare technological development between countries. In addition, the number of researchers employed in R&D is included as an indicator for human resources. In fact, scientific literature reveals that the investment in R&D personnel working in this field is the main indicator of the level of innovation [48].

Performance indicators are classified in 3 different ways as economic, technological, and scientific [39]. As an example of an economic indicator, the percentage of exports of high-tech products in a country's total exports is a useful indicator for evaluating economic performance.

On the other hand, patents and patent applications are one of the most frequently used indicators to measure scientific and technological progress. These are considered as domestic and foreign patent applications.

Research publications, such as scientific and technical journal articles, is an output indicator which is necessary and useful for evaluating the scientific development performance of countries and comparing them with others [11]. The number of publications also shows the number of important studies of countries in innovation and technology fields, which will have an increasing effect on economic performance in the medium and long term.

A country's innovation potential is mainly the combination of various factors that stimulate the innovation process in the country. R&D expenditures are one of the key factors that ensure long-term economic growth in the innovation and technological development of countries. While new products and processes can be created by means of R&D expenditures, the decrease in the R&D budget causes a decrease in the number of patent applications [24]. Past research also highlights a strong relationship between R&D expenditures and number of new products [26]. Firm-level R&D expenditures have a positive impact on the future investment capacity of the enterprise by minimizing costs and/or maximizing profits. On the other hand, R&D activities not only contribute to the acquisition of new knowledge, but also strengthen the relationship among various organizations such as research institutions, industries, and universities. While technological innovation is an important tool in having competitive advantage, patents are important tools for protecting the innovation process and therefore strengthening patent laws is of great importance [30]. This situation prevents organizations from being imitators and enables them to transform into innovative organizations. Because innovation and technology development are ultimately costly, risky, and time-consuming processes and enterprises use patents as a tool to protect innovations from competitors and keep their innovative efforts worthy.

One of the most important elements of innovation management and technological development is the capacity to create and implement an appropriate technology strategy [14]. Organizations that fail to identify the requirement to develop, continually monitor and review their technology strategies will lag their competitors over time. Undoubtedly, the technology strategies of companies cannot be sustained independently of the national policies of the countries. Some government policies to encourage innovation include increasing R&D subsidies, decreasing taxes and complex bureaucratic procedures, building and financing technology transfer institutions like incubation centers and techno-parks, and attracting entrepreneurial capital to reduce the innovation costs of organizations [24]. Accordingly, it can be said that it is almost impossible to achieve structural change and sustainable growth of the entire economy without appropriate government strategies and policies on technology and innovation. Thus, the implementation of the right policies will increase the competitiveness of especially developing countries and bring them economic success in the medium and long term.

Cavdar & Aydin [11] have focused in their research on indicators that provide a better understanding of the impact of programs and policies that help define technological development, innovation, society, and economy; and aimed to examine whether economic growth, innovation and technological development indicators of the countries are affected by the variables in the analysis. They have used monthly data covering the 1996-2011 period.

Research and development expenditures (RDE), high-tech exports (HTE), long-term unemployment (LTU), domestic patent applications (PA), foreign patent applications (PAF), total health expenditure (HE), GNP per capita (PPP), the share of women employed in the non-agricultural sector (SWE), the total stocks traded (ST), the number of internet users (IU), the number of scientific and technical journal articles (STJ) are the main indicators used. In the study, the similarities, differences, and distances between the variables are determined with the MDS method. Afterwards, the HCA method is applied for the variables to compare the similarities or differences between the variables. As a result of the analysis, HTE and PA's made in foreign countries (PAF) are determined as the most effective variables in technological development for Türkiye. In addition, RDE, domestic PA, HE, GDP per capita (PPP), SWE, IU, and STJ have significant effects on technological development and innovation. According to their findings, it is seen that LTU is not an effective variable in technological development.

The experiences of Central and Eastern European Countries in technology transfer and innovation policies during economic transition period and the difficulties they faced during European Union (EU) enlargement was studied by Gurbiel [24]. According to the findings, technology transfer and innovation are the driving forces of economic growth and Central and Eastern European countries lag other EU member countries in these fields. Therefore, it is necessary to reduce the technology gaps with EU countries. Imports and foreign investments have become the main elements of technology transfer, as there is not enough investment for R&D activities. Therefore, there is a strong need to encourage local R&D work and its integration with the EU.

A detailed analysis of Chinese PA's in terms of patent quantity and quality showed that the rapid increase in PA's does not fully represent China's innovation capacity, especially considering its domestic heterogeneity [51]. While interpreting the patent numbers, the 2007 and 2008 World Intellectual Property Organization (WIPO) patent reports were considered.

Technology strategy is the set of projects that organizations want to implement; that is, determining a strategy and choosing the projects to be implemented. This process, on the other hand, goes through difficult stages that require risk-taking. It is seen that Chinese firms can mobilize large resources to help them implement a strategy once it has been determined [13].

It was observed that the R&D sector does not provide sufficient development due to the lack of financial investment in both public and private sectors in Sudan, and in the light of this information, it was determined that Sudan lags developing countries regarding S&T activities [17].

R&D expenditure is considered to be the main proxy for gauging the ability of innovation in companies. The low-tech sector's struggle to capture high-profit markets and produce high-quality products was moving towards compatibility with existing technologies. Technological potential was identified as the key factor to be competitive in the low-tech sector [48].

Boeing et al. [9] created a model to measure the relationship between scientific innovation and economy in Beijing with the Vector Autoregressive Model (VAR) method. The number of PA's, the sum of commercial transactions in the technology market and direct foreign investment were chosen as indicators of S&T output, while GDP was chosen as an indicator of economic growth. As a result of VAR analysis, it was seen that PA's played a key role in economic growth. While patents contribute to the development of technologies, they also protect the interests of inventors. Although the sum of commercial transactions in the technology market and direct foreign investment affects economic growth, time is still needed. Scientific innovation supports economic growth, and economic growth increases the demand for scientific innovation. Based on this fact, it is understood that scientific innovation and economic growth have a positive cycle.

In terms of innovation indicators, countries in the OECD community, of which Türkiye is also a member, showed similarities and differences. In the related study, 12 variables representing the innovation performance of OECD countries were used [23]. While determining the indicators, 12 innovation indicators including Türkiye's data from the 25 indicators of the 2007 European Innovation Scoreboard was taken into consideration [19]. Triadic patent family (Patents filed in European, the USA and Japanese Patent Offices), R&D expenditures, number of R&D personnel (per 1000 people), health expenditures per capita (USD), number of internet users (per 100 inhabitants), fixed telephone lines (per 100 people), population ratio in secondary education (gross), number of scientific and technical articles and journals, exports of advanced technology (manufacturing-export ratio), fixed broadband subscriptions (per 100 people), wireless mobile broadband subscriptions (per 100 inhabitants), industrial production (change in production output volume) were used as indicators. The suitability of the variables was tested by looking at the results of Kaiser-Meyer-Olkin (KMO) and Bartlett Test of Sphericity and it was determined that the variables were suitable for the factor analysis. According to the explanatory factor analysis performed on 11 variables, a total of 4 factors were determined and the weighted averages of the factor scores were calculated. These averages were called the general factor score and the countries were ranked according to the scores. On the other hand, countries were classified by cluster analysis and as a result of the cluster analysis, it was revealed that there were 5 clusters, and the general factor score average of each cluster was given. Based on all these analyzes, it was determined that Denmark, Finland, and Sweden in the 5th cluster had the highest general factor scores. Türkiye, on the other hand, is in the 4th cluster, which includes countries with weak innovation performance.

In another study, 12 innovation indicators including Türkiye's data from a total of 25 indicators of the 2007 European Innovation Scorecard were taken into consideration [19]. Number of young people (20-29 years old) graduated from physics and engineering sciences per 1000 population, number of people completed post-secondary education (25-64 years old) per 100 people (school, university, etc.), prevalence rate of broadband data transfer (above 144 kilobits/sec), government's R&D expenditures (as a percentage of GDP), R&D expenditures of the civil sector (as a percentage of GDP), information and communication technologies expenditures (as a percentage of GDP), advanced share of technology products in total exports, number of patents obtained from the European patent office (EPO) per 1 million population, number of patents obtained from the United States patent office (USPTO) per 1 million population, number of patents obtained from its office (EPO) per 1 million population, number of tripartite patents (Patents from all of the EPO, USPTO and Japanese Patent Offices (JPO)), number of social trademarks received per 1 million population, social industrial design per 1 million population were all used as main indicators. According to the results of cluster analysis, it was seen that the countries were clustered in 4 groups except Luxembourg and Türkiye was in the first group. It was observed that similar results were obtained in the MDS analysis as in cluster analysis. While Luxembourg is further away from other countries, countries in the same groups seem to be closer to each other. Finally, as a result of the discriminant analysis made using data that varies according to countries, it was determined that 96,7% of the countries were classified correctly and only one country was classified incorrectly in the 3rd group. As a result of all these analyses, it was concluded that Türkiye was in the low category of innovation indicators.

When the relative positions of the world economies researched by using the competitiveness data published by the World Economic Forum (WEF), 12 variables of Global Competitiveness Index (GCI) calculations surfaced [4]. These 12 variables are listed under 3 main pillar groups as basic requirements, efficiency enhancers, innovation and sophistication factors (WEF, 2010). The scope of basic requirements includes institutions, infrastructure, macroeconomic environment, health and primary education. Efficiency enhancers comprise higher education and training, labor market efficiency, goods market efficiency, financial market sophistication, market size and technological readiness. Finally, within the scope of innovation and sophistication factors, there are business sophistication and innovation variables. First, NHCA was conducted for 139 countries and clusters between 2 and 10 were compared. Pseudo-F and r^2 values of these 9 clusters showed that they are close to 4 or 5 cluster solutions. Using 5 cluster solutions, 5 groups were compared with country typology according to GDP and export structure. The 5 cluster solutions were chosen because they were optimal in terms of cluster sizes, sum of squares distribution, and fit of solutions. 139 countries were divided into 5 different groups and cluster centers were specified. As a result of the analysis, the first group, which includes countries such as the USA, Denmark, Finland, and Germany, is the most developed group. The order goes as 5, 4, 2 and 3. The 3rd most undeveloped group includes mostly African countries. Finally, the distances between countries were determined by MDS and thus, a 2-dimensional visualization of the countries was provided.

3. Material and Methods

The significance of this research lies in its focused examination of the science, technology, and innovation indicators within Türkiye′s automotive industry, employing advanced statistical methodologies to analyze historical data effectively.

3.1. Purpose of Research

The aim of this research is to analyze specifically the science, technology and innovation indicators of Türkiye's automotive industry sector based on historical data, to identify and interpret the groupings, meaningful subsets, similarities, and distances between the indicator variables, and thus to guide the sector managers during their strategic planning studies. This way, industry managers will be able to better observe the relationships between industry parameters and understand which areas they should focus on.

On the other hand, when similar studies are conducted in the automotive sectors of other countries in the future, it will allow the interpretation of structural differences and similarities between countries.

To do this, the similarities, which constitute a set of rules that serve as criteria for separating or grouping items based on either single or multiple dimensions, were determined by HCA using square Euclidean distance measures. The number of clusters from HCA was confirmed by NHCA. The distances were determined by MDS using Euclidean distance measures and finally the number of main clusters and relationships between variables was reconfirmed by correlation analysis and factor analysis separately.

3.2. Determining the Research Process

No other study has been found in the literature in which science, technology and innovation indicators for the automotive sector are directly defined and analyzed as in the scope of this study. Nevertheless, there are studies in which technological development and innovation indicators were determined and used on a country basis as the study done by Cavdar & Aydin [11], shown in Table 5.

Table 5. Technological Development and Innovation indicators on country basis [11]

1	RDE	Research and Development Expenditure *(% of GDP)*
2	HTE	High-technology Exports *(% of manufactured exports)*
3	LTU	Long-term Unemployment *(% of total unemployment)*
4	PA	Number of Patent Applications *(residents)*
5	PAF	Number of Patent Applications *(nonresidents)*
6	HE	Health Expenditure, total *(% of GDP)*
7	PPP	GNI per capita, PPP
8	SWE	Share of Women Employed in the non-agricultural sector *(% of total non-agricultural employment)*
9	ST	Stocks Traded, total value *(% of GDP)*
10	IU	Internet Users *(per 100 people)*
11	STJ	Number of Scientific and Technical Journal articles

Since the aforementioned study is country-based and not directly suitable for sectoral application, science, technology and innovation indicators were reconsidered for the automotive industry, which is the locomotive sector of Türkiye's industry, and redefined by also considering the accessible data.

As a result of the examinations, 10 different indicators given in Table 6. were determined for Türkiye's automotive sector. S&T indicators were taken into account first and then, the data and reports summarizing the situation of Türkiye's automotive industry were examined in detail.

The main reason why some of the indicators determined for Türkiye's automotive sector are different is that the dynamics of the sector and the factors affecting the sectoral development are different. For this reason, indicators that are more relevant to the sector were added instead, and while doing this, their similarities to the S&T indicators were considered.

Since the automotive sector is a sector in need of sustainable development with intensive competition, continuous R&D activities are required. On the other hand, considering developed or developing countries, it seems that the automotive sector has a high share of R&D expenditure. That is why the variables of R&D expenditure and number of R&D employees, which are the input indicators of S&T, were included in this study.

HTE, which is one of the output indicators of S&T and under the heading of economy, is related to the automotive sector. It was taken as an indicator since the automotive sector also has a share in HTE. Because considering a vehicle as a complete product, there are various high-tech electronic controls with many chips on, various control and management software and drive system elements that require high technology today.

PA's fall under the technology element, which is one of the output indicators as well. The more PA's there are, the more technological studies are carried out in the sector. However, due to the existence of relatively smaller number of patents directly in the automotive sector, the countrywide figures were taken as a variable in this current study.

Production volume is naturally a main indicator for the sector, which must be included in any case. In this study it was divided into 3 as productions of total, cars, and commercial vehicles.

Automotive export volume change gives information about the growth and situation in the sector. As production and exports increase, the financial resources of the enterprise are strengthened and in response to this, R&D opportunities and capabilities are developed. Additionally, the ever-increasing competition in the sector makes R&D a must.

On the other hand, Automotive import volume is also an indicator providing information about the competitiveness of the sector.

STJ articles reveal the total research capacity of the country as well as the sector. Due to the existence of relatively smaller number of journal articles directly in the automotive sector, the countrywide figures were taken as an indicator variable.

As a result, the indicators presented in Table 6. were determined as the scientific, technology and innovation indicators for Türkiye's automotive industry and used in the subsequent analyzes.

Table 6. Technological Development & Innovation indicators for Türkiye's automotive industry (Authors)

1	RDE	Research and Development Expenditure *(% of GDP)*
2	HTE	High-technology Exports *(% of manufactured exports)*
3	NRD	Number of R&D employees
4	PA	Number of Patent Applications
5	PVT	Production Volume increase Total *(%)*
6	PVC	Production Volume increase total Cars *(%)*
7	PVCV	Production Volume increase total Commercial Vehicles *(%)*
8	AEV	Automotive Export Volume change *(%)*
9	AIV	Automotive Import Volume change *(%)*
10	STJ	Number of Scientific and Technical Journal articles

Since the automotive industry data is published annually, it was used on an annual basis during the analysis by using the SPSS 22.0 program.

3.3. Significance and Contributions of Research Methodology

The significance of employing Cluster Analysis (CA) and Multidimensional Scaling (MDS) methodologies in research cannot be overstated. Both techniques provide robust frameworks for uncovering patterns and relationships within complex datasets, enhancing the research's depth and implications.

Cluster Analysis facilitates the identification of meaningful subgroups within data, promoting the understanding of inherent patterns that may not be readily apparent through traditional analysis. By classifying observations into distinct clusters based on their similarities, researchers can derive insights into underlying structures within data. This is particularly vital in areas requiring nuanced interpretations, such as market segmentation, social sciences, and biological classifications [25].

In parallel, Multidimensional Scaling offers a powerful visual representation of data, translating complex similarities and differences into accessible formats. This capability is crucial for effectively communicating results to diverse audiences and stakeholders. Unlike factor analysis, which relies heavily on correlation matrices, MDS allows researchers to analyze various types of similarity matrices, broadening its applicability [10]. The visual tools provided by MDS, such as scatterplots and coordinate diagrams, not only simplify interpretation but also reveal relationships and dimensions that numerical data may obscure [52].

Together, CA and MDS enrich the analytical process, enabling researchers to uncover hidden insights, validate findings, and inform decision-making. Their contributions significantly enhance the overall quality and applicability of research outcomes.

3.4. Research Methods

By utilizing Hierarchical Cluster Analysis (HCA) and Multidimensional Scaling (MDS), this study aims not only to uncover meaningful groupings and relationships among indicator variables but also to provide practical insights for industry managers in their strategic planning efforts.

3.4.1. Cluster Analysis (CA)

CA is a multivariate statistical method that divides the data in the data matrix into meaningful subsets according to their similarities or distances. The main purpose of CA is to determine the most appropriate grouping between units or observations so that they are similar in each cluster, and it is the principle that there is no similarity between the classified clusters. In other words, CA classifies ungrouped data according to their homogeneous characteristics and provides appropriate and summative information.

CA is divided into HCA and NHCA types. The main difference between these 2 techniques is that the number of clusters is determined differently. In the HCA method, the number of clusters is determined by graphical methods such as a dendogram which is actually a tree graph. NHCA is used when the number of clusters is known or determined from the beginning by the researcher, and it validates HCA at the same time [3].

3.4.2. Multidimensional Scaling (MDS)

MDS is a tool to express the level of similarity of cases in a dataset visually and it can be seen as an alternative to factor analysis. The purpose of MDS is to identify significant underlying dimensions that enable explaining the observed similarities or differences between the objects under study. In factor analysis, however, the similarities between the variables are given in the correlation matrix. By means of MDS, any similarity or difference matrices can be analyzed besides correlation matrices [11]. The purpose of the MDS method is to express the results graphically rather than numerically. On the other hand, the most important thing that statistical methods need when explaining the application is an explanatory graphical technique. In this context, the MDS method is one of the good methods that can meet the necessary need [52]. In the MDS method, formal methods such as 2-dimensional coordinate drawings and scatter diagrams are included in order to determine similarities, differences, and distances. In addition to numerical values, visual expressions are also provided.

Table 7. Agglomeration schedule

Stage	Cluster Combined		Coefficients	Stage Cluster First Appears		Next Stage
	Cluster 1	Cluster 2		Cluster 1	Cluster 2	
1	7	8	51,789	0	0	4
2	1	3	887,051	0	0	3
3	1	2	7303,825	2	0	5
4	5	7	30454,348	0	1	5
5	1	5	58061,678	3	4	6
6	1	4	121696,091	5	0	7
7	1	6	2926037247	6	0	8
8	1	9	32744888170	7	0	9
9	1	10	3,320E+11	8	0	0

3.5. Obtaining Data

In this study, 33 years of data for 10 variables between 1990-2022 were collected from various sources. Due to the lack of data on the parameters used in the model for the previous years, it was not easy to go back further than this for the indicator variables determined.

4. Results

4.1. Hierarchical Cluster Analysis (HCA) Results

Table 7. explains at what stage 2 variables combine with the other variables to form a cluster. In the 1st stage, #7 and #8 form a cluster. The next step is the 4th line, and they create a new set by taking #5 among them. The process continues in this way until the last stage.

The rescaled distance cluster combine is presented in Figure 4. as a dendogram. Dendogram gives visual information about clustering of variables and by looking at the results of the cluster analysis, it seems that the variables are mainly divided into 2 clusters.

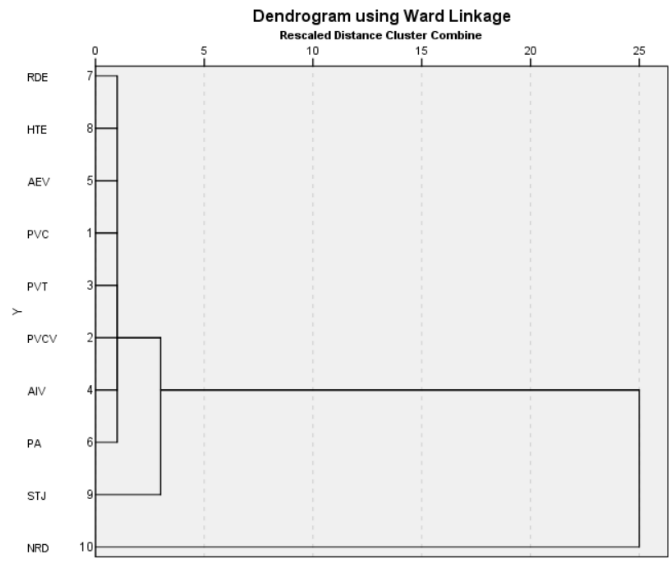

Fig. 4. Rescaled distance cluster combine

4.2. Non-Hierarchical Cluster Analysis (NHCA) Results

Iteration history, final cluster centers and distances between final cluster centers for NHCA are given in Tables 8., 9. and 10. below.

Table 8. Iteration history

Iteration	Change in Cluster Centers	
	1	2
1	73759,882	42924,510
2	9159,589	3454,365

Table 9. Final cluster centers

	Cluster	
	1	2
PVC	1,99	10,27
PVCV	3,16	15,13
PVT	2,22	11,51
AIV	3,22	29,69
AEV	5,21	24,89
PA	17571	4467
RDE	1,23	0,53
HTE	2,89	2,10
STJ	54689	16755
NRD	182697	46663

Table 10. Distances between final cluster centers

Cluster	1	2
1		141831,038
2	141831,038	

In the HCA above, it was determined that there were 2 clusters as seen in Table 8. and Table 9. showing the results of the NHCA, the values are reset in the 2nd iteration and there are again 2 clusters.

4.3. Multidimensional Scaling (MDS) Results

Table 11. is a distance matrix that shows the distances between 10 selected variables. On the other hand, the iteration history for 2D solutions is given on Figure 5.

Table 11. Raw data for subject 1

	1	2	3	4	5	6	7	8	9	10
1	,000									
2	4,045	,000								
3	1,764	2,448	,000							
4	4,340	3,356	3,566	,000						
5	7,338	7,037	7,258	7,594	,000					
6	8,894	9,189	9,081	9,246	9,618	,000				
7	8,918	9,117	9,039	9,241	9,568	1,425	,000			
8	9,010	8,883	9,012	9,004	8,254	6,074	5,926	,000		
9	8,771	8,918	8,862	9,057	9,577	1,984	1,407	6,248	,000	
10	8,856	8,921	8,918	8,985	9,514	2,075	1,506	6,190	1,300	,000

```
Iteration history for the 2 dimensional solution (in squared distances)

                  Young's S-stress formula 1 is used.

                Iteration     S-stress      Improvement

                    1           ,10923
                    2           ,08546         ,02378
                    3           ,08515         ,00031

                       Iterations stopped because
                 S-stress improvement is less than   ,001000


                                    Stress and squared correlation (RSQ) in distances

                          RSQ values are the proportion of variance of the scaled data (disparities)
                                     in the partition (row, matrix, or entire data) which
                                      is accounted for by their corresponding distances.
                                        Stress values are Kruskal's stress formula 1.


                For  matrix
    Stress  =   ,11626      RSQ =  ,96357
```

Fig. 5. Iteration history for the 2-D solution

Table 12. Goodness of fit for stress value [46]

Stress	Goodness of fit
>0,2	Bad
>0,1	Appropriate
>0,05	Good
>0,025	Excellent
>0	Perfect

In this method, iterations should be continued until the improvement value is less than 0.001. At the end of the analysis, it was observed that an acceptable improvement value of 0.00031 was reached at the end of 3 iterations.

Additionally, an S-stress value of 0.08515 was calculated at the end of 3 iterations and it is larger than 0.05 according to the compliance criteria given in Table 12. below used in the literature. So, S-stress value corresponds to a good fit.The Stimulus Coordinates Dimension is given on Table 13.

Table 13. Stimulus coordinates dimension

Stimulus Number	Stimulus Name	Dimension	
		1	2
1	PVC	1,2345	-0,5020
2	PVCV	1,3133	-0,3247
3	PVT	1,2825	-0,4431
4	AIV	1,3203	-0,5043
5	AEV	0,9803	1,5191
6	PA	-1,3535	-0,2098
7	RDE	-1,3437	-0,1775
8	HTE	-0,8547	1,1731
9	STJ	-1,2879	-0,2822
10	NRD	-1,2910	-0,2486

Table 14. Optimally scaled data for subject 1

	1	2	3	4	5	6	7	8	9	10
1	,000									
2	0,993	,000								
3	0,158	0,390	,000							
4	1,034	0,699	0,771	,000						
5	2,053	1,951	2,026	2,140	,000					
6	2,582	2,683	2,646	2,702	2,829	,000				
7	2,591	2,658	2,632	2,701	2,812	0,043	,000			
8	2,622	2,579	2,623	2,620	2,365	1,623	1,573	,000		
9	2,541	2,591	2,572	2,638	2,815	0,232	0,036	1,683	,000	
10	2,570	2,592	2,591	2,614	2,793	0,264	0,070	1,663	0,000	,000

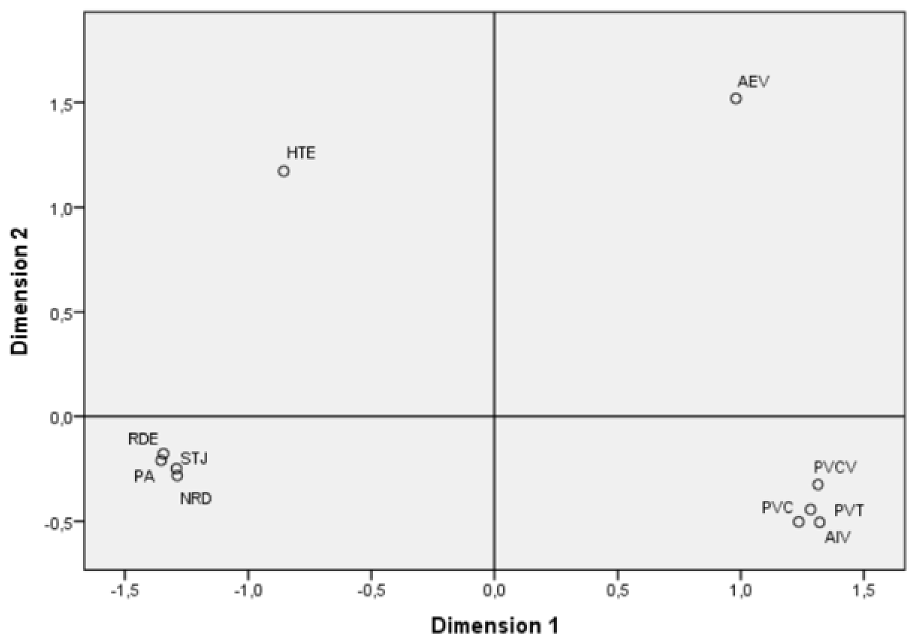

Fig. 6. Euclidean Distance Model according to the MDS Analysis

These values are related to the coordinates when 2 dimensions are considered in Table 14. Figure 6. is a visualization according to 2-dimensional Euclidean space coordinates, and the variables that are similar to each other are located closer. According to this figure, it is observed that there are 2 different main clusters and 2 separate variables among 10 different S&T variables.

4.4. Correlation Analysis Results and Relationship Levels Between Group Members

In order to determine the correlations between the members of the 2 main clusters identified and the HTE and AEV variables located separately from these 2 main clusters, an additional correlation analysis was conducted for the entire data set and the results are given in Table 15.

The classification shown on Table 16. was used for correlations.In order to see the expected high correlation relationships between the members of the 2 main clusters and the expected low correlation relationships between variables that do not fall into these clusters, the statistical analysis results were rearranged on a cluster basis as shown in Table 17. below.

Table 15. Results of correlation analysis

		PVC	PVCV	PVT	AIV	AEV	PA	RDE	HTE	STJ	NRD
PVC	Pearson Correlation	1	0,744	0,951	0,706	0,159	-0,236	-0,243	-0,268	-0,202	-0,226
	Sig. (2-tailed)		0,000	0,000	0,000	0,378	0,186	0,174	0,131	0,260	0,207
PVCV	Pearson Correlation	0,744	1	0,906	0,824	0,226	-0,319	-0,299	-0,233	-0,243	-0,243
	Sig. (2-tailed)	0,000		0,000	0,000	0,205	0,070	0,091	0,192	0,174	0,172
PVT	Pearson Correlation	0,951	0,906	1	0,801	0,177	-0,288	-0,277	-0,269	-0,227	-0,243
	Sig. (2-tailed)	0,000	0,000		0,000	0,325	0,103	0,119	0,130	0,203	0,174
AIV	Pearson Correlation	0,706	0,824	0,801	1	0,099	-0,336	-0,334	-0,267	-0,282	-0,261
	Sig. (2-tailed)	0,000	0,000	0,000		0,584	0,056	0,057	0,133	0,112	0,147
AEV	Pearson Correlation	0,159	0,226	0,177	0,099	1	-0,445	-0,430	-0,065	-0,433	-0,414
	Sig. (2-tailed)	0,378	0,205	0,325	0,584		0,009	0,012	0,721	0,012	0,016
PA	Pearson Correlation	-0,236	-0,319	-0,288	-0,336	-0,445	1	0,968	0,424	0,939	0,933
	Sig. (2-tailed)	0,186	0,070	0,103	0,056	0,009		0,000	0,014	0,000	0,000
RDE	Pearson Correlation	-0,243	-0,299	-0,277	-0,334	-0,430	0,968	1	0,451	0,969	0,965
	Sig. (2-tailed)	0,174	0,091	0,119	0,057	0,012	0,000		0,008	0,000	0,000
HTE	Pearson Correlation	-0,268	-0,233	-0,269	-0,267	-0,065	0,424	0,451	1	0,390	0,401
	Sig. (2-tailed)	0,131	0,192	0,130	0,133	0,721	0,014	0,008		0,025	0,021
STJ	Pearson Correlation	-0,202	-0,243	-0,227	-0,282	-0,433	0,939	0,969	0,390	1	0,974
	Sig. (2-tailed)	0,260	0,174	0,203	0,112	0,012	0,000	0,000	0,025		0,000
NRD	Pearson Correlation	-0,226	-0,243	-0,243	-0,261	-0,414	0,933	0,965	0,401	0,974	1
	Sig. (2-tailed)	0,207	0,172	0,174	0,142	0,016	0,000	0,000	0,021	0,000	

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

c. Listwise N=33

Table 16. Correlations Classification

0-0,25	Very weak
0,26-0,49	Weak
0,50-0,69	Medium
0,70-0,89	High
0,90-1,00	Very high

Table 17. Correlation coefficients on cluster basis

		Cluster 1			
		RDE	**STJ**	**PA**	**NRD**
Cluster 1	**RDE**		0,969	0,968	0,965
	STJ			0,939	0,974
	PA				0,933
	NRD				
		Cluster 2			
		PVCV	**PVC**	**PVT**	**AIV**
Cluster 2	**PVCV**		0,744	0,906	0,824
	PVC			0,951	0,706
	PVT				0,801
	AIV				

	HTE	AEV
HTE		0,065
AEV		

Accordingly, as expected, there are very high correlations ranging between 0.933-0.974 among the 1st cluster variables, high and very high correlations ranging between 0.706-0.951 among the 2nd cluster variables, and finally a very low correlation of 0.065 between HTE and AEV variables which did not fall into any clusters. These results reconfirm the group formations obtained by the MDS analysis.

At this stage, as an alternative to the MDS analysis, the results can be checked and confirmed in another way by performing factor analysis to understand in how many different dimensions these 10 variables are identified and perceived subject to statistical analysis; in other words, how these variables are classified.

4.5. Factor Analysis and Results

The result of the KMO and Barlett's Test is given on Table 18. The KMO test result is 0.09 > 0.50. Therefore, the data set is suitable for factor analysis.

There are 2 factors with total initial eigen values > 1.0 in Table 19. The first factor explains 43.104% of the total variance and both of them explain 78.183% of the total variance.

Table 18. KMO and Barlett's test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0,709
Bartlett's Test of Sphericity	Approx. Chi-Square	469,242
	df	45
	Sig.	0,000

Table 19. Total variances

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5,176	51,764	51,764	5,176	51,764	51,764	4,310	43,104	43,104
2	2,642	26,419	78,183	2,642	26,419	78,183	3,508	35,079	78,183
3	0,937	9,371	87,554						
4	0,622	6,219	93,773						
5	0,339	3,392	97,165						
6	0,167	1,675	98,840						
7	0,069	0,690	99,530						
8	0,024	0,241	99,771						
9	0,020	0,197	99,968						
10	0,003	0,032	100,000						

Since AEV (0.268) and HTE (0.268) both have communality (common variance) values <0.50 in Table 20. and relatively lower values in Table 21. of rotated component matrix, they can be cancelled from the main list and the factor analysis can be repeated for better results.

Table 20. Communalities

	Initial	Extraction
PVC	1,000	0,841
PVCV	1,000	0,867
PVT	1,000	0,968
AIV	1,000	0,792
AEV	1,000	0,268
PA	1,000	0,942
RDE	1,000	0,972
HTE	1,000	0,268
STJ	1,000	0,955
NRD	1,000	0,946

Table 21. Rotated Component Matrix with 10 variables

	Component	
	1	2
RDE	0,975	-0,150
STJ	0,973	-0,093
NRD	0,967	-0,100
PA	0,958	-0,160
AEV	-0,509	0,092
HTE	0,455	-0,248
PVT	-0,138	0,974
PVCV	-0,168	0,916
PVC	-0,114	0,910
AIV	-0,190	0,869

As seen from Table 21., Factor 1 includes the variables RDE, STJ, NRD and PA and Factor 2 includes PVT, PVCV, PVC and AIV variables as in the MDS analysis. On the other hand, HTE and AEV variables both behave differently.

In the next step, the variables HTE and AEV with very low coefficients are excluded from the variables, and the factor analysis is repeated with the remaining 8 variables.

KMO test result with only 8 variables is 0.714 > 0.50. Therefore, the data set is again suitable for factor analysis.

When the results of the factor analysis in Table 22. with 8 variables examined, it is clearly observed that 2 factors are formed which are exactly the same as the previous 2 clusters.

Table 22. Rotated Component Matrix with 8 variables

	Component	
	1	2
RDE	0,980	-0,113
STJ	0,977	-0,168
NRD	0,976	-0,119
PA	0,960	-0,179
AEV	-0,119	0,977
HTE	-0,148	0,922
PVT	-0,093	0,912
PVCV	-0,187	0,872
PVC	-0,114	0,910
AIV	-0,190	0,869

Thus, it is confirmed that the applied HCA, NHCA, MDS, correlation analysis and factor analysis methods reveal the same cluster formations. Accordingly, variables in the same cluster would naturally be expected to show similar behaviors as a group.

5. Discussion and Conclusions

The study of the dendrogram and hierarchical cluster analysis (HCA) in Türkiye's automotive sector reveals significant insights into the relationships among various indicators, highlighting the importance of research and development (R&D) activities. The identification of two distinct clusters reinforces the notion that R&D (represented as NRD) stands apart from other variables, emphasizing its critical role in driving innovation and competitiveness. This separation signifies that the most valuable aspects of any business, particularly in automotive, revolve around human resources and knowledge.

The analysis indicates that as investment in R&D rises, there is a corresponding increase in scientific output, such as patents and academic publications, particularly when linked to new product development. This relationship underscores the necessity for the Turkish automotive industry to prioritize R&D to enhance product quality and overall productivity.

Additionally, the findings suggest that commercial indicators are closely tied to economic conditions, with positive economic climates fostering increased domestic production and imports.

The study further reveals that specific variables, such as HTE and AEV, operate independently and require long-term strategic planning to align with R&D investments.

The insights derived from this research lay a foundation for policy recommendations, urging government support for R&D initiatives to bolster technological advancement and export opportunities.

Ultimately, this pioneering work not only informs the Turkish context but also serves as a model for similar analyses in other countries and industrial sectors. By promoting sustained R&D efforts, the automotive industry can secure a competitive edge and contribute to broader economic growth.

Looking at the shape of the dendogram in the HCA, it is seen that the variables form 2 separate clusters. In the NHCA, the values are reset in the 3rd iteration, and this is a result confirming that there are only 2 clusters.

When we look at the Euclidean distance model in the MDS analysis, it is observed that there are 2 main clusters, and 2 other separate variables and analysis results show that interrelated variables cluster together due to their similarities.

The indicators NRD, RDE, STJ, and PA are clustered in the lower left corner. This means that when the NRD and RDE, which correspond to also number of new products are increased, then a proportional increase in the number and quality of scientific articles and patents can be expected and for this reason, these 4 interrelated variables form a group.

Market size or in other words commercial indicators PVC, PVCV, PVT, and AIV are clustered in the lower right corner. This is an expected situation because when the economic conditions in the country are positive, then the purchasing power of the population increases and therefore both domestic production and also import volumes of the automotive sector increase or vice versa.

Nevertheless, it is seen that the HTE and AEV variables are located far away from other variables and also each other, and therefore do not make any group with any other variable.

HTE is a separate issue and cannot be explained only by production increases and an economy getting better. This goal can only be achieved over time with long-term strategies, a large number and variety of R&D investments and projects, and an accumulated know-how as also stressed by Cavdar & Aydin [11] in their work as one of the most effective variables for Türkiye on innovation.

The second indicator was PAF which corresponds to PA in the current study and was in parallel to the analysis from Zhang et al. [11] to measure the relationship between scientific innovation and economy as in China, where it played a key role in economic growth by contributing to the development of technologies and also protecting the interests of inventors.

On the other hand, the increase in AEV is not only related to the well-being of the local economy or being in crisis, but more complicatedly to the international economic market balances and the international competitiveness of products and production processes which is closely related with S&T and innovation capacity. Therefore, development in this field can only be achieved with original, and strategic long-term approaches.

Supporting and increasing R&D studies in Türkiye's automotive sector will not only provide employment for many people but will also positively affect the technological development and adaptation abilities of the sector, primarily by developing various products of high quality, increasing total sales and providing export opportunities. As a matter of fact, according to the comparative results obtained in the study conducted by Nour [39] on Sudan using OECD's S&T indicators, R&D activities play an important role in the production of domestic technologies and in adapting to imported technology. Therefore, the government's strategies, initiatives, and investments to develop R&D activities are extremely important in this locomotive sector.

According to the results obtained within the scope of this study based on 33 years of sector data, the actions for improvement given in Table 23. below can be proposed, taking into account the science, technology and innovation indicators determined at the beginning.

It would be beneficial to use data containing longer periods in order to strengthen the study and observe the similarities and distances among clusters better, however, there is difficulty in accessing data prior to 1990. Nevertheless, no problems were encountered during the application of the statistical tests with 33 years of data.

This study can also be applied to the automotive industries of other countries by using the original data of each country for comparison purposes.

This current study is the first in this scope in literature and paves the way in the field to understand the characteristics of the automotive sector indicators and take necessary precautions wherever required for its sustainability. If similar studies are conducted further, they will enable the sector players to obtain comparative results based on the country's general economic and automotive industry data.

Finally, it can be said that similar analyses can also be carried out for industrial sectors other than automotive as well.

Table 23. Proposed improvement actions

Indicator		Indicator Name	Proposed Improvement Actions
Cluster 1	**RDE**	**R**esearch and **D**evelopment **E**xpenditure *(% of GDP)*	Increase it >2% at first hand on a country basis.
	STJ	Number of **S**cientific and **T**echnical **J**ournal articles	Keep current momentum for increment and accelerate with increased budgets and incentives. Take new measures and prepare incentive packages that will encourage research across the country and make academic life more attractive and productive.
	PA	Number of **P**atent **A**pplications	Develop and strengthen existing mechanisms and add new ones where necessary to enable patents to be transformed into final products and income.
	NRD	Number of **R&D** employees	Keep current momentum for increment and accelerate with increased budgets and incentives.
Cluster 2	**PVCV**	**P**roduction **V**olume increase total **C**ommercial **V**ehicles *(%)*	Take permanent measures against the constantly fluctuating production amount structure depending on internal and external factors. Protect your current markets and find new permanent markets.
	PVC	**P**roduction **V**olume increase total **C**ars *(%)*	
	PVT	**P**roduction **V**olume increase **T**otal *(%)*	
	AIV	**A**utomotive **I**mport **V**olume change *(%)*	Just like domestic production figures, it has a constantly fluctuating structure depending on internal and external factors. Take measures to improve the quality of domestic automotive products and diversify them. Try to attract new global investors to the country for better quality and more diverse domestic production.
HTE		**H**igh-**t**echnology **E**xports *(% of manufactured exports)*	Try to maintain and increase the general upward trend in the last 15 years. Increase it with special infrastructure and incentives. Use the defense industry, which is leading in this regard, as a core.
AEV		**A**utomotive **E**xport **V**olume change *(%)*	It shows extreme dynamic fluctuation. Take additional measures that will ensure the permanence of export markets, increase quality and diversity, and increase the competitive power of the Turkish Automotive Industry. Support and further encourage domestic automotive investment and R&D studies.

Conflict of Interest Statement

We declare that there is no conflict of interest in the study.

CRediT Author Statement

Üzeyir Pala: Conceptualization, Investigation, Data curation, Methodology, Validation, Writing-original draft
Taseer Salahuddin: Conceptualization, Supervision, Review & editing.

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