Heliyon 6 (2020) e04006

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

R&D investments and quality of life in Turkey

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A R T I C L E I N F O

Keywords:
Regional development
Research and development
Economic inequality
Fuzzy analytic hierarchy process
TOPSIS
Quality of life
Turkey
Inequality
Public economics
Economic development
Economic growth
Employment

A B S T R A C T

The standards of development and life quality of cities play an important role in the investment and career planning of the investors and the qualified people who will work in R&D and Technoparks. Also, all the leading cities in the world are the most developed cities in the regions and countries in terms of R&D and innovation. Therefore, all cities in Turkey are compared by using the R&D investment data and TurkStat "Quality of Life Index for Cities". The criteria are weighted by the Fuzzy Analytic Hierarchy Process (FAHP). Then 81 cities are compared with the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method. The article aims to provide information about the current situation of Turkey's cities regarding R&D, Technology Development Zones and quality of life. According to the results, the quality of life and socio-economic development has a very close relationship with the existence of R&D investments. If the current development policy continues, the regions with low quality of life will continue to lag behind the other cities in terms of development. The study indicates that there are remarkable differences between eastern and western Turkey in terms of living standards and the contribution of R&D and Technoparks to economic development.

1. Introduction

When the growth trends in the world economy are analyzed, it is observed that developed countries have lost momentum in terms of real gross national product and developing countries have gained momentum [1]. A major reason for this acceleration is the relocation of production from developed countries to developing countries due to cheap labour and access to raw materials. When we examine the 34-year period between 1980 and 2014, the economic growth rate in developed countries decreased from 3.2 percent in 1980–1989 to 1.5 percent in the 2009–2014 period, and in developing countries it increased from 2.2 percent to 3.5 percent. In the less developed countries, an increase from 2.5 percent to 4.8 percent is observed during the same period [2]. Therefore, the direction of the global trend in production-value chains is towards developing countries and supports growth in these geographies.

One of the most important indicators of social welfare and development is economic growth. In growth theories, the main explanatory of growth has been mostly technology. In addition, the main factors affecting growth are productivity levels and production structures [3]. The shift of production towards high-tech products and the increase in innovation production and R&D activities also have supported the economic growth in the developing countries of Asia, especially China. Economic growth has historically played an important role in the development of societies and the rise of living standards. Also, innovation contribute positively to growth and prosperity [4].

R&D activities are of great importance in the development of technology and manufacturing of high value-added products. Both scientific institutions such as TUBITAK (the Scientific and Technological Research Council of Turkey) as well as universities, should be co-partner with industry organizations in such activities. The share allocated from the GDP, the funds coming from the annual turnover of the industrial firms and the studies of the universities constitute the R&D capital of a country. It is not possible to talk about a sufficient R&D capital unless the necessary equipment, human capital, engineering skills, education, software and database etc. are sufficient [5]. The top 10 countries in the 2016–2017 Global Competitiveness Report of the World Economic Forum are R&D intensive growing countries. For example, Finland, which ranks second in competitiveness, ranks third in terms of R&D intensity. Likewise, countries such as Japan, Germany, Sweden, and USA are R&D intensive countries. Obviously, development and growth concepts are closely related to the increase in R&D intensity [6]. Considering the share of R&D expenditures in the gross national product, Israel takes the first place and South Korea is the second. While the average share of each European Union country is 1.91 percent, the shares of OECD countries is 2.36 percent. Also, these rates are 3.47 percent in Japan, 2.85 percent in Germany and 2.73 in the US. Therefore, they are at the top of the world

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https://doi.org/10.1016/j.heliyon.2020.e04006
Received 27 January 2020; Received in revised form 29 March 2020; Accepted 13 May 2020

ranking with their R&D expenditures [7]. R&D expenditures play an important role in international competition, efficiency and sustainable economic growth. Turkey tries to reach 1.8% R&D expenditure share in GDP in 2023 [8]. According to the EU's Industrial R&D Investment Scoreboard 2016 report, which examines the R&D performance of 2,500 selected companies, most of the companies with a high R&D intensity in net sales are from the US. There are only 6 Turkish companies on this list. When 2500 companies are examined in terms of their performance in R&D activities, there are only two Turkish companies in the first 1000 [9].

Turkey performs typical features of developing countries in terms of investment in R&D expenditure. According to the World Economic Forum's Global Competitiveness Report covering the period 2016–2017, Switzerland, Singapore, USA, Netherlands, Germany, Sweden, Britain, Japan and Hong Kong are the top 10 countries among the 138 countries respectively whereas Turkey is ranked 55th. Turkey has a very poor performance score in the category of preparation of innovation and technology during the period of 2016–2017, so it ranks 71st and 67th in these areas respectively. Similarly, Turkey is the 57th in the category of adaptation to new technologies and also it is the 46th in the category of the sufficiency for the latest technology at the company level [6]. Therefore, Turkey should take the necessary measures for a sustainable economy and development as soon as possible. In addition, the development of the cities is very important for the employees and skilled human resources who plan to work there. As shown in Table 1, the world's leading R&D, Techno park and innovation centers are located in the most developed cities in order to attract these people [10].

The Quality of Life Index, which is determined for the criteria of the article, is a study that covers all aspects of life, including the material aspects of life as well as concepts such as subjective perception, social life, life satisfaction and the living environment [11]. The criteria of analysis are overall index score, housing, work life, income and wealth, health, education, environment, safety, civic engagement, access to infrastructure services, social life and life satisfaction.

Determining the development of a region and comparing it with others is a multi-criteria decision making (MCDM) problem. Thus, it requires evaluation of many conflicting criteria [12, 13]. According to the sort of the problem, proper MCDM techniques have been determined after the experiments carried out over the years. Therefore, FAHP method has been proposed for weighting of criteria. This method is the most popular method among the all MCDM for weighting. In addition, TOPSIS method is preferred in order to sort the cities according to the selected criteria. The article proposes a method to make some inferences and suggestions in the framework of R&D, Techno park and the Quality of Life Index for Cities.

There are many different studies in the literature on similar subjects with MCDM methods. Minouei and abd Rozan [14] proposed a TOPSIS approach for university entrepreneurship center identity factors prioritization. Minarcíková [15] used TOPSIS and VIKOR methods for evaluation of regional innovation performance. Mavi [16] suggested a Fuzzy AHP and Fuzzy TOPSIS approach to assess the indicators of entrepreneurial university. Poledníková and Kashi [17] evaluated the regional innovation performance in the Czech Republic through AHP and TOPSIS methods. Özkan, *et al.* [18] utilized a GIS-based DANP-VIKOR approach to evaluate R&D performance of Turkish cities. Chu and Lai [19] tried to select the most appropriate location for distribution centre using an improved fuzzy MCDM approach. Kubickova, *et al.* [20] investigates the relationship between tourism competitiveness and quality of life in developing economies. Craglia, *et al.* [21] reviews the comparable indicators of the quality of life to monitor development and policy implementation. Morais, *et al.* [22] provided an assessment of urban quality of life (QoL) of European cities from the perspective of qualified human resources. Also, they stated that the competitiveness of cities relies increasingly in their capacity to attract highly educated workers, as they are important assets for firms when choosing a location. Turkoglu [23] evaluated the sustainability and quality of life concept based on quality of life (QoL) researches. Environmental, economic, social, physical and health related indicators are discussed to contribute to the sustainable development strategies. Arifwidodo and Perera [24] examined the connection between QOL and selected attributes of compact development for Bandung city, Indonesia. Easterlin and Angelescu [25] provide a selective survey of -cross-sectional and time series evidence on the empirical relation between quality of life and modern economic growth. Peterson and Ekici [26] aim to better understand consumer attitude toward marketing and how it relates to quality of life (QOL) in a developing country. Woo, *et al.* [27] tried to show the impact of education and R&D investment on regional economic growth. Erdin and Ozkaya [28] aim to show the contribution of small and medium enterprises to economic development and quality of life in Turkey. Erdin and Ozkaya [29] evaluated the performance of the ASEAN countries and Turkey in the sustainable development index framework with the TOPSIS method. Ozkaya [30] evaluated the priorities of smart city concept based on quality of life (QoL) by using ANP method.

The broad scope of the criteria and the lack of experts who have knowledge of all indicators are the major challenges of FAHP studies and they are the limitations of such research. Five academicians from the Department of Humanities and Social Sciences specialized in the fields of culture and arts, science and technology, economics, sociology, and psychology were interviewed. Then their evaluations and opinions about quality of life in a city were taken. The Department of Humanities and

Table 1. Innovation cities index, 2018: the top 15 cities [10].

Rank	City Name	Country	State	Region	Subregion	Index Score
1	Tokyo	Japan	Tokyo	ASIA	JAPAN	56
2	London	United Kingdom		EUROPE	UK	56
3	San Francisco - San Jose	United States	California	AMERICAS	USA	55
4	New York	United States	New York	AMERICAS	USA	55
5	Los Angeles	United States	California	AMERICAS	USA	55
6	Singapore	Singapore	Singapore	ASIA	ASIA PAC	54
7	Boston	United States	Massachusetts	AMERICAS	USA	53
8	Toronto	Canada	Ontario	AMERICAS	CANADA	53
9	Paris	France	Ile-de-France	EUROPE	EURO CONT	53
10	Sydney	Australia	NSW	ASIA	ANZ	53
11	Chicago	United States	Illinois	AMERICAS	USA	53
12	Seoul	South Korea	Seoul	ASIA	ASIA PAC	52
13	Dallas-Fort Worth	United States	Texas	AMERICAS	USA	52
14	Berlin	Germany		EUROPE	EURO CONT	51
15	Seattle	United States	Washington	AMERICAS	USA	51

Social Sciences has been studying almost any kind of issues about "people" and "society" in the perspective of "social sciences", "humanities", "engineering", and "science and technology", "philosophy". The subjective evaluations of experts were collected by means of the pairwise comparison matrices after the criteria, dimensions and the network relations of criteria had been determined by them. The geometric means of these pairwise comparison matrices were used in FAHP analysis. The geometric mean method was used to obtain group decisions from individual scores of expert evaluations. Thus, it was tried to prevent the analysis from being affected by outliers. Eventually, the priority values (weights) were obtained from the Super Decision program, and then they were interpreted.

The study informs everyone related to R&D and innovation about Turkey's current and future R&D and Techno park situation, and it also presents Turkey's next five and ten years goals. Also, regions and cities are analyzed in terms of quality of life. The existing R&D and Techno park investments of the regions are compared with these results. It also seeks to determine whether there is a significant difference between regions or cities in terms of technological investment and quality of life. The rest of the study is organized as follows: Section 2 gives some information about the potential of Turkey and presents a literature review for this topic. Section 3 explains all the steps of the proposed MCDM methods. Section 4 presents the obtained results. Section 5 presents discussions and Section 6 presents the conclusion.

2. The potential of Turkey

It is very important for countries to benefit from all qualified human resources (engineers, technicians, scientists) and include everyone in development and industry. In developed countries, R&D personnel per million people vary between 3,100 and 6,300. In Turkey, this value is 502 people [7]. One of the basic elements of development is a well-trained, skilled workforce. For example, in the rapid development process of East Asian countries, in many respects, it is accepted that well-trained, skilled labour force and rapid productivity increases are the determinants of catching developed countries [31]. Turkey is not in a good position in terms of quality of education. No Turkish university is among the top 100 most successful universities in the world. In the top 500, there are only 6 universities [32]. According to the results of the 2017 PISA (The Programme for International Student Assessment) test, Turkey ranks 50th among 72 countries [33]. These rankings are quite contrary to qualified growth and industrialization. In addition, Turkey ranks 20th in the ranking of scientific publications since 2008. As technological developments increase in the world, there is an increase in scientific publications. However, there has not been any progress in the ranking of scientific publications in Turkey since 2008 [34]. When higher education expenditures are analyzed according to R&D field, health sciences attracted attention with 33.2% as the highest expenditure in 2017. This area was followed by social sciences (23.4%), engineering sciences (18.7%), humanities (12.6%) and natural sciences (8%). Agricultural sciences had the lowest R&D expenditure in higher education with 4%. In addition, the information and communication sector was the other commercial sector with the highest amount of R&D activities with 8.6% [35].

According to various growth studies, the R&D expenditure (% of GDP) is high in countries trying to grow their economy. Figure 1 shows the share of R&D in the Gross National Product. Other country groups can also be seen in the Figure 1 so we can make a comparison.

The vertical axis of this graph, prepared by OECD data, shows the researcher human resources. Turkey (TUR) has a bad value as shown in the chart [36]. Between 2006 and 2015, there was a regular increase in R&D human resources per 10,000 employees calculated by TurkStat. While 27 R&D human resources were employed in full-time equivalent (FTE) in 2006, this number reached 46 in 2015. When the number of researchers in terms of FTE is examined, it was 2 in 2006 and this number reached 36 in 2015 [37]. As of 2016, 47 percent of total general government R&D expenditures are allocated to R&D personnel. The total number of academicians working in the field of higher education is approximately 152 thousand [37].

Turkey currently has 1178 R&D centers, but there were only 168 five years ago. The total number of employees is approximately 59,000. According to the 5-year plan, more than 600 companies are planned to establish in TeknoHAB Technology Development Zone, and more than 8,000 qualified R&D personnel will be employed. As of June 2019, there are a total of 84 Technology Development Zones. Within the framework of the 10-year plan, it is planned to operate over 800 companies and to employ 12,000 qualified R&D employees [8]. About 50% of companies are software companies. The total number of personnel in the Technology Development Zones is 54,030 [38]. Here are a few of the planned Technology Development Zones: The Çankırı Technology Development Zone is planned to include 40 companies and 100 researchers in the fields of biotechnology, nanotechnology, defence, chemistry, software, information, electronics and communication technologies. The Çankırı Technology Development Zone is expected to provide 3–4 billion dollars annually for the next 5 years [38, 39]. Energy, food, machinery, manufacturing and health sectors are targeted to operate in Kastamonu University Technology Development Zone. 30 companies will be in operation at the end of the first year in the region [38, 39]. R&D activities in food technology, nanotechnology, materials and robotics will be carried out in Kırklareli University Technology Development Zone. More than 100 entrepreneurs are expected to work in the next 10 years there [38, 39]. The government aims to gather the defence industry companies under one roof in Ankara Space and Aviation Specialized Industrial Zone.

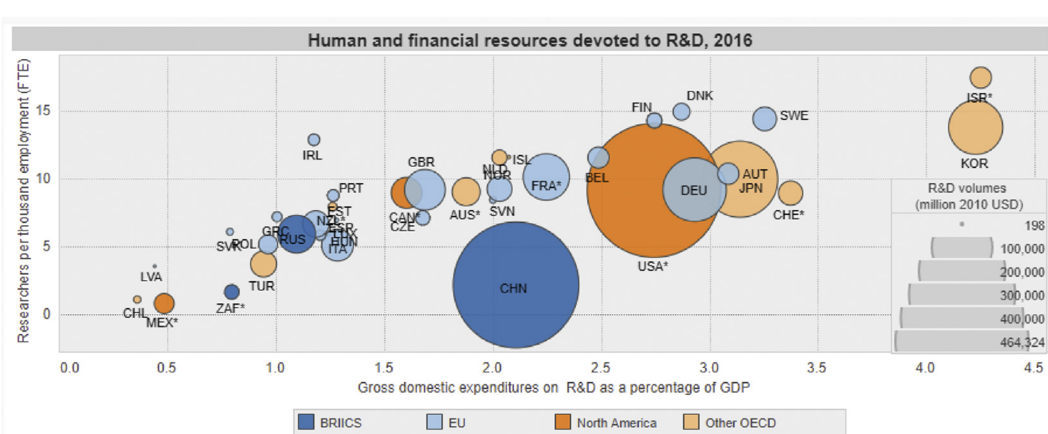

Figure 1. Human and financial resources devoted to R&D, 2016 [36].

This zone is planned to work in cooperation with TAI, ASELSAN and Gazi University.

When the general government R&D expenditure is analyzed, defence expenditure comes first with a share of 20.5 percent. The defense expenditures are followed by agriculture expenditures and education expenditures with a share of 4.6 percent [37]. There is serious public support in R&D centers. For example, if $ 100 is spent by the company, $ 89 of it can be taken as an incentive. In other words, R&D activities in Turkey are mostly carried out with public resources. The top 10 companies which are the most beneficiary of government incentives are; ASELSAN, TAI, Ford, Tofas, Roketsan, Koc Holding, Arcelik, Vestel, Havelsan and TEDAS. Therefore, the defence, automotive and IT sectors are in the top three [40]. On the other hand, the low share of pharmacy sector is interesting. Because most of the R&D companies are in the chemical, petrochemical and pharmaceutical sectors worldwide.

3. The proposed method: fuzzy analytic hierarchy process (FAHP) and TOPSIS

This section describes the process steps of the methods used in this article.

3.1. Fuzzy analytic hierarchy process (FAHP)

The quantification of linguistic expressions that are the product of the human thought system provides the possibility of evaluating the qualitative and quantitative criteria together. It is difficult for a person to use exact values when comparing two alternatives. This uncertainty is reduced by fuzzy numbers. Because fuzzy numbers are simpler to use with intuition [41].

This study used the extended FAHP method developed by Chang [42]. The extended FAHP method has the capacity to work with the uncertainty of the human thinking style [43]. Chang [42] proposed a method called "extent analysis method" by using triangular fuzzy numbers for measurement of pairwise comparisons with Fuzzy AHP. According to the extent (extended) analysis method;

$X = \{x_1, x_2, \ldots, x_n\}$ is the set of objects, $U = \{u_1, u_2, \ldots, u_m\}$ is the target set, and each object is utilized to serve a purpose. This way, m extended analysis values are obtained and shown as below;

$$M^1_{g_i},\ M^2_{g_i}, \ldots,\ M^m_{g_i}, i = 1, 2, \ldots, n.$$

here, the $M^j_{g_i}\ (j = 1, 2, \ldots, m)$ values are triangular fuzzy numbers, and the step-by-step solution of the extended analysis of Chang (1996) may be summarized as shown below.

Step 1

Fuzzy magnitude value based on the i^{th}object is calculated as formula 1:

$$S_i = \sum_{j=1}^{m} M^j_{g_i} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M^j_{g_i}\right]^{-1} \tag{1}$$

Thus, a type of normalization is carried out on the fuzzy numbers.

To obtain the $\sum_{j=1}^{m} M^j_{g_i}$ value, fuzzy addition of m number of degree analysis values is performed as shown in formula 2:

$$\sum_{j=i}^{m} M^j_{g_i} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \quad i = 1, 2, \ldots, n \tag{2}$$

and in order to obtain the $[\sum_{i=1}^{n}\sum_{j=1}^{m} M^j_{g_i}]^{-1}$ value, fuzzy addition is performed as shown in formula 3:

$$\sum_{i=1}^{n}\sum_{j=i}^{m} M^j_{g_i} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right),\quad M^j_{g_i} = (j = 1, 2, \ldots, m) \tag{3}$$

Then, the inverse of the vector is calculated as shown in formula 4:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M^j_{g_i}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \tag{4}$$

Step 2

The essence of this method is to compare the synthesis values that are obtained and derive the weight values from these comparison values. In the comparison, while $\tilde{M}_1 = (l_1, m_1, u_1)$ and $\tilde{M}_2 = (l_2, m_2, u_2)$ are two triangular fuzzy numbers, the probability value of the equation, that is, the probability of preference of $\tilde{M}_2 \geq \tilde{M}_1$ is defined as formula 5:

$$V(\tilde{M}_2 \geq \tilde{M}_1) = {}_{y \geq x}\sup\lfloor \min(\mu_{\tilde{M}_1}(x), \mu_{\tilde{M}_2}(y))\rfloor \tag{5}$$

As seen in Figure 2, between two fuzzy numbers as $\tilde{M}_1$ and $\tilde{M}_2$, the probability of $\tilde{M}_2$ to be greater than $\tilde{M}_1$ is equal to the value of the membership function at the intersection point of the two fuzzy numbers. That is, this probability is expressed as the following for the fuzzy numbers $\tilde{M}_1 = (l_1, m_1, u_1)$ and $\tilde{M}_2 = (l_2, m_2, u_2)$. Here, d is the ordinate of the highest intersection point between μ_{M_1} and μ_{M_2}.

$$V(\tilde{M}_2 \geq \tilde{M}_1) = y\ddot{u}kseklik(\tilde{M}_1 \cap \tilde{M}_2) = \mu_{M_2}(d) \tag{6}$$

$$= \begin{cases} if\, m_2 \geq m_1, 1 \\ if\, l_1 \geq u_2, 0 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, theothersituations \end{cases} \tag{7}$$

The degree of likelihood of a convex fuzzy number than the fuzzy number of k $M_i (i = 1, 2, \ldots, k)$ is shown in formula 8:

$$V(M \geq M_1, M_2, \ldots, M_k) = V[(M \geq M_1) ve (M \geq M_2) ve (M \geq M_k)] = \min_i V(M \geq M_i), i = 1, 2, 3, \ldots, k \tag{8}$$

With the assumption that $d'(A_i) = \min V(S_i \geq S_k) k = 1, 2, \ldots, n$ and $k \neq j$, the weight vector is obtained as shown in formula 9 where $A_i (i = 1, 2, \ldots n)$ has n elements:

$$W' = (d'(A_1), d'(A_2), \ldots, d'(A_n))^T \tag{9}$$

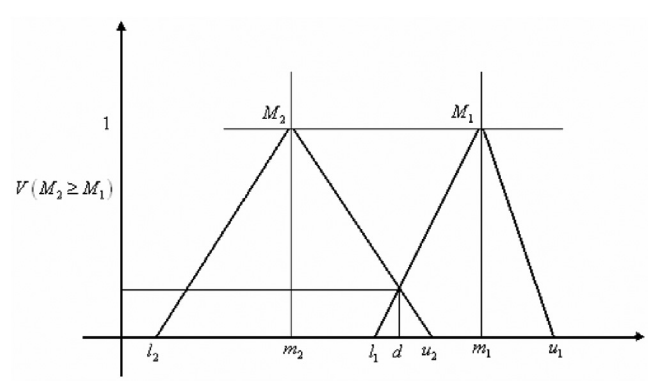

Figure 2. Comparison of the magnitudes of the number M_1 and M_2 [42].

Step 3

Step 4

After normalizing the weight vector calculated in the previous step, the normalized weight vector is obtained as formula 10:

$$W = \left(d'(A_1), d'(A_2), \ldots, d'(A_n)\right)^T \tag{10}$$

The calculated weight vector is not a fuzzy number.

3.2. TOPSIS (Technique for Order Preference by similarity to ideal solution)

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) was developed by Yoon [44] and uses the basic approaches of the ELECTRE method. The closeness of decision points to the ideal solution is based on the main principle and the solution process is shorter than the ELECTRE method. The TOPSIS method involves a 6-step solution process. The first two steps of the method are common to the ELECTRE method. The steps of the TOPSIS method are described below [44].

Step 1: Formation of Decision Matrix (A)

In the rows of the decision matrix, there are decision points whose superiorities are to be listed. In the columns, there are evaluation factors in order to use in decision making. Matrix A is the initial matrix created by the decision maker. It is shown as formula 11:

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \ldots & a_{1n} \\ a_{21} & a_{22} & \ldots & a_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ a_{m1} & a_{m2} & \ldots & a_{mn} \end{bmatrix} \tag{11}$$

In matrix A_{ij}, m represents the number of decision points, n represents the number of evaluation factors.

Step 2: Creating the Standard Decision Matrix (R)

The Standard Decision Matrix is calculated by using the elements of matrix A and the formula 12:

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{m} a_{kj}^2}} \tag{12}$$

The matrix R is constructed as follow (13):

$$R_{ij} = \begin{bmatrix} r_{11} & r_{12} & \ldots & r_{1n} \\ r_{21} & r_{22} & \ldots & r_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ r_{m1} & r_{m2} & \ldots & r_{mn} \end{bmatrix} \tag{13}$$

Step 3: Creating the Weighted Standard Decision Matrix (V).

Firstly, the weight values (w_i) of the evaluation factors are determined ($\sum_{i=1}^{n} w_i = 1$). Then the elements of each column in the R matrix are multiplied by the corresponding w_i value in order to form the V matrix. The V matrix is shown below:

$$V_{ij} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \ldots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \ldots & w_n r_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ w_1 r_{m1} & w_2 r_{m2} & \ldots & w_n r_{mn} \end{bmatrix} \tag{14}$$

Step 4: Creating ideal (A^*) and negative ideal (A^-) solutions:

The TOPSIS method assumes that each evaluation factor has a monotonous increasing or decreasing trend. In order to create an ideal solution set, the largest of the weighted evaluation factors in the V matrix (the smallest if the corresponding evaluation factor is in the minimization direction) is selected. Finding an ideal solution set is shown in the formula 15:

$$A^* = \left\{ \left(\max_i v_{ij} \middle| j \in J\right), \left(\min_i v_{ij} \middle| j \in J'\right\} \right. \tag{15}$$

The set calculated with formula (15) can be shown as $A^* = \{v_1^*, v_2^*, \ldots, v_n^*\}$.

The set of negative ideal solutions is formed by selecting the smallest of the weighted evaluation factors in the V matrix, namely, the column values (the largest if the corresponding evaluation factor is in maximization direction). Creating the negative ideal solution set is shown in the following formula 16.

$$A^- = \left\{ \left(\min_i v_{ij} \middle| j \in J\right), \left(\max_i v_{ij} \middle| j \in J'\right\} \right. \tag{16}$$

The set calculated from the formula (16) can be shown as $A^- = \{v_1^-, v_2^-, \ldots, v_n^-\}$.

In both formulas, J represents the benefit (maximization) and J' indicates the loss (minimization).

The ideal and negative ideal solution set consists of m elements as many as the number of evaluation factors.

Step 5: Calculation of discrimination measures

In the TOPSIS method, Euclidian Distance Approach is used to find the deviations of the evaluation factor value for each decision point from the ideal and negative ideal solution set. The deviation values of the decision points obtained here are called ideal discrimination (S_i^*) and negative ideal discrimination (S_i^-) measure. The calculation of the ideal discrimination (S_i^*) measure is shown in the formula (17) and the calculation of the negative ideal discrimination (S_i^-) measure is shown in the formula (18):

$$S_i^* = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^*\right)^2} \tag{17}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2} \tag{18}$$

The number of S_i^* and S_i^- calculated here will naturally be the number of decision points.

Step 6: Calculating proximity to the ideal solution

The ideal and negative ideal separation measures are used to calculate the proximity (C_i^*) of each decision point relative to the ideal solution. The criterion used here is the share of the negative ideal discrimination measure within the total discrimination measure. The calculation of the proximity to the ideal solution is shown in the following formula 19:

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \tag{19}$$

The value C_i^* is in the range $0 \le C_i^* \le 1$and $C_i^* = 1$indicates the absolute proximity of the corresponding decision point to the ideal solution, and $C_i^* = 0$indicates the absolute proximity of the corresponding decision point to the negative ideal solution. For example, $C_1^* = \frac{0{,}1428}{0{,}1606+0{,}1428} =$

Table 2. Criteria and sub-criteria for FAHP.

Goal	Identifying the cities with the best living standard for R&D and Technopark Centers			
Criteria	**C_1** Basic Needs	**C_2** Sustainable Living	**C_3** Satisfaction	**C_4** Economy
Sub-Criteria	C_1 Housing C_2 Access to infrastructure services C_3 Safety	C_4 Education C_5 Health C_6 Environment	C_7 Social life C_8 Civic engagement C_9 Life satisfaction	C_{10} Work life C_{11} Income and wealth C_{12} Overall index

Table 3. Linguistic terms and the corresponding triangular fuzzy numbers.

linguistic terms	triangular fuzzy numbers
Definitely Important (criterion in row, relative to column)	(7/2, 4, 9/2)
Very important (criterion in row, relative to column)	(5/2, 3, 7/2)
Important (criterion in row, relative to column)	(3/2, 2, 5/2)
Less Important (criterion in row, relative to column)	(2/3, 1, 3/2)
Equally Important	(1, 1, 1)
Less Important (criterion in column, relative to row)	(2/3, 1, 3/2)
Important (criterion in column, relative to row)	(2/5, 1/2, 2/3)
Very important (criterion in column, relative to row)	(2/7, 1/3, 2/5)
Definitely Important (criterion in column, relative to row)	(2/9, 1/4, 2/7)

Table 4. Pairwise comparison matrix of criteria according to goal.

Criteria		C_1	C_2	C_3	C_4
Basic Needs	C_1	**(1, 1, 1)**	(2/3, 1, 3/2)	(3/2, 2, 5/2)	(3/2, 2, 5/2)
Sustainable Living	C_2	(2/3, 1, 3/2)	**(1, 1, 1)**	(2/3, 1, 3/2)	(3/2, 2, 5/2)
Satisfaction	C_3	(2/5, 1/2, 2/3)	(2/3, 1, 3/2)	**(1, 1, 1)**	(2/3, 1, 3/2)
Economy	C_4	(2/5, 1/2, 2/5)	(2/5, 1/2, 2/3)	(2/3, 1, 3/2)	**(1, 1, 1)**

$0,4707$; $C_2^* = \frac{0,1490}{0,1428+0,1490} = 0,5106$; and $C_3^* = \frac{0,1830}{0,1400+0,1830} = 0,5666$ when these values are placed in order of importance, the importance order of the decision points are A_3, A_2 and A_1 respectively from the most important to the less important.

4. Results

The criteria of the Quality of Life Index for Cities, which was made by Turkey Statistical Institute (TurkStat) in 2015, was chosen as the most appropriate criteria for this issue. Hierarchical criteria and sub-criteria were given to decision makers in pairwise comparison matrices during the Fuzzy Analytical Hierarchy Process (FAHP). Decision-makers used them for evaluation. The criteria and sub-criteria are shown in Table 2:

Criteria: C1 = Basic Needs, C2 = Sustainable Living, C3 = Satisfaction, C4 = Economy.

Sub-criteria: c1 = Housing, c2 = Access to infrastructure services, c3 = Safety, c4 = Education, c5 = Health, c6 = Environment, c7 = Social life, c8 = Civic engagement, c9 = Life satisfaction, c10 = Work life, c11 = Income and wealth, c12 = Overall index.

While making pairwise comparisons, the decision-makers used "Saaty Scale" given in Table 3 in order to assess the qualitative variables. Thus, we had opportunity in order to convert their thoughts into triangular fuzzy numbers.

Table 4 shows the group decision of the individual pairwise comparisons. The consistency of the decision matrices were checked before they were fuzzy. Consistency should not exceed 0.10.

Firstly, fuzzy synthetic extent values (S_i) are calculated by the data in Table 5. They are in compliance with the extended analysis of Chang [42]:

$Sc_1 = (0,22, 0,34, 0,47)$; $Sc_2 = (0,18, 0,29, 0,47)$; $Sc_3 = (0,14, 0,20, 0,33)$ and $Sc_4 = (0,11, 0,17, 0,27)$ values were calculated.

The significance (priority) weights of the criteria were calculated with the calculated fuzzy synthetic extent values. These weights show the preference degree of each criterion over another:

$V(Sc_1 \geq Sc_2, Sc_3, Sc_4) = \min(1, 1, 1) = 1$; $V(Sc_2 \geq Sc_1, Sc_3, Sc_4) = \min(0,83, 1, 1) = 0,83$;

$V(Sc_3 \geq Sc_1, Sc_2, Sc_4) = \min(0,44, 0,63, 1) = 0,44$; $V(Sc_4 \geq Sc_1, Sc_2, Sc_3) = \min(0,23, 0,52, 0,81) = 0,23$.

After calculating these results, the priority values and weight vectors (W′) were calculated:

$d'(C_1) = \min V(Sc_1 \geq S_K) = 1$; $d'(C_2) = \min V(Sc_2 \geq S_K) = 0,83$

$d'(C_3) = \min V(Sc_3 \geq S_K) = 0,44$; $d'(C_4) = \min V(Sc_4 \geq S_K) = 0,23$.

$W' = (d'(C_1), d'(C_2), d'(C_3), (d'(C_4))^T$; $W' = (1, 0,83, 0,44, 0,23)^T$

After normalization, the priority matrix (W_G) is obtained as $W_G = (0,40, 0,33, 0,18, 0,99)$. Then the decision-makers assessed the sub-criteria (Tables 5, 6, 7, and 8):

Table 5. Pairwise comparison matrix of the sub-criteria according to "**Basic Needs**" (C_1).

Basic Needs C_1	c_1	c_2	c_3
c_1	(1, 1, 1)	(2/3, 1, 3/2)	(3/2, 2, 5/2)
c_2	(2/3, 1, 3/2)	(1, 1, 1)	(2/3, 1, 3/2)
c_3	(2/5, 1/2, 2/3)	(2/3, 1, 3/2)	(1, 1, 1)

$W_{C1} = (0,45, 0,33, 0,22)$.

Table 6. Pairwise comparison matrix of the sub-criteria according to "**Sustainable Living**" (C_2).

Sustainable Living C_2	c_4	c_5	c_6
c_4	(1, 1, 1)	(2/3, 1, 3/2)	(3/2, 2, 5/2)
c_5	(2/3, 1, 3/2)	(1, 1, 1)	(5/2, 3, 7/2)
c_6	(2/5, 1/2, 2/3)	(2/7, 1/3, 2/5)	(1, 1, 1)

$W_{C2} = (0,30, 0,49, 0,21)$.

Table 7. Pairwise comparison matrix of the sub-criteria according to" **Satisfaction**" (C_3).

Satisfaction C_3	c_7	c_8	c_9
c_7	(1, 1, 1)	(2/3, 1, 3/2)	(3/2, 2, 5/2)
c_8	(2/3, 1, 3/2)	(1, 1, 1)	(2/3, 1, 3/2)
c_9	(2/5, 1/2, 2/3)	(2/3, 1, 3/2)	(1, 1, 1)

$W_{C3} = (0,44, 0,12, 0,44)$.

Table 8. Pairwise comparison matrix of the sub-criteria according to "**Economy**" (C_4).

Economy C_4	c_{10}	c_{11}	c_{12}
c_{10}	(1, 1, 1)	(3/2, 2, 5/2)	(2/3, 1, 3/2)
c_{11}	(2/5, 1/2, 2/3)	(1, 1, 1)	(2/5, 1/2, 2/3)
c_{12}	(2/3, 1, 3/2)	(3/2, 2, 5/2)	(1, 1, 1)

$W_{C4} = (0.44, 0.33, 0.23)$.

Table 9. Weights of the main criteria and sub-criteria.

Criteria		Sub-criteria		General Weights (Priorities)
Criteria	Weights	Subcriteria	Weights	
C1 Basic Needs	0,40	c1	0,45	0,18
		c2	0,33	0,13
		c3	0,22	0,09
C2 Sustainable Living	0,33	c4	0,30	0,10
		c5	0,49	0,16
		c6	0,21	0,07
C3 Satisfaction	0,18	c7	0,44	0,04
		c8	0,12	0,01
		c9	0,44	0,04
C4 Economy	0,09	c10	0,44	0,08
		c11	0,33	0,06
		c12	0,23	0,04

Table 10. Relative closeness to the ideal solution based on TOPSIS; and cities with R&D and TeknoHAB in Turkey.

Istanbul[c]	0.783232	Manisa[c]	0.639586	Bayburt[d]	0.523145
Ankara[c]	0.758455	Artvin[d]	0.63805	Erzurum[b]	0.517578
Izmir[c]	0.744532	Samsun[c]	0.631189	Corum[c]	0.515606
Yalova[a]	0.734751	Afyonkarahisar[b]	0.629515	Gaziantep[c]	0.504963
Eskisehir[c]	0.721796	Mugla[c]	0.627373	Yozgat[b]	0.502151
Isparta[c]	0.717016	Aydin[c]	0.625483	Tunceli[d]	0.498107
Bursa[c]	0.701905	Nevsehir[b]	0.617924	Kahramanmaras[c]	0.495225
Trabzon[c]	0.700979	Giresun[b]	0.615145	Aksaray[a]	0.492032
Sakarya[c]	0.694346	Amasya[a]	0.609936	Hatay[c]	0.463262
Konya[c]	0.69302	Kirsehir[d]	0.595351	Osmaniye[c]	0.431214
Balikesir[c]	0.691759	Sinop[d]	0.595316	Diyarbakir[b]	0.413875
Bolu[c]	0.68332	Cankiri[c]	0.595249	Bingol[d]	0.388599
Bilecik[c]	0.679658	Zonguldak[c]	0.591229	Siirt[d]	0.34978
Karabuk[b]	0.678366	Erzincan[a]	0.590764	Van[b]	0.347291
Kocaeli[c]	0.670993	Sivas[c]	0.587369	Kilis[d]	0.328671
Antalya[c]	0.669773	Bartin[d]	0.584006	Kars[d]	0.31372
Rize[b]	0.662402	Kastamonu[b]	0.583953	Bitlis[d]	0.310301
Kirklareli[c]	0.65628	Tokat[b]	0.579021	Batman[b]	0.306025
Denizli[c]	0.651955	Burdur[c]	0.578127	Sanliurfa[c]	0.305061
Kayseri[c]	0.65149	Malatya[c]	0.566635	Adiyaman[a]	0.302655
Tekirdag[c]	0.650757	Adana[c]	0.56505	Igdir[d]	0.276924
Karaman[c]	0.648538	Gumushane[d]	0.564021	Hakkari[d]	0.252562
Usak[c]	0.647477	Mersin[c]	0.548884	Ardahan[d]	0.244615
Edirne[b]	0.647135	Ordu[a]	0.539146	Mardin[d]	0.243146
Kutahya[c]	0.643844	Nigde[c]	0.538395	Sirnak[d]	0.22887
Kirikkale[b]	0.642321	Duzce[c]	0.53531	Agri[d]	0.202277
Canakkale[c]	0.639893	Elazig[c]	0.527943	Mus[d]	0.189363

[a] Red: R&D.
[b] Green: TeknoHAB Technology Development Zones.
[c] Blue: Both R&D 369 and TeknoHab.
[d] Black: none.

After calculating the weight values of the criteria and sub-criteria, the general weights of the criteria were obtained. The values are shown in Table 9:

After determining the priority weights of the criteria with fuzzy AHP, these weights were used as the weights of the relevant criteria in the TOPSIS method. Conclusively, the TOPSIS analysis produced the results presented in Table 10 and Figure 3.

5. Discussion

Quality of life assessment is an interesting and difficult issue. As stated in the literature review, many factors have been tried to explain by the quality of life. The study tries to show industrial investments in regions with a low quality of life. It also demonstrates that eastern cities have not been governed fairly in terms of technology and R&D investments. Although there are universities in all the cities of the East and Southeast Anatolia, none of them do not have adequate quality of life and development conditions. Also, they do not have any R&D center. In addition, there are only 3 TeknoHAB Technology Development Zones in the entire Eastern and Southeastern Anatolia. Moreover, there is not any investment plan in these areas according to the 2019–2023 development plan. These regions consist of the cities with the lowest score in education. The standard of living between these cities and other cities is increasing day by day. Unfortunately, Turkey does not benefit adequately

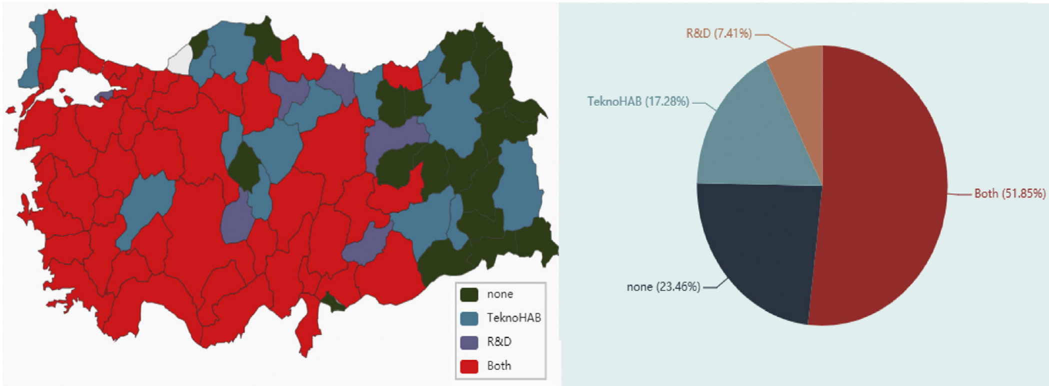

Figure 3. Ratio of cities with R&D and TeknoHAB in Turkey (created by authors).

from the young and educated population and geographical opportunities of these cities. The central government and the private sector prefer to invest in cities with high living standards. The supporting sources for investment and living standards are mostly spent on cities in western Turkey. According to the analysis result, all of the cities in the last 16 of the list are located in the Eastern and Southeastern Anatolia region. It is obvious that researchers should elaborate on these regions. This study is one of the studies that draw attention to these regions. These regions are most densely populated by children and young people. If this education and R&D policies continue in the same way, Turkey's human resources will not be able to use effectively.

The method applied in our analysis is done with the subjective opinions of experts. This also applies to surveys. In addition, finding a person who is an expert on the related issue is one of the limitations of the analysis. In addition, it takes a lot of time to make calculations from pairwise comparisons and introduce them to the program. Future studies may be analyzed by applying other methods and compared with our results.

Turkey's sustainable growth and regional development of the cities have not been considered together by assessing the quality of life and the contribution of R&D investment so far. In this context, the study proposes a significant novelty with the combined method of FAHP and TOPSIS. Also, the paper offers a detailed analysis of Turkey's economy and demographic structure.

6. Conclusion

The paper detailed Turkey's R&D targets and opportunities within the framework of the 2023 strategic plan and statistics. The 2019–2023 development plan aims to double GDP and increase per capita income from $ 8,000 to $ 12,484. Furthermore, it is aimed to create an additional 4.3 million jobs between these periods and reduce the unemployment rate from 14% to 9.9%. The estimated R&D investment will be approximately $60 billion up to 2023. Therefore, Turkey is a significant market for companies and investors operating in the R&D sector. Turkey has a great potential for development. Defense, IT and software are at the top industries in Turkey in terms of R&D and technology investment. These sectors have become attractive for local and foreign investors since 2012. Because many positive regulations and incentive plans came into force.

The study makes recommendations to country managers and researchers with using the most preferred MCDM methods (FAHP and TOPSIS). "The Quality of Life Index for Cities" was applied in order to compare the cities of Turkey. Because the cities with the highest quality of life in the world are the cities where these investments are made most. Hence, the recommended approach (FAHP and TOPSIS) estimated the allocation of R&D with considering the scores of cities. Basic needs, sustainable living, satisfaction, economic criteria and access to housing, infrastructure services, security, education, health, environment, social life, civic participation, life satisfaction, work-life, income and wealth and general index are the sub-criteria for the evaluation. Data were taken from the "2015 TurkStat Quality of Life Index for Cities" report. Marmara Region is the most suitable region for R&D and TeknoHab investments according to FAHP - TOPSIS method. The ranking is Marmara, Central Anatolia, Aegean, Mediterranean, Black Sea, Southeast Anatolia and Eastern Anatolia respectively. Istanbul (0.783232), Ankara (0.758455), Izmir (0.744532), Yalova (0.734751), Eskisehir (0.721796), Isparta (0.717016), Bursa (0.701905), Trabzon (0.700979), Sakarya (0.694346) and Konya (0.69302) are the cities with the highest scores respectively. While Yalova has only R&D centers, all other cities of Marmara have both R&D and TeknoHab Centers. All cities of Marmara, Central Anatolia, Aegean and Mediterranean regions have at least one R&D or TeknoHab center. Almost none of the Southeast and Eastern Anatolia cities do not have any of them. According to the result of the analysis based on the Quality of Life Index, all the cities in the last 16 are located in these two regions. 12 of these 16 cities do not have any of these technology centers. There is a significant difference between eastern cities and western cities in terms of living standards and investment. If policymakers want to achieve more sustainable economic growth and prosperity, they need to put forward more efforts and attention to solving the social and economic problems of these cities. Furthermore, they should provide the same quality of living standards for all citizens. When the developed countries are examined, Turkey and other developing countries may provide sustainable living standards, economic growth and prosperity for all their citizens with the contribution of research, development and innovation.

Declarations

Author contribution statement

G. Ozkaya and C. Erdin: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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