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Occupational health and safety performance evaluation of countries based on MAIRCA

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Abstract

Purpose – The purpose of this paper is to develop an approach to compare occupational health and safety (OHS) performances of countries. Additionally, another aim is to debate the impacts of using recorded data and ratios for OHS performance evaluations.

Design/methodology/approach – The number of fatal accidents (NFAs), fatal accident rates (FARs), numbers of lost days (NLDs) and accident severity rates (ASRs) are determined as main criteria and six economic activity areas (EAAs) are considered as sub-criteria. Two different initial decision matrices are used as the initial decision matrix, the first of which consists of recorded data of countries related to NFAs and NLDs, and the second consists of FAR and ASR values as ratios. Importance weights of main and sub-criteria regarding the recorded data and ratios are determined using four different weighting ways. Countries are ranked via utilizing Multi-Attributive Ideal-Real Comparative Analysis considering two different initial decision matrices.

Findings – It can be stated that an evaluation based on ratios for comparison of OHS performance provides more realistic results. Additionally, increasing the effect of the FAR values using the 6,000 equivalent lost days factor is also important in terms of differentiating the data of the countries in question.

Originality/value – To the best of the authors' knowledge, there is no study in literature that discusses the ranking of countries by means of recorded data and ratios considering different criteria. Additionally, this study is a first in terms of the number of countries evaluated and the comparison of these countries according to their respective EAAs.

Keywords MAIRCA, Criteria weighting, Multi-criteria decision making, OHS performance

Paper type Research paper

1. Introduction

Occupational health and safety (OHS) has become one of the most important issues for all companies operating in various different industries. The main reason for this is that companies without an effective OHS management incur great losses in terms of finance, production and reputation. The OHS performance of a country is the value or a combination of different values that determine the total risk level of all companies in various industries in that country. Indicators that obtained from numbers such as number of fatal accidents (NFAs) and number of lost days (NDLs) are used to obtain such values (Rogers *et al.*, 2019; Wegman and Oppe, 2010). The most important characteristic that these indicators must have is being able to be indicated as a ratio. In terms of OHS, ratios can be obtained by utilizing worked hours and/or employed personnel. By using ratios, we can avoid making decisions based on only occurrence results. For example, if only the occurred accident numbers were to be considered, then the workplaces that work for longer durations or employ more personnel will always seem riskier as they will have a higher number of accidents.

When the situation is reviewed in terms of OHS records, the fact that there is a lack of sufficient records makes it harder to compare countries' OHS performances. Even the International Labor Office (ILO), to which almost all countries are a member of, does not have all the OHS statistics of all countries. Yet, it is quite important for a country to compare

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its OHS performance with that of other countries in order to determine its current standing and what it must do in order to improve it (Gigović *et al.*, 2016). In this respect, the study aims to develop an approach to compare the OHS performances of countries without any subjectivity by using the recorded ILO data of countries that have no missing data. As such, a total of 15 countries that have no missing data for 20 different industries within a certain number of years were identified from the ILO's recorded OHS data. It was determined that there was no loss of data for these countries in the period of 2009–2015, and the OHS data belonging to these years were used. Afterwards, these data were combined in accordance with the fourth revision of the International Classification of All Economic Activity (ISIC, Rev.4) as used by the ILO and the United Nations (UN). Thus, the OHS performance indicators of 15 countries in terms of six economic activity areas (EAAs) where obtained. A two-phase multi-criteria decision-making (MCDM) approach was proposed for the evaluation of the OHS performance. The use of the MCDM in the study is due to the consideration of different OHS performance criteria to rank country performances. From this aspect, the question of ranking of countries gains a decision-making characteristic. However, in order to completely remove subjectivity from this process, evaluation is conducted solely based on the recorded OHS data of countries, without utilizing the opinion or views of experts. In the first phase of the proposed approach, four different methods of criteria weighting in line with OHS logic are suggested. In the first method, the fatal accident rates (FARs) and accident severity rates (ASRs) for the different EAAs were calculated by using the relevant ILO recorded NFAs and NDLs. Then the weighting was done by using the arithmetic mean of the ratios. In the second method, the equivalence of 1 fatality being 6,000 equivalent lost days is used to factor in an increase in weight of the FAR's with the arithmetic average ratios. In the third method, the weightings of the ratios were done by utilizing the geometric average. In the fourth and last method, the weightings were calculated after supplementing the FARs with the 1 fatality being 6,000 equivalent lost days factor and later by using the geometric averages of the ratios. In the second phase of the proposed approach, the weightings obtained by four different methods were individually integrated to the Multi-Attributive Ideal-Real Comparative Analysis (MAIRCA) method, resulting in four different rankings of countries. MAIRCA is a method developed in Gigovic *et al.* (2016) that operates with the assumption that each alternative in the initial decision process has an equal chance of being selected. As such, each country evaluated in the MAIRCA method has an equal probability of having the highest performance in the initial stage of the evaluation. The MAIRCA includes comparison of theoretical and empirical alternative ratings. Relying on theoretical and empirical ratings, the distance between the empirical and ideal alternative is determined. According to Pamučar *et al.* (2018), MAIRCA has a stable and well-structured analytical framework for ranking the alternatives. MAIRCA also has mathematical framework which remains the same regardless of the number of alternatives and criteria. MAIRCA can be applied in a case of a large number of alternatives and criteria. It can clearly define alternative rank presented by numerical value, enabling easier comprehension of results. Qualitative and quantitative criteria type can be evaluated in MAIRCA. It can take into account the distance between ideal and anti-ideal solutions. Finally, MAIRCA gives stable solutions regardless of changes in the qualitative criteria measurement scale and changes in quantitative criteria formulation.

Afterwards in the course of the evaluation of their performance levels, the countries are subjected to the respective weights based on the relevant values for each criterion. In the study, two different initial decision matrices were adopted in accordance with the different criteria weighting methods to be used with the MAIRCA method. The first initial decision matrix is formed from ILO's recorded OHS data (NFAs and NDLs for each EAA). In this scope, the criteria weights obtained from the ratios with the arithmetic averages with and without the factor were used for the first initial decision matrix for the MAIRCA method, thus resulting in the first and second ranking results. The second decision matrix is formed from the calculated FAR and ASR values for each EAA of the respective countries. Accordingly, the criteria weights obtained from the ratios with the geometric averages with and without the factor were used for the first second decision matrix for the MAIRCA method, thus resulting in the third and fourth ranking results. As such, it has been shown in the study the differences that may arise in the comparison and evaluation of OHS performances when using recorded raw data and calculated ratios.

It has been observed that there are few studies in the literature that compare the overall OHS performances of countries. Ahn *et al.* (2004) studied and compared the fatal accidents that occurred in Korea and America between 1998 and 2001 according to their industries (Ahn *et al.*, 2004). Horgen *et al.* (2005) investigated and compared the short- and long-term effects of ergonomic interventions on muscoskeletal discomfort, eyestrain and psychosocial stress in VDT operators in Norway, USA and Poland. In his study, Baradan (2006) investigated where OHS stands in the construction industry in Turkey, its structuring in the state from a legislative perspective and compared results with America. Wegman *et al.* (2010) compared the performances of 23 different countries in terms of road safety and traffic accidents in their study. Ceylan (2011) compared three different accident frequency rates of occupational accidents that occurred in Turkey between 2004 and 2009 with those of 4–11 different countries. Additionally, studies related to OHS performance for companies and special sectors are also limited in the literature. These are given below briefly.

Lin *et al.* (2000) performed a benchmarking study of 44 construction companies in Victoria, Australia, in term of OHS performances. The results show that the major factors influencing safety performance were; company size, and management and employee commitment to OHS. Saracino *et al.* (2012) aimed to develop a methodology that quantifies the "health and safety" level of a company. The tool worthiness is strictly operative and allows the company organization to improve its performances by acting on the identified critical issues, in any case ensuring that the model tested and licensed contains a high level of reliability. Idoro (2011) compared the management efforts and performance of construction contractors in Nigeria with regard to OHS. He aimed to help all categories of construction contractors in Nigeria to improve their management efforts related to OHS. Ng *et al.* (2005) tried to define the importance of safety performance evaluation factors through a questionnaire survey conducted in Hong Kong. The results of the questionnaire survey are used to develop a safety performance evaluation framework suitable for use in the construction industry and protocols for evaluating the safety performance at the organizational and project levels. Priyadarshani *et al.* (2013) aimed to introduce a benchmark to measure construction safety via utilizng proposed safety management assessment framework. Factors affecting construction safety performance were explored through a questionnaire survey conducted in Sri Lanka. As a result of the survey, it was identified that a benchmark of construction safety should be considered across six dominant groups of factors: management commitment, management measures, implementation, project nature, individual involvement and economic investment. Management commitment is the most dominant factor that affects construction safety and consists of implementing organizational safety policies, assigning safety responsibilities at all levels, etc. Han *et al.* (2014) examined schedule delays and rework as critical variables affecting safety performance in construction sites. A simulation model was used for the evaluation of effective policies for safety enhancement. Yakubu and Bakri (2013) investigated safety and health performance of contractors on construction sites. As aresult of the study it was determined that successful implementation of the safety program depends on management commitment, safe work condition and safe work habit. Ghasemi *et al.* (2015) compared the effectiveness of a new incentive system and the surprising incentive system interm of safety performance of frontline employees. One year after the implementation of this new incentive system, behavioral changes of employees with respect to seven types of activities were observed. The results of this study showed that there is a significant relationship between the new incentive system and the safety performance of frontline employees. İnan *et al.* (2017) proposed a multiple attribute decision-making model to determine and to compare the firms' OHS management system performances. The model utilizes the firms' OHSAS 18001: 2007 implementation performances and compares them with respect to the standard's conditions. Importance of criteria (requirements of OHSAS) was determined by Simos' procedure and firms were ranked in terms of the quality consultants' assessments by VIKOR.

When the literature was reviewed in terms of the MAIRCA method, it was seen that the method had not yet been used in the field of OHS, and that its use outside of the field of OHS was very less as well. In their study, Gigovic *et al.* (2016) used the MAIRCA method together with the Geographic Information System (GIS) to identify suitable locations for ammunition depots. Pamučar *et al.* (2017) used the MAIRCA method for selecting contractor companies to state public contracts and evaluated the resulting the contracting company alternatives. Badi and Ballem (2018) used a combination of rough numbers and the best-worst method integrated into the MAIRCA method to handle a problem regarding supplier selection in their study. Mamak Ekinci and Can (2018) utilized the combination of Criteria Importance through Intercriteria Correlation and MAIRCA methods to evaluate the ergonomic risk levels that operators are subjected to by considering the workloads and the working positions. As seen from the literature review, the conducted studies are focused on specific industries such as construction or traffic, or on certain subjects. To the best of our knowledge, there is also no study in literature that discusses the ranking of countries by means of recorded data and ratios and uses these results for guidance toward future analyses. Within this scope, this study is able to contribute to the literature. Additionally, this study is a first in terms of the number of countries evaluated and the comparison of these countries according to their respective EAAs. The studies in the literature located above for OHS evaluation and MAIRCA was summarized in Table I.

The rest of the study is organized as follows: in Section 2, the implementation steps of the proposed approach are explained and the application of the comparison of country OHS performances is conducted. Section 3 discusses the obtained results and provides suggestions for future studies.

2. The proposed approach

The proposed approach to comparing the OHS performances of countries consists of two phases. In the first phase, the weights of criteria that are identifiers of OHS performance are determined in four different methods. In the second phase, the results of the four different methods are integrated to MAIRCA and as a result, four different OHS performance rankings are obtained.

First phase: calculating the criteria importance weights

Step 1: determination of criteria and alternatives. When the OHS records of the ILO are reviewed, it is seen that each country is separated into 20 different sectors. In Table II, the aforementioned 20 sectors and their classification into the 6 EEAs according to the UN Statistics Division is shown.

In the study, the countries are compared based on the six different EEAs. Additionally, the FARs and ASRs for each industry of the countries are calculated using the ILO records regarding NFAs and numbers of lost days (NLDs). The data set for Turkey for the relevant years is presented in Table AI (https://data.oecd.org/emp/hours-worked.htm, 2018). Accordingly, for the four different weighting methods, FAR (MC_1) and ASR (MC_2) are

Reference	Focal point	Country/countries/companies
OHS comparison-related studies		
Lin *et al.* (2000)	OHS performances	44 construction companies in Victoria, Australia
Ahn *et al.* (2004)	Fatal accidents in industries	Korea and America
Horgen *et al.* (2005)	Short- and long-term effects of ergonomic interventions on muscoskeletal discomfort, eyestrain and psychosocial stress in VDT operators	Norway, USA and Poland
Ng *et al.* (2005)	Importance of safety performance evaluation factors	Hong Kong
Baradan (2006)	Construction industry situation in term of OHS	Turkey and USA
Wegman *et al.* (2010)	Performances of countries in terms of road safety and traffic accidents	23 different countries
Ceylan (2011)	Three different accident frequency rates of occupational accidents	12 different countries
Idoro (2011)	The management efforts and performance for OHS	Construction contractors in Nigeria
Saracino *et al.* (2012)	Health and safety management system development	Small- and large-size companies
Priyadarshani *et al.* (2013)	A benchmark to measure construction safety via utilizing the proposed safety management assessment framework	Construction sites in Sri Lanka
Yakubu and Bakri (2013)	Safety and health performance of contractors	Construction sites
Han *et al.* (2014)	Schedule delays and rework as critical variables affecting safety performance	Construction sites
Ghasemi *et al.* (2015)	The effectiveness of a new incentive system and the surprising incentive system interm of safety performance of frontline employees	Construction sites
İnan *et al.* (2017)	Firms' OHS management system performances	Companies
Reference	Focal point	Integration with the other method
MAIRCA-related studies		
Gigovic *et al.* (2016)	To identify suitable locations for ammunition depots	Geographic Information System (GIS)
Pamučar *et al.* (2017)	To select contractor companies to state public contracts	–
Badi and Ballem (2018)	To handle a problem regarding supplier selection	Rough numbers and the best-worst method (BWM)
Mamak Ekinci and Can (2018)	To evaluate the ergonomic risk levels that operators	Criteria Importance through Intercriteria Correlation (CRITIC)

Table I. Literature review summary

considered as the main criteria (MC_z, $z = 1, 2$). On the other hand, as can be seen from Figure 1, the EEAs form the sub-criteria (MC_{zk}, $z = 1, 2$; $k = 1, \ldots, 6$).

When the ILO records are reviewed, it is determined that 15 countries conform to the no-data-loss condition between the years 2009 and 2015. These constitute the set of

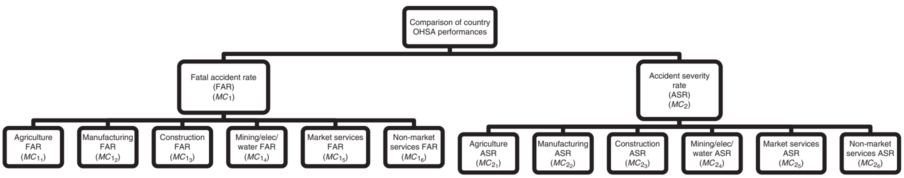

Figure 1. Criteria set

Table II.
Six EEAs

Aggregate economic activity	Sector code	EEA number
Agriculture	A	1
Non-agriculture		
Industry		
Manufacturing	C	2
Construction	F	3
Mining and quarrying; electricity, gas and water supply	B, D, E	4
Services		
Market services (trade, transportation, accommodation and food, business and administrative services)	G, H, I, J, K, L, M, N	5
Non-market services (public administration, community, social and other services and activities)	O, P, Q, R, S, T,	6

alternatives (A_i; $i=1, 2, \ldots, 15$) as Bulgaria (A_1), Cyprus (A_2), Estonia (A_3), France (A_4), Hungary (A_5), Ireland (A_6), Lithuania (A_7), Poland (A_8), Portugal (A_9), Romania (A_{10}), Slovakia (A_{11}), Slovenia (A_{12}), Spain (A_{13}), Switzerland (A_{14}) and Turkey (A_{15}). Additionally, the 20 sectors that make up the EEAs are expressed through S_j; $j=a, b, \ldots, t$, each EEA is expressed through EEA_k; $k=1, 2, \ldots, 6$, and the years to which the data belongs are expressed through Y_l; $l=2009, 2010, \ldots, 2015$.

Step 1.1: obtaining the FAR values for each EEA. Considering the classification of the 20 sectors into six different EEAs, the following equation is used to calculate the six different NFAs for the countries in the respective years:

$$NFA_{ikl} = \sum_{j=a}^{t} NFA_{ijl}, \tag{1}$$

where NFA_{ikl} refers to the NFA value of i country for k EEA belonging to l year, whereas NFA_{ijl} refers to the NFA value of i country for j sector (determined according to Table I) belonging to l year. In the follwing equations, the equations for the first and sixth EEA are presented:

$$NFA_{i1l} = NFA_{ial}, \tag{2}$$

$$NFA_{i6l} = NFA_{iol} + NFA_{ipl} + NFA_{iql} + NFA_{irl} + NFA_{isl} + NFA_{itl}. \tag{3}$$

Using the NFA_{ikl} values along with the number of workers (NW) in each EEA for the relevant country, the FAR values for six of the EEAs of each country are calculated using the following equation:

$$FAR_{ikl} = \frac{NFA_{ikl}}{NW_{ikl}} \times 100, \tag{4}$$

where FAR_{ikl}; refers to the FAR value of i country for k EEA belonging to l year, whereas NW_{ikl} refers to the number of workers of i country for k EEA in belonging to l year. The NW_{ikl} values for Turkey are provided as an example in Table AI. The reason why the multiplication factor is 100 in Equation (4) is because the NW given for each EEA is in the form of ×1,000 (Table AI). The FAR value of all years combined for each EEA of a country is calculated as follows:

$$FAR_{ik} = \frac{\sum_{l=2009}^{2015} NFA_{ikl}}{\sum_{l=2009}^{2015} NW_{ikl}}, \tag{5}$$

where FAR_{ik} refers to the FAR value of i country for k EEA considering all years within the range. The FAR_{ikl} and FAR_{ik} values for Slovakia, Slovenia, Switzerlanda, Spain and Turkey have been provided as examples in Table AII. Furthermore, the FAR_{ik} values of seven years for each EEA for all countries are added, as shown in the following equation, and the FAR value specific to the EEA, $FAREEA_k$, is found:

$$FAREEA_k = \sum_{i=1}^{15} FAR_{ik}; k = 1, 2, \ldots 6, \tag{6}$$

where $FAREEA_k$ refers to the total of all FAR values for all countries for EEA_k. The arithmetic average of all $FAREEA_k$ values ($FAREEA_{art.av}$) and the ratio of each $FAREEA_k$ to the arithmetic average ($R_{FAREEA_{art.av}}$) are obtained by the respective equations:

$$FAREEA_{art.av} = \frac{\sum_{k=1}^{6} \mathrm{FAREEA}_k}{6}, \tag{7}$$

$$R_{FAREEA_{art.avk}} = \frac{\mathrm{FAREEA}_k}{FAREEA_{art.av}}. \tag{8}$$

The geometric average of all $FAREEA_k$ values ($FAREEA_{geo.av}$) and the ratio of each $FAREEA_k$ to the geometric average ($R_{FAREEA_{geo.av}}$) are obtained by Equations (9) and (10) respectively. The $FAREEA_k$, $R_{FAREEA_{art.av}}$ and $R_{FAREEA_{geo.av}}$ values are presented in Table III:

$$FAREEA_{geo.av} = \prod_{k=1}^{6} \mathrm{FAREEA}_k^{1/6}, \tag{9}$$

	Average yearly working hours (man-hours)						
A_i	2009	2010	2011	2012	2013	2014	2015
A_1	1,778	1,777	1,772	1,742	1,732	1,734	1,734
A_2	1,906	1,909	1,886	1,867	1,878	1,886	1,894
A_3	1,831	1,875	1,919	1,886	1,866	1,859	1,852
A_4	1,521	1,528	1,534	1,529	1,514	1,509	1,510
A_5	1,781	1,777	1,770	1,750	1,744	1,751	1,749
A_6	1,713	1,702	1,702	1,707	1,720	1,731	1,741
A_7	1,863	1,884	1,859	1,857	1,841	1,833	1,860
A_8	1,948	1,940	1,938	1,929	1,918	1,923	1,963
A_9	1,887	1,890	1,867	1,849	1,859	1,867	1,875
A_{10}	1,687	1,694	1,689	1,677	1,670	1,666	1,672
A_{11}	1,780	1,805	1,793	1,789	1,772	1,760	1,754
A_{12}	1,678	1,680	1,663	1,644	1,662	1,682	1,688
A_{13}	1,720	1,710	1,715	1,701	1,693	1,694	1,699
A_{14}	1,651	1,624	1,619	1,603	1,583	1,575	1,589
A_{15}	1,881	1,877	1,864	1,855	1,832	1,835	1,832

Table III. Average yearly working hours of an employee by country

$$R_{FAREEA_{geo.av_k}} = \frac{\mathrm{FAREEA}_k}{FAREEA_{geo.av}}. \tag{10}$$

Step 1.2: obtaining the ASR values for each EEA. Considering the classification of the 20 sectors into six different EEAs, the following equation is used to calculate the six different NLDs for the countries in the respective years:

$$NLD_{ikl} = \sum_{j=a}^{t} NLD_{ijl}, \tag{11}$$

where NLD_{ikl}; refers to the NLD value of i country for k EEA belonging to l year, whereas NLD_{ijl} refers to the NFA value of i country for j sector (determined according to Table I) belonging to l year. The NLD value for the first and sixth EEA is obtained by using the following:

$$NLD_{i1l} = NLD_{ial}, \tag{12}$$

$$NLD_{i6l} = NLD_{iol} + NLD_{ipl} + NLD_{iql} + NLD_{irl} + NLD_{isl} + NLD_{itl}. \tag{13}$$

On the other hand, in order to calculate the ASR for each EEA in every country, the respective NLD_{ikl} value must be divided by the total working hours. In order to obtain the working hours, the NW_{ikl} value is multiplied by the yearly average working hours per employee (AWH_{il}) for each country which is published by the Organization for Economic Cooperation and Development (www.ilo.org/global/statistics-and-databases/standards-and-guidelines/resolutions-adopted-by-international-conferences-of-labour-statisticians/WCMS_087528/lang–en/index.htm, 2018). The yearly average working hours of countries is given in Table III.

However, as the value obtained by multiplying the NW_{ikl} and AWH_{il} values also includes the hours that should have been lost due to occurred accidents, the days and hours lost that correspond to these accidents must be subtracted. In order to achieve this, the ASR values of EEA for countries are obtained as follows:

$$ASR_{ikl} = \frac{NLD_{ikl}}{(NW_{ikl} \times 1,000 \times AWH_{il}) - (NLD_{ikl} \times 7.5)} \times 1{,}000{,}000, \tag{14}$$

where the reason for multiplying the NLD_{ikl} value by 7.5 is because 7.5 h is universally considered as the daily average working time. Thus, the ASR values of 15 countries for six different EEAs for each year are obtained. The ASR values for each EEA of every country considering all seven years is obtained as follows:

$$ASR_{ik} = \frac{\sum_{l=2009}^{2015} NLD_{ikl}}{\sum_{l=2009}^{2015} (NW_{ikl} \times AWH_{il}) - (NLD_{ikl} \times 7.5)} \times 1{,}000{,}000, \tag{15}$$

where ASR_{ik} refers to the ASR value of i country for k EEA considering all years within the range. The 1,000,000 value in Equation (15) is the factor for total working hours (14). Furthermore, the ASR_{ik} values of seven years for each EEA for all countries are added as follows and the ASR value specific to the EEA, $ASREEA_k$, is found:

$$ASREEA_k = \sum_{i=1}^{15} KAO_{ik}; k = 1, 2, \ldots 6. \quad (16)$$

The arithmetic average of all $ASREEA_k$ values ($ASREEA_{art.av}$) and the ratio of each $ASREEA_k$ to the arithmetic average ($R_{ASREEA_{art.av}}$) are obtained by the following equations, respectively:

$$ASREEA_{art.av} = \frac{\sum_{k=1}^{6} \mathrm{ASREEA}_k}{6}, \quad (17)$$

$$R_{ASREEA_{art.av_k}} = \frac{\mathrm{ASREEA}_k}{ASREEA_{art.av}}. \quad (18)$$

The geometric average of all $ASREEA_k$ values ($ASREEA_{geo.av}$) and the ratio of each $ASREEA_k$ to the geometric average ($R_{ASREEA_{geo.av}}$) are obtained by the following equations, respectively:

$$ASREEA_{geo.av} = \prod_{k=1}^{6} \mathrm{ASREEA}_k^{1/6}, \quad (19)$$

$$R_{ASREEA_{geo.av_k}} = \frac{\mathrm{ASREEA}_k}{ASREEA_{geo.av}}. \quad (20)$$

The ASR_{ikl} and ASR_{ik} values for Slovakia, Slovenia, Switzerland, Spain and Turkey have been provided as examples in Table AIII. The $ASREEA_k$, $R_{ASREEA_{art.av}}$ and $R_{ASREEA_{geo.av}}$ values are presented in Table IV.

Step 1.3: obtaining the importance weights for EEA's with four different methods. In the study, four different methods to determine the importance weights (w_{zk}; $z = 1, 2$; $k = 1, \ldots, 6$) of the EEAs. The first method utilizes the arithmetic ratios ($R_{FAREEA_{art.av_k}}$ and $R_{ASREEA_{art.av_k}}$) without any additional factor. The second method utilizes the arithmetic ASR ratio ($R_{ASREEA_{art.av_k}}$) without any modification; however, the arithmetic ratio of the FAR values

EEA_k	$FAREEA_k$	$R_{FAREEA_{art.av_k}}$	$R_{\mathrm{FAREEA}_{geo.av_k}}$	ASREEA_k	$R_{ASREEA_{art.av_k}}$	$R_{ASREEA_{geo.av_k}}$
EEA_1	74.4918	0.9811	1.3175	1,303.8106	0.5726	0.6443
EEA_2	40.5942	0.5347	0.7179	2,572.8862	1.1299	1.2715
EEA_3	149.2937	1.9663	2.6404	3,999.2435	1.7563	1.9763
EEA_4	140.5417	1.8511	2.4856	3,162.6038	1.3889	1.5629
EEA_5	36.5317	0.4812	0.6461	1,633.1949	0.7172	0.8071
EEA_6	14.0978	0.1857	0.2493	990.8306	0.4351	0.4896
Total	455.5508	6.0000	8.0568	13,662.5696	6.0000	6.7518
Arithmetic average	75.9251			2,277.0949	–	–
Geometric average	56.5423			2,023.5589	–	–

Table IV. $FAREEA_k$, $R_{\mathrm{FAREEA}_{art.av_k}}$, $R_{\mathrm{FAREEA}_{geo.av_k}}$, $ASREEA_k$, $R_{ASREEA_{art.av_k}}$ and $R_{ASREEA_{geo.av_k}}$ values for EAAs

($R_{FAREEA_{art.av_k}}$) is multiplied with a factor of 6,000 with the assumption that a death has 6,000 equivalent lost days (www.ilo.org/wcmsp5/groups/public/—dgreports/—stat/documents/meetingdocument/wcms_088373.pdf, 2018; www.cdc.gov/niosh/mining/UserFiles/data/codes.pdf, 2018; Probst *et al.*, 2008). The third method utilizes the geometric ratios ($R_{FAREEA_{geo.av_k}}$ and $R_{ASREEA_{geo.av_k}}$) without any additional modifications. The fourth ratio utilizes the geometric ASR ratio ($R_{ASREEA_{geo.av_k}}$) without any alteration while the geometric FAR ratio ($R_{FAREEA_{geo.av_k}}$) is once again multiplied by the 6,000 equivalent lost days factor. The criteria importance weights of the first and second methods are presented in Table V, whereas the weights for the third and fourth methods are presented in Table VI.

When Table V is examined, it is seen that the most hazardous EEA in terms of FAR is Construction (EFA_3) followed by mining-quarrying, electricity, gas and water supply (EEA_4) which both have similar weights, whereas the least hazardous EEA is

Table V. The weights of EAAs for the first and second methods

		First method		Second method	
MC_1	EEA_k	$R_{FAREEA_{Art.av_k}}$	w_{1k} (%)	$R_{FAREEA_{Art.av_k}} \times 6{,}000$	w_{1k} (%)
FAR	EEA_1	0.9811	8.1760	5,886.7263	16.3493
	EEA_2	0.5347	4.4555	3,207.9631	8.9095
	EEA_3	1.9663	16.3861	11,797.9667	32.7667
	EEA_4	1.8511	15.4255	11,106.3402	30.8458
	EEA_5	0.4812	4.0096	2,886.9253	8.0179
	EEA_6	0.1857	1.5473	1,114.0784	3.0941
MC_2	EEA_k	$R_{ASREEA_{Art.av_k}}$	w_{2k}	$R_{ASREEA_{Art.av_k}}$	w_{2k}
ASR	EEA_1	0.5726	4.7715	0.5726	0.0016
	EEA_2	1.1299	9.4158	1.1299	0.0031
	EEA_3	1.7563	14.6358	1.7563	0.0049
	EEA_4	1.3889	11.5740	1.3889	0.0039
	EEA_5	0.7172	5.9769	0.7172	0.0020
	EEA_6	0.4351	3.6261	0.4351	0.0012
Total		12.0000	100		

Table VI. The weights of EAAs for the third and fourth methods

		Third method		Fourth method	
MC_1	EEA_k	$R_{FAREEA_{Geo.av_k}}$	w_{1k} (%)	$R_{FAREEA_{Geo.av_k}} \times 6{,}000$	w_{1k} (%)
ÖKO	EEA_1	1.3175	8.8966	7,904.7168	16.3497
	EEA_2	0.7179	4.8482	4,307.6642	8.9098
	EEA_3	2.6404	17.8302	15,842.3514	32.7676
	EEA_4	2.4856	16.7849	14,913.6329	30.8466
	EEA_5	0.6461	4.3630	3,876.5735	8.0181
	EEA_6	0.2493	1.6837	1,495.9884	3.0942
MC_2	EEA_k	$R_{ASREEA_{Geo.av_k}}$	w_{2k}	$R_{ASREEA_{Geo.av_k}}$	w_{2k}
KAO	EEA_1	0.6443	4.3510	0.6443	0.0013
	EEA_2	1.2715	8.5860	1.2715	0.0026
	EEA_3	1.9763	13.3459	1.9763	0.0041
	EEA_4	1.5629	10.5540	1.5629	0.0032
	EEA_5	0.8071	5.4502	0.8071	0.0017
	EEA_6	0.4896	3.3065	0.4896	0.0010
Total		14.8086	100		

non-market services (EEA_6). When the situation is examined in terms of ASR, it is seen that there is no change in the aforementioned order. As this method utilizes an arithmetic average with no additional factoring, it is seen that the sub-totals of the weights for the FARs and ASRs both contribute to a total of 50 percent each. As can be seen from Table IV, the weights for the most and least hazardous EEAs are ranked the same as in the first method. However, as this method utilizes the multiplication of FARs with the 6,000 equivalent lost days factor, the importance of the ASRs has been reduced to much lower levels. Correspondingly, the importance weights of the FARs have almost doubled. In this method, utilizing arithmetic averages, as the FAR weights are multiplied with 6,000, their sub-total of the weights corresponds to 99.98 percent of the total whereas the sub-total of the weights of the ASRs were reduced to 0.02 percent.

When Table VI is examined, it is seen that there is no change in the most and least hazardous EEAs in the third method. As this method utilizes ratios stemming from geometric averages instead of arithmetic averages without any additional factors, the importance weights of FARs and ASRs are not equally distributed as they were in the first method. Here, the sub-total weights of the FARs make up 54.41 percent of the total, whereas the weights of the ASR contribute to 45.59 percent. As can again be seen from Table V, the most and least hazardous EEAs have not changed in the fourth method as well. Since the fourth method utilizes ratios based on a geometric average with the FAR weights being modified with the 6,000 equivalent lost days factor, the difference between the FAR and ASR weights is even larger than that in the second method. The sub-total weights regarding FARs make up 99.99 percent of the total, whereas the ASR weights contribute only 0.01 percent.

Step 2: ranking countries with MAIRCA. The implementation of MAIRCA is explained below by exemplifying it on the first weighting method. The results for the other methods were obtained through the same implementation.

Step 2.1: formation of the initial decision matrix. The initial decision matrix [B] that shows the values of the alternatives according to the criteria, as given in Equation (21) is formed by the alternatives depicted by A_i; $i=1, 2, \ldots, m$, main criteria depicted by MC_z; $z=1, 2, \ldots, x$, and sub-criteria depicted by MC_{zk}; $z=1, 2, \ldots, x$; $k=1, \ldots, y$. Two separate [B] were formed in the study. The first initial decision matrix consists of the values of the NFAs and NLDs of countries. These values are referred to as recorded data in the study. The second initial decision matrix consists of the FAR and ASR values of the countries. The first initial decision matrix is given as an example in Table VII:

$$B = \left[b_{i_{zk}}\right] = \begin{bmatrix} b_{1_{11}} & b_{1_{12}} & \cdots & b_{1_{xy}} \\ b_{2_{11}} & b_{2_{12}} & \cdots & b_{2_{xy}} \\ \vdots & \vdots & \vdots & \vdots \\ b_{m_{11}} & b_{m_{12}} & \cdots & b_{m_{xy}} \end{bmatrix}, \tag{21}$$

where b_{izk} refers to the value of i alternative for k sub-criteria in z main criteria.

Step 2.2: normalization of the initial decision matrix. The components of [B] are normalized in two different ways according to whether they are benefit or cost type criteria by using Equations (22) and (23). It is important for the selection of alternatives that they attain low values for cost type criteria and attain high values for benefit type criteria. The normalized decision matrix is depicted with [N] while with each of its components are

Table VII. First initial decision matrix

Countries	NFA (MC_1)					
	Agriculture (MC_{1_1})	Construction (MC_{1_2})	Manufacturing (MC_{1_3})	Mining and quarrying; electricity, gas and water supply (MC_{1_4})	Market services (MC_{1_5})	Non-market services (MC_{1_6})
Bulgaria (A_1)	6.4286	21.2857	21.5714	10.2857	32.0000	4.2857
Cyprus (A_2)	1.0000	3.0000	1.1429	0.1429	2.2857	1.0000
Estonia (A_3)	1.2857	4.2857	2.2857	0.7143	6.2857	2.5714
France (A_4)	8.7143	125.7143	79.1429	17.0000	272.5714	48.8571
Hungary (A_5)	10.5714	21.8571	11.5714	3.8571	27.1429	5.5714
Ireland (A_6)	21.7143	7.4286	1.7143	3.0000	7.5714	2.5714
Lithuania (A_7)	7.5714	12.7143	6.8571	3.1429	19.2857	2.7143
Poland (A_8)	18.7143	86.8571	66.1429	42.8571	106.4286	29.0000
Portugal (A_9)	26.7143	55.4286	26.5714	8.2857	57.2857	5.4286
Romania (A_{10})	34.8571	73.4286	66.7143	23.8571	96.2857	17.2857
Slovakia (A_{11})	5.1429	8.2857	9.7143	2.7143	19.4286	2.2857
Slovenia (A_{12})	1.8571	7.8571	5.1429	0.4286	6.2857	1.1429
Spain (A_{13})	40.8571	83.1429	52.8571	13.2857	112.1429	24.2857
Switzerland (A_{14})	4.4286	17.5714	11.1429	2.7143	24.4286	8.2857
Turkey (A_{15})	18.0000	422.0000	228.4286	150.5714	315.8571	192.0000

Countries	NLD (MC_2)					
	Agriculture (MC_{2_1})	Construction (MC_{2_2})	Manufacturing (MC_{2_3})	Mining and quarrying; electricity, gas and water supply (MC_{2_4})	Market services (MC_{2_5})	Non-market services (MC_{2_6})
Bulgaria (A_1)	2,094.2857	7,823.0000	23,632.7143	10,083.5714	22,897.4286	12,311.4286
Cyprus (A_2)	554.4286	4,815.0000	5,146.0000	642.8571	8,916.8571	2,780.4286
Estonia (A_3)	9,598.8571	29,570.0000	59,012.5714	6,982.2857	34,183.2857	20,639.2857
France (A_4)	89,278.5714	1,753,462.5714	15,885,12.1429	173,235.5714	5,391,160.5714	2,799,443.8571
Hungary (A_5)	14,059.7143	16,194.2857	114,375.0000	14,332.7143	107,961.0000	57,787.1429
Ireland (A_6)	21,442.0000	24,931.7143	30,270.5714	6,534.7143	83,901.7143	82,213.1429
Lithuania (A_7)	2,904.0000	8,088.8571	16,818.5714	1,979.1429	20,268.7143	10,602.7143
Poland (A_8)	42,729.5714	257,207.8571	798,932.5714	209,357.8571	674,940.8571	433,038.0000
Portugal (A_9)	125,994.2857	546,196.4286	700,465.0000	61,095.7143	1,061,860.4286	201,893.1429
Romania (A_{10})	3,558.0000	12,115.0000	35,893.7143	11,401.4286	21,593.0000	5,506.1429
Slovakia (A_{11})	11,822.0000	11,257.0000	67,654.2857	7,254.1429	49,121.5714	19,565.8571
Slovenia (A_{12})	7,604.1429	34,960.0000	86,133.8571	12,308.1429	77,821.5714	43,241.1429
Spain (A_{13})	498,702.0000	1,106,211.5714	1,360,539.1429	204,553.1429	2,917,571.4286	1,673,990.8571
Switzerland (A_{14})	31,726.7143	379,136.5714	234,739.5714	23,338.4286	642,576.8571	225,009.5714
Turkey (A_{15})	19,940.7143	358,939.1429	976,575.7143	200,224.8571	378,863.5714	50,351.1429

depicted by n_{izk}:

$$\text{For cost type criteria} \quad n_{i_{zk}} = \frac{b_{zk}^{\max} - b_{i_{zk}}}{b_{zk}^{\max} - b_{zk}^{\min}}, \tag{22}$$

$$\text{For benefit type criteria} \quad n_{i_{zk}} = \frac{b_{i_{zk}} - b_{zk}^{\min}}{b_{zk}^{\max} - b_{zk}^{\min}}, \tag{23}$$

where n_{izk} refers to the normalized value of b_{izk}, $b_{zk}^{\min}$ refers to the lowest value among the alternatives belonging to k sub-criterion in z main criterion and $b_{zk}^{\max}$ refers to the largest value among the alternatives belonging to k sub-criterion in z main criterion. As all the criteria used in the study are cost type criteria, [N] is formulated as below by use of Equation (22):

$$N=\begin{bmatrix}0.8638&0.9564&0.9101&0.9326&0.9052&0.9828&0.9969&0.9983&0.9883&0.9548&0.9974&0.9966\\1.0000&1.0000&1.0000&1.0000&1.0000&1.0000&1.0000&1.0000&1.0000&1.0000&1.0000&1.0000\\0.9928&0.9969&0.9950&0.9962&0.9872&0.9918&0.9818&0.9858&0.9660&0.9696&0.9953&0.9936\\0.8065&0.7071&0.6568&0.8879&0.1380&0.7494&0.8219&0.0000&0.0000&0.1731&0.0000&0.0000\\0.7599&0.9550&0.9541&0.9753&0.9207&0.9761&0.9729&0.9935&0.9310&0.9344&0.9816&0.9803\\0.4803&0.9894&0.9975&0.9810&0.9831&0.9918&0.9581&0.9885&0.9841&0.9718&0.9861&0.9716\\0.8351&0.9768&0.9749&0.9801&0.9458&0.9910&0.9953&0.9981&0.9926&0.9936&0.9979&0.9972\\0.5556&0.7999&0.7140&0.7160&0.6679&0.8534&0.9153&0.8557&0.4987&0.0000&0.8763&0.8462\\0.3548&0.8749&0.8881&0.9459&0.8246&0.9768&0.7482&0.6904&0.5609&0.7104&0.8044&0.9288\\0.1505&0.8319&0.7115&0.8424&0.7002&0.9147&0.9940&0.9958&0.9806&0.9485&0.9976&0.9990\\0.8961&0.9874&0.9623&0.9829&0.9453&0.9933&0.9774&0.9963&0.9605&0.9683&0.9925&0.9940\\0.9785&0.9884&0.9824&0.9981&0.9872&0.9993&0.9858&0.9828&0.9489&0.9441&0.9872&0.9855\\0.0000&0.8087&0.7725&0.9126&0.6497&0.8781&0.0000&0.3701&0.1440&0.0230&0.4596&0.4024\\0.9140&0.9652&0.9560&0.9829&0.9294&0.9619&0.9374&0.7859&0.8550&0.8913&0.8823&0.9205\\0.5735&0.0000&0.0000&0.0000&0.0000&0.0000&0.9611&0.7975&0.3865&0.0438&0.9313&0.9830\end{bmatrix}.$$

Step 2.3: the selection possibility determination of the alternatives and theoretical evaluation matrix formation. In the MAIRCA method, the possibility of choosing one out of m alternatives is $1/m$, and the selection possibility for each alternative (P_i) is equal to each other ($P_i = P_{i+1} = \cdots = P_m = 1/m$). In the study, the selection of each country based on their OHS performance is $P_i = 1/15 = 0.0667$. The theoretical evaluation matrix $[T]$ is obtained by multiplying the criteria weights (w_{zk}) with the $P_i = 1/m$ value as shown in the following equation:

$$[T]=\left[t_{i_{zk}}\right]=\begin{matrix}P_1\\P_2\\\vdots\\P_m\end{matrix}\begin{bmatrix}t_{1_{11}}&t_{1_{12}}&\cdots&t_{1_{xy}}\\t_{2_{11}}&t_{1_{12}}&\cdots&t_{2_{xy}}\\\vdots&\vdots&\vdots&\vdots\\t_{m_{11}}&t_{1_{12}}&\cdots&t_{m_{xy}}\end{bmatrix}=\begin{bmatrix}P_1w_{11}&P_1w_{12}&\cdots&P_1w_{xy}\\P_2w_{11}&P_2w_{12}&\cdots&P_2w_{xy}\\\vdots&\vdots&\vdots&\vdots\\P_mw_{11}&P_mw_{12}&\cdots&P_mw_{xy}\end{bmatrix},\qquad(24)$$

where $t_{i_{zk}}$ refers to the theoretical preference value of i alternative for k sub-criterion in z main criterion. The importance weights according to the first method are as presented in Table IV. The $[T]$ formed by multiplying these weights with the $P_i = 0.0667$ value is given as follows:

$$[T]=\begin{bmatrix}0.0055&0.0109&0.0030&0.0103&0.0027&0.0010&0.0032&0.0098&0.0063&0.0077&0.0040&0.0024\\0.0055&0.0109&0.0030&0.0103&0.0027&0.0010&0.0032&0.0098&0.0063&0.0077&0.0040&0.0024\\0.0055&0.0109&0.0030&0.0103&0.0027&0.0010&0.0032&0.0098&0.0063&0.0077&0.0040&0.0024\\0.0055&0.0109&0.0030&0.0103&0.0027&0.0010&0.0032&0.0098&0.0063&0.0077&0.0040&0.0024\\0.0055&0.0109&0.0030&0.0103&0.0027&0.0010&0.0032&0.0098&0.0063&0.0077&0.0040&0.0024\\0.0055&0.0109&0.0030&0.0103&0.0027&0.0010&0.0032&0.0098&0.0063&0.0077&0.0040&0.0024\\0.0055&0.0109&0.0030&0.0103&0.0027&0.0010&0.0032&0.0098&0.0063&0.0077&0.0040&0.0024\\0.0055&0.0109&0.0030&0.0103&0.0027&0.0010&0.0032&0.0098&0.0063&0.0077&0.0040&0.0024\\0.0055&0.0109&0.0030&0.0103&0.0027&0.0010&0.0032&0.0098&0.0063&0.0077&0.0040&0.0024\\0.0055&0.0109&0.0030&0.0103&0.0027&0.0010&0.0032&0.0098&0.0063&0.0077&0.0040&0.0024\\0.0055&0.0109&0.0030&0.0103&0.0027&0.0010&0.0032&0.0098&0.0063&0.0077&0.0040&0.0024\\0.0055&0.0109&0.0030&0.0103&0.0027&0.0010&0.0032&0.0098&0.0063&0.0077&0.0040&0.0024\\0.0055&0.0109&0.0030&0.0103&0.0027&0.0010&0.0032&0.0098&0.0063&0.0077&0.0040&0.0024\\0.0055&0.0109&0.0030&0.0103&0.0027&0.0010&0.0032&0.0098&0.0063&0.0077&0.0040&0.0024\\0.0055&0.0109&0.0030&0.0103&0.0027&0.0010&0.0032&0.0098&0.0063&0.0077&0.0040&0.0024\end{bmatrix},$$

Step 2.4: the real evaluation matrix formation. The real evaluation matrix R, is obtained by multiplying the theoretical evaluation matrix T by the normalized decision matrix N as shown in the following equation:

$$R = \left[r_{i_{zk}}\right] = \begin{bmatrix} r_{1_{11}} & r_{1_{12}} & \cdots & r_{1_{xy}} \\ r_{2_{11}} & r_{2_{12}} & \cdots & r_{2_{xy}} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m_{11}} & r_{m_{12}} & \cdots & r_{m_{xy}} \end{bmatrix} = \begin{bmatrix} t_{1_{11}} n_{1_{11}} & t_{1_{12}} n_{1_{12}} & \cdots & t_{1_{xy}} n_{1_{xy}} \\ t_{2_{11}} n_{2_{11}} & t_{1_{12}} n_{1_{12}} & \cdots & t_{2_{xy}} n_{2_{xy}} \\ \vdots & \vdots & \vdots & \vdots \\ t_{m_{11}} n_{m_{11}} & t_{m_{12}} n_{m_{12}} & \cdots & t_{m_{xy}} n_{m_{xy}} \end{bmatrix}, \quad (25)$$

where $r_{i_{zk}}$ refers to the real value of i alternative for k sub-criterion in z main criterion The $[R]$ that consists of the real evaluation values of the countries is formed as below using Equation (25):

$$[R] = \begin{bmatrix} 0.0047 & 0.0104 & 0.0027 & 0.0096 & 0.0024 & 0.0010 & 0.0032 & 0.0097 & 0.0062 & 0.0074 & 0.0040 & 0.0024 \\ 0.0055 & 0.0109 & 0.0030 & 0.0103 & 0.0027 & 0.0010 & 0.0032 & 0.0098 & 0.0063 & 0.0077 & 0.0040 & 0.0024 \\ 0.0054 & 0.0109 & 0.0030 & 0.0102 & 0.0026 & 0.0010 & 0.0031 & 0.0096 & 0.0061 & 0.0075 & 0.0040 & 0.0024 \\ 0.0044 & 0.0077 & 0.0020 & 0.0091 & 0.0004 & 0.0008 & 0.0026 & 0.0000 & 0.0000 & 0.0013 & 0.0000 & 0.0000 \\ 0.0041 & 0.0104 & 0.0028 & 0.0100 & 0.0025 & 0.0010 & 0.0031 & 0.0097 & 0.0058 & 0.0072 & 0.0039 & 0.0024 \\ 0.0026 & 0.0108 & 0.0030 & 0.0101 & 0.0026 & 0.0010 & 0.0030 & 0.0096 & 0.0062 & 0.0075 & 0.0039 & 0.0023 \\ 0.0046 & 0.0107 & 0.0029 & 0.0101 & 0.0025 & 0.0010 & 0.0032 & 0.0097 & 0.0062 & 0.0077 & 0.0040 & 0.0024 \\ 0.0030 & 0.0087 & 0.0021 & 0.0074 & 0.0018 & 0.0009 & 0.0029 & 0.0083 & 0.0031 & 0.0000 & 0.0035 & 0.0020 \\ 0.0019 & 0.0096 & 0.0026 & 0.0097 & 0.0022 & 0.0010 & 0.0024 & 0.0067 & 0.0035 & 0.0055 & 0.0032 & 0.0022 \\ 0.0008 & 0.0091 & 0.0021 & 0.0087 & 0.0019 & 0.0009 & 0.0032 & 0.0097 & 0.0062 & 0.0073 & 0.0040 & 0.0024 \\ 0.0049 & 0.0108 & 0.0029 & 0.0101 & 0.0025 & 0.0010 & 0.0031 & 0.0097 & 0.0060 & 0.0075 & 0.0040 & 0.0024 \\ 0.0053 & 0.0108 & 0.0029 & 0.0103 & 0.0026 & 0.0010 & 0.0031 & 0.0096 & 0.0060 & 0.0073 & 0.0039 & 0.0024 \\ 0.0000 & 0.0088 & 0.0023 & 0.0094 & 0.0017 & 0.0009 & 0.0000 & 0.0036 & 0.0009 & 0.0002 & 0.0018 & 0.0010 \\ 0.0050 & 0.0105 & 0.0028 & 0.0101 & 0.0025 & 0.0010 & 0.0030 & 0.0077 & 0.0054 & 0.0069 & 0.0035 & 0.0022 \\ 0.0031 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0031 & 0.0078 & 0.0024 & 0.0003 & 0.0037 & 0.0024 \end{bmatrix}.$$

Step 2.5: total difference matrix formation. The total difference matrix $[G]$, is obtained by subtracting R from T as shown in the following equation:

$$[G] = \left[g_{i_{zk}}\right] = \begin{bmatrix} g_{1_{11}} & g_{1_{12}} & \cdots & g_{1_{xy}} \\ g_{2_{11}} & g_{2_{12}} & \cdots & g_{2_{xy}} \\ \vdots & \vdots & \vdots & \vdots \\ g_{m_{11}} & g_{m_{12}} & \cdots & g_{m_{xy}} \end{bmatrix}$$

$$= \begin{bmatrix} t_{1_{11}} - r_{1_{11}} & t_{1_{12}} - r_{1_{12}} & \cdots & t_{1_{xy}} - r_{1_{xy}} \\ t_{2_{11}} - r_{2_{11}} & t_{1_{12}} - r_{1_{12}} & \cdots & t_{2_{xy}} - r_{2_{xy}} \\ \vdots & \vdots & \vdots & \vdots \\ t_{m_{11}} - r_{m_{11}} & t_{m_{12}} - r_{m_{12}} & \cdots & t_{m_{xy}} - r_{m_{xy}} \end{bmatrix}, \quad (26)$$

where $g_{i_{zk}}$ refers to the difference value of i alternative for k sub-criterion in z main criterion. The total difference matrix $[G]$ for countries is obtained as below by using

Equation (26):

$$[G]=\begin{bmatrix}
0.0007 & 0.0005 & 0.0003 & 0.0007 & 0.0003 & 0.0000 & 0.0000 & 0.0000 & 0.0001 & 0.0003 & 0.0000 & 0.0000\\
0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000\\
0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0001 & 0.0001 & 0.0002 & 0.0002 & 0.0000 & 0.0000\\
0.0011 & 0.0032 & 0.0010 & 0.0012 & 0.0023 & 0.0003 & 0.0006 & 0.0098 & 0.0063 & 0.0064 & 0.0040 & 0.0024\\
0.0013 & 0.0005 & 0.0001 & 0.0003 & 0.0002 & 0.0000 & 0.0001 & 0.0001 & 0.0004 & 0.0005 & 0.0001 & 0.0000\\
0.0028 & 0.0001 & 0.0000 & 0.0002 & 0.0000 & 0.0000 & 0.0001 & 0.0001 & 0.0001 & 0.0002 & 0.0001 & 0.0001\\
0.0009 & 0.0003 & 0.0001 & 0.0002 & 0.0001 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000\\
0.0024 & 0.0022 & 0.0008 & 0.0029 & 0.0009 & 0.0002 & 0.0003 & 0.0014 & 0.0031 & 0.0077 & 0.0005 & 0.0004\\
0.0035 & 0.0014 & 0.0003 & 0.0006 & 0.0005 & 0.0000 & 0.0008 & 0.0030 & 0.0028 & 0.0022 & 0.0008 & 0.0002\\
0.0046 & 0.0018 & 0.0009 & 0.0016 & 0.0008 & 0.0001 & 0.0000 & 0.0000 & 0.0001 & 0.0004 & 0.0000 & 0.0000\\
0.0006 & 0.0001 & 0.0001 & 0.0002 & 0.0001 & 0.0000 & 0.0001 & 0.0000 & 0.0002 & 0.0002 & 0.0000 & 0.0000\\
0.0001 & 0.0001 & 0.0001 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0002 & 0.0003 & 0.0004 & 0.0001 & 0.0000\\
0.0055 & 0.0021 & 0.0007 & 0.0009 & 0.0009 & 0.0001 & 0.0032 & 0.0061 & 0.0054 & 0.0075 & 0.0022 & 0.0014\\
0.0005 & 0.0004 & 0.0001 & 0.0002 & 0.0002 & 0.0000 & 0.0002 & 0.0021 & 0.0009 & 0.0008 & 0.0005 & 0.0002\\
0.0023 & 0.0109 & 0.0030 & 0.0103 & 0.0027 & 0.0010 & 0.0001 & 0.0020 & 0.0039 & 0.0074 & 0.0003 & 0.0000
\end{bmatrix}.$$

Step 2.6: calculating the criteria function values for the alternatives. The criteria function value for each alternative, Q_i, is calculated as in Equation (27). The alternatives are prioritized by ranking them according to a descending order of Q_i values. The alternative with the lowest Q_i value is the best alternative. However, as the country with the highest risk is being investigated in the study, the country with the highest Q_i value shall be the country with the highest level of risk. The Q_i values for each country obtained by integrating MAIRCA with the first weighting method are calculated as shown in the following equation and presented in Table VIII:

$$Q_i = \sum_{z=1}^{x}\sum_{k=1}^{y} g_{i_{zk}}. \tag{27}$$

As can be seen from Table VIII, the country with the lowest OHS performance according to the integration of MAIRCA with the first weighting method is Turkey and is thus determined to be the country with the highest risk level.

A_i	Country	Q_i	Ranking
A_1	Bulgaria	0.0029	10
A_2	Cyprus	0.0000	15
A_3	Estonia	0.0008	14
A_4	France	0.0384	2
A_5	Hungary	0.0036	9
A_6	Ireland	0.0039	8
A_7	Lithuania	0.0017	12
A_8	Poland	0.0228	4
A_9	Portugal	0.0160	5
A_{10}	Romania	0.0104	6
A_{11}	Slovakia	0.0018	11
A_{12}	Slovenia	0.0014	13
A_{13}	Spain	0.0360	3
A_{14}	Switzerland	0.0061	7
A_{15}	Turkey	0.0439	1

Table VIII. Q_i values for the integration of MAIRCA with the first weighting method

3. Results and suggestion

The obtained Q_i values and their respective rankings from the integration of the four different weighting methods into the MAIRCA method are presented in Table IX.

The "Method 1" term in Table IX refers to the integration of the first weighting method into the MAIRCA method. Similarly, "Method 2" refers to the integration of the second weighting method into the MAIRCA method. The same applies for "Method 3" and "Method 4." For the first method in the study, the weightings were obtained by utilizing the ratios of the FARs and ASRs for respective EEAs to their arithmetic averages and were projected to the MAIRCA method. In the second method, the ratio of FARs to their arithmetic averages were multiplied with the 6,000 Equivalent Lost Days factor and the weighting for FARs and ASRs were obtained and projected to the MAIRCA method. For each of these methods, the initial decision matrix in the MAIRCA method consists of the NFAs and NLDs data in the ILO records. In the third method, the weightings were obtained by utilizing the ratios of the FARs and ASRs for respective EEAs to their geometric averages and were projected to the MAIRCA method. In the fourth method, the ratio of FARs to their arithmetic averages were multiplied with the 6,000 equivalent lost days factor, and the weighting for FARs and ASRs were obtained and projected to the MAIRCA method. The initial decision matrix for these methods consisted of the FAR and ASR values, which is the reason for the utilization of the geometric average and ratio to the geometric average. When the obtained results are examined, it is seen that Turkey (A_{15}) was the country with the highest Q_i value in all methods except the third method. On the other hand, Cyprus (A_2) was the least dangerous country in the first two methods, whereas Slovakia (S_{11}) was determined to be the least dangerous country in the third and fourth methods. When the rankings of all four methods are examined, it is seen that no country has remained in the same position. The countries which have the least change in position were Turkey (A_{15}) (1-1-2-1), Ireland (A_6) (8-7-8-5) and Slovakia (A_{11}) (11-12-15-15).

According to the results of the first method, the most dangerous three countries with the highest Q_i values are Turkey, France and Spain. On the other hand, the three countries with the lowest Q_i values and thus the least dangerous are Cyprus, Estonia and Slovenia. These results obtained from the first method are not considered to be very accurate in terms of representing actual state of OHS performance and danger levels of countries around the world, with the exception of Turkey. The first reason for this is that this method used the data in the ILO records, meaning that the country population has a direct effect on the data

		Method 1		Method 2		Method 3		Method 4	
A_i	Country	Q_i	Rank	Q_i	Rank	Q_i	Rank	Q_i	Rank
A_1	Bulgaria	0.0029	10	0.0049	8	0.0103	12	0.0175	6
A_2	Cyprus	0.0000	15	0.0000	15	0.0101	13	0.0140	8
A_3	Estonia	0.0008	14	0.0003	14	0.0190	7	0.0131	9
A_4	France	0.0384	2	0.0180	5	0.0258	4	0.0102	13
A_5	Hungary	0.0036	9	0.0049	9	0.0090	14	0.0113	10
A_6	Ireland	0.0039	8	0.0064	7	0.0163	8	0.0189	5
A_7	Lithuania	0.0017	12	0.0032	10	0.0155	9	0.0260	3
A_8	Poland	0.0228	4	0.0188	4	0.0119	11	0.0105	11
A_9	Portugal	0.0160	5	0.0125	6	0.0418	1	0.0278	2
A_{10}	Romania	0.0104	6	0.0197	3	0.0121	10	0.0222	4
A_{11}	Slovakia	0.0018	11	0.0023	12	0.0070	15	0.0083	15
A_{12}	Slovenia	0.0014	13	0.0007	13	0.0226	6	0.0158	7
A_{13}	Spain	0.0360	3	0.0204	2	0.0284	3	0.0103	12
A_{14}	Switzerland	0.0061	7	0.0028	11	0.0255	5	0.0088	14
A_{15}	Turkey	0.0439	1	0.0604	1	0.0373	2	0.0555	1

Table IX.
Country Q_i values and rankings according to the four weighting methods

regarding the NW and thus the overall result. The second reason is due to both main criteria values being utilized without any sort of factoring between them. This means that an occupational fatality has similar weight levels with a day lost due to an occupational accident.

According to the results of the second method, which utilizes the same data of the ILO records but with the addition of the 6,000 equivalent lost days factor being used, it is observed that there are some changes in the ranking of the countries when compared to the results of the first method, but no major change of country rankings. Six countries appear to have the same ranking with the first method (A_2, A_3, A_5, A_8, A_{12}, A_{15}), whereas Switzerland (A_{14}) is shown to be the country that has had the greatest change in ranking (7–11). When logically considered, the utilization of the 6,000 factor in the second method gives slightly more realistic results when compared to the first method, but still the use of the raw data of the ILO records causes the population of countries to have a direct effect, thus failing to deliver the desired level of realistic results. In this sense, it can be said that the use of the arithmetic average does not have any distinctive effect on the ranking results. In the third method where FAR and ASR values are used instead of the ILO data, a more significant change is seen in the ranking of countries in comparison to the first two methods. Only Ireland (A_6) has the same ranking it had in the first method, while all other countries had their rankings changed. The country with the highest Q_i value and, thus, the most dangerous country according to the third method is Portugal (A_9), while Slovakia (A_{11}) has become the least dangerous country with the lowest Q_i value. Turkey (A_{15}), which was ranked to be the most dangerous country according to the first two methods went down to second place, whereas Cyprus (A_2) which was the least dangerous country according to the first two methods went up to 13th place. In this method, the changes in the rankings were more significant. The main reason for this is the use of ratios instead of ILO data, thus removing the effect of country population from the overall result.

When the results of the fourth method are examined, it stands out by providing the most realistic result among all the methods. Once again, Turkey (A_{15}) is the country with the highest Q_i value and thus the most dangerous country, whereas the least dangerous country with the lowest Q_i value is once again Slovakia (A_{11}) as in the third method. However, apart from these two, there have been significant changes in the rankings of the rest of the countries. France (A_4), which changed ranking between second and fifth place in the first three methods has gone back all the way to 13th place in the fourth method. Cyprus (A_2), which was one of the least dangerous countries according to the first three methods went up to 8th place in the fourth method. Considering that the effect of country populations were removed by utilizing FAR and ASR values, while also implementing the 6,000 equivalent lost days factor led to a much more sensible scaling between fatalities and lost days; the fourth method is believed to be the most accurate and realistic among all four methods. Additionally, the Q_i value of Cyprus (A_2) was found to be "0.00" in the first two methods. The reason for this is that the population of Cyprus is much lower in comparison to all other countries, resulting in much lower recorded ILO data values. In none of the other methods is there a country with a Q_i value of "0.00."

From the scope of the study, when evaluating the ranking results obtained from the four proposed weighting methods, it is not possible to claim that any of the results from any one of the methods has absolute accuracy. The main reason for this is that the recorded accidents in developing countries, such as Turkey, do not correspond to the actual accident statistics. While the lack of reporting and recording is at much lower levels in countries that shape the world economy such as France, Switzerland and Spain; it is possible to say that such levels are much higher in countries such as Turkey, Romania and Bulgaria. According to a research conducted by EUROSTAT and a study by Probst *et al.* (2008), non-reporting of accidents in companies without a developed HSE culture can go up to 80 percent. It was also stated that such levels were also possible when considering countries, especially in developing countries and countries where the insurance systems are not adequately inspected and audited by the state (Paksoy, 2015; İnan *et al.*, 2017). Nonetheless, it can be stated that an evaluation based on ratios for comparison of OHS performance will provide more realistic results. Additionally, increasing the effect of the FAR values using the 6,000 equivalent lost days factor is also important in terms of differentiating the data of the countries in question.

This study aims to develop an approach to compare OHS performances of countries without any subjectivity by using the recorded ILO data of countries that have no missing data. As such, only a total of 15 countries that have no missing data for 20 different industries within a certain number of years were identified from the ILO's recorded OHS data. It was determined that there was no loss of data for these countries in the period of 2009–2015, and the OHS data belonging to these years were used. The number of countries that can be reached with full data is the main limitation of the study. This limitation is also a shortcoming related to OHS evaluations for countries. The lack of sufficient information, even in the ILO registers, makes it difficult to determine the situation of countries in term of OHS. Yet, it is quite important for a country to compare its OHS performance with that of other countries in order to determine its current standing and what it must do in order to improve it (Gigović *et al.*, 2016).

The proposed approach completely removes subjectivity from evaluation process because this process is conducted solely based on the recorded OHS data of countries, without utilizing the opinions or views of experts.

Additionally, another aim of the study is to debate the impacts of using recorded data and ratios for OHS performance evaluations. For this aim, four different weighting procedure were employed in the study. It was attempted to determine whether the use of records in evaluating countries produced sensitive results. It was seen from the results, weighting procedure should be implemented based on ratio values considering 6,000 equivalent lost days factor. In this way, more logical rankings for countries were obtained.

In the future, a wider variety of data for countries can be obtained and an evaluation based on such data can be made. Different criteria weights can be obtained using different methods in line with OHS logic. Different criteria can be considered to evaluate the OHS performances of countries. Evaluations of OHS performances can be done based on different data sources and the result can be compared. The proposed approach may be performed for different aspects of OHS performance evaluation.

This is study includes methodological aspects of OHS. For this reason, OHS performance values of different countries may be used based on information from different organizations. This methodological debate for evaluation of OHS performances for countries is a novel and powerful approach for the practitioners and literature. Experts can show the ranking results of countries in four different manner and they can make more logical evaluations.

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Appendix 1

Sectors	2009	2010	2011	2012	2013	2014	2015
Turkey							
Number of fatal accidents (NFA)							
Agriculture; forestry and fishing	4	22	27	9	23	20	21
Mining and quarrying	20	125	117	44	87	382	79
Manufacturing	97	267	330	136	285	253	231
Electricity; gas, steam and air conditioning supply	1	16	15	6	10	15	30
Water supply; sewerage, waste management	5	20	22	11	12	15	22
Construction	156	475	570	256	521	502	474
Wholesale and retail trade; repair of motor vehicles	21	75	84	43	83	79	71
Transportation and storage	49	160	229	90	230	219	190
Accommodation and food service activities	9	10	25	14	17	28	33
Information and communication	6	10	4	3	3	6	1
Financial and insurance activities	1	3	1	1	0	3	0
Real estate activities	0	0	0	0	1	1	3
Professional, scientific and technical activities	1	41	35	6	18	16	11
Administrative and support service activities	5	30	43	20	43	68	68
Public administration and defence	0	3	1	0	3	1	1
Education	1	5	4	1	3	3	5
Human health and social work activities	0	3	3	1	8	1	7
Arts, entertainment and recreation	2	113	136	13	0	1	2
Other service activities	793	61	47	90	13	14	3
Activities of households as employers	0	0	0	0	1	0	1
Number of lost days due to injury (NLDs)							
Agriculture; forestry and fishing	13,480	14,280	17,439	17,491	21,005	21,474	34,416
Mining and quarrying	172,758	173,756	198,778	173,404	173,322	133,430	155,668
Manufacturing	758,869	723,744	819,749	749,070	1,195,616	1,093,269	1,495,713
Electricity; gas, steam and air conditioning supply	12,617	7,716	8,808	8,771	9,902	10,832	18,054
Water supply; sewerage, waste management	11,990	11,273	12,710	12,799	18,678	23,082	53,226
Construction	264,286	241,134	319,209	309,441	457,437	358,536	562,531
Wholesale and retail trade; repair of motor vehicles	73,453	76,966	85,957	80,907	112,619	103,170	152,538
Transportation and storage	120,357	128,614	138,994	120,021	179,660	138,559	201,649
Accommodation and food service activities	28,122	35,787	42,484	47,281	68,896	63,348	107,659
Information and communication	662	926	2,203	2,036	2,598	2,094	3,889
Financial and insurance activities	844	1,364	1,140	1,027	1,374	583	1,136
Real estate activities	171	393	255	232	1,486	1,963	5,054
Professional, scientific and technical activities	22,539	16,156	18,683	18,068	17,354	13,533	25,117
Administrative and support service activities	29,013	29,473	37,948	33,281	54,532	71,553	126,324

(*continued*)

Table AI. Recorded OHS data of ILO for Turkey

Sectors	2009	2010	2011	2012	2013	2014	2015
Public administration and defence	920	1,739	717	712	1,147	925	3,812
Education	1,680	1,936	1,868	3,087	4,402	3,291	7,188
Human health and social work activities	2,066	4,042	3,029	4,580	6,085	6,071	10,948
Arts, entertainment and recreation	11,300	5,236	4,687	6,739	2,846	2,980	5,436
Other service activities	45,454	28,091	42,502	57,736	27,766	16,211	20,939
Activities of households as employers	857	175	124	394	695	1,239	806
Number of workers (×1,000)							
Agriculture	4,881	5,355	5,822	5,846	5,850	5,468	5,432
Construction	1,305	1,432	1,674	1,709	1,780	1,911	1,907
Manufacturing	3,867	4,213	4,366	4,419	4,632	4,935	4,966
Mining + electricity + water supply	210	279	336	332	323	378	374
Market services	6,907	7,154	7,510	7,918	8,277	8,628	9,059
Non-market services	4,100	4,159	4,390	4,595	4,658	4,612	4,881

Table AI.

Appendix 2

EEA	2009	2010	2011	2012	2013	2014	2015	AVG.
Slovakia FAR								
Agriculture	4.71	4.00	7.04	5.33	11.69	6.02	7.79	6.63
Construction	5.45	1.16	1.24	5.39	3.00	3.14	5.14	3.48
Manufacturing	1.42	2.08	1.60	2.11	2.41	1.27	1.34	1.74
Mining + electricity + water supply	4.00	4.17	1.52	4.76	3.23	1.56	9.52	4.09
Market services	1.33	2.60	1.87	2.11	2.32	2.21	2.77	2.38
Non-market services	0.71	1.22	0.87	0.70	0.83	0.32	0.16	0.39
Slovenia FAR								
Agriculture	1.12	0.00	5.00	2.60	1.30	4.55	1.56	2.32
Construction	19.05	20.69	9.26	12.73	9.26	13.46	13.21	14.14
Manufacturing	2.10	2.14	1.38	3.40	2.46	1.94	3.26	2.37
Mining + electricity + water supply	4.55	0.00	0.00	4.35	0.00	0.00	4.35	1.89
Market services	1.46	2.06	2.10	1.21	1.54	1.57	1.54	1.90
Non-market services	0.91	0.00	0.00	0.44	1.81	2.24	0.88	0.51
Spain FAR								
Agriculture	4.70	4.58	5.56	4.98	5.16	7.47	5.56	5.41
Construction	6.51	6.06	7.55	5.86	5.64	5.94	6.33	6.32
Manufacturing	2.31	2.58	2.43	2.25	1.98	1.26	3.28	2.31
Mining + electricity + water supply	6.59	5.31	6.27	4.23	5.91	2.93	5.84	5.31
Market services	1.37	1.31	1.37	1.21	0.97	1.15	1.34	1.39
Non-market services	0.76	0.38	0.60	0.71	0.80	0.77	0.69	0.45
Switzerland FAR								
Agriculture	6.11	2.88	2.08	4.73	0.67	3.23	1.97	3.04
Construction	8.03	6.91	3.83	7.61	6.06	7.19	4.00	6.18
Manufacturing	1.98	2.22	1.88	1.40	2.57	1.37	1.93	1.91
Mining + electricity + water supply	10.53	10.26	9.52	2.33	4.65	9.30	0.00	6.48
Market services	1.00	1.58	0.66	0.96	1.07	1.26	0.98	1.33
Non-market services	1.15	1.51	1.22	0.71	1.38	0.67	0.50	0.64
Turkey FAR								
Agriculture	0.08	0.41	0.46	0.15	0.39	0.37	0.39	0.33
Construction	11.95	33.17	34.05	14.98	29.27	26.27	24.86	25.21
Manufacturing	2.51	6.34	7.56	3.08	6.15	5.13	4.65	5.09
Mining + electricity + water supply	12.38	57.71	45.83	18.37	33.75	108.99	35.03	47.22
Market services	1.26	4.18	5.03	1.98	4.25	4.08	3.41	3.99
Non-market services	19.54	5.17	5.33	2.72	1.52	1.91	1.78	4.28

Table AII. Annual and average FAR values of EAAs of countries

Appendix 3

EEA	2009	2010	2011	2012	2013	2014	2015	AVG.
Slovakia ASR								
Agriculture	93.58	90.65	87.46	82.14	96.78	71.07	78.74	85.75
Construction	33.74	22.98	26.50	22.53	26.88	22.79	30.56	26.56
Manufacturing	73.50	61.28	66.99	62.16	69.33	74.76	68.58	68.08
Mining + electricity + water supply	43.21	28.12	41.74	40.24	93.64	100.64	93.09	61.39
Market services	31.93	28.37	34.19	33.33	36.94	34.87	37.74	33.90
Non-market services	20.05	15.73	18.78	17. .70	20.20	19.53	17.91	18.56
Slovenia ASR								
Agriculture	69.27	61.58	63.73	34.67	32.26	54.08	84.37	56.91
Construction	481.77	455.02	387.50	355.31	294.77	304.25	337.32	377.53
Manufacturing	253.90	249.40	262.87	250.60	222.72	210.22	211.80	237.91
Mining + electricity + water supply	384.16	392.88	313.98	346.93	291.22	286.77	269.24	325.11
Market services	160.45	152.35	143.54	138.80	130.77	128.65	131.57	141.16
Non-market services	132.05	124.50	116.00	115.35	108.63	105.54	108.57	115.77
Spain ASR								
Agriculture	365.38	371.92	378.97	351.48	386.17	420.68	451.07	388.80
Construction	558.53	549.87	525.89	427.10	411.33	440.20	458.69	494.81
Manufacturing	416.33	415.93	359.23	297.82	303.29	309.68	324.77	349.71
Mining + electricity + water supply	552.61	565.76	486.24	409.88	429.58	455.83	467.26	481.41
Market services	233.02	227.25	223.05	187.90	196.79	203.37	217.99	213.12
Non-market services	177.26	176.30	157.44	150.53	206.38	199.99	213.21	182.67
Switzerland ASR								
Agriculture	137.86	130.70	130.81	133.02	140.09	132.68	146.06	135.93
Construction	795.65	777.55	800.25	817.91	867.69	911.24	877.96	836.56
Manufacturing	227.34	241.77	245.40	265.07	257.60	256.96	262.69	250.60
Mining + electricity + water supply	309.78	324.87	321.45	366.99	372.88	372.36	364.05	348.28
Market services	202.09	217.42	218.23	220.75	224.72	222.82	217.54	217.78
Non-market services	92.12	113.41	113.21	110.47	113.83	111.40	106.80	108.56
Turkey ASR								
Agriculture	1.47	1.42	1.61	1.61	1.96	2.14	3.46	1.95
Construction	107.75	89.77	102.38	97.68	140.42	102.34	161.19	115.92
Manufacturing	104.41	91.59	100.80	91.44	141.04	120.86	164.59	117.65
Mining + electricity + water supply	501.52	369.08	352.67	317.34	342.08	241.75	332.01	340.12
Market services	21.18	21.58	23.41	20.62	28.93	24.95	37.57	25.83
Non-market services	8.08	5.28	6.47	8.59	5.03	3.63	5.49	6.06

Table AIII.
Annual and average ASR values of EAAs of countries

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