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# Comparing the innovation performance of EU candidate countries: an entropy-based TOPSIS approach

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## ABSTRACT

Innovation is important for countries in the competitive global economy. It is one of the main criteria for countries to be superior, to remain competitive, and to produce high technology products. Countries allocate different types of incentives to encourage innovation activities in their countries. Innovation is also one of the strategic issues for the European Union (EU). The aim of this study is to compare the innovation performance of four EU candidate countries, Macedonia (FYR), Iceland, Serbia and Turkey. The entropy-based Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) approach is proposed in this paper. First, the importance of each variable is computed by the entropy method to reflect on the differences among the variables in the calculation process. Subsequently, the TOPSIS method is performed by using the value and importance of variables for prioritisation of the candidate countries with respect to their innovation performance. Four case studies are conducted to show the viability of the proposed approach. Each case study uses different reports, namely The Global Competitiveness Index, Innovation Union Scoreboard, Knowledge Assessment Methodology (KAM) and Global Innovation Index. The results of this study show that the proposed approach provides the same ranking as Innovation Union Scoreboard and KAM.

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O31; O32; O57

## 1. Introduction

Innovation provides economic growth for a country, region or enterprise (Paas & Poltimäe, 2010). There is no doubt that the effect of innovation on economic growth positively enhances the competitive power of countries in the present knowledge-based economy. Furthermore, there is a strong relationship between innovation, economic development and welfare (Autant-Bernard, Chalaye, Manca, Moreno, & Surinach, 2010). Seeing the benefits many countries allocate different types of incentives to entrepreneurs for spurring innovation in their country. The importance of innovation has increased for European policymaking over the last several years following the financial crisis of 2008 (Dodd, Franke, & Moody, 2011).

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The European Union (EU) determined its *Europe 2020 strategy* in 2010 to address growing economic concerns (Leschke, Theodoropoulou, & Watt, 2012). One of the main strategic issue and factor mentioned in Europe 2020 strategy was ‘innovation’. The First Action Plan for Innovation in Europe report was published in 1996 to create awareness for innovation among EU countries. Innovation makes a significant contribution to growth (Torun & Çiçekci, 2007). It also enhances countries’ current marketing potentials, competitive power and affects many different areas in social life positively by means of its positive effect on economy. Therefore, the EU also published the Innovation Union (IU) report in 2010 (Soylu, 2011). The aim of the IU is to increase the innovation activities in Europe region. The EU established a significant step for providing improvements in its economic development by the IU (Vaidere, 2011). Details on IU can be found in Karataş and Ayrım (2010).

It has been emphasised in many studies that there is a positive correlation between economic development and innovation (Işık & Kılınç, 2012). The countries that are aware of the importance of innovation want to be leaders in innovative activities, while others fall in follower class for innovative activities. If one does not conduct innovative activities within its own country, there is a high possibility that this country will go abroad for many products and create a high current account deficit ratio. In this case, technology transfer takes place from the developed country to developing/underdeveloped country. In addition, the countries want to decrease current account deficit ratio in their economy. On the other hand, they would like to improve export potential and have high growing ratio in their economies. However, there is a trade-off herein between the current account deficit and high growing ratio. Because, if a country’s growing ratio begins to increase year by year, this generally causes high current account deficit in the economy. In order to cope with this paradox, the importance of innovation-driven development for countries appears due to the fact that innovation provides both higher growing ratio and lowers current account deficit simultaneously in the country. The importance of innovation is gaining more attention from the EU because of the fact that EU countries want to be leader and avoid possible financial crisis in the future. In this regard, an objective examination of ‘innovation performance’ of EU candidate countries is quite vital. Hence, this research has attempted to compare the ‘innovation performance’ of EU candidate countries.

Candidate countries, which are striving for full EU membership, are carrying out structural reforms by means of negotiations while simultaneously targeting innovation based strategies in science and technology areas to increase their competitive power. Paas and Poltimäe (2010) emphasised that ‘the assessment of innovation is important for the development and implementation of public policies’. Europe has to create innovative strategies and develop a strong, competitive framework for innovations (Vaidere, 2011). Innovation has been recognised as one of the key EU strategies (Ramadani, Gërguri, Rexhepi, & Abduli, 2013). Therefore, comparison of the innovation performance of EU candidate countries emerged as an important research question. This article attempts to find reasonable answers through comparing several EU candidate countries. The results of this work, of course, are expected to be used by policymakers of those countries as well as their innovators.

The EU should consider the innovation potential of candidate countries during their negotiation to make certain countries less likely to fall behind the EU countries’ innovation potential. A candidate country with high innovation potential should take high priority among candidate countries during negotiation. High innovation potential means that there is a high probability for the country to conduct successful innovation activity and to manufacture high technology in the future.

The EU countries have increased their internal and external trade volume, their balance of payments, and decreased their inflation and unemployment rates since their membership was accepted (Akal & Şen, 2004). Hence, most of the countries want to join the EU. Currently, four countries, namely Iceland, Turkey, Serbia and Macedonia (FYR) are official candidates for EU membership, which is actually the reason why we selected these countries for this study. Motivation details are presented below.

Iceland started considering EU membership more seriously after economic and political crisis in the country (Weber, 2010). Iceland applied for EU membership in July 2009 (<http://ec.europa.eu>, accessed 9 March 2014). Discussions on Iceland's membership in the EU and some of the benefits and costs resulting from its membership for both Iceland and the union can be found in Busch and Molendowski (2011).

The second country under consideration in this study is Turkey. 'Turkey's relationship with the EU dates back to the late 1950s when the Democrat Party government applied for an associate membership in the European Economic Community' (Yesilada, 2002, p. 94). Turkey has insisted on being accepted into the EU since then. EU membership is still one of the main issues for Turkey's government. There are more studies related to EU membership for Turkey than other countries because of the fact that Turkey is the oldest candidate country among the other three, namely Iceland, Serbia and Macedonia. Among these studies, details on the future of Turkey in the EU are discussed in Güney (2005). Tokgöz et al. (2002) also examined relationship between Turkey and the EU. Şahinöz (2004) studied this relationship in terms of commercial relations and the customs union.

The third country analysed in this study is Serbia. Serbia submitted its formal application in December 2009 for EU membership (Archick & Morelli, 2014). According to the some experts, Serbia may not be admitted by the EU until issues related to Kosovo's independence status are fully resolved (Archick & Morelli, 2014). Although Grk (2012) mentioned that Serbia is far away from Europe, Đekić (2010) summarised Serbia's path to the EU and emphasised that Serbia has also made improvements in the fulfilment of the economic demands for EU membership.

The last country considered in this article is Macedonia. Macedonia applied for EU membership in March 2004 (Archick & Morelli, 2014). The EU is the main economic partner of Macedonia because many companies from the EU affect sectors such as banking and telecommunications in Macedonia (Mavromatidis, 2010). Therefore, EU membership for Macedonia has a special property in terms of economy.

These four countries are ranked by the proposed approach with respect to their innovation performance in this article. It should be noted that all four countries are classified in Europe and Central Asia Group by the World Bank (<http://www.worldbank.org>).

The contribution of the present study is threefold. Firstly, the proposed approach takes the importance of the variables into account in the calculation process. Secondly, the entropy-based Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) approach is employed for ranking. Thirdly, comparison with the other methods is also presented and discussed in detail.

The article is organised as follows. The literature review is outlined in Section 2. The proposed approach is presented in Section 3. An application of the proposed approach is given in Section 4. A discussion and recommendations are provided in Section 5 and Section 6 concludes.

## 2. Literature review

The majority of the literature focused on the countries' relations with the EU, preconditions, procedures, structural reforms and requirements that should be done by EU candidate countries, advantage and disadvantage of EU membership; and peoples' attitude towards EU membership for the candidate countries. Comparing some of the countries' innovation potential, especially in the context of the EU candidate countries, has great importance as mentioned in the introduction section. In this section, studies that examined the EU member states in terms of innovation from different perspectives are considered and summarised.

Lööf, Heshmati, Asplund, and Nåås (2001) examined the relationship between 'innovation' and 'productivity' using data from a Community Innovation Survey and a model named CDM for three countries, namely; Finland, Norway and Sweden. Borrás (2003) discussed the innovation policy of the EU from different perspectives. Jungmittag (2004) assessed the effects of innovations, technological specialisation and technology diffusion on economic growth and convergence of EU countries from 1969 to 1998 by using a panel data model. Dikbaş and Akkoyun (2006) evaluated European Technology Platforms in the context of national technology, Research and Development (R&D) and innovation policies. Oprean and Tănăsescu (2007) examined innovation potential of the Romanian economy in comparison with Turkey as a candidate country in 2007 and EU-25 member, non-members and non-candidate countries through using data obtained from the European Innovation Scoreboard. Tokumasu and Watanabe (2008) analysed 15 EU member states (Belgium, Denmark, Germany, Greece, Spain, France, Ireland, Italy Luxembourg, the Netherlands, Austria, Portugal, Finland, Sweden, and the UK) with respect to their innovation capability using three indicators, namely innovation capability, innovation generation, and institutional structure. They performed the principal component analysis, multi-regression analysis, and cluster analysis in their paper. Ünlükaplan (2009) examined the relation between economic development, competitiveness and innovation in EU using canonical correlation analysis. Autant-Bernard et al. (2010) assessed the magnitude of innovation adoption for 22 EU countries and different industries. They suggested new indicators based on the Community Innovation Survey for innovation adaptation. Roper, Youtie, Shapira, and Fernández-Ribas (2010) compared the US and Europe with respect to factors which effect innovation performance of manufacturing firms in Georgia (US), Wales (UK), the West Midlands (UK), and Catalonia (Spain) by using multivariate probit models. De Saá-Pérez and Díaz-Díaz (2010) analysed ultra-peripheral region of the EU, namely the Canary Islands to find the relationship between innovation and human resource. To obtain data from firms which operate in the Canary Islands, an empirical study was conducted in their study. Suurna and Kattel (2010) examined the EU's impact on innovation policies in Central and Eastern Europe. Paas and Poltimäe (2010) assessed national innovation performance of the Baltic States based on European Innovation Scoreboard in the EU Context by using factor analysis. Pan, Hung, and Lu (2010) measured the performance of the national innovation system in 33 Asian and European countries by using a Data Envelopment Analysis approach. Kaynak (2010) used Knowledge Assessment Methodology (KAM) to compare innovation performances of Croatia, Macedonia and Turkey. However, general ranking with respect to overall innovation performance was not performed in this study and the importance of the variables was not considered. Filippetti, Frenz, and Ietto-Gillies (2011) investigated relationship between innovation and internationalisation for European countries using

correlation analyses based on the data obtained from European Innovation Scoreboard. Ökem (2011) conducted a study based on SWOT analysis to evaluate innovation performance of Turkey with respect to health care during the negotiation with the EU. She suggested constructive comments to improve innovation activity for health care in Turkey. Işık and Kılınc (2012) compared the EU countries and Turkey with respect to innovation by using raw data included in The Global Competitiveness Report 2010–2011. Ramadani et al. (2013) examined innovation and economic development in Macedonia (FYR), which is currently an EU candidate country by using Innovation Union Scoreboard. Hashi and Stojčić (2013) revealed the impact of innovation activities on ‘firm performance’ by using a multi-stage model and the data obtained from fourth Community Innovation Survey which includes the data gathered from 90,000 firms established in 16 European countries. Şahinli and Kılınc (2013) compared the EU countries and Turkey with respect to innovation indicators through data obtained from Eurostat and World Databank, Their comparison is just based on raw data included in these databanks. Özbek and Atik (2013) analysed the place of Turkey within the EU countries in terms of innovation indicators using hierarchical clustering analysis. Ünlü (2013) compared the EU and candidate countries with respect to innovation indicators by using data obtained from TÜBİTAK, Turkish Patent Institute and Innovation Union Scoreboard 2013. The article includes the results from the raw data found in these data sources.

Baležentis and Balkienė (2014) used three indexes, namely the Innovation Union Scoreboard, which provides Summary Innovation Index, the Global Innovation Index and the Global Competitiveness Index to analyse the innovation policy of Lithuania. They discussed the Lithuanian innovation policy based on the raw data provided in these three indexes.

Majerová (2015) recently presented the innovation performances of four EU countries, namely; the Czech Republic, Poland, Austria, and Germany along with Switzerland through using the Summary Innovation Index. Eurostat Pocketbooks (2013) provided the information on activities and processes devoted to science, technology and innovation within Europe together with several EU candidate countries.

In addition to the above studies, the following are also examined in the literature: the impact of institutional quality on regional innovation performance of EU countries (Laboutkova, 2013); innovation policies in the context of knowledge-based economy for three EU member states, Bulgaria, Finland and the UK (Galabova, 2012); the role of innovation in the technological development of four new members of the EU, the Czech Republic, Hungary, Poland, and Slovakia through using the data obtained from the OECD and Eurostat (Uzagalieva, Kočenda, & Menezes, 2012); the impact of innovations on regional development in the EU (Vaidere, 2011); and the factors influencing innovation performance in new EU member countries, particularly in the Czech Republic (Müller, 2006).

Details on innovation policy in candidate countries can be found in studies conducted by Enterprise Directorate-General Innovation Directorate(2003) and Mickiewicz and Radosevic (2001).

The EU candidate countries are also compared with each other in terms of different criteria in the literature. For example, Akyazı (1998) compared the EU countries and the EU candidate countries with respect to some economic and socio-economic indicators. Bilgin, Cin, and Lopcu (2006) also compared the EU candidate countries in terms of the Maastricht criteria using logit analysis.

The entropy-based TOPSIS approach was also conducted to assess some systems in the literature. Hsu and Hsu (2008) proposed the entropy-based TOPSIS approach to assess the quality of an information technology supplier for clinics. Li et al. (2011) used the entropy and the TOPSIS method to evaluate safety conditions in four coal mines. Akyene (2012) evaluated cell-phones using the entropy and the TOPSIS method. Li, Zhao, and Suo (2014) assessed the sustainable development of highway transportation capacity based on the entropy and TOPSIS method. Aksakal and Dagdeviren (2015) incorporated the entropy and the TOPSIS method to select a suitable wind-turbine for personal use in rural areas. Dashore, Pawar, Sohani, and Verma (2013) proposed the entropy-based TOPSIS approach to assess personal data assistant design alternatives

As can be seen from the above-mentioned literature, the entropy-based TOPSIS approach was not performed previously in order to compare the innovation performance of the EU-candidate countries. The concluding remarks of most of the studies that used some reports and databanks, such as the Global Competitiveness Report, the Innovation Union Scoreboard, Eurostat and World Databank are based on raw data included in these reports and databanks. However, the raw data in this article is processed by using the entropy-based TOPSIS approach. The proposed approach in this article calculates the importance of each variable with respect to innovation by the entropy method. Based on the results obtained from the entropy method, it then sorts the EU candidate countries in descending order with respect to their innovation potential by using the TOPSIS method.

### 3. The proposed approach

There are multiple criteria affecting the innovation performance of countries. It is necessary to consider all these criteria to prioritise countries with respect to their innovation performance. Therefore, the problem this article is concerned with is the multiple criteria decision-making (MCDM) problem. MCDM is extensively utilised to rank alternatives from a set of available alternatives with multiple criteria (Wang & Lee, 2009). In this article, the entropy method is used to determine the weight of each variable. There are many methods used in the literature for weighing, such as the Analytical Hierarchy Process (Lee, Mogi, & Kim, 2008; Zhao, Zhou, Xie, & Li, 2011) and the Analytical Network Process (Bayazit & Karpak, 2007; Khadivi & Fatemi Ghomi, 2012). However, these methods are only suitable if there is a need to consult the experts' or decision-makers' opinions. One of the main disadvantages of the usage of the experts' or decision-makers' opinions is subjectivity and the results mostly includes the preference or judgements of the experts or decision-makers. On the other hand, the entropy method is objective, far from the experts' or decision-makers' bias, and therefore, it does not need experts' or decision-makers' opinion. Lastly, in this article the TOPSIS method is used to compare the innovation performance of the EU candidate countries based on the entropy weight. The TOPSIS method can effectively be used to order the alternatives in terms of considered criteria, when the alternatives, criteria, criteria values for each alternative, and the weight of each criterion, are known.

The four main steps, that involve the entropy method and the TOPSIS method, are conducted to compare the 'innovation performance' of candidate countries are presented below.

**Step 1:** Determine countries which are candidates for the EU

**Step 2:** Determine variables that affect the innovation potential of countries

**Step 3:** Calculate the weight of each variable by using the entropy method

**Step 4:** Rank all candidate countries by using the TOPSIS method

### 3.1. The entropy method

The entropy method is developed by Shannon (1948). This method has been widely used for evaluating the weights of indicators (Hsu, 2013). Several studies, such as Çakır and Perçin (2013), Akyene (2012) and Hsu (2013), used the entropy method for weighing. The method composed of five steps which are presented next.

**Step 1:** Construct decision matrix. This matrix described by:

$$X = \begin{matrix} & C_1 & C_2 & \dots & C_n \\ \begin{matrix} A_1 \\ A_2 \\ \cdot \\ \cdot \\ \cdot \\ A_m \end{matrix} & \left[ \begin{array}{cccc} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \cdot & \cdot & \dots & \cdot \\ \cdot & \cdot & \dots & \cdot \\ \cdot & \cdot & \dots & \cdot \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{array} \right] \end{matrix} \quad (1)$$

Where,

m: number of alternatives,  $A = (a_i, i=1,2, \dots, m)$

n: number of criteria,  $C = (c_j, j = 1,2, \dots, n)$

$X_{ij}$ : the performance rating of  $i^{\text{th}}$  alternative with respect to  $j^{\text{th}}$  criteria

**Step 2:** Normalise the decision matrix by using formula (2)

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^m x_{ij}}, \forall i, j \quad (2)$$

**Step 3:** Compute  $E_j$  value by using formula (3)

$$E_j = -k \sum_{i=1}^m p_{ij} \ln p_{ij}, \forall j \quad (3)$$

Where,  $k = 1/\ln(m)$

**Step 4:** Compute  $d_j$  value by using formula (4)

$$d_j = 1 - E_j, \forall j \quad (4)$$

**Step 4:** Calculate  $w_j$  value, which shows the weight of  $j^{\text{th}}$  criteria, by using formula (5). The sum of the weights of all criteria must be equal to 1.

$$w_j = \frac{d_j}{\sum_{j=1}^n d_j}, \forall j \quad (5)$$

### 3.2. The TOPSIS method

The TOPSIS method was introduced by Hwang and Yoon (1981). It finds the relative closeness of each alternative to the ideal solution. Alternatives are sorted in descending order based on this closeness in the method. The importance of the each criterion can be



considered in the computational process. Details on the TOPSIS method and its various applications can be found in Behzadian, Khanmohammadi Otaghsara, Yazdani, and Ignatius (2012). The entropy weight is used for weighing each criterion in this study and the overall methodology is presented in a stepwise manner below.

**Step 1:** Construct decision matrix. This matrix is the same as the available decision matrix given in (1).

**Step 2:** Calculate the normalised decision matrix ( $R_{ij}$ ) by using formula (6).

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^k x_{ij}^2}} \tag{6}$$

Then, calculated the normalised decision matrix should be like a matrix depicted in (7).

$$R_{ij} = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ r_{k1} & r_{k2} & \dots & r_{kn} \end{bmatrix} \tag{7}$$

**Step 3:** Compute the weighted normalised decision matrix ( $V_{ij}$ ). This matrix calculated as:

$$V_{ij} = w_j x r_{ij} \tag{8}$$

$w_i$  is the weight of the  $j^{\text{th}}$  criterion which are obtained from the entropy method.

Then, calculated the weighted normalised decision matrix should be like a matrix depicted in (9).

$$V_{ij} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \dots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \dots & w_n r_{2n} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ w_1 r_{k1} & w_2 r_{k2} & \dots & w_n r_{kn} \end{bmatrix} \tag{9}$$

**Step 4:** Determine the positive ideal and negative ideal solutions by using formula (10) and (11).

$$A^* = \{v_1^*, v_2^*, \dots, v_n^*\} = \left\{ (\max_i v_{ij} \mid j \in J), (\min_i v_{ij} \mid j \in J') \right\} \tag{10}$$

$$A^- = \{v_1^-, v_2^-, \dots, v_n^-\} = \left\{ (\min_i v_{ij} \mid j \in J), (\max_i v_{ij} \mid j \in J') \right\} \tag{11}$$

**Step 5:** Calculate the separation measures. The separation of each alternative from the ideal solution is calculated by using formula (12) and (13).

$$S_i^* = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^*)^2} \quad (12)$$

$$S_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2} \quad (13)$$

**Step 6:** Calculate the relative closeness to the ideal solution for each alternative by using formula (14) and rank the alternatives in descending order with respect to their relative closeness to the ideal solution.

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \quad (14)$$

## 4. Applications of the proposed approach

Four case studies illustrate viability of the proposed approach.

### 4.1. Case study 1

KAM is used in case study 1. The proposed approach is conducted based on variables used in KAM 2012 to compare the innovation performance of four EU candidate countries, Macedonia (FYR), Iceland, Serbia and Turkey as shown in Figure 1. The steps of the proposed approach are conducted and explained as follows.

**Step 1:** Determine countries which are candidate for the EU:

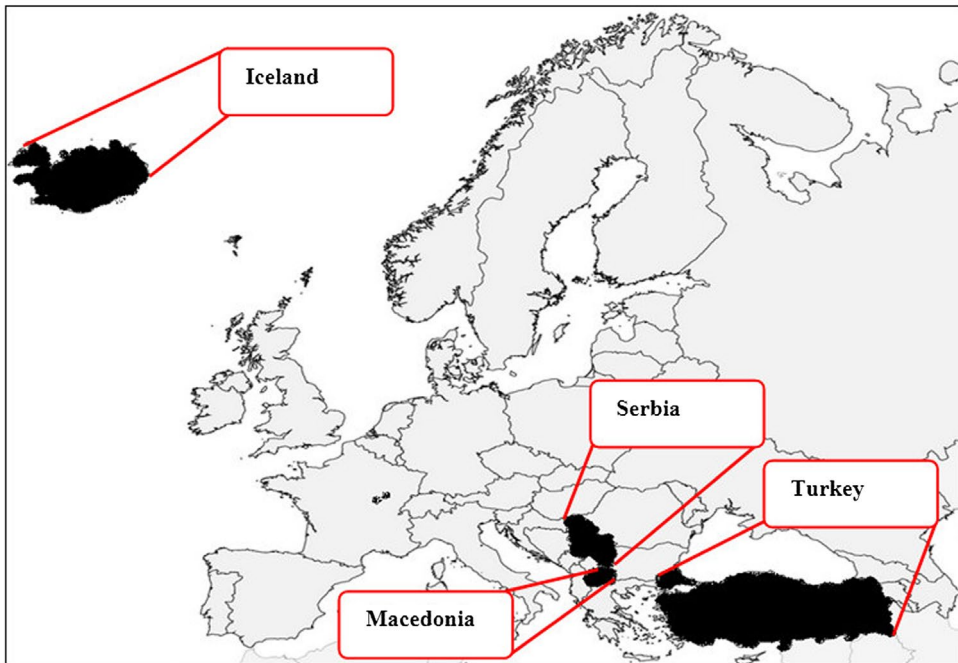
As mentioned previously, the four EU candidate countries, Macedonia (FYR), Iceland, Serbia and Turkey are considered in this study.

**Step 2:** Determine variables that affect the innovation potential of countries:

The 16 variables, which are given in Table 1, are determined and the value of each variable is obtained from the Custom Scorecards mode included in KAM ([www.worldbank.org/kam](http://www.worldbank.org/kam), accessed 10 February 2014) for comparison. Table 1 shows the definitions of these variables. Actually, there are 29 variables used for innovation system in the Custom Scorecards. However, 13 variables are not available for at least one country considered. Therefore, 13 variables are excluded in the computational process. KAM has been extensively used by government officials, policymakers, researchers, etc. (Chen & Dahlman, 2005). Details on KAM can be found in the KAM 2008 Booklet.

**Step 3:** Calculate the weight of each variable by using the entropy method:

In this step, the weight of each variable is calculated by the entropy method. Table 2 shows the normalised decision matrix for the method. Table 3 also presents  $E_j$ ,  $d_j$  and  $w_j$  values obtained from the method. As can be seen from Table 3, the weights ( $w_j$ ) take the values between 0 and 1, and they sum to 1. The variable called 'J' (Patents Granted by USPTO / Mil. People) is the most important variable because it has the highest weight based on



**Figure 1.** Map of Europe and the candidate countries. Source: <http://www.worldatlasbook.com/europe/europe-blank-map.html>

**Table 1.** Evaluation variables for case study 1.

No.	Abbreviation	Variables
1	A	FDI Inflows as % of GDP <sup>a</sup>
2	B	Royalty and Licence Fees Payments (US\$/population)
3	C	Royalty Payments and receipts(US\$/ population)
4	D	Science and Engineering Enrolment Ratio (%)
5	E	Science Enrolment Ratio (%)
6	F	Total Expenditure for R&D <sup>b</sup> as % of GDP
7	G*	University-Company Research Collaboration (1–7)
8	H	S&E <sup>c</sup> Journal Articles / Million People
9	I*	Availability of Venture Capital (1–7)
10	J	Patents Granted by USPTO <sup>d</sup> / Mil. People
11	K*	Private Sector Spending on R&D (1–7)
12	L*	Firm-Level Technology Absorption (1–7)
13	M*	Value Chain Presence (1–7)
14	N	S&E articles with foreign co-authorship (%)
15	O	Avg number of citations per S&E article
16	P*	Intellectual Property Protection (1–7)

<sup>a</sup>GDP: *Gross Domestic Product*.

<sup>b</sup>R&D: *Research and Development*.

<sup>c</sup>S&E: *Science and Engineering*.

<sup>d</sup>USPTO: *United States Patent and Trademark Office*.

\*Indicates that the variable is measured by 7-point Likert scale.

the entropy method. This implies that the number of patents produced per population million in a country is vital for measuring innovation potential of a country. It also signs that it is one of the most significant variable to see a big picture of the conducted innovation-based research in service and manufacturing systems in the countries. The remaining

**Table 2.** The normalised decision matrix ( $P_{ij}$ ) for the entropy method in case study 1.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Macedonia	0.228	0.203	0.214	0.290	0.321	0.058	0.227	0.027	0.269	0.001	0.215	0.211	0.239	0.365	0.177	0.231
Iceland	0.362	0.287	0.233	0.194	0.205	0.664	0.325	0.720	0.258	0.989	0.322	0.335	0.282	0.339	0.436	0.381
Serbia	0.321	0.404	0.468	0.277	0.265	0.095	0.227	0.138	0.237	0.005	0.215	0.191	0.204	0.201	0.186	0.194
Turkey	0.089	0.106	0.085	0.239	0.209	0.183	0.221	0.114	0.237	0.005	0.248	0.263	0.275	0.096	0.201	0.194

**Table 3.**  $E_j$ ,  $d_j$  and  $w_j$  values in Case study 1.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
$E_j$	0.927	0.928	0.890	0.992	0.987	0.700	0.990	0.618	0.999	0.050	0.989	0.983	0.994	0.924	0.940	0.969
$d_j$	0.073	0.072	0.110	0.008	0.013	0.300	0.010	0.382	0.001	0.950	0.011	0.017	0.006	0.076	0.060	0.031
$w_j$	0.0345	0.0341	0.0517	0.0039	0.0059	0.1413	0.0048	0.1803	0.0005	0.4483	0.0050	0.0082	0.0027	0.0358	0.0281	0.0149

first four highest weights are allocated to ‘S&E Journal Articles / Mil. People’ (0.1803), ‘Total Expenditure for R&D as % of GDP’ (0.1413), ‘Royalty Payments and receipts’ (0.0517), and ‘S&E articles with foreign co-authorship’ (0.0358). Finally, ‘Availability of Venture Capital’ (0.0005) has the lowest weight.

**Step 4:** Rank all candidate countries by using the TOPSIS method:

The normalised decision matrix ( $R_{ij}$ ) for the TOPSIS method and the result of the TOPSIS method are given in Table 4 and Table 5, respectively. As can be seen from Table 5, Iceland ranked first based on the results of the entropy-based TOPSIS method. Iceland has the highest innovation potential compared to the others. The ranking produced by the proposed approach is Iceland > Serbia > Turkey > Macedonia. This ranking is the same as KAM 2012, which assumes that the variables have the same importance. The results of this study obviously show that considering the ‘importance of the variables’ does not produce any different ranking for KAM 2012.

## 4.2. Case study 2

The Global Competitiveness Index 2014–2015 report (Schwab & Sala-i-Martin, 2015) is used in case study 2. The first step of the algorithm is the same as in case study 1. Thus, application of the proposed approach in case study 2 begins at Step 2 as presented next.

**Step 2:** Determine variables that affect the innovation potential of countries:

In this case study, the proposed approach is conducted based on the variables used for innovation in The Global Competitiveness Index, which is published by World Economic Forum. Seven variables, which are presented in Table 6, are determined in case study 2. The value of each variable is obtained from The Global Competitiveness Index 2014–2015 report. There are 12 main criteria included in the index. One of these main criteria is innovation. This case study takes into account innovation criteria and its sub criteria to present the proposed methodology.

**Step 3:** Calculate the weight of each variable by using the entropy method:

In this step, the normalised decision matrix for the entropy method and the weight of each variable are presented in Tables 7 and 8, respectively. The variable called ‘G\_2’ (PCT Patents, Applications/Million Pop.) is the most important variable because it has the highest weight based on the entropy method. The remaining variables have low weight compared to ‘PCT Patents, Applications/Million Pop’ criteria.

**Step 4:** Rank all candidate countries by using the TOPSIS method:

The normalised decision matrix ( $R_{ij}$ ) for the TOPSIS method and the result of the TOPSIS method are given in Table 9 and Table 10. As can be seen from Table 10, Iceland ranked first based on the results of the entropy-based TOPSIS method. Iceland has the highest innovation potential compared to the others. The ranking produced by the proposed approach for The Global Competitiveness Index 2014–2015 report is Iceland > Turkey > Serbia > Macedonia. This ranking is not the same as The Global Competitiveness Index 2014–2015 that assumes that the variables have the same importance. The results of this study show that considering the ‘importance of the variables’ produce different ranking for The Global Competitiveness Index 2014–2015 which sorts the candidate countries as Iceland > Turkey > Macedonia > Serbia.

### 4.3. Case study 3

Innovation Union Scoreboard (2015) report is used in case study 3. The first step of the algorithm is the same as in case studies 1 and 2. Macedonia (FYR), Iceland, Serbia and Turkey are considered in the first step of the algorithm. Therefore, like cases study 2, the application of the proposed approach in case study 3 begins at Step 2, as presented next.

**Step 2:** Determine variables that affect the innovation potential of countries:

The variables and the value of each variable are obtained from Innovation Union Scoreboard (2015) report, which is published by European Commission. Table 11 presents the evaluation variables for case study 3.

**Step 3:** Calculate the weight of each variable by using the entropy method:

The normalised decision matrix for the method is given in Table 12, while  $E_j$ ,  $d_j$  and  $w_j$  values are presented in Table 13. The most important variable is 'Intellectual Assets' (F\_3). It is followed by 'Open, Excellent and Attractive Research Systems' (B\_3), 'Linkages & Entrepreneurship' (E\_3), 'Finance and Support' (C\_3), 'Human Resources' (A\_3), 'Firm Investments' (D\_3), 'Innovators' (G\_3), 'Economic Effects' (H\_3)

**Step 4:** Rank all candidate countries by using the TOPSIS method:

The normalised decision matrix ( $R_{ij}$ ) for the TOPIS method in case study 3 is presented in Table 14. The result of the proposed approach for case study 3 is presented in Table 15. As can be seen from Table 15, the countries ranked as Iceland > Serbia > Turkey > Macedonia. The results of case study 3 show that considering the 'importance of the variables' does not produce any different ranking for Innovation Union Scoreboard (2015) which does not consider the 'importance of the variables'.

### 4.4. Case study 4

The Global Innovation Index, 2015 report is used in this case study. The first step of the algorithm is the same as in all case studies. Hence, application of the proposed approach in case study 4 begins at Step 2, as presented next.

**Step 2:** Determine variables that affect the innovation potential of countries:

In this case study, the proposed approach is conducted based on the variables used for innovation in Global Innovation Index, 2015. Global Innovation Index, 2015 considers seven variables, which are presented in Table 16 to measure the innovation performance of the countries.

**Step 3:** Calculate the weight of each variable by using the entropy method:

Table 17 presents the normalised decision matrix for the entropy method and Table 18 shows the weight of each variable for case study 4. As can be seen from Table 18, Creative (G\_4) has the highest weight and is the most important variable. It is followed by Business sophistication (E\_4), Human capital and research (B\_4), Knowledge and technology (F\_4), Infrastructure (C\_4), Market sophistication (D\_4), Institutions (A\_4).

**Step 4:** Rank all candidate countries by using the TOPSIS method:

The normalised decision matrix ( $R_{ij}$ ) for the TOPSIS method and the result of the TOPSIS method are given in Table 19 and Table 20. Iceland ranked first again based on the proposed approach. The ranking produced by the proposed approach in case study 4 is Iceland > Turkey > Macedonia > Serbia. This ranking is not obtained before. Considering the 'importance



**Table 4.** The normalised decision matrix ( $R_{ij}$ ) for the TOPSIS method in case study 1.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Macedonia	0.421	0.372	0.374	0.573	0.630	0.083	0.448	0.037	0.537	0.001	0.423	0.413	0.475	0.669	0.326	0.442
Iceland	0.668	0.526	0.407	0.384	0.404	0.952	0.640	0.970	0.515	1.000	0.635	0.654	0.559	0.622	0.801	0.728
Serbia	0.592	0.740	0.820	0.547	0.520	0.136	0.448	0.186	0.472	0.005	0.423	0.372	0.405	0.368	0.341	0.371
Turkey	0.164	0.194	0.149	0.473	0.411	0.262	0.435	0.154	0.472	0.005	0.488	0.513	0.545	0.175	0.369	0.371

**Table 5.** Result of the entropy-based TOPSIS approach in case study 1.

	S <sup>+</sup>	S <sup>-</sup>	C <sup>+</sup>	Rank by the Entropy-based TOPSIS approach
Macedonia	0.4947	0.0238	0.0459	4
Iceland	0.0226	0.4948	0.9563	1
Serbia	0.4823	0.0510	0.0957	2
Turkey	0.4822	0.0331	0.0643	3

**Table 6.** Evaluation variables in case study 2.

No.	Abbreviation	Variables
1	A_2*	Capacity for Innovation
2	B_2*	Quality of Scientific Research Institutions
3	C_2*	Company Spending on R&D
4	D_2*	University-Industry Collaboration in R&D
5	E_2*	Gov't Procurement of Advanced Tech Products
6	F_2*	Availability of Scientists and Engineers
7	G_2	PCT Patents, Applications/Million Pop.

\*Indicates that the variable is measured by 7-point Likert scale.

**Table 7.** The normalised decision matrix ( $P_{ij}$ ) for the entropy method in case study 2.

	A_2	B_2	C_2	D_2	E_2	F_2	G_2
Macedonia	0.246	0.230	0.254	0.243	0.252	0.235	0.002
Iceland	0.282	0.298	0.303	0.303	0.252	0.277	0.908
Serbia	0.211	0.230	0.205	0.211	0.203	0.235	0.023
Turkey	0.261	0.242	0.238	0.243	0.294	0.253	0.068

**Table 8.**  $E_j$ ,  $d_j$  and  $w_j$  values in case study 2.

	A_2	B_2	C_2	D_2	E_2	F_2	G_2
$E_j$	0.996	0.996	0.993	0.994	0.994	0.998	0.266
$d_j$	0.004	0.004	0.007	0.006	0.006	0.002	0.734
$w_j$	0.0050	0.0058	0.0094	0.0082	0.0079	0.0022	0.9614

**Table 9.** The normalised decision matrix ( $R_{ij}$ ) for the TOPSIS method in case study 2.

	A_2	B_2	C_2	D_2	E_2	F_2	G_2
Macedonia	0.490	0.457	0.503	0.483	0.499	0.469	0.002
Iceland	0.560	0.593	0.601	0.600	0.499	0.553	0.997
Serbia	0.420	0.457	0.406	0.417	0.402	0.469	0.025
Turkey	0.518	0.481	0.471	0.483	0.583	0.505	0.074

**Table 10.** Result of the entropy-based TOPSIS approach in case study 2.

	S <sup>+</sup>	S <sup>-</sup>	C <sup>+</sup>	Rank by the Entropy-based TOPSIS approach
Macedonia	0.9563	0.0014	0.0014	4
Iceland	0.0007	0.9563	0.9993	1
Serbia	0.9343	0.0220	0.0230	3
Turkey	0.8871	0.0692	0.0724	2



**Table 11.** Evaluation variables for case study 3.

No.	Abbreviation	Variables
1	A_3	Human Resources
2	B_3	Open, Excellent and Attractive Research Systems
3	C_3	Finance and Support
4	D_3	Firm Investments
5	E_3	Linkages & Entrepreneurship
6	F_3	Intellectual Assets
7	G_3	Innovators
8	H_3	Economic Effects

**Table 12.** The normalised decision matrix ( $P_{ij}$ ) for the entropy method in case study 3.

	A_3	B_3	C_3	D_3	E_3	F_3	G_3	H_3
Macedonia	0.310	0.100	0.038	0.124	0.136	0.058	0.244	0.181
Iceland	0.282	0.625	0.483	0.296	0.571	0.664	0.352	0.308
Serbia	0.324	0.142	0.287	0.280	0.185	0.095	0.237	0.308
Turkey	0.085	0.133	0.193	0.301	0.108	0.182	0.166	0.204

**Table 13.**  $E_j$ ,  $d_j$  and  $w_j$  values for case study 3.

	A_3	B_3	C_3	D_3	E_3	F_3	G_3	H_3
$E_j$	0.933	0.771	0.830	0.964	0.825	0.701	0.975	0.980
$d_j$	0.067	0.229	0.170	0.036	0.175	0.299	0.025	0.020
$w_j$	0.0653	0.2240	0.1667	0.0353	0.1714	0.2932	0.0246	0.0195

**Table 14.** The normalised decision matrix ( $R_{ij}$ ) for the TOPIS method in case study 3.

	A_3	B_3	C_3	D_3	E_3	F_3	G_3	H_3
Macedonia	0.578	0.151	0.063	0.237	0.217	0.084	0.473	0.352
Iceland	0.525	0.944	0.811	0.568	0.914	0.952	0.681	0.599
Serbia	0.604	0.214	0.482	0.537	0.296	0.136	0.458	0.599
Turkey	0.158	0.201	0.325	0.577	0.173	0.262	0.321	0.397

**Table 15.** Result of the entropy-based TOPSIS approach for case study 3.

	$S^+$	$S^-$	$C^+$	Rank by the Entropy-based TOPSIS approach
Macedonia	0.3555	0.0287	0.0748	4
Iceland	0.0052	0.3590	0.9858	1
Serbia	0.3134	0.0822	0.2078	2
Turkey	0.3038	0.0699	0.1871	3

of the variables' produce different ranking for Global Innovation Index, 2015 which sorts the candidate countries as Iceland > Macedonia > Turkey > Serbia.

## 5. Benchmarking innovation performance

Table 21 summarises countries' innovation performance with respect to case studies. As can be seen from a comparative assessment of innovation performance in Table 21, the ranking produced by the proposed approach, KAM and Innovation Union Scoreboard is Iceland > Serbia > Turkey > Macedonia. Iceland is the overall innovation leader (see Figure 2). The

**Table 16.** Evaluation variables in case study 4.

No.	Abbreviation	Variables
1	A_4	Institutions
2	B_4	Human capital and research
3	C_4	Infrastructure
4	D_4	Market sophistication
5	E_4	Business sophistication
6	F_4	Knowledge and technology
7	G_4	Creative

**Table 17.** The normalised decision matrix ( $P_{ij}$ ) for the entropy method in case study 4.

	A_4	B_4	C_4	D_4	E_4	F_4	G_4
Macedonia	0.248	0.222	0.188	0.264	0.259	0.216	0.204
Iceland	0.321	0.330	0.311	0.266	0.334	0.334	0.390
Serbia	0.227	0.204	0.255	0.221	0.218	0.227	0.187
Turkey	0.204	0.244	0.246	0.249	0.189	0.223	0.219

**Table 18.**  $E_j$ ,  $d_j$  and  $w_j$  values in case study 4.

	A_4	B_4	C_4	D_4	E_4	F_4	G_4
$E_j$	0.989	0.987	0.989	0.998	0.983	0.987	0.965
$d_j$	0.011	0.013	0.011	0.002	0.017	0.013	0.035
$w_j$	0.1056	0.1278	0.1086	0.0182	0.1652	0.1264	0.3482

**Table 19.** The normalised decision matrix ( $R_{ij}$ ) for the TOPSIS method in case study 4.

	A_4	B_4	C_4	D_4	E_4	F_4	G_4
Macedonia	0.488	0.436	0.371	0.526	0.505	0.424	0.388
Iceland	0.632	0.649	0.612	0.530	0.653	0.655	0.742
Serbia	0.448	0.401	0.503	0.441	0.425	0.446	0.355
Turkey	0.402	0.478	0.484	0.498	0.370	0.438	0.416

**Table 20.** Result of the entropy-based TOPSIS approach in case study 4.

	$S^+$	$S^-$	$C^*$	Rank by the Entropy-based TOPSIS approach
Macedonia	0.1352	0.0272	0.1676	3
Iceland	0.0000	0.1534	1.0000	1
Serbia	0.1478	0.0179	0.1081	4
Turkey	0.1307	0.0267	0.1696	2

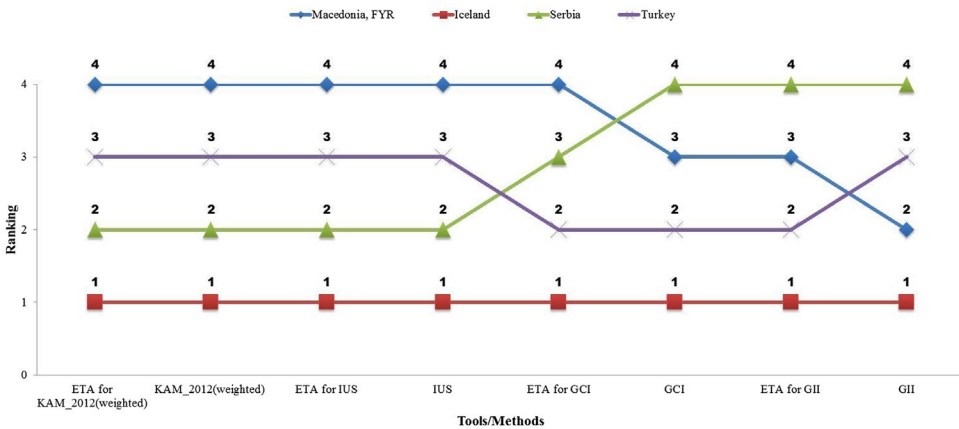
main difference occurs in case study 2 and case study 4. The results of case studies show that considering the 'importance of the variables' does not produce any different ranking for Innovation Union Scoreboard (2015), KAM and the proposed approach corresponding to these. It should be noted that the variables considered are also different in each case study.

It should also be noted that Iceland has the highest 'innovation potential' among the candidate countries for the results obtained by all methods mentioned above. According to the income categories created by the World Bank (<http://go.worldbank.org/Q08GIVEDK0>, accessed 26 April 2014), Iceland is in the 'High Income' category, while Serbia, Turkey and Macedonia are in the 'Upper-Middle Income' category. This result also implies that there is a positive relationship between 'income' and 'innovation' in a typical country.

**Table 21.** Benchmarking innovation performance.

Case Study	Data Resource	The number of variables	Ranking by data resource	Ranking by the proposed approach
Case Study 1	Knowledge Assessment Methodology	16	I > S > T > M	I > S > T > M
Case Study 2	The Global Competitiveness Index (Innovation pillar)	7	I > T > M > S	I > T > S > M
Case Study 3	Innovation Union Scoreboard	8	I > S > T > M	I > S > T > M
Case Study 4	Global Innovation Index	7	I > M > T > S	I > T > M > S

I: Iceland, S: Serbia, T: Turkey, M: Macedonia (FYR).



**Figure 2.** Ranking with respect to different tools/methods.

## 6. Conclusion

In this article, the entropy-based TOPSIS approach was proposed and employed for comparison of innovation performances of EU candidate countries. First, the weight of each variable (together with the value of the variables) that affects innovation potential was computed for EU candidate countries, including Turkey. The results of the entropy method provides information for both governments and investors to sort the variables in descending order with respect to importance of the variables in innovation process. Based on the results obtained from the entropy method, all candidate countries were then examined in a comparative way with respect to their ‘innovation performance’ by using the TOPSIS method. Four case studies were conducted to demonstrate the viability of the proposed approach. This study differs from previous work, such as the Global Competitiveness Index, Innovation Union Scoreboard, Global Innovation Index and KAM, in that it considers the weight of each variable reflecting the importance of the variable in the calculation process.

The results of this study demonstrate that Iceland emerged ahead of the other three countries. Developments in manufacturing and service sectors, computer equipment as well as bio-technology inclined Iceland’s economy positively because of the energy-intensive industries established in recent years (<http://www.ekonomi.gov.tr>, accessed 6 March 2016). Iceland is the overall innovation leader for all case studies presented in this article. The

innovation success of Iceland above other countries under consideration can be explained by several economic facts. Among these facts, Iceland has a population of less than half a million and the unemployment rate in Iceland is approximately 4.9%, which is the lowest unemployment-rate among the countries considered in this study, and the GDP for Iceland is \$43,993 (OECD, 2014). Furthermore, Iceland is in the 'High Income' category according to the income categories created by the World Bank (<http://go.worldbank.org/Q08GIVEDK0>, accessed 26 April 2014). Finally, it is emphasised in 'the 'Human Development Report 2015' that Iceland has the highest telecommunication infrastructure, which is very important for innovation capability, and included in the Very High Human Development category with respect to the Human Development Index.

The economy in Macedonia is generally based on agriculture (<http://www.ekonomi.gov.tr>, accessed 6 March 2016). In addition, R&D expenditure is approximately 0.2% (Human Development Report, 2015). Therefore, we cannot expect high innovation performance in an economy based on agriculture with a low percentage of R&D expenditure. Although the decision-makers in Macedonia tried to join the EU, it is necessary to modernise almost every field of economy. Furthermore, the unemployment rate in Macedonia is about 26% (<http://www.mfa.gov.tr>, accessed 6 March 2016). The current bureaucracy also negatively upsets the innovation environment in Macedonia.

The economy in Serbia is mainly based on public sector investments and many structural reforms are still needed to prepare innovation environment. R&D expenditure in Serbia is around 0.78% whereas it is approximately 2% in EU countries (<http://ec.europa.eu/eurostat>, accessed 6 March 2016). GDP growth in Serbia is unstable. GDP growth in 2012 and 2014 is negative (<http://www.tradingeconomics.com/serbia/gdp-per-capita>, accessed 19 March 2016). Therefore, in case study 4, Serbia ranked fourth based on the results of the entropy-based TOPSIS method and Global Innovation Index 2015 report. It is vital to construct an innovation- and technology-based eco-system for the economy to accelerate Serbia on the road to EU accession.

Although Turkey is the first country that applied for EU membership among the candidates considered in this study, it comes second and third in case studies in terms of 'innovation performance' among the candidates. Therefore, in order to change and improve the current situation, it is quite obvious that Turkey should allocate more incentives to the investors who will produce high-added value products and provide more qualified innovation facilities through a well-structured R&D strategy. A law related to promoting research infrastructure (law no: 6550) was approved by the presidency of the Republic of Turkey on 9 July 2014 and published in the official gazette on 10 July 2014. This law can be considered as one of the most important initiatives to support R&D activities and sustain innovation-driven development in Turkey. Turkey should also pay more attention to innovation activities and create awareness for the contribution of innovation to both country and investors sides. This will help Turkey jump to the top stage of development in the future. It should be underlined here that investment in innovation also plays an important role in meeting a broad range of challenges and opportunities that our society faces today (Dikbaş & Akkoyun, 2006). It means that making the right investment decisions (at the right time) are as important as innovation itself. Therefore, it is vital to develop an effective eco-system for innovators, investors and policy-/decision-makers that gathers efforts in evaluation measurement, prioritisation and commercialisation of both innovations and investments

in Turkey (Altuntas, 2014; Altuntas & Dereli, 2012). This will probably accelerate Turkey on the road to EU accession.

There are some limitations to this study. Iceland had ongoing candidate status at the time the study was conducted, although it withdrew its application for EU membership on 12 March 2015. Montenegro and Albania were accepted for candidate status in 2015. However, these two countries were not considered in this study for two reasons: First, their negotiations for EU membership had only recently started so that the data related to these two countries was not included in the Innovation Union Scoreboard, 2015 report; Second, the population, geographic size, and economic potential of Montenegro and Albania are quite different from the other countries discussed in this article, and considering these two countries could lead to misleading results with respect to comparisons.

As for future research, the proposed approach in this study can be conducted including all EU countries, along with the comparison of the candidate countries. Furthermore, other weighing methods can be used instead of the entropy method to reflect the importance of the variables in the calculation process.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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