EGE AKADEMİK BAKIŞ / *EGE ACADEMIC REVIEW*

Cilt 23 • Sayı 3 • Temmuz 2023
SS. 341/362
Doi: 10.21121/eab.986122
Başvuru Tarihi: 23.08.2021 • Kabul Tarihi: 29.08.2022

Article Type: *Research Article*

Comparative Analysis of MCDM Methods for the Assessment of Corporate Sustainability Performance in Energy Sector

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ABSTRACT

Energy is a significant input for production, growth, and development. A sustainable energy sector, where energy production and consumption balance are ensured, constitutes a key point for nature and humanity. In this study, a multidimensional framework is presented to measure corporate sustainability in the energy sector. Based on this framework, the sustainability performance of energy companies operating in the Asia and Europe regions is measured by hybrid multiple-criteria decision-making (MCDM) methods, considering the economic, social and environmental dimensions of sustainability. The Entropy method is preferred to specify the criteria weights, the Proximity Indexed Value (PIV) - Range of Value (ROV) - Grey relational analysis (GRA) - Measurement Alternatives and Ranking according to Compromise Solution (MARCOS) methods are used to rank the alternatives. Sensitivity analysis was applied to test the robustness of the model and it was determined that the criterion weights obtained by different methods had different effects on the rankings. The Copeland method is used to obtain a single rational ranking from different rankings. According to Copeland's results, EN13, EN3, EN10 companies took the first place in economic, environmental and social dimensions, respectively. It is concluded that energy companies in the Asian region are more sustainable than in the European region. Moreover, Thailand is the most sustainable country in the Asian region. The proposed framework can be contributed to the development of the energy sector.

Keywords: Corporate Sustainability Performance, Energy Sector, PIV, ROV, GRA, MARCOS.

JEL Classification Codes: D81, C44, C63

Referencing Style: APA 7

INTRODUCTION

Energy is an important variable that determines the degree of economic development of countries. All societies ask for energy services to satisfy the basic needs of humans such as lighting, space comfort, cooking, mobility, and communication (Edenhofer et al., 2011: 7). Energy production, conversion, and consumption are important inputs for the environment and sustainable development. However, the ever-increasing world energy production and consumption disrupt the ecosystem and cause important environmental problems. As a result of burning fossil fuels, air pollution has increased, the rate of greenhouse gas in the atmosphere has gradually increased, causing many problems, especially global warming. The emerging problems have led countries and companies to clean and sustain energy resources and to take various measures against environmental pollution. This situation has increased the importance of sustainability in the energy sector.

Sustainable energy refers to energy production models that can meet the current and future needs of the society at the lowest economic, environmental and social costs. The life cycle refers to the cost of a product from obtaining its original raw materials to production, shipping, and final destruction and disposal (Randolph and Masters, 2008: 3). It is clear that using renewable energy sources that include hydroelectric, bioenergy, geothermal energy, wind, direct solar energy and ocean energy (tides and waves) instead of fossil fuel-based energy sources will slowly help the world reach the idea of sustainability (Owusu and Asumadu-Sarkodie, 2016: 3). Corporate sustainability in the energy sector is to ensure the balance of energy production and consumption in a way that protects nature and the environment. To ensure corporate sustainability in the energy sector, all the countries of the world need to develop their energy policies in a way to ensure

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This article is based on the PhD thesis of Nazlı Ersoy, completed under the supervision of Soner Taslak at Muğla Sıtkı Koçman University, Institute of Social Sciences in 2021, in Muğla, Turkey.

sustainable development, use energy efficiently, and diversify in renewable energy sources (Johansson et al., 1992: 210-211). The duty of companies in ensuring sustainability is to transfer resources to future generations and to continue their activities without harming the environment.

Although most studies have examined sustainability performance measurement with multiple-criteria decision-making (MCDM) methods, the number of studies evaluating corporate sustainability in the energy sector is limited. Performance evaluation in the energy sector, which is strategically and vitally important for countries, will contribute to the development of the sector and contribute to economic, social and environmental developments. Therefore, in this study, a framework based on hybrid MCDM methods was proposed to evaluate corporate sustainability performance in the energy sector. Accordingly, the sustainability performance of energy companies operating in Asia and Europe was evaluated using Entropy-based Proximity indexed value (PIV)-Range of value (ROV)-Grey relational analysis (GRA)-Measurement alternatives and ranking according to compromise solution (MARCOS)-Copeland methods. Also, a comparative analysis was conducted.

The motivation and superiority of the proposed model in this paper are outlined as follows:

- It provides an overview of evaluating corporate sustainability based on three dimensions.
- It is benefited from the advantageous aspects of the different methods and a multiple comparisons are made between the results of the different MCDM techniques.
- The suitability of the ROV, PIV and MARCOS models is tested for the first time for corporate sustainability performance measurement.
- The proposed integrated model is used for the first time for performance measurement in the energy sector.
- The regions, countries and companies are compared in different years.

The rest of the paper is summarized as follows. Section 2 discusses the relevant previous literature studies. In section 3, the research methodology of the study is included. The application results are given in section 4. In the last section, the obtained results are given.

REVIEW OF PREVIOUS LITERATURE

MCDM methods provide a suitable framework for decision-makers to reach a solution in the case of multiple criteria and alternatives. In recent years, MCDM methods have been handled under many different topics such as performance evaluation (Abdel-Basset et al. 2020), location selection (Tadić et al. 2020), supplier selection (Stević et al. 2020), agriculture (Mishra and Satapathy, 2019), transport (Yannis et al. 2020) and energy (Alizadeh et al. 2020).

As in other topics, MCDM methods are frequently applied in sustainability assessment. The results obtained from the bibliometric analysis presented by Chowdhury and Paul (2020) also support this opinion. Accordingly, in 50 of the 52 articles reviewed by the authors, at least 1 MCDM technique was used to solve corporate sustainability problems. Wicher et al. (2019) conducted a Fuzzy Analytic Network Process (FANP) to evaluate the sustainability performance of the industrial corporations. In the study, where two different weights (local and global) were assigned to the criteria, it is concluded that the proposed methodology is a suitable tool for measuring the sustainability of industrial companies. Cui et al. (2019) used grey theory and the decision-making trial and evaluation laboratory (DEMATEL) to measure the sustainability of high technology companies in China. It was concluded that companies should give more importance to their social and environmental strategies in order to improve their sustainability performance. Yi et al. (2019) assessed the sustainability of cities using MCDM methods. In the study, which includes 18 criteria under three dimensions, Beijing was determined as the most sustainable city. Mao et al. (2019) evaluated and selected the supplier using a heterogeneous MCDM framework. They used TOPSIS to aggregate the heterogeneous evaluation information and Interval Valued Intuitionistic Fuzzy (IVIF)-Iterative Multi-Criteria Decision Making (TODIM) method to rank the alternative sustainable suppliers. Li et al. (2020) applied MCDM methods to measure the sustainability performance of hydrogen production technologies. The combined GRA and DEMATEL methods were preferred to specify the criteria weights.

Most of the studies using MCDM techniques in the energy sector have focused on subjects such as energy technology selection (Ali et al. 2019), evaluation of energy projects (San Cristóbal, 2011), power plant location selection (Wang et al. 2018), evaluation of energy technologies (Siksnelyte-Butkiene et al. 2020). On the other hand, the number of studies evaluating corporate sustainability performance in the energy sector with integrated MCDM methods is quite limited. Ghasemi and Nadiri (2016) evaluated the sustainability performance of 21 companies operating in the Iranian petrochemical industry using the

Table 1: Alternatives

Firms	Country/Region	Firms	Country/Region
EN1=Akenerji Elektrik Uretim	Turkey/Asia	**EN16=**A2A Spa	Italy/Europe
EN2=Aksa Enerji	Turkey/Asia	**EN17=**Energias de Portugal	Portugal/Europe
EN3=Aygaz	Turkey/Asia	**EN18=**Enagas S.A.	Spain /Europe
EN4=Bangchak Petroleum	Thailand/Asia	**EN19=**Endesa	Spain /Europe
EN5= Electricity Generating Public Company EGCO	Jordan/Asia	**EN20=**Energeticky a Prumyslovy Holding	Czech Republic/ Europe
EN6=Glow	Thailand/Asia	**EN21=**Gruppo ERG	Italy/Europe
EN7=IRPC	Thailand/Asia	**EN22=**Gruppo Hera	Italy/Europe
EN8=KazMunay Gas	Kazakhistan/Asia	**EN23=**Iberdrola	Spain /Europe
EN9=OPET Petrolculuk	Turkey/Asia	**EN24=**INA Group	Croatia/Europe
EN10=PTT Public Company Limited	Thailand/Asia	**EN25=**Iren	Italy/Europe
"EN11=Ratchaburi Electricity Generating Holding Public Company Limited"	Thailand/Asia	**EN26=**Naturgy Energy Group, S.A	Spain /Europe
EN12=Star Petroleum Refining	Thailand/Asia	**EN27=**PKN Orlen	Poland/Europe
EN13=Thai Oil	Thailand/Asia	**EN28=**Repsol	Spain /Europe
EN14=Towngas	Hong Kong /Asia	**EN29=**SNAM	Italy/Europe
EN15=Zorlu Energy Group	Turkey/Asia	**EN30=**Terna Group	Italy/Europe

Source: (http://database.globalreporting.org)

H3SE excellence model and the DEMATEL, TOPSIS, and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) methods. At the end of the study, it was determined that the rankings obtained by the different techniques were similar. González et al. (2016) measured the sustainability performance of four power plants operating in Cuba using the integrated Analytic Network Process (ANP)-Analytic Hierarchy Process (AHP)-Balanced Scorecard techniques. In the study where three dimensions of sustainability were discussed, 18 indicators were determined based on ISO 14031 and Global Reporting Initiative (GRI) guidelines. It was concluded that the proposed model is suitable for corporate sustainability performance measurement. Vivas et al. (2019) used Principal Component Analysis (PCA), Multiple Linear Regression (MLR), and PROMETHEE methods to evaluate the sustainability performance of Brazilian oil and gas companies. Three dimensions namely economic, social and, environmental and 20 criteria were included in the study. It was concluded that the company achieved its best sustainability performance in 2011 and 2010.

METHODOLOGY

In this section, the alternatives and criteria used in the study are explained. Then, the mathematical notations of the MCDM methods used in this study are given.

Alternatives

Alternatives were identified to provide a comprehensive corporate sustainability assessment framework in the energy sector. In the process of determining the alternatives, the GRI database was used. Accordingly, 30 large-scale energy companies reporting based on the GRI guidelines and operating in the energy & energy utilities sectors were included in the scope of the study. There are six regions in the GRI database: Asia, Europe, Africa, North America, Oceania, and Latin America &

the Caribbean. However, only the European and Asian regions were included in the scope of this study because of the following reasons: i. The number of companies operating in the different regions was different from each other, ii. There was no report within the specified period, and data were missing. The period range is from 2016-2018. The alternatives are as shown in Table 1.

Evaluation Criteria

Criteria are the elements that allow a healthy assessment and they are effective in the process of the selection of alternatives. In this study, the evaluation process was carried out under three dimensions of sustainability. A total of 23 corporate sustainability criteria, 8 economic (Table 2), 8 environmental (Table 3), and 7 social (Table 4), representing the energy sector, were determined. The economic, environmental and social indicators of the companies were obtained from the reports titled sustainability report, integrated report, corporate social responsibility report, annual report, integrated annual report and corporate responsibility report in the GRI database (http://database.globalreporting.org). To obtain financial data, besides the sustainability reports of the companies, annual and financial reports were used. The distribution and explanations of the 23 sustainability criteria according to the dimensions are given in Tables 2-4, respectively.

Methods

Sustainable performance measurement is inherently a multidimensional problem and MCDM methods offer a suitable framework for corporate sustainability performance evaluation. In this study, hybrid MCDM methods were used to measure the sustainability performance of energy companies. The Entropy method was used to designate the criteria weights and the PIV-ROV-GRA-MARCOS methods were used to rank the alternatives according to their performance. In the last phase, the Copeland method was preferred to achieve a single rational ranking using the rankings obtained

Table 2: Economic Criteria

Criteria	Opt.	Unit/Formulation	Criteria	Opt.	Formulation
EC1: Personnel expenses	min	Million euro	**EC5:** Return on assets	max	Net Profit/Total assets
EC2: Earnings per share	max	Period Income/Number of shares	**EC6:** Return on equity	max	Net Profit /Shareholders Equity
EC3: Current ratio	max	Current assets / Short term liabilities	**EC7: "**Asset turnover ratio"	max	"Net Sales/ Total assets"
EC4: "Quick ratio"	max	(Current assets - Inventories) / Short term liabilities	**EC8:** Leverage ratio	min	Liability/ Total assets

Source: (http://database.globalreporting.org)

Table 3: Environmental Criteria

Criteria	Opt.	Unit	Criteria	Opt.	Unit
ENV1: Total energy consumption	min	Million GJ	**ENV5:** Water discharge	min	Million m^3
ENV2: Water withdrawal	min	Million m^3	**ENV6:** Total waste	min	Million ton
ENV3: Total GHG emissions, scope1+2	min	Million Tco_2eq.	**ENV7:** Hazardous waste	min	%
ENV4: Direct GHG emissions, Scope 1	min	%	**ENV8:** Recycled waste	max	%

Source: (http://database.globalreporting.org)

Table 4: Social Criteria

Criteria	Opt.	Unit	Criteria	Opt.	Unit
SO1: Turnover rate	min	%	**SO5:** Average hours of training per employee	max	Hour
SO2: New employees	max	Number	**SO6:** Total number of employees	max	Number
SO3: Occupational fatality	min	Number	**SO7:** Female employees rate	max	%
SO4: Occupational disease	min	Number			

Source: (http://database.globalreporting.org)

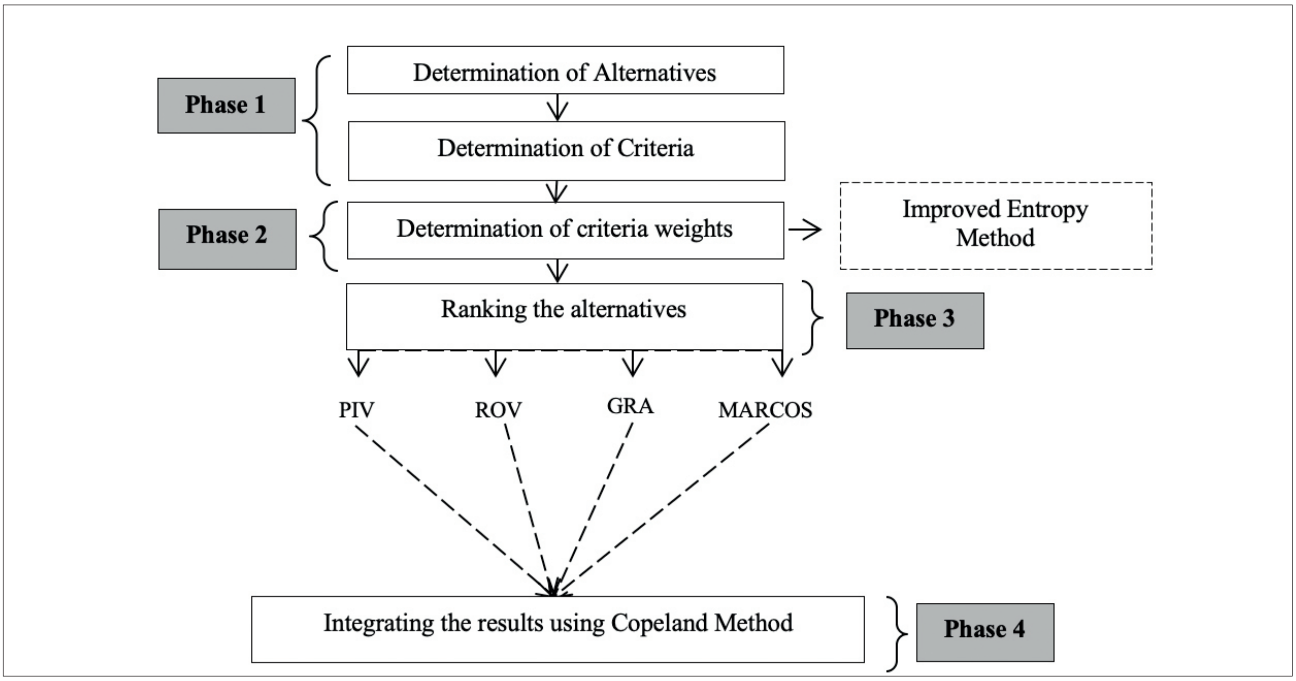

Figure 1: The Procedure of the Research Study

by different methods. In this direction, the design of the study is shown in Figure 1.

Improved Entropy Method: Entropy was first defined by Clausius (1865) as a measure of uncertainty and disorder in a system. In the Entropy method, the natural logarithm function is used to calculate the significance of the criteria. Serious problems may arise during the logarithmic calculation phase in case of negative or zero values in the decision matrix. To prevent problems that may arise, corrections can be made for negative data using the Improved Entropy method developed by Zhang et al. (2014). The steps of the Improved Entropy method are as follows (Wang and Lee, 2009: 8982; Zhang et al., 2014: 3).

Step 1: The decision matrix is created.

Step 2: Decision matrix elements are transformed by standardizing the Z-score using equation (1).

$$x_{ij} = \frac{X_{ij} - \bar{X}_i}{S_i} \qquad (1)$$

x_{ij} shows the standardized data of the index ith located in the region jth.

X_{ij} shows the original data,

x_i and S_i show the arithmetic mean and standard deviation values, respectively.

Step 3: Decision matrix elements are made positive using equation (2).

$$x'_{ij} = x_{ij} + A \quad A > \left|\min x_{ij}\right| \tag{2}$$

A indicates the smallest value in the decision matrix; x'_{ij}, indicates the standard value after conversion. x'_{ij} must be>0.

Step 4: Decision matrix elements are normalized using equation (3);

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{3}$$

P_{ij} shows the value of normalized decision matrix elements.

Step 5: Entropy measure of each criterion is found using equation (4).

$$e_j = -k\sum_{i=1}^{n} P_{ij} In P_{ij} \quad \forall_j \tag{4}$$

$$k = \frac{1}{\ln(m)}$$

K represents a constant and indicated by the formula.

e_j is the Entropy value of the jth criterion.

m indicates the number of alternative.

Step 6: The degree of differentiation of the criteria is calculated using equation (5).

$$d_j = 1 - e_j, \quad \forall_j \tag{5}$$

d_j shows a contrast density in the j structure.

Step 7: Criterion weights are calculated using equation (6).

$$W_j = \frac{d_j}{\sum_{k=1}^{n} d_k} \forall_i \tag{6}$$

W_j shows the criteria weight; $\sum_{wj}=1,\ 0 \leq w_j \leq 1$

PIV Method: This method was introduced by Mufazzal and Muzakkir (2018) to prevent the rank reversal phenomenon and has a simple calculation procedure. The steps of this method are as follows (Ulutaş and Karaköy, 2019: 56-57):

Step 1: Decision matrix is constituted

In the first step, the decision matrix is constituted.

Step 2: Decision matrix elements are normalized

Decision matrix elements are normalized using the vector normalization formula in equation (7).

$$a_{ij} = \frac{b_{ij}}{\sqrt{\sum_i^m b_{ij}^2}} \tag{7}$$

b_{ij} shows the original data; a_{ij} shows the real decision value based on the ith alternative.

Step 3: The weighted normalized decision matrix is determined

A weighted normalized decision matrix is constituted using equation (8).

$$v_{ij} = w_{jc} * a_{ij^{\cdot}} \tag{8}$$

w_{jc} indicates the criteria weights, $a_{ij^{\cdot}}$ indicates the normalized decision matrix elements, v_{ij} indicates the weighted decision matrix.

Step 4: Weighted proximity index is evaluated

The deviation of each alternative from the best value is measured by considering the benefit and cost-oriented criteria, using the equation (9) and equation (10).

$$e_{ij} = v_{max} - v_{ij^{\cdot}} \tag{9}$$

$$e_{ij} = v_{ij^{\cdot}} - v_{min} \tag{10}$$

v_{max} and v_{min} represent the largest and smallest value in weighted decision matrix, respectively.

Step 5: The total proximity value is determined

The total proximity value is calculated for each alternative using equation (11).

$$z_i = \sum_{j=1}^{n} e_{ij^{\cdot}} \tag{11}$$

(j= 1,2,3,…,n) indicates decision criteria and (i=1,2,3,…,m) indicates available alternatives. (z_i) and ($e_{ij^{\cdot}}$) show the overall proximity value of each alternative and the weighted proximity values of criteria, respectively.

Step 6: The alternatives are ranked.

The alternative with the lowest dj value representing the minimum deviation from the best solution takes first place. Other alternatives with increasing d_j value are also ranked by considering similar dimensions.

ROV Method: This method was proposed by Yakowitz et al. (1993). The steps of the ROV method are as follows (Madić and Radovanović, 2015: 198-199):

Step 1: Decision matrix is created

A decision matrix is created that includes alternatives in rows and criteria in columns.

Step 2: Decision matrix elements are normalized.

Utility-side criteria and cost-side criteria are normalized using equation (12) and equation (13), respectively.

$$\bar{x}_{ij} = \frac{x_{ij} - x_{ij}^{\min}}{x_{ij}^{\max} - x_{ij}^{\min}} \tag{12}$$

$$\bar{x}_{ij} = \frac{x_{ij}^{\max} - x_{ij}}{x_{ij}^{\max} - x_{ij}^{\min}} \tag{13}$$

x_{ij}^{min} *and* x_{ij}^{max} represent the smallest and largest value in decision matrix, respectively.
x_{ij} shows the original data

Step 3: Utility functions (the best and worst) are calculated

In the last step, separate utility functions are created for the criteria. Utility functions (u_i^+, u_i^-) for benefit and cost criteria are shown in equations (14) and (15), respectively.

$$Max: u_i^+ = \sum_{j=1}^{n} \bar{x}_{ij}.w_j \tag{14}$$

$$Min: u_i^- = \sum_{j=1}^{n} \bar{x}_{ij}.w_j \tag{15}$$

u_i^+ and u_i^- shows the utility function for benefit and cost criteria. Wj shows the criterion weights. Weights must necessarily meet the following two conditions:

$$\sum_{j=1}^{n} w_j = 1 \tag{16}$$

$$w_j \geq 0$$

If $u_i^- > u_i^+$ the alternative i can be said to be better than the *i* alternative, regardless of the total score.

$$u_i = \frac{u_i^- + u_i^+}{2} \tag{17}$$

u_i represent the final utility function. The alternative with the highest value of u_i is determined as the best alternative.

GRA Method: GRA is an effective tool for decision making that takes its place in the literature under the title of Grey System Theory (Wang and Tong, 2004: 3). The steps of the method are as follows (Wu, 2002: 211-212):

Step 1: Decision matrix is normalized

Decision matrix is normalized in 3 different ways: "higher is better", "lower is better" and "nominal solution is better". Benefit and cost criteria and the criteria required to be in nominal value are normalized with the help of equations (18-20), respectively.

$$x_i^*(\mathrm{k}) = \frac{x_i(\mathrm{k}) - \min_k x_i(\mathrm{k})}{\max_k x_i(\mathrm{k}) - \min_k x_i(\mathrm{k})} \tag{18}$$

$$x_i^*(\mathrm{k}) = \frac{\max_k x_i(\mathrm{k}) - x_i(\mathrm{k})}{\max_k x_i(\mathrm{k}) - \min_k x_i(\mathrm{k})} \tag{19}$$

$$x_i^*(\mathrm{k}) = \frac{|x_i(\mathrm{k}) - x_{ob}(\mathrm{k})|}{\max_k x_i(\mathrm{k}) - x_{ob}(\mathrm{k})} \tag{20}$$

Step 2: Reference series is created

The reference series is created by taking the largest value in the relevant column in the decision matrix.

$$x_0 = (\mathrm{x}_0(1), \mathrm{x}_0(2), ..., \mathrm{x}_0(\mathrm{j}), ..., \mathrm{x}_0(\mathrm{n}))$$

$$i = 1, 2, 3, \ldots, m.$$

x_0 indicates the largest value of the criterion j. within the normalized values. The reference series is added as the first row to the decision matrix created in the previous step and converted into a comparison matrix.

Step 3: The absolute value table is created using equation (21).

$$\Delta_{0i}(\mathrm{k}) = |x_0^*(\mathrm{k}) - x_i^*(\mathrm{k})| \tag{21}$$

$\mathrm{x}_0^*(\mathrm{k})$ shows the reference value for each column.

$\mathrm{x}_i^*(\mathrm{k})$ shows the normalized value in the decision matrix.

Step 4: Grey relationship coefficients are calculated with the help of equation (22).

$$\gamma_{0i}(k)=\frac{\Delta_{\min}+\varsigma\Delta_{\max}}{\Delta_{0i}(k)+\varsigma\Delta_{\max}} \quad (22)$$

$$\Delta_{\max}=\max_i\max_k\Delta_{0i}(\mathrm{k}) \quad \Delta_{\min}=\min_i\min_k\Delta_{0i}(\mathrm{k})$$

ζ is expressed as a discriminating coefficient and it generally takes the value 0.5 in practice (Zhai et al., 2009: 7074).

Step 5: Grey Relationship degree is calculated using equation (23).

$$\Gamma_{0i}=\sum_{k=1}^{n}\left[w_i(\mathrm{k})\,\mathrm{x}\,r_{0i}(\mathrm{k})\right] \quad (23)$$

The priority of the alternatives is ranked according to the value of Γ_{0i}.

MARCOS Method: This method was introduced by Stević et al. (2020) to define the relationship between reference values and alternatives. The steps of the MARCOS method are as follows (Stević et al., 2020: 4-5):

Step 1: As a first step, a decision matrix is formed.

Step 2: The extended initial matrixis created by defining ideal (AI) and non-ideal (AAI) solutions.

The worst alternative (AAI) and the alternative with the best features (AI) are defined using the equations (24) and (25), respectively.

$$\mathrm{AAI}=\min_i x_{ij}\ \ if\ j\in \mathrm{B}\ \text{and}\ \max_i x_{ij}\ \ if\ j\in C \quad (24)$$

$$\mathrm{AI}=\max_i x_{ij}\ \ if\ j\in \mathrm{B}\ \text{and}\ \min_i x_{ij}\ \ if\ j\in C \quad (25)$$

$\min_i x_{ij}$ and $\max_i x_{ij}$ represents the smallest and largest value in related column.
B represents the utility criteria group; C represents the cost-side criteria group.

Step 3: Extended initial matrix is normalized.

$$n_{ij}=\frac{x_{ai}}{x_{ij}} \quad \text{for cost criteria} \quad (26)$$

$$n_{ij}=\frac{x_{ij}}{x_{ai}} \quad \text{for benefit criteria} \quad (27)$$

The x_{ij} and x_{ai} are the elements of the X initial matrix.

Step 4: The weighted normalized decision matrix $V=[v_{ij}]mxn$ is constructed.

The weighted matrix V is obtained using equation 28.

$$v_{ij}=n_{ij}*w_j \quad (28)$$

w_j indicates the criteria weights, n_{ij} indicates the normalized decision matrix elements, v_{ij} indicates the weighted decision matrix.

Step 5: The utility degree (K_i) of the alternatives is calculated.

The utility degrees of each alternative are calculated using equations (29) and (30), respectively.

$$K_i^-=\frac{S_i}{S_{aai}} \quad (29)$$

$$K_i^+=\frac{S_i}{S_{ai}} \quad (30)$$

S_i ($i = 1,2, .., m$) consists of the sum of the elements in the weighted matrix (V) and it is expressed as in equation (31).

$$S_i=\sum_{i=1}^{n}v_{ij} \quad (31)$$

Step 6: Determining the utility functions $f(K_i)$ of the alternatives

The utility function is identified using equation (32).

$$f(K_i)=\frac{K_i^++K_i^-}{1+\frac{1-f(K_i^+)}{f(K_i^+)}+\frac{1-f(K_i^-)}{f(K_i^-)}} \quad (32)$$

$f(K_i^-)$ and $f(K_i^+)$ show the utility function associated with the non-ideal solution and the ideal solution, respectively. Solutions are expressed by equations (33) and (34), respectively.

$$f(K_i^-)=\frac{K_i^+}{K_i^++K_i^-} \quad (33)$$

$$f(K_i^+)=\frac{K_i^-}{K_i^++K_i^-} \quad (34)$$

Step 7: The alternatives are ranked

The alternatives are sorted according to the final values of the utility functions. The alternative with the highest utility function value is preferred.

Copeland Method: The Copeland method which ranks the alternatives according to their superiority (victorious and defeated) (Naderi et al., 2013: 63) provides reconciliation of the results obtained by different methods. The steps of the method are as follows (Eş, 2013: 57-58):

Step 1: The rank values of the alternatives are determined.

The matrix in Table 5 is prepared by determining the rank value of each alternative obtained by each method.

Table 5: Rank Values of Alternatives

Method / Alternative	Y_1	Y_2	Y_3	Y_M
A_1	X_{11}	X_{12}	X_{13}	X_{1M}
A_2	X_{21}	X_{22}	X_{23}	X_{2M}
A_3	X_{31}	X_{32}	X_{33}	X_{3M}
A_N	X_{41}	X_{42}	X_{43}	X_{NM}

M: The total number of MCDM methods,

N: The total number of alternatives,

X_{NM}: The ranking value of the alternative N obtained in the method M.

Step 2: Rank values are standardized.

The rank values of the alternatives are rearranged according to the values in Table 6 and the matrix is reconstructed. The standard values of the alternatives are obtained by multiplying the alternative rank values by 2 and subtracting 1.

Table 6: Standard Rank Values of Alternatives

Alternative Rank Value	1	2	3	4	5	6	7	8	9	10
Standard Value	1	3	5	7	9	11	13	15	17	19

Step 3: Average rank values are obtained.

The mean rank values are obtained by dividing the sum of the standard values obtained from the alternatives by the number of alternatives. The alternative with the lowest average rank value is the alternative with the highest performance.

RESULTS

In this study, hybrid MCDM methods were used to evaluate the corporate sustainability performance of energy companies operating in Asia and Europe during the period of 2016 to 2018. The data was collected in March 2020 and was retrieved from the global reporting initiative database. In the first stage of the analysis, the Entropy method was used to specify the criteria weights. Then, PIV-ROV-GRA-MARCOS methods were used to sort the alternatives according to performance scores. In the last stage, the Copeland method was used to obtain a single rational ranking using the rankings obtained by different methods.

Determination of Alternatives and Criteria

The alternatives and criteria are the basic elements of the decision matrix in MCDM methods. In this study, the GRI database was preferred to determine the alternatives. To determine the criteria, a comprehensive literature review was carried out.

Determination of Criteria Weights via the Improved Entropy Method

The improved entropy method is a suitable model for continuing the transaction steps when there are negative and zero-valued data in the decision matrix. The improved entropy method was preferred in this study because it allows an objective evaluation by using only decision matrix elements. In order to preserve the integrity of the text, only 2018 economic dimension performance results are given in detail in this section. The decision matrices for all three dimensions and all three years (2016-2018) are presented in Appendix A-C.

The first step in determining criterion weights with the Entropy method is to constitute a decision matrix that includes evaluation criteria and alternatives. The decision matrix is given in Table 7.

Table 7: Economic Dimension Decision Matrix for 2018

	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8
EN1	7	-0.36	0.22	0.22	-0.27	3.38	0.39	0.92
EN2	4	0.007	0.86	0.74	0.02	0.08	0.73	0.72
EN3	17	0.13	1.09	0.86	0.05	0.09	1.91	0.50
EN4	99	0.05	1.47	0.80	0.05	0.06	1.64	0.58
EN5	63	1.20	1.51	1.51	0.10	0.22	0.17	0.51
EN6	34	0.17	1.90	1.40	0.08	0.17	0.51	0.56
EN7	278	0.01	0.95	0.37	0.04	0.09	1.42	0.52
EN8	1162	0.002	1.81	1.64	0.05	0.10	0.50	0.50
EN9	17	0.76	1.52	1.18	0.09	0.25	5.46	0.66
EN10	1539	0.12	2.11	1.80	0.07	0.14	0.99	0.44
EN11	22	0.12	2.22	2.22	0.06	0.09	0.45	0.41
EN12	34	0.02	1.6	0.81	0.04	0.06	3.80	0.30
EN13	31	0.15	4.3	3.5	0.04	0.08	1.45	0.53
EN14	362	0.07	0.79	0.69	0.08	0.15	0.29	0.47
EN15	29	0.003	0.55	0.55	0.002	0.01	0.39	0.86
EN16	492	0.11	1.09	1.02	0.03	0.10	0.63	0.66
EN17	652	0.14	0.79	0.75	0.02	0.06	0.09	0.69
EN18	131	1.86	2.80	2.75	0.05	0.15	0.14	0.68
EN19	947	1.34	0.73	0.54	0.04	0.15	0.62	0.71
EN20	506	0.05	1.06	0.97	0.05	0.20	0.53	0.76
EN21	64	0.70	2.31	2.26	0.03	0.07	0.22	0.61
EN22	551	0.19	1.03	0.98	0.03	0.10	0.67	0.69
EN23	2679	0.48	0.83	0.69	0.03	0.07	0.31	0.61
EN24	270	2.98	0.99	0.54	0.06	0.10	1.08	0.43
EN25	394	0.19	1.00	0.96	0.03	0.11	0.47	0.70
EN26	1010	-2.86	1.19	1.07	-0.07	-0.19	0.60	0.64
EN27	604	2.99	1.79	0.94	0.09	0.16	1.71	0.44
EN28	1874	1.45	1.35	1.01	0.04	0.08	0.82	0.49
EN29	201	0.29	0.61	0.59	0.04	0.16	0.11	0.73
EN30	64	0.35	0.74	0.74	0.04	0.18	0.14	0.76

According to Table 7, the criteria of some companies (E2 (Earnings per share), E5 (Return on assets), E6 (Return on equity)) are negative because the net profits of the mentioned companies in the relevant periods are negative. Since the criteria E2, E5 and E6 are calculated by taking into account the net profit of the period, the values of the companies with negative net profit for these criteria are also negative.

In the second step, the Z score standardization transformation of the decision matrix data was carried out using equation (1). In the third step, equation (2) was used to transform negative and 0 values in the decision matrix to positive (Table 8).

In the fourth step, the decision matrix elements in Table 8 are normalized using equation (3). In the last step, the Entropy measure of the criteria is calculated using equation (4) and the degree of differentiation of information is calculated using equation (5). Criteria weights were determined using equation (6). All results are presented in Table 9.

Ranking Energy Companies via the PIV Method

In this section, the positive decision matrix in Table 8 will be used to apply the PIV method. In the first step, the elements in Table 8 are normalized using equation (7). In the second step, the weighted normalized matrix was obtained by multiplying the normalized criteria values and the criteria weights in Table 9. Then, considering the benefit-oriented (EC2-EC7) and cost-oriented criteria (EC1, EC8), the deviation of each alternative from the best value was measured using equations (9-10) and the sum of elements in each row was calculated using equation (11).

Table 8: Positive Decision Matrix

	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8
EN1	3,99981	3,973	3,3031	3,4796	0,079	9,979	4,246	6,967
EN2	3,99511	4,327	4,0938	4,188	4,518	4,503	4,543	5,556
EN3	4,01551	4,445	4,3779	4,3514	4,977	4,52	5,576	4,004
EN4	4,14419	4,368	4,8473	4,2697	4,977	4,47	5,34	4,568
EN5	4,08769	5,476	4,8968	5,2369	5,743	4,736	4,053	4,075
EN6	4,04218	4,484	5,3786	5,0871	5,437	4,653	4,351	4,427
EN7	4,4251	4,33	4,2049	3,6839	4,824	4,52	5,147	4,145
EN8	5,81236	4,322	5,2674	5,414	4,977	4,536	4,342	4,004
EN9	4,01551	5,052	4,9091	4,7874	5,59	4,785	8,685	5,133
EN10	6,40399	4,436	5,638	5,632	5,283	4,603	4,771	3,581
EN11	4,02335	4,436	5,7739	6,2041	5,13	4,52	4,298	3,369
EN12	4,04218	4,339	5,0079	4,2833	4,824	4,47	7,231	2,593
EN13	4,03748	4,465	8,3435	7,9478	4,824	4,503	5,174	4,216
EN14	4,55692	4,388	4,0073	4,1199	5,437	4,619	4,158	3,792
EN15	4,03434	4,323	3,7108	3,9291	4,243	4,387	4,246	6,544
EN16	4,76093	4,426	4,3779	4,5694	4,671	4,536	4,456	5,133
EN17	5,01201	4,455	4,0073	4,2016	4,518	4,47	3,983	5,345
EN18	4,19441	6,112	6,4904	6,9261	4,977	4,619	4,027	5,274
EN19	5,47496	5,611	3,9332	3,9155	4,824	4,619	4,447	5,486
EN20	4,7829	4,368	4,3408	4,5013	4,977	4,702	4,368	5,838
EN21	4,08926	4,994	5,8851	6,2586	4,671	4,487	4,097	4,78
EN22	4,85352	4,503	4,3038	4,5149	4,671	4,536	4,491	5,345
EN23	8,19299	4,783	4,0567	4,1199	4,671	4,487	4,176	4,78
EN24	4,41254	7,191	4,2544	3,9155	5,13	4,536	4,85	3,51
EN25	4,60713	4,503	4,2667	4,4877	4,671	4,553	4,316	5,415
EN26	5,57383	1,565	4,5014	4,6375	3,14	4,055	4,429	4,992
EN27	4,93669	7,2	5,2427	4,4604	5,59	4,636	5,401	3,581
EN28	6,9297	5,717	4,6991	4,5558	4,824	4,503	4,622	3,933
EN29	4,30426	4,6	3,7849	3,9836	4,824	4,636	4	5,627
EN30	4,08926	4,657	3,9455	4,188	4,824	4,669	4,027	5,838

Table 9: e_j, d_j and w_j Values

	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8
e_j	0.9943	0.9933	0.9942	0.9942	0.9894	0.9951	0.99449	0.9936
d_j	0.0057	0.0067	0.0058	0.0058	0.0106	0.0049	0.00551	0.0064
w_j	0.1111	0.1303	0.113	0.1132	0.2059	0.0948	0.10687	0.1248

Ranking Energy Companies via the ROV Method

As the first step of ranking the alternatives with the ROV method, the decision matrix in Table 7 is used. Since the normalization method in the algorithm of this method turns negative data into positive, analysis will be performed with the decision matrix (Table 7). In the second step, benefit-oriented criteria (EC2-EC7) are normalized using equation (12), and cost-oriented criteria (EC1, EC8) are normalized using equation (13). In the third step, the best and worst benefit functions are calculated using equation (14) for benefit-oriented criteria and (15) for cost-oriented criteria. In the last step, performance ranking is obtained using equation (16).

Table 10: Ranking Results Obtained by the PIV, ROV, GRA and MARCOS Methods

Firms	PIV	ROV	GRA	MAR-COS	Firms	PIV	ROV	GRA	MARCOS
EN1	30	30	28	30	EN16	18	18	23	20
EN2	24	22	18	21	EN17	26	26	27	26
EN3	12	12	11	12	EN18	4	5	8	5
EN4	13	13	14	13	EN19	22	24	24	23
EN5	7	7	6	7	EN20	20	21	21	19
EN6	10	10	9	9	EN21	9	9	10	10
EN7	17	16	15	17	EN22	19	19	25	24
EN8	14	14	16	15	EN23	28	28	29	28
EN9	3	2	2	3	EN24	8	8	5	8
EN10	11	11	13	11	EN25	21	20	22	22
EN11	6	6	7	6	EN26	29	29	30	29
EN12	5	4	4	4	EN27	2	3	3	2
EN13	1	1	1	1	EN28	16	17	19	16
EN14	15	15	12	14	EN29	25	25	20	25
EN15	27	27	26	27	EN30	23	23	17	18

Ranking Energy Companies via the GRA Method

Since the normalization method in the algorithm of this method turns negative data into positive, analysis will be performed with the decision matrix (Table 7). As the first step of ranking the alternatives with the GRA method, benefit-oriented criteria (EC2-EC7) are normalized using equation (18), and cost-oriented criteria (EC1, EC8) are normalized using equation (19). In the second step, the reference series is created by taking the largest value in the relevant column in the decision matrix. In the third step, the absolute value table is created using equation (21). In the fourth step, the grey relationship coefficients are calculated using equation (22). In the last step, grey relationship degree is calculated using equation (23).

Ranking Energy Companies via the MARCOS Method

In this section, the positive decision matrix in Table 8 will be used to apply the MARCOS method. In the first step, ideal (AI) and non-ideal (AAI) solutions, depending on the nature of the criteria, an expanded initial matrix was created by using equations (24) and (25). In the second step, the expanded initial matrix was normalized using equation (27) for benefit-oriented criteria (EC2-EC7) and equation (26) for cost-oriented criteria (EC1, EC8). In the third step, the normalized expanded matrix elements are multiplied by the criterion weights (Table 9) obtained by the Entropy method. In the fourth step, the degree of utility for the non-ideal solution was calculated using equation (29) and the degree of utility for the ideal solution was calculated using equation (30). Then, the utility function ($f(K_i)$) of the alternatives is defined using equations (33) and (34). In the last step, the alternatives are ranked based on the final values of the utility functions using equation (32).

The PIV, ROV, GRA and MARCOS steps given in the third section were applied respectively and all results are presented in Table 10.

SENSITIVITY ANALYSIS

Although MCDM methods are seen as reliable decision-making models, several relevant parameters can have serious effects on final decisions. Therefore, the initial model needs to be resolved under different conditions to observe the reliability of initial decisions and the effect of model parameters (Torkayesh et al., 2021: 8). In this section, the differences in the ranking results by changing the criteria weights are realized through sensitivity analysis. The analysis was performed by giving equal weight (1/8=0.125) to each criterion using equation 35 (Jahan et al., 2012, p. 413).

$$w_j = \frac{1}{n} \tag{35}$$

Table 11: Comparative Results

	Entropy Based				Equal weight based			
	PIV	ROV	GRA	MARCOS	PIV	ROV	GRA	MARCOS
EN1	30	30	28	30	29	28	15	29
EN2	24	22	18	21	22	21	17	18
EN3	12	12	11	12	12	11	11	11
EN4	13	13	14	13	13	13	12	13
EN5	7	7	6	7	7	7	8	7
EN6	10	10	9	9	10	10	9	10
EN7	17	16	15	17	16	16	16	17
EN8	14	14	16	15	14	14	19	14
EN9	3	2	2	3	2	2	2	3
EN10	11	11	13	11	11	12	14	12
EN11	6	6	7	6	6	6	7	6
EN12	5	4	4	4	5	3	3	2
EN13	1	1	1	1	1	1	1	1
EN14	15	15	12	14	15	15	13	15
EN15	27	27	26	27	27	27	25	27
EN16	18	18	23	20	18	18	23	19
EN17	26	26	27	26	26	26	28	26
EN18	4	5	8	5	4	5	6	5
EN19	22	24	24	23	23	24	27	24
EN20	20	21	21	19	21	22	24	22
EN21	9	9	10	10	9	9	10	9
EN22	19	19	25	24	19	19	26	23
EN23	28	28	29	28	29	29	29	28
EN24	8	8	5	8	8	8	5	8
EN25	21	20	22	22	20	20	22	21
EN26	29	29	30	29	30	30	30	30
EN27	2	3	3	2	3	4	4	4
EN28	16	17	19	16	17	17	21	16
EN29	25	25	20	25	25	25	20	25
EN30	23	23	17	18	24	23	18	20

n represents the number of criteria and the sum of the weights must equal 1.

According to Table 11, Entropy-based PIV, ROV, GRA, MARCOS rankings and EW-based PIV, ROV, GRA, MARCOS rankings are not exactly the same and there are small deviations. This also shows the effect of criterion weights on MCDM ranking results.

Application of Copeland Method for Integrated Evaluation Approach

The sustainability performance rankings of 30 energy companies obtained by the Copeland method are given in Table 12.

DISCUSSION

The model developed in this study to perform the corporate sustainability assessment of energy firms contains 23 indicators involving three dimensions of sustainability – economic, social and environmental. To more clearly indicate the change in the sustainability performance values of energy companies over different years, Figure 2 shows the improvement trend of the sustainability of energy firms from 2016 to 2018 is shown below. The results in Figure 2 are obtained using Copeland values. It is seen that Asian region companies (EN1-EN15) outperformed European region companies (EN16-EN30) during a three-year period.

Table 12: Copeland Ranking Results for All Dimensions

	Economic			Environmental			Social		
	2016	2017	2018	2016	2017	2018	2016	2017	2018
EN1	17	23	26	10	7	9	22	21	17
EN2	29	14	18	8	12	16	25	26	28
EN3	6	5	10	1	1	1	23	24	25
EN4	8	13	11	17	8	12	4	3	9
EN5	13	8	6	4	6	5	9	14	16
EN6	11	9	8	2	2	2	6	6	7
EN7	15	17	14	13	13	14	16	15	10
EN8	10	16	13	18	23	27	8	12	14
EN9	5	4	2	3	4	3	22	20	22
EN10	12	10	9	27	24	25	1	1	1
EN11	3	6	5	7	5	4	7	8	5
EN12	2	2	3	12	9	11	10	7	8
EN13	1	1	1	16	10	13	2	4	3
EN14	25	15	12	9	6	5	5	3	2
EN15	28	26	23	22	15	15	23	23	26
EN16	21	21	16	18	17	18	24	25	27
EN17	26	24	22	14	11	10	18	19	24
EN18	14	7	4	11	8	6	3	2	6
EN19	20	20	20	23	21	20	12	17	15
EN20	9	13	17	19	16	18	19	22	23
EN21	7	12	8	6	2	8	15	9	19
EN22	19	23	19	28	25	26	13	13	16
EN23	27	25	24	20	14	17	11	11	13
EN24	22	11	7	15	11	19	19	18	20
EN25	18	18	18	25	19	22	17	16	18
EN26	16	20	25	29	26	28	3	5	12
EN27	4	3	2	21	18	21	21	23	21
EN28	24	21	15	26	20	24	14	10	4
EN29	23	22	21	5	3	7	20	22	24
EN30	17	19	17	24	22	23	9	17	11

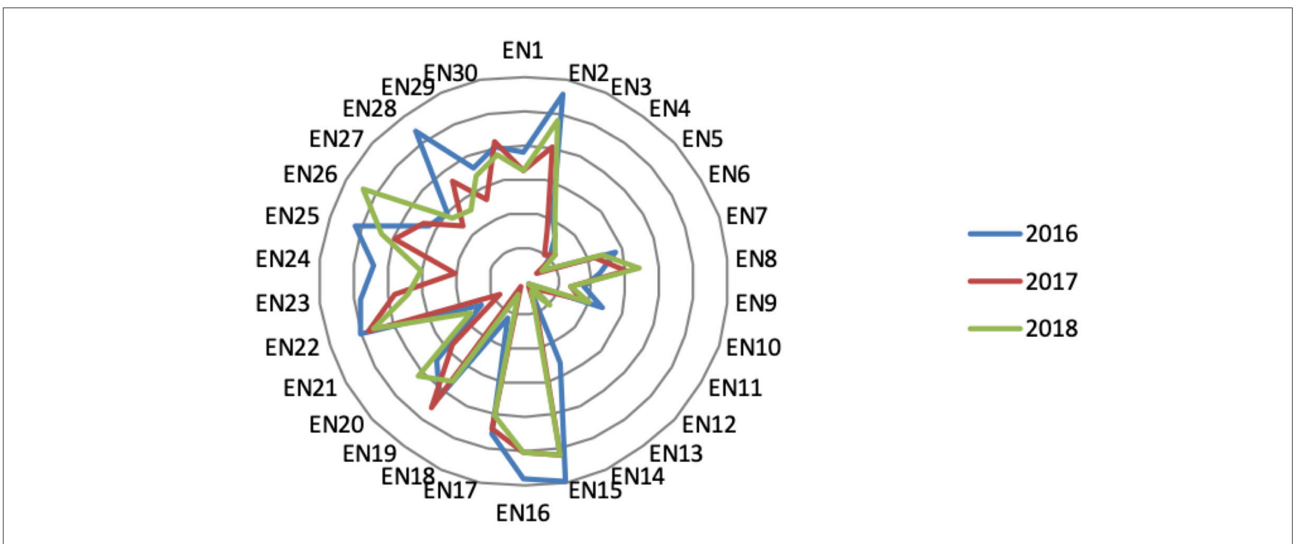

Figure 1: The Average Sustainability Performance of Energy Companies Relating to Three Years

The criteria weights are part of the MCDM methods and affect the evaluation process (Zavadskas and Podvezko, 2016). As can be seen from the studies carried out, the importance of the criteria has a strong effect on the MCDM results (Zavadskas and Podvezko, 2016; Alemi-Ardakani et al. 2016; Kumar and Parimala, 2019). Table 10 shows the criteria weights for all dimensions and years. It was determined that criterion weights generally vary according to years and dimensions. Many studies have obtained similar results using the objective weighting method (Wicher et al. 2019; González et al. 2016; Zhang et al. 2014). This situation is directly related to the different data sets used. On the other hand, in studies where subjective weighting is used, the weights of the criteria do not change according to years and dimensions (Yi et al., 2019). However, studies show that objective weighting is more advantageous than subjective weighting (Deepa et al., 2019).

According to Table 13, the importance of the criteria in the economic dimension has changed over the years. In the social and environmental dimension, the most important and least important criteria remained the same in all three years. The criteria weights vary according to the data set used and the accuracy of comparing them with different study results is debatable. However, to give an example, Yalçın and Karakaş (2019) determined the most important and least important criteria in their study as follows; environmental dimension (recycled waste amount: max; electricity consumption: min), economic dimension (total assets: max; asset profitability ratio: min), social dimension, total vehicle accident rate: max; total number of employees: min). Öztel et al. (2018) determined the most important and least important criteria in their study as follows; environmental dimension (disposal amount: max; total water consumption: min), economic dimension (Operating profit ratio: max; number of shares: min), social dimension (occupational accident frequency rate: max; total number of employees: min). Alp et al. (2015) determined the most important and least important criteria in their study as follows; environmental dimension (nitrogen oxide amount: max; per million euros) oscillation: min), economic dimension (stock minimum price: max; operating margin ratio: min), social dimension (senior employee ratio: max; employee ratio between 31-50 years: min).

Table 12 presents the final ranking results obtained by the Copeland method. Certainly that the companies that ranked first based on all three dimensions and every three years did not change. In terms of economic sustainability; EN13 (Thai Oil) company operating in Thailand ranked first in every three years. On the other hand, 73.33% of the top five companies operate in the Asian region, while 26.6% operate in the European region. While 73% of the top five companies in the Asian region operate in Thailand, 27% operate in Turkey.

EN3 (Aygaz), operating in Turkey, ranked at the top in terms of environmental sustainability performance in each of the three years. The company that ranked lowest is EN26 (Naturgy Energy Group, S.A) operating in Spain.

Table 13: The Criteria Weights for All Dimensions and Years

Economic dimension								
	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8
2016	10.75%	10.66%	11.32%	11.41%	13.43%	20.25%	10.51%	11.68%
2017	11.19%	11.03%	12.06%	12.14%	16.63%	12.81%	10.87%	13.27%
2018	11.11%	13.03%	11.30%	11.32%	20.60%	9.48%	10.69%	12.48%
Social dimension								
	SO1	SO2	SO3	SO4	SO5	SO6	SO7	
2016	14.44%	11.08%	10.76%	13.22%	18.01%	12.74%	19.75%	
2017	13.60%	12.16%	11.00%	13.10%	17.54%	12.78%	19.82%	
2018	14.93%	12.09%	11.57%	11.90%	18.14%	12.62%	18.74%	
Environmental dimension								
	ENV1	ENV2	ENV3	ENV4	ENV5	ENV6	ENV7	ENV8
2016	11.36%	10.94%	10.14%	19.35%	10.87%	9.90%	12.74%	14.71%
2017	11.38%	10.69%	9.93%	20.50%	10.58%	9.64%	12.76%	14.52%
2018	11.44%	10.91%	10.08%	19.76%	10.81%	9.76%	12.75%	14.49%

80% of the top five companies operate in the Asian region, while 20% operate in the European region. While 50% of the top five companies in the Asian region operate in Thailand, 42% operate in Turkey. In terms of social sustainability performance, EN10 (PTT Public Company Limited), operating in Thailand, ranked at the top in each of the three years. 73.33% of the top five companies operate in the Asian region, while 26.6% operate in the European region. A total of 91% of the companies in Asia, which are ranked among the top five, operate in Thailand.

CONCLUSIONS, BOUNDARIES, AND FUTURE RESEARCH DIRECTION

This paper proposed an evaluation approach that utilizes MCDM methods to evaluate the corporate sustainability performance of 30 energy firms operating in Asian and European regions for the 2016-2018 period. In this study, a framework was created to measure the corporate sustainability performance of companies operating in the energy sector. The purpose of establishing such a framework is to reveal the sustainability performance levels of the companies and compare them based on different countries and regions.

According to the final results obtained by the Copeland method, it has been determined that top-ranking companies operate in Thailand. On the other hand, it has been determined that the companies that rank first based on all three dimensions (economic, environmental, social) and three years (2016-2018) are located in the Asian region. It can be concluded that energy companies operating in the Asian region are more sustainable. The most sustainable country in the Asian region is Thailand.

The common factors that enable companies operating in Thailand to be at the forefront in terms of economic, environmental and social sustainability performance were examined. Accordingly, the effect of financial ratios (current ratio, leverage ratio) is great in providing superiority in terms of economic dimension. In terms of the social dimension, the high average training hours and the high rate of female employees ensured that the companies were at the forefront. It can be said that the total energy consumption, the amount of waste water, the total greenhouse gas emission, the low amount of total waste and the high amount of recycled waste increase the environmental sustainability performance of Thai companies.

With a general evaluation, it has been determined that the economic sustainability of the companies with high profitability is high. In order to increase environmental sustainability performance, it is necessary to increase the use of renewable energy sources that do not harm the nature. In order to increase social sustainability performance, companies need to give more importance to education and increase the rate of female employees. The five important contributions of this study can be indicated as follows:

- Provided a research strategy using the integrated MCDM model (Entropy-PIV-ROV-GRA-MARCOS) to tackle complex sustainability issues
- This study is the first in the literature in terms of the model and approach used.
- The suitability of the integrated method used and the PIV, ROV and MARCOS methods for corporate sustainability measurement was tested for the first time.
- The results obtained with the four methods used were able to be compared.
- Providing the opportunity to compare countries, regions and companies with each other in terms of corporate sustainability performance.

The integrated model used in this study is a suitable model for corporate sustainability performance measurement. It is thought that the results obtained will contribute to the development of the energy sector. This study has two main limitations: i. The alternatives included in the scope of the study were selected from among the companies that report based on the GRI guide. ii. Accessibility was the main reference point when determining the criteria. For this reason, many companies that do not report under the GRI guidelines and whose data are not available were excluded from the analysis. This has caused many regions in the GRI database (Africa, Latin America, North America, Oceania) to be excluded from the analysis. On the other hand, in this study, in which a common indicator pool was created, some criteria considered important such as "renewable energy usage rate", "energy-saving amount", "environmental investments and expenditures", "distribution of employees on the board of directors by age", and "absenteeism rate" could not be included in the scope of the study since the indicators announced by the companies were different from each other.

In future studies, performance measurement can be carried out to cover different periods by expanding the alternative and criteria set. The weighting methods such as AHP and DELPHI, which include subjective evaluations of decision-makers, can be used instead of Entropy method. In the selection process of alternatives, a different perspective can be brought to the study by choosing DJSI instead of the GRI database.

Appendix A

Table A1. Economic dimension decision matrix

2016	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8	2017	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8
EN1	10	-0,20	1,11	1,07	-0,11	0,50	0,28	0,78	EN1	8	-0,15	0,28	0,28	-0,09	0,27	0, 32	0,68
EN2	4	-0,16	0,71	0,53	-0,09	-0,94	0,77	0,91	EN2	5	0,13	0,69	0,50	0,08	0,23	0,69	0,68
EN3	18	0,37	1,38	1,18	0,10	0,15	1,60	0,35	EN3	16	0,42	1,24	0,99	0,12	0,20	1,71	0,41
EN4	87	0,10	1,69	1,10	0,08	0,13	1,42	0,57	EN4	98	0,13	1,52	0,80	0,07	0,14	1,51	0,54
EN5	60	0,47	1,49	1,49	0,04	0,10	0,12	0,58	EN5	61	0,67	2,26	2,26	0,06	0,16	0,15	0,57
EN6	36	0,18	1,43	1,06	0,08	0,18	0,46	0,48	EN6	42	0,19	1,53	1,12	0,08	0,18	0,47	0,45
EN7	254	0,01	0,76	0,27	0,06	0,12	0,98	0,53	EN7	272	0.02	0,96	0, 36	0,06	0,13	1,07	0,53
EN8	1009	-0,000003	2,54	2,46	0,03	0,07	0,16	0,47	EN8	1109	0,003	1,94	1,82	0,04	0,08	0, 35	0,49
EN9	18	0,72	1,27	0,97	0,08	0,22	3,87	0,66	EN9	18	0,90	1,40	1,00	0,10	0,27	4,43	0,64
EN10	1313	0,10	2,18	1,84	0,06	0,13	0,77	0,48	EN10	1475	0,14	2,21	1,86	0,08	0,17	0,89	0,44
EN11	19	0,13	2,42	2,42	0,06	0,10	0,53	0,35	EN11	20	0,12	2,44	2,44	0,06	0,10	0,50	0,37
EN12	31	0,06	1,7	0,84	0,15	0,23	2,61	0,31	EN12	30	0,05	1,7	0,86	0,15	0,21	2,74	0,30
EN13	28	0,31	3,4	2,4	0,11	0,21	1,26	0,49	EN13	30	0,37	3,8	2,7	0,12	0,22	1,48	0,44
EN14	355	0,06	1,08	0,98	0,07	0,13	0,24	1,12	EN14	334	0,06	0,76	0,68	0,07	0,13	0,25	0,46
EN15	2	-0,00001	0,47	0,47	-0,0005	0,03	0,16	1,02	EN15	30	0,004	0,51	0,51	0,003	0,03	0,41	0,91
EN16	450	0,0745	1,21	1,15	0,02	0,07	0,47	0,68	EN16	475	0,09	1,21	1,15	0,03	0,10	0,58	0,70
EN17	661	0,26	0,86	0,81	0,02	0,06	0,06	0,69	EN17	681	0,31	1,13	1,09	0,02	0,06	0,06	0,68
EN18	109	1,75	0,94	0,93	0,05	0,17	0,13	0,73	EN18	129	2,06	2,50	2,45	0,05	0,17	0,14	0,69
EN19	1128	1,33	0,72	0,56	0,05	0,16	0,59	0,71	EN19	917	1,38	0,73	0,57	0,05	0,16	0,63	0,70
EN20	503	0,09	2,05	1,93	0,07	0,26	0,41	0,74	EN20	482	0,12	1,06	0,97	0,07	0, 3	0,47	0,79
EN21	69	0,689	2,25	2,20	0,03	0,07	0,23	0,62	EN21	63	0,72	2,20	2,16	0,04	0,11	0,23	0,60
EN22	524	0,141	1,14	1,09	0,03	0,09	0,62	0,69	EN22	552	0,17	1,09	0,96	0,03	0,10	0,64	0,69
EN23	2367	0,423	0,77	0,65	0,03	0,07	0,27	0,62	EN23	2776	0,46	0,83	0,71	0,03	0,07	0,28	0,61
EN24	271	0,20	0,76	0,46	0,005	0,01	0,77	0,48	EN24	234	2,80	1,02	0,56	0,06	0,11	0,96	0,40
EN25	360	0,14	1,26	1,20	0,02	0,08	0,42	0,71	EN25	390	0,19	1,38	1,33	0,03	0,11	0,47	0,68
EN26	974	1,22	1,14	1,04	0,03	0,07	0,46	0,60	EN26	1031	0,94	1,46	1,36	0,03	0,07	0,49	0,61
EN27	507	2,83	1,52	0,85	0,10	0,20	1,08	0,47	EN27	574	3,73	1,77	1,01	0,12	0,20	1,57	0,42
EN28	2501	1,11	1,08	0,84	0,03	0,06	0,53	0,52	EN28	1892	1,29	1,23	0,91	0,04	0,07	0,69	0,50
EN29	167	0,17	0,42	0,39	0,04	0,13	0,12	0,68	EN29	171	0,26	0,61	0,59	0,04	0,15	0,12	0,72
EN30	82	0,32	0,76	0,76	0,04	0,18	0,13	0,78	EN30	66	0,34	0,91	0,90	0,04	0,18	0,13	0,77

Appendix B

Table B1. Environmental dimension decision matrix

2016	ENV1	ENV2	ENV3	ENV4	ENV5	ENV6	ENV7	ENV8	2017	ENV1	ENV2	ENV3	ENV4	ENV5	ENV6	ENV7	ENV8	2018	ENV1	ENV2	ENV3	ENV4	ENV5	ENV6	ENV7	ENV8
EN1	0,54	2,2	1,2	98,69	10,4	0,0001	93,46	100	EN1	0,80	2,7	1,6	99,54	13,1	0,0001	66,56	100	EN1	0,69	2,2	1,3	99,87	10,0	0,00006	84,11	100
EN2	58,1	8,1	4,4	96,29	1,5	0,001	22,11	77,89	EN2	68,0	8,0	5,1	96,39	1,9	0,006	7,69	6,78	EN2	58,2	7,2	4,6	96,07	1,7	0,64	0,09	0,043
EN3	0,17	0,15	0,02	38	0,06	0,01	5, 30	98,11	EN3	0,16	0,110	0,01	32,73	0,06	0,01	4,79	99,74	EN3	0,13	0,10	0,01	33,72	0,05	0,01	5,62	99,50
EN4	14,4	2,4	1,0	98,45	0,84	0,01	81,16	72,82	EN4	14,7	2,5	1,00	97,64	0,9	0,002	80,74	94	EN4	13,4	2,4	0,91	98,46	0,9	0,02	30,26	31,92
EN5	42,8	1,4	6	99,93	1,4	0,07	0,18	83,69	EN5	42,0	1,2	5,8	99,88	1,2	0,05	0,45	60,09	EN5	48,4	1,1	6,7	99,87	1,1	0,05	0, 39	66,75
EN6	69,9	2,5	12	100	2,6	0,23	0,52	98,60	EN6	67,8	2,4	11,3	100	2,4	0,23	0,52	97,88	EN6	68,2	2,6	11,5	100	2,5	0,24	0,44	98,52
EN7	50,6	47,6	7,5	99,99	28,6	0,04	33,82	76	EN7	52,1	41,5	7,6	99,99	22,1	0,05	48,21	57,71	EN7	59,0	42,3	8,4	99,99	24,8	0,06	30,61	57,77
EN8	113,2	89,5	15,4	83,77	8,8	0,27	91	86,20	EN8	119,5	92,5	16,6	83,73	9,0	0,34	95,34	30	EN8	167,6	101,9	17,9	82,12	10,9	0,29	93,27	3,96
EN9	0,07	0,11	0,01	52,69	0,08	0,002	74,63	96,91	EN9	0,10	0,09	0,01	60,07	0,07	0,002	84	86,39	EN9	0,1	0,13	0,01	57,95	0,15	0,004	90,25	85,91
EN10	47,1	3,6	10,7	97	1,5	16,9	28,33	40,77	EN10	47,7	3,6	11,3	97,97	1,4	20,0	17,10	30,22	EN10	46,8	3,7	10,6	97,87	1,41	20,5	19, 37	24,72
EN11	121,8	31,7	9,3	99,61	4,5	0,01	14,70	99,22	EN11	101,7	22,1	8,1	99,54	4,0	0,01	14,93	98,51	EN11	87,5	19,7	7,0	99,52	4,0	0,003	14,72	98,99
EN12	20,1	3,0	1,4	99,84	2,0	0,01	96,70	97,82	EN12	19,0	2,9	1,3	99,87	1,9	0,01	97,25	99,82	EN12	19,9	2,9	1,2	99,88	1,7	0,02	81,19	88,68
EN13	27,4	23,3	3,7	100	19,5	0,01	94,36	91	EN13	29,4	22,9	3,4	100	18,7	0,01	94,66	94,89	EN13	31,6	22,9	3,5	100	18,6	0,01	96,01	95,15
EN14	11,3	3,7	1,2	67,64	2,1	0,22	0,54	0,67	EN14	11,2	4,1	1,3	66	1,9	0,20	0,53	1,07	EN14	12,3	4,2	1,3	63,95	1,1	0,22	0,53	1
EN15	4,8	30,8	1,1	99,49	0	0,23	49,57	5,60	EN15	5,3	36,3	0,96	99,64	0	0,14	19,15	5,67	EN15	2,5	73,6	1,8	99,55	0,15	0,15	18,49	23,43
EN16	177,8	112,0	6,6	98,18	3,2	0,53	15,96	47	EN16	266,0	124,0	8,2	98,50	4,5	0,62	16,87	52	EN16	239,6	94,0	7,6	98,56	4,3	0,64	17,43	52
EN17	220,6	1,7	19,5	97,19	1,5	0,48	1, 35	61	EN17	291,0	1,9	24,0	96,59	1,8	0,67	0,94	46	EN17	234,8	1,7	19,0	96,84	1,5	0,35	1,55	78
EN18	3,9	0,11	0,29	90,70	0,02	0,004	42,10	60,99	EN18	4,6	0,13	0,29	92,06	0,02	3,1	31,26	68	EN18	4,7	0,10	0,30	90,06	0,02	0,004	40,73	78
EN19	615,7	61,0	30,2	97,21	20,3	0,05	18,63	66	EN19	684,0	66,0	35,5	98	78,2	0,06	19,70	78,72	EN19	615,3	56,5	32,7	97,03	70,3	0,08	13,20	85,95
EN20	182,8	1,4	14,4	100	1,3	0,16	6,07	29,10	EN20	214,0	2,0	16,0	100	1,9	0,25	2,31	24,44	EN20	271,8	2,4	17,7	100	2,3	0,28	2,56	33, 38
EN21	21,3	223	7,8	15,56	222,8	0,01	94,24	59,90	EN21	19,9	205,0	3,3	33,95	205,0	0,01	93,24	85	EN21	17,7	203,0	2,5	40,22	202,8	0,01	93,75	82
EN22	23,6	422,1	1,7	82,54	393,0	2,5	4, 35	8,45	EN22	18,8	430,0	1,6	88,04	364,0	2,4	6,90	5,68	EN22	19,5	421,8	1,5	90,13	382,0	2,8	1,95	2,73
EN23	442,2	1,9	31,0	85,49	1,8	0,99	1,07	48,33	EN23	440,5	2,0	30,1	86,87	1,9	1,1	0,86	43,02	EN23	400,7	2,0	26,8	90,75	1,9	0,56	2,34	54
EN24	21,25	29,9	1,8	93,85	26,0	0,03	40,19	51,12	EN24	23,4	34,4	1,9	95,81	30,2	0,02	57,97	51,63	EN24	23,0	36,4	1,9	95,81	31,8	0,03	56,95	36,53
EN25	55,34	490,6	5,5	97,31	480,9	0,47	7,03	64,51	EN25	54,6	518,0	3,5	97,25	518,0	0,45	8,45	71,65	EN25	53.1	504,9	3,5	96,72	503,6	0,49	7,90	69,90
EN26	248,2	816,7	19,6	99,45	783,4	1,0	0,92	14,98	EN26	248,6	907,0	20,6	99,44	879,7	0,82	1,19	18,62	EN26	218,2	777,5	18,4	99,42	753,7	0,45	1,87	34,54
EN27	48,6	82,6	13,0	100	46,1	0,17	43,50	56,94	EN27	31,7	88,4	14,4	100	51,3	0,21	47	53,87	EN27	38,2	90,3	15,0	100	51,6	0,18	47,41	31,21
EN28	218,1	54,2	25,5	97,81	44,0	0,27	20,74	19,49	EN28	214,0	55,7	23,3	98,33	34,8	0,39	10,21	7,31	EN28	208,9	53,5	22,3	98,18	43,0	0,22	32,30	12,77
EN29	11,0	4,2	1,5	98,09	4,1	0,05	6,78	77	EN29	12,6	4,2	1,5	98,10	4,1	0,05	7	80	EN29	13,3	4,1	1,5	97,91	4,1	0,03	14,49	60
EN30	804,7	0,16	136,7	45,35	1,4	4,9	37,29	92,71	EN30	813,0	0,17	148,3	51,11	1,2	4,8	46,87	87,22	EN30	790,7	0,18	127,1	49,59	1,8	6,8	51,43	85,61

Appendix C

Table C1. Social dimension decision matrix

2016	SO1	SO2	SO3	SO4	SO5	SO6	SO7	2017	SO1	SO2	SO3	SO4	SO5	SO6	SO7	2018	SO1	SO2	SO3	SO4	SO5	SO6	SO7
EN1	25	18	0	0	36	209	22	EN1	21,2	30	0	0	34	194	21,13	EN1	9,2	25	0	0	43	200	20,5
EN2	22,12	163	0	0	9,3	782	4,73	EN2	34,84	237	0	0	20,8	1019	8,24	EN2	29,17	201	1	0	26,4	977	8,90
EN3	26,73	330	0	0	47	1182	9,48	EN3	20,75	261	0	0	38	1195	9,87	EN3	18,03	147	0	0	39	1115	11,03
EN4	3,20	121	0	0	44	1196	29,18	EN4	4,0	104	0	0	45	1240	30,16	EN4	3,55	67	0	0	46	1254	29,74
EN5	2,76	22	0	0	28,07	995	30,35	EN5	4,30	74	0	0	26,62	1328	27,26	EN5	2,86	68	0	0	30,39	1361	23,14
EN6	7,47	50	0	0	58,37	726	26,03	EN6	7,42	56	0	0	52,93	736	26,63	EN6	4,54	36	0	0	60,10	739	27,06
EN7	2,66	125	0	0	32,67	5418	17,29	EN7	1,11	32	0	0	38	5498	16,82	EN7	0,16	9	0	0	48	5466	17,23
EN8	13,8	18685	7	0	33,6	90267	21	EN8	14	7902	5	0	16,1	84061	19,20	EN8	14	9551	1	0	15,0	78933	18,80
EN9	6,73	90	0	0	12,22	810	18,40	EN9	6,02	81	0	0	17,71	842	19,24	EN9	6,05	82	0	0	17,35	872	20,64
EN10	3,68	149	0	0	49,84	4616	33,88	EN10	3,64	144	0	0	39,80	4697	34,43	EN10	4,29	222	0	0	73,68	3715	38
EN11	3,85	48	0	0	27,79	439	33,03	EN11	6,95	65	0	0	33,80	445	33,26	EN11	3,1	40	0	0	47	453	33,33
EN12	3	7	0	0	47	455	22,20	EN12	2	30	0	0	49	472	23,31	EN12	1,97	40	0	0	53	496	23,79
EN13	3,14	66	0	0	62,5	1437	26,51	EN13	3,25	55	0	0	49,5	1447	26,81	EN13	2,91	70	0	0	67,5	1480	26,49
EN14	2,3	1853	0	0	6,6	46803	31,72	EN14	4,1	1196	0	0	10,5	46772	32,87	EN14	4,1	3558	0	0	28,6	49489	32,63
EN15	13,68	124	0	0	25,04	643	14,93	EN15	10,11	141	0	0	20,43	673	14,56	EN15	10,45	120	0	0	10,39	919	15,56
EN16	6,8	728	0	8	16,8	9777	15,32	EN16	5,9	906	0	3	18,7	11416	16,06	EN16	6,3	956	0	9	20,3	11196	16,45
EN17	6,38	722	0	3	37	11992	24	EN17	9,04	939	0	2	33	11657	24	EN17	10,32	1174	0	5	41	11631	25
EN18	4,35	103	0	0	61,75	1337	23	EN18	4,64	72	0	0	65,14	1426	23	EN18	4,8	110	0	0	61,44	1449	27
EN19	8,90	556	0	0	45,8	9694	22,36	EN19	7,3	256	1	0	35,3	9706	23,16	EN19	4,58	393	0	0	37,9	9763	23,34
EN20	11	516	0	0	27,5	10310	17,62	EN20	9	872	1	0	25,0	10237	18,07	EN20	12	1014	0	0	23,0	10711	17,61
EN21	6,8	71	0	0	39,3	715	20,98	EN21	10,2	36	0	0	61,9	714	20,87	EN21	13,4	61	0	0	49	737	20,08
EN22	3,4	310	0	0	29,3	8502	24	EN22	3,7	291	0	0	28,6	8847	24,30	EN22	5,9	391	0	0	29,8	8777	24,76
EN23	7,3	2434	0	2	46	34082	23,93	EN23	7,9	3210	0	3	42	34255	23,43	EN23	10,7	3413	0	2	45	34078	23,36
EN24	10,37	1514	0	0	15,19	10861	21	EN24	7,55	771	0	0	15,52	10884	24	EN24	9,35	718	0	0	20,9	10849	24
EN25	4,9	108	0	0	15,6	6226	25,23	EN25	2,6	152	0	0	16,5	6285	25,51	EN25	6,2	313	0	0	18,9	7042	25,66
EN26	7,1	1059	0	0	51	17229	29	EN26	6,4	945	0	0	38,4	15375	29	EN26	17,4	503	0	0	49,9	12700	31
EN27	4,22	323	0	6	40	4786	20	EN27	7,55	532	0	3	28,77	4980	21	EN27	6,2	603	0	3	39	5250	21,73
EN28	13	2445	0	6	41	25469	34,45	EN28	9	3157	0	6	40	25085	35,13	EN28	23	3810	0	0	45	25288	36,47
EN29	6,4	144	0	0	28,5	2883	12,80	EN29	7,4	146	0	0	29,2	2919	13,46	EN29	13	196	0	0	35,7	3016	13,89
EN30	1,5	186	0	0	61	3468	11,71	EN30	5,9	243	0	0	50	3508	12,31	EN30	2,4	420	0	0	55	3843	13,45

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