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Measuring Road Transport Sustainability Using MCDM-Based Entropy Objective Weighting Method

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Abstract: Road haulage solutions are incredibly adaptable, having the capacity to link domestically and internationally. Road transportation offers a greener, more efficient, and safer future through sophisticated technology. Symmetry and asymmetry exist widely in industrial applications, and logistics and supply chains are no exception. The multi-criteria decision-making (MCDM) model is considered as a complexity tool to balance the symmetry between goals and conflicting criteria. This study can assist stakeholders in understanding the current state of transportation networks and planning future sustainability measures through the MCDM approach. The main purpose of this paper is to evaluate and compare the sustainable development of existing road transportation systems to determine whether any of them can be effectively developed in the Organization for Economic Cooperation and Development (OECD) countries. The integrated entropy–CoCoSo approach for evaluating the sustainability of road transportation systems is introduced, and the framework process is proposed. The entropy method defines the weight of the decision criteria based on the real data. The advantage of the entropy method is that it reduces the subjective impact of decision-makers and increases objectivity. The CoCoSo method is applied for ranking the road transportation sustainability performance of OECD countries. Our findings revealed the top three countries' sustainability performance: Japan, Germany, and France. These are countries with developed infrastructure and transportation services. Iceland, the United States, and Latvia were in the last rank among countries. This approach helps governments, decision-makers, or policyholders review current operation, benchmark the performance of other countries and devise new strategies for road transportation development to achieves better results.

Keywords: road transport; sustainability; OECD countries; conflicting criteria; objective weighting; entropy; CoCoSo; MCDM

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1. Introduction

The rapid global population growth in the 20th century led to increasing demand for transportation and put great pressure on the fuel and transportation sectors. Transportation is an indispensable factor in shipping goods and services to consumers. However, the existing transportation system has a host of problems, including global warming, environmental degradation, health implications (physical, emotional, mental, spiritual), degraded air quality, and increased greenhouse emissions. The transportation sector accounts for 27% of global greenhouse gas emissions due to fossil fuel use, and road transportation contributes significantly to air pollution and smog [1]. This trend is expected to continue to increase in the future if the government of countries does not take practical actions to reduce greenhouse gas emissions as well as the oil demand. Road transport is the most important sector and the most flexible of all modes of transportation because this mode has the role of transit from other types. The road network covers the whole territory and plays the main connecting role for the transport network between areas, regions, airports, seas, border gates, and important traffic hubs. The share of road freight transport reached 76.3% of total inland freight transport in the European Union in 2019, while rail freight and inland waterways transport accounted for the remaining 23.7% [2]. As an important component of transportation systems, the roadway network should be planned and invested in contributing to the country's sustainable development.

Today, one of the biggest challenges to the road transportation sector is its effects on the environment and social life, which are linked to economic and commercial concerns. Therefore, environmental protection and sustainability have become important requirements in road transportation development. A transportation system development considering necessary economic, social, and ecological aspects is essential to overcome the rising demand for moving with a vision of sustainable development. Road transportation planning has multiple objectives and criteria that make it more difficult to attain a sustainable system. The multi-criteria decision-making (MCDM) method has proven to be one of the better tools in solving complicated transportation problems, especially in the field of quality and safety of transportation, development scenarios selection for transportation systems, location analyses of transport projects, as well as in other problems related to transport infrastructure investment [3].

MCDM is considered as a complexity tool to balance the goals, risks and constraints regard a problem. The symmetry related to the assessment obtained from the MCDM method can be modeling [4]. This research aims to evaluate and compare the sustainable development of existing road transportation systems to determine whether any of them can be effectively developed in Organization for Economic Cooperation and Development (OECD) countries. The integrated entropy–CoCoSo approach for evaluating the sustainability of road transportation systems is introduced, and the framework process is proposed. The entropy method defines the weight of the decision criteria based on the real data. The advantage of the entropy method is that it reduces the subjective impact of decision-makers and increases objectivity. The CoCoSo method is applied for ranking the road transportation sustainability performance of OECD countries. This research also indicates the action to improve the benefits of sustainability for road transportation networks.

The contributions of the research can be summarized as follows:

- This work proposed a novel indicator system for measuring the road transport sustainability including systematic effectiveness, economic, social, and environmental aspects, decomposition into 12 sub-criteria with a case study in 28 OECD countries.
- To the best of the author's knowledge, this paper is the first to combine entropy and CoCoso methodology in the existing road transport evaluation literature. This integrated MCDM model is conducted with the real data.
- For managerial implication, the model's results can support government or policymakers in dealing with the sustainable development of the national road transportation systems, especially in the post-pandemic period.

The remaining sections of this research are organized as follows. A literature review of MCDM techniques for sustainable transportation systems is presented in Section 2. Section 3 proposed methodologies that are used for transport sustainability measurement. Section 4 illustrates the application of the proposed method through a real-world case study in OECD countries. Furthermore, the evaluation and analysis of the road transportation systems sustainability in 2019 for OECD countries are discussed in Section 5. Finally, Section 6 presents some conclusions and scope for future work.

2. Related Work

In the last decades, there is a change in transportation planning, from an engineering-focused approach and ignoring social or environmental issues to an approach supporting sustainable transportation [5]. Sustainable transportation is the ability to support the mobility requirements of society in a manner that is safe, saving, and least damaging to the environment now and in the future [6,7]. Many researchers have developed models, frameworks, measurement, evaluation, and analysis methods relating to the planning, design, and management of sustainable transportation systems. Dernir et al. reviewed the scientific research on green road freight transportation [8]. Litman and Burwell [9] and Jeon [10] identified the definition, issues, indicators, and methodologies for evaluating sustainable transportation. Shiau and Jhang [11] integrated data envelopment analysis (DEA) and rough set theory (RST) approaches to evaluate the sustainable transportation system by using different efficiency indicators. Castillo and Pitfield presented a framework to select indicators for measuring transport sustainability [12]. A macroscopic framework of control models for the planning of sustainable transportation systems was developed by Maheshwari et al. [13]. Lopez and Monzon integrated the sustainability paradigm into strategic transportation planning by using a multi-criteria assessment model [14]. An analytic hierarchy process (AHP) multi-criteria decision model have been applied to evaluate sustainable public road transportation system in Madrid (Spain) according to both economic and environmental criteria in [15].

Sustainability evaluation is not only essential for improving the current operational transportation systems but also considering for the transportation planning strategies of countries. There are various parameters to measure sustainable transportation systems in aspects of social, economic, and environmental components. However, some parameters are conflicting, leading to less performance. In MCDM, problems are often characterized by several incommensurable and conflicting criteria, and there is no solution to satisfy all the criteria simultaneously. A compromise solution, combining complexity with simplicity, is determined to make a final decision [16,17]. Numerous MCDM approaches have been suggested to create the best compromises. MCDM is considered as a complex decision-making process for the evaluation of problems according to quantitative and qualitative criteria [18]. MCDM helps a decision-maker quantify criteria based on their importance in various objectives. According to Kumar et al. [19], MCDM can be classified into two groups: multi-attribute decision making (MADM) and multi-objective decision making (MODM). MADM relates to the evaluation of discrete alternatives, whereas MODM relates to the evaluation of continuous alternatives.

Numerous studies on the application of MCDM in transport sustainability measurement have been developed in recent years. Table 1 presents the overview of related studies using the MDCM method. Most of the methods used in sustainable transportation systems are traditional AHP/ANP models [20–26]. Moreover, the analytic hierarchy process (AHP) and analytic network process (ANP) methods have been used together with other methods to generate an approach that is as accurate as possible. For example, Yang et al. (2016) presented the integrated DEMATEL-ANP model to assess the sustainable public transport infrastructure projects [23]. Pathak et al. employed a framework by integrating fuzzy analytic hierarchy process (FAHP), total interpretive structural modeling (TISM), and Delphi study to measure the performance of sustainable freight transportation [24]. In addition to that, it is possible to see some methods have been widely applied in the sustainability evaluation of transport systems, such as Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Decision Making Trial and Evaluation Laboratory (DEMATEL), Data Envelopment Analysis (DEA), Multi-Objective Optimization method based on Ratio Analysis (MOORA), Step-wise Weight Assessment Ratio Analysis (SWARA), Multi-Attribute Border Approximation area Comparison (MABAC), ELimination Et Choix Traduisant la REalité (ELECTRE), and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), to name a few [23,26–35]. In this paper, we propose a Combined Compromise Solution (CoCoSo) approach for the evaluation of sustainable transportation systems. The CoCoSo is a new MCDM model which integrated the idea of three different approaches including simple additive weighting (SAW), multiplicative exponential weighting (MEW), and weighted aggregated sum product assessment (WASPAS) methods [36].

Table 1. Overview of related studies using MCDM method.

No.	Authors	Year	Multi-Criteria Decision-Making Method													Sensitivity Analysis
			AHP/ANP	TOPSIS	CODAS	VIKOR	DEA	DEMATEL	Delphi	MABAC	SWARA	MOORA	MIVES	ELECTRE	REMBRANDT	
1	Yedla and Shresth [20]	2003	x													
2	Bojković et al. [33]	2010												x		
3	Bojković et al. [21]	2011	x													
4	Awasthi et al. [27]	2011		x												x
5	Jones et al. [22]	2013	x													
6	Li et al. [28]	2014		x												
7	Yang et al. [23]	2016	x					x								
8	Mavi et al. [34]	2017									x	x				
9	Oses et al. [35]	2018											x			
10	Pathak et al. [24]	2019	x						x							
11	Tian et al. [31]	2020					x									
12	Seker and Aydin [25]	2020	x		x											x
13	Yazdani et al. [29]	2020						x		x						x
14	Rao [26]	2021	x					x								
15	Broniewicz et al. [30]	2021				x		x							x	
16	Wang et al. [32]	2022					x									

Note: AHP: analytic hierarchy process, ANP: analytic network process, TOPSIS: technique for order of preference by similarity to ideal solution, CODAS: combinative distance-based assessment, VIKOR: visekriterijumska optimizacija I kompromisno resenje, DEA: data envelopment analysis, DEMATEL: decision-making trial and evaluation laboratory, MABAC: multi-attribute border approximation area comparison, SWARA: step-wise weight assessment ratio analysis, MOORA: multi-objective optimization method based on ratio analysis, ELECTRE: elimination et choix traduisant la realité, REMBRANDT: ratio estimation in magnitudes or decibels to rate alternatives which are non-dominated.

Determining criteria weights plays a pivotal role in the process of MCDM because it has a profound impact on the results [37,38]. Determining the weights of the selection criteria can be classified into three categories: subjective weighting, objective weighting, and combination weighting methods [39]. The subjective weighting methods are assigned to the thoughts and experiences of the experts, and in order to obtain the relative importance of the criteria, decision-makers directly express their opinion on the questions of the analyst. Contrarily, the objective weighting methods are obtained weights through mathematical methods based on the structural analysis of the data, and they neglect the subjective judgment information of the decision-makers. The subjective weighting methods are a very time-consuming process, especially when decision-makers fail to consistently take into consideration discussion of the weight value [40]. The objective weighting methods can be a great advantage in terms of computation efficiency. Thus, it is necessary to apply objective weighting methods to obtain more meaningful results and improve the quality of decision making. The popular objective weighting methods include Mean Weight, Standard Deviation, Statistical Variance Procedure, Entropy method, Criteria Importance Through Inter-criteria Correlation (CRITIC) and Simultaneous Evaluation of Criteria and Alternatives (SECA) [41–45]. All of us have advantages and disadvantages and have efficiency in different situations. Four objective weighting methods, namely, Shannon entropy, CRITIC, ideal point, and distance-based approach were also introduced and compared for industrial robot selection problems [46]. Here, we do not intend to compare these advantages and disadvantages. This paper used entropy, which is the objective weight method to calculate the weights of the relevant criteria. The entropy method was introduced by Shannon, which calculates the weight for each criterion based on data obtained [44]. The advantages and limitations of the entropy method in multi-objective optimization problems are presented by Kumar et al. [47] The entropy method has been widely used in various fields. For example, Hafezalkotob developed the Shannon entropy–MULTIMOORA integration method for materials selection problems [48]. The AHP–entropy–ANFIS model had been established for predicting the unfrozen water of saline soil by Wang et al. [49]. Sengül et al. [50] used the Shannon entropy method to identify the weight value of each criterion and employed the fuzzy TOPSIS method for analyzing renewable energy supply systems. The framework for the sustainability assessment of port regions is proposed through the aggregate entropy–PROMETHEE method [51].

Devoted to bridging the gap of the existing literature, the innovations of this paper are three-fold: (1) this paper proposed a new indicator measurement in road transport with four criteria and 12 sub-criteria, which is a significant advantage of the work, (2) the combination of entropy (objective weighting for criteria) and CoCoSo (alternatives ranking) model is established as a relevant and successful approach for sustainable transportation evaluation, and (3) the model's results help governments, decision-makers, or policyholders review current operation, benchmark the performance of other countries and devise new strategies for road transportation development to achieve better results.

3. Materials and Methods

In this research, an integrating MCDM entropy–CoCoSo approach is proposed for the sustainability evaluation of road transportation systems. The detailed framework for conducting the research is shown in Figure 1, which has two phases, as follows.

- Phase 1: Identify the criteria list and calculate the weight of criteria by using the entropy method. In the first step, the sustainability criteria are identified from the literature review. In the next step, the entropy approach is applied to determine the importance weight of each criterion.
- Phase 2: Evaluation of the sustainable road transportation systems and determine final ranking by using the CoCoSo approach. In this phase, the CoCoSo method is used to identify the ranking of candidates, and the highest performance is selected as the best choice. After evaluating the importance of alternatives, a sensitivity analysis of the

study is presented. In the final stage, the paper's results and managerial implications are presented.

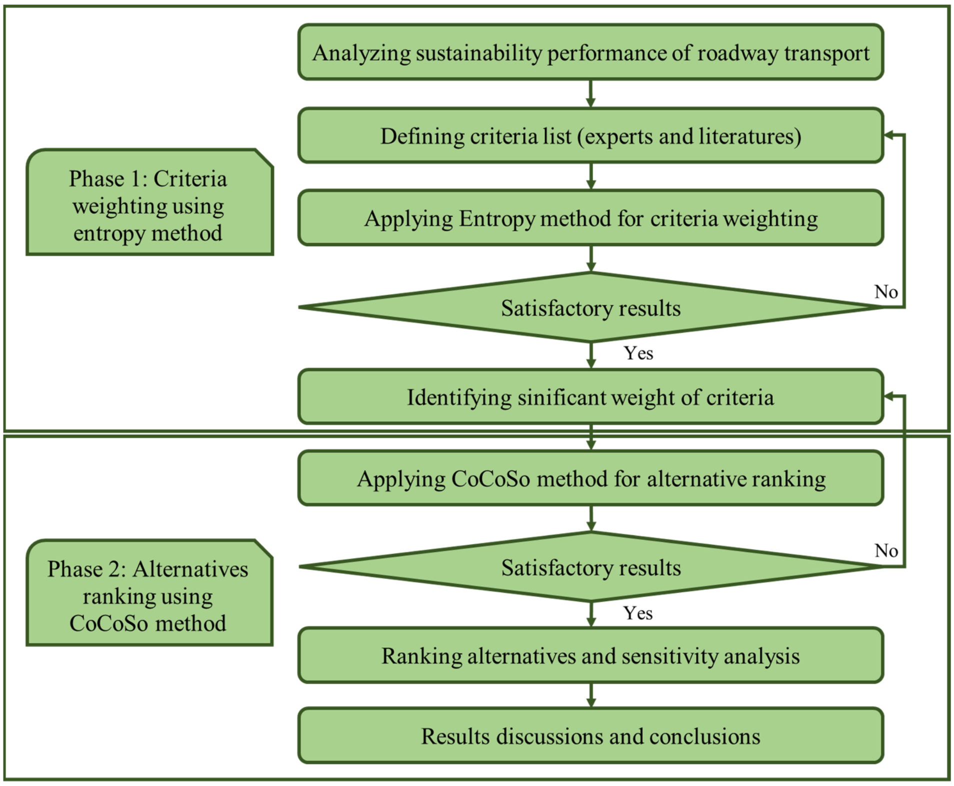

Figure 1. The proposed research framework.

3.1. Entropy Objective Weighting Method

The concept of entropy was proposed by Shannon [52] to deal with uncertain information and missing data. Then, entropy was introduced to determine the objective weight of criteria in the decision-making process based on the value dispersion [53]. The calculation process of the entropy objective weighting method is presented step-by-step as follows.

Step 1: Build the initial decision-making matrix, as can be seen in Equation (1).

$$X = \left[x_{ij}\right]_{m\times n} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}; \; i = 1, 2, \ldots, m; \; j = 1, 2 \ldots n \tag{1}$$

where x_{ij} is the performance of the i^{th} alternative to the j^{th} criterion, m is the number of alternatives and n is the number of criteria.

Step 2: Normalize the actual performance data using Equation (2).

$$v_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{2}$$

where v_{ij} means the normalized value of alternative A_i about C_j. x_{ij} denotes the crisp value of alternative A_i with respect to C_j; m is the total number of evaluated alternatives.

Step 3: Calculate the entropy value of the j^{th} criterion using Equation (3).

$$e_j = -k\sum_{i=1}^{m} v_{ij}\ln\left(v_{ij}\right) = -\frac{1}{\ln(m)}\sum_{i=1}^{m} v_{ij}\ln\left(v_{ij}\right) \tag{3}$$

where ln (■) is logarithm based on e and e_j is [0, 1].

Step 4: Calculate the degree of diversification d_j using Equation (4).

$$d_j = 1 - e_j,\ j \in [1, \ldots, n] \tag{4}$$

Step 5: Calculate the objective weighting of the j^{th} criterion, which is given by Equation (5), as follows.

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{5}$$

This objective weight will be used in the CoCoSo model in the next stage to calculate the performance of each alternative.

3.2. Combined Compromise Solution (CoCoSo) Method

The Combined Compromise Solution (CoCoSo) method is based on an integrated exponentially weighted product and simple additive weighting model. It can be a compromised solution in solving MCDM problems. After defining the alternative and relevant criteria, the procedure of the CoCoSo model is shown as follows [54].

Step 1: A decision matrix is constructed as shown in Equation (6).

$$X = \left[x_{ij}\right]_{m\times n} = \begin{bmatrix} x_{11} & x_{12} & \ldots & x_{1n} \\ x_{21} & x_{22} & \ldots & x_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ x_{m1} & x_{m2} & \ldots & x_{mn} \end{bmatrix};\ i = 1, 2, \ldots, m;\ j = 1, 2 \ldots n \tag{6}$$

where x_{ij} is the performance of the i^{th} alternative to the j^{th} criterion, m is the number of alternatives and n is the number of criteria.

Step 2: The compromise normalization Equations (7) and (8) are used to normalize the values of the criteria, respectively.

$$r_{ij} = \frac{x_{ij} - min_i x_{ij}}{max_i x_{ij} - min_i x_{ij}};\ \text{for benefit criterion} \tag{7}$$

$$r_{ij} = \frac{max_i x_{ij} - x_{ij}}{max_i x_{ij} - min_i x_{ij}};\ \text{for}\ \cos\text{t criterion} \tag{8}$$

Step 3: The sum of the weighted comparability sequence S_i and the total of the power weighted comparability sequence P_i for each alternative are calculated using Equations (9) and (10), respectively.

$$S_i = \sum_{j=1}^{n} \left(w_j r_{ij}\right) \tag{9}$$

$$P_i = \sum_{j=1}^{n} \left(r_{ij}\right)^{w_j} \tag{10}$$

Step 4: The relative weights of the alternatives are calculated based on the following aggregating strategies. Three performance score strategies are applied in this stage to calculate the relative weights of other options.

The arithmetic means of the sums of the WSM (weighted sum method) and WPM (weighted product method) scores are expressed by Equation (11). Equation (12) is the sum of the relative scores of WSM and WPM compared to the best. Equation (13) generates the balanced compromise of the WSM and WPM model scores, as follows.

$$k_{ia} = \frac{S_i + P_i}{\sum_{i=1}^{m} (P_i + S_i)} \tag{11}$$

$$k_{ib} = \frac{S_i}{min_i S_i} + \frac{P_i}{min_i P_i} \tag{12}$$

$$k_{ic} = \frac{\lambda(S_i) + (1-\lambda)(P_i)}{\lambda max_i S_i + (1-\lambda) max_i P_i}; \ 0 \le \lambda \le 1 \tag{13}$$

In this paper, the value of λ is considered as 0.5 ($\lambda = 0.5$) for the beginning analysis.

Step 5: The final ranking of the alternatives is calculated based on the k_i value, i.e., appraisal score (as more significant as better), as can be seen in Equation (14).

$$k_i = (k_{ia} k_{ib} k_{ic})^{\frac{1}{3}} + \frac{1}{3}(k_{ia} + k_{ib} + k_{ic}) \tag{14}$$

The optimal alternative is selected with the highest appraisal score of the CoCoSo model.

4. Results Analysis

4.1. A Case Study in OECD Countries

The entropy and CoCoSo techniques have been integrated to solve a real problem in the sustainable road transportation system of OECD countries. In this section, the list of OECD countries is introduced in Table 2.

Table 2. The list of OECD countries used in this study.

Alternative	Country	DMU	Alternative	Country	DMU
A1	Australia	AUS	A15	Italy	ITA
A2	Austria	AUT	A16	Japan	JPN
A3	Belgium	BEL	A17	Korea	KOR
A4	Canada	CAN	A18	Lithuania	LTU
A5	Switzerland	CHE	A19	Latvia	LVA
A6	Czech Republic	CZE	A20	The Netherlands	NLD
A7	Germany	DEU	A21	Norway	NOR
A8	Denmark	DNK	A22	New Zealand	NZL
A9	Spain	ESP	A23	Poland	POL
A10	Finland	FIN	A24	Slovak Republic	SVK
A11	France	FRA	A25	Slovenia	SVN
A12	United Kingdom	GBR	A26	Sweden	SWE
A13	Hungary	HUN	A27	Turkey	TUR
A14	Iceland	ISL	A28	United States	USA

Sustainability is a broad concept, so we must determine the scope of sustainable transportation. In order to achieve a sustainable transportation system, an indicator list is identified from the sustainability dimensions related to system effectiveness, economic, environmental and social sustainability. Indicators must be easily understandable, reasonable, specific, measurable, accessible, comprehensive, clearly defined and cover all aspects of the internal and external factors of the transportation system [55]. The availability and reliability of data, impact of the indicators on the area sustainability, and area's decisions to implement are also important drivers [56]. If these indicators are reviewed and used by a transportation organization to evaluate their projects, it helps them achieve long-term goals, which will be a reference for decision-making of the transportation sector [26]. The detailed indicators for measuring road transportation sustainability are presented in Table 3. The information was collected from the databases of OECD, UNECE Transport Statistics, World Bank, and the European Statistics website for 28 countries of OECD in 2019 [57–60]. Table 4 summarizes the statistical data of the road transportation including maximum, minimum, average, and standard deviation values. There is a great difference in the value of criteria among various countries. For example, the roadway network ranges from 13,000 to 6,853,024 km, and the standard deviation is 1,264,278 km. The capital investment is highest in the USA, which is 108,996 million USD, while the lowest is in Iceland with 115 million USD and 9553 million USD on average.

Table 3. The list of criteria and description.

Sustainability Dimension	Criteria	Definition	References
C1. System effectiveness	C11. Roadway length	The total length of transport routes available for the use of roadway vehicles	[31,61,62]
	C12. Vehicles in use	The number of vehicles registered to the authorities	[31,35,61–63]
	C13. Freight turnover volume	The total movement of goods by using road transportation mode on the national network	[31]
	C14. Passenger turnover volume	The total movement of passengers by using road transportation mode on the national network	[31,64]
C2. Economic	C21. Capital investment	The total spending on new road transport construction and the improvement of the existing road network	[31,63,65,66]
	C22. Infrastructure maintenance	The total spending on the preservation of the existing road transportation network. It only covers maintenance expenditures financed by public administrations	[63,65,66]
	C23. GDP	The total monetary value of all goods and services produced in a country during a specific time	[62]
C3. Social	C31. Number of employees	The number of people of working age who have a contract of employment and receive compensation at the organization, the place of business in a country or area	[31,61,66]
	C32. Road accidents	The number of traffic accidents, which is defined as a collision involving one or more vehicles on the road	[31,35,63–65]
C4. Environmental	C41. Fuel consumption	The amount of fuel consumed by road transport modes	[31,35,61–64]
	C42. CO_2 emissions	The gross direct emissions stemming from the combustion of fuels	[31,35,61,63,64]
	C43. Air pollution emissions	The amount of air pollutants emitted into the atmosphere including emissions of sulfur oxides (SOx) and nitrogen oxides (NOx), emissions of carbon monoxide (CO)	[31,61–63,65,66]

Table 4. Statistical analysis on data collection.

Criteria	Unit	Max	Min	Average	SD
Roadway length	Km	6,853,024	13,000	543,212	1,264,278
Vehicles in use	Thousands of vehicles	268,521	269	25,425	50,272
Freight turnover volume	Million ton–kilometer	2,871,321	1178	209,013	524,043
Passenger turnover volume	Million passenger–kilometer	6,758,274	2142	519,152	1,239,966
Capital investment	Millions USD	108,996	115	9553	20,584
Infrastructure maintenance	Millions USD	54,749	97	4660	10,527
GDP	Millions USD	21,433,225	24,837	1,804,107	3,970,529
Number of employees	Thousands of persons	167,329,067	215,408	20,217,316	32,571,282
Road accidents	Number of accidents	1,839,311	770	134,298	342,284
Fuel consumption	Thousand tons of oil equivalent	718,375	360	44,831	131,040
CO_2 emissions	Million tons	4744	2	376	877
Air pollution emissions	Thousand tons	50,135	130	3684	9182

4.2. Calculation of Criteria Weights with Entropy Model

As in MCDM problems, first of all, the initial decision-making matrix is constructed. The initial decision matrix of this paper is as follows in Table 5. Applying the entropy method for determining criteria weights, the weights of all criteria for each indicator of sustainability (system effectiveness, economic, social, and environmental) are obtained in Table 6. The top five significant criteria of impact are depicted in Figure 2, including C41. Fuel consumption, C32. Road accidents, C43. Air pollution emissions, C13. Freight turnover volume, and C22. Infrastructure maintenance.

Table 5. The initial decision-making matrix.

Country	C11	C12	C13	C14	C21	C22	C23	C31	C32	C41	C42	C43
Australia	904,927	18,008	218,903	317,158	16,070	12,495	1,396,567	13,500,080	16,145	41,760	381	7265
Austria	137,492	5357	26,502	81,118	652	872	445,075	4,622,075	35,736	8895	63	650
Belgium	167,205	6614	34,829	119,774	897	563	533,255	5,137,174	37,699	8841	90	553
Canada	1,083,239	24,144	275,821	592,038	8750	5109	1,741,576	20,743,970	104,829	68,544	571	7510
Switzerland	71,545	5081	17,426	105,245	4765	2784	731,474	4,965,077	17,761	7211	36	224
Czech Republic	130,585	6149	39,059	91,726	1604	1140	250,686	5,441,332	20,806	6778	94	1070
Germany	650,000	48,529	311,869	1,033,501	19,314	2626	3,861,124	43,871,267	300,143	56,351	644	4278
Denmark	74,801	2905	13,298	67,196	1355	1345	350,104	3,023,904	2808	4293	28	316
Spain	165,683	27,711	249,555	375,891	1998	1998	1,393,491	23,227,683	104,077	32,940	231	2398
Finland	109,080	2756	28,847	74,700	1766	573	268,966	2,748,960	3984	4178	40	488
France	1,114,011	39,124	181,400	859,367	11,387	2697	2,715,518	30,385,859	56,016	45,208	294	3254
United Kingdom	422,134	38,879	160,550	709,254	11,185	2682	2,830,814	34,639,274	153,158	41,463	342	2578
Hungary	220,402	3772	36,951	85,756	2655	436	163,504	4,750,636	16,627	5068	45	485
Iceland	13,000	269	1178	8200	115	97	24,837	215,408	770	360	2	196
Italy	252,003	42,799	127,225	849,198	3485	10,273	2,004,913	25,787,158	172,183	35,861	309	2795
Japan	1,281,000	77,889	213,836	909,598	34,307	19,172	5,064,873	68,838,956	381,237	38,215	1056	4962
Korea	111,079	22,144	145,225	394,954	15,318	2868	1,646,739	28,541,664	229,600	43,819	586	2166
Lithuania	85,429	1257	53,117	32,669	408	171	54,640	1,469,927	3289	2151	11	178
Latvia	61,695	722	14,965	2142	259	208	34,055	983,777	3724	1102	7	156
The Netherlands	137,603	9651	42,905	202,105	1211	1197	907,051	9,374,012	14,829	10,933	146	862
Norway	95,946	3329	20,526	71,342	4537	2624	405,510	2,829,759	3579	4457	35	570
New Zealand	96,817	3994	25,372	3578	1208	1266	209,127	2,787,494	11,737	5565	33	986
Poland	423,997	26,241	395,311	280,716	2802	558	595,862	18,318,734	30,288	22,782	287	3223
Slovak Republic	44,499	2563	33,888	34,803	981	335	105,119	2,749,141	5410	2790	30	355
Slovenia	38,985	1213	2306	10,955	237	239	54,174	1,028,117	6025	1927	13	130
Sweden	216,180	5415	42,601	125,406	2904	1160	531,283	5,455,406	13,684	7016	34	481
Turkey	247,563	16,856	267,579	339,601	8332	249	761,428	33,318,941	174,896	28,389	366	4895
United States	6,853,024	268,521	2,871,321	6,758,274	108,996	54,749	21,433,225	167,329,067	1,839,311	718,375	4744	50,135

Table 6. The criteria weights calculated using entropy method.

Criteria	C11	C12	C13	C14	C21	C22	C23	C31	C32	C41	C42	C43	$\sum_{j=1}^{12} w_j$
w_j	0.0814	0.0702	0.0879	0.0852	0.0794	0.0856	0.0779	0.0568	0.0982	0.1045	0.0847	0.0881	1

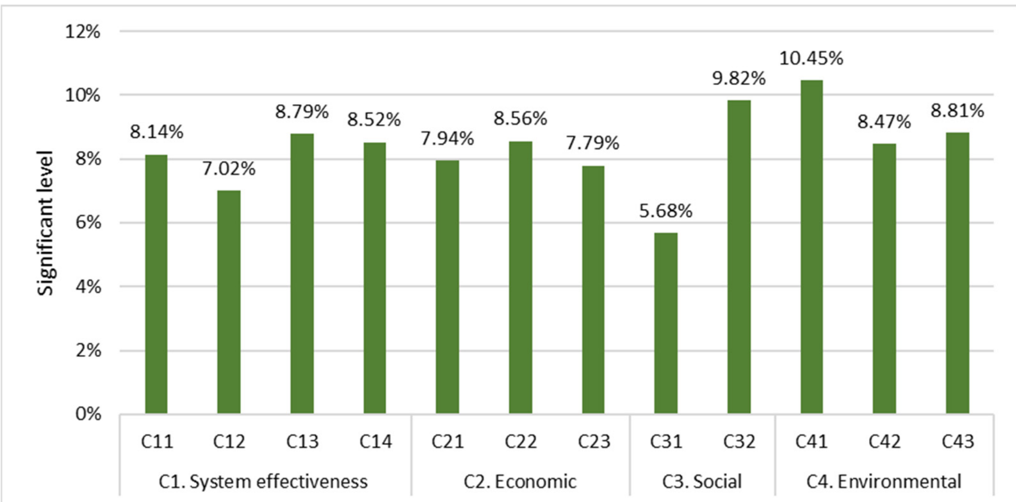

Figure 2. The significant level of criteria.

4.3. Ranking Alternatives with CoCoSo Model

In the CoCoSo model, the compromise solution is determined based on a compositive simple additive (SAW) and exponentially weighted product (EWP) model, which can evaluate and rank the alternatives with a high order of reliability. In this stage, the relative weights of criteria are determined by the entropy model. The hierarchical tree for evaluation of sustainability performance of roadway transport is shown in Figure 3.

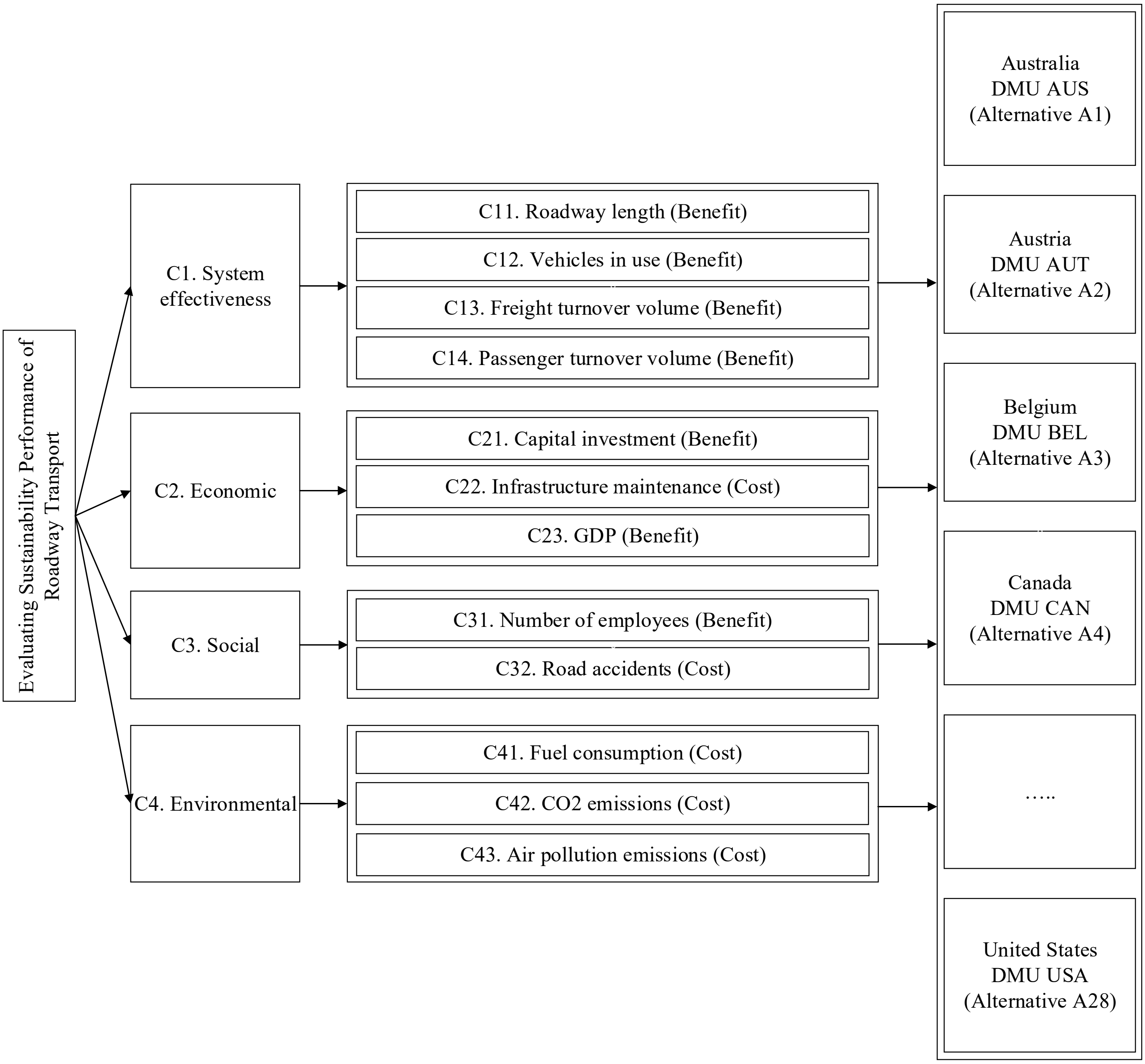

Figure 3. The hierarchical tree for evaluation of sustainability performance of roadway transport.

According to the CoCoSo procedure, from the initial integrated matrix, the normalized matrix, the weighted comparability sequence (Table A1—Appendix A), and the exponentially weighted comparability sequence (Table A2—Appendix A) are calculated, respectively. Finally, the final aggregation and ranking are determined, as seen in Table 7. The result suggests that Japan, Germany, France, the United Kingdom, and Canada are the top five countries with a high score in sustainability performance in roadway transport, with the scores of 1.8669, 1.8581, 1.8520, 1.8291, and 1.8048, respectively. Iceland is ranked with the lowest performance with a score of 1.1229. The performance score of OECD countries is shown in Figure 4. In North America, the United States has invested in the road transportation system, and the number of vehicles, length of roadway, freight and passenger turnover volume are larger compared with Canada. However, Canada placed 5th while the United States is near the bottom in the ranking of performance. The reason may be that the United States has the highest energy consumption and emissions in the world. Motor gasoline is the most consumed fuel in transportation in the United States [56]. In Asia, Japan and Korea are placed first and ninth in the performance rankings. This result is consistent with the level of road infrastructure in Korea, which lags significantly behind that of Japan.

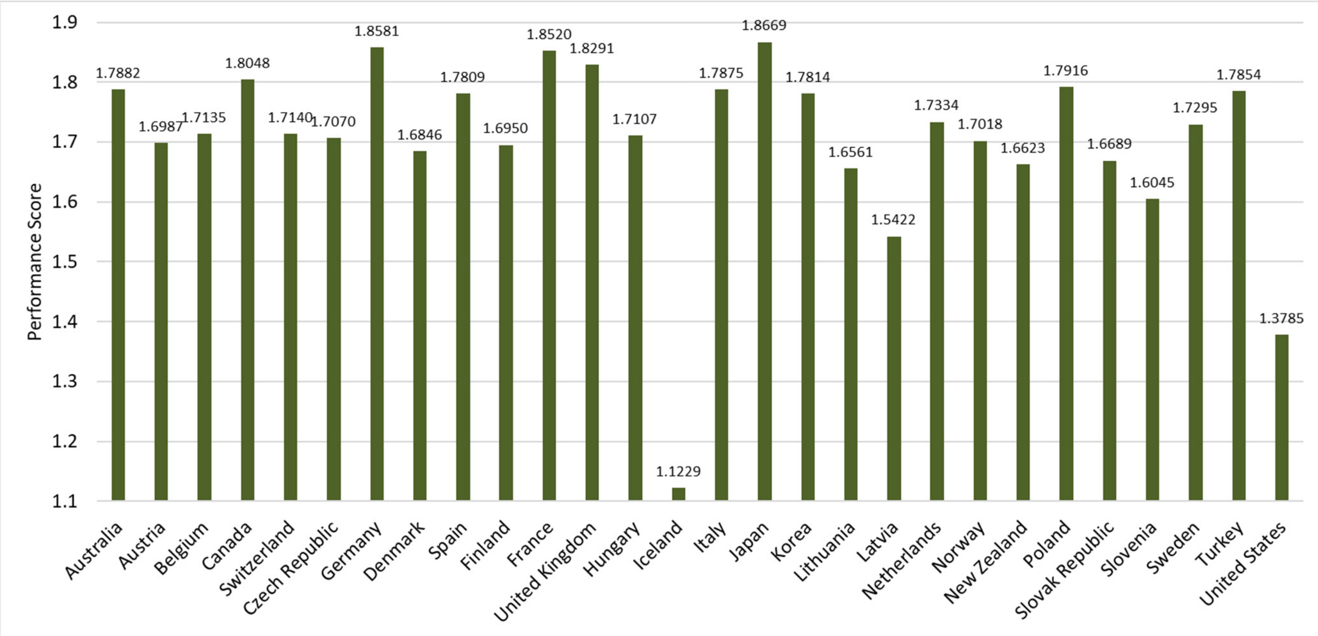

Figure 4. The performance score of OECD countries.

Table 7. Alternatives ranking using the CoCoSo model.

Alternative	Country	Ka	Ranking	Kb	Ranking	Kc	Ranking	K	Final Ranking
A1	Australia	0.0382	6	2.9357	10	0.9620	6	1.7882	7
A2	Austria	0.0358	19	2.8099	19	0.9017	19	1.6987	19
A3	Belgium	0.0362	15	2.8328	15	0.9106	15	1.7135	15
A4	**Canada**	**0.0386**	**5**	**2.9648**	**5**	**0.9698**	**5**	**1.8048**	**5**
A5	Switzerland	0.0362	14	2.8340	14	0.9106	14	1.7140	14
A6	Czech Republic	0.0361	17	2.8220	17	0.9072	17	1.7070	17
A7	**Germany**	**0.0393**	**2**	**3.0678**	**2**	**0.9897**	**2**	**1.8581**	**2**
A8	Denmark	0.0355	21	2.7906	21	0.8920	21	1.6846	21
A9	Spain	0.0378	11	2.9370	9	0.9505	11	1.7809	11
A10	Finland	0.0357	20	2.8066	20	0.8982	20	1.6950	20
A11	**France**	**0.0391**	**3**	**3.0637**	**3**	**0.9831**	**3**	**1.8520**	**3**
A12	**United Kingdom**	**0.0387**	**4**	**3.0193**	**4**	**0.9746**	**4**	**1.8291**	**4**
A13	Hungary	0.0361	16	2.8308	16	0.9076	16	1.7107	16
A14	Iceland	0.0205	28	2.0003	28	0.5169	28	1.1229	28
A15	Italy	0.0381	7	2.9393	8	0.9590	7	1.7875	8
A16	**Japan**	**0.0396**	**1**	**3.0785**	**1**	**0.9965**	**1**	**1.8669**	**1**
A17	Korea	0.0380	9	2.9303	11	0.9551	9	1.7814	10
A18	Lithuania	0.0347	24	2.7513	24	0.8724	24	1.6561	24
A19	Latvia	0.0317	26	2.5892	26	0.7971	26	1.5422	26
A20	The Netherlands	0.0367	12	2.8636	12	0.9223	12	1.7334	12

Table 7. *Cont.*

Alternative	Country	Ka	Ranking	Kb	Ranking	Kc	Ranking	K	Final Ranking
A21	Norway	0.0359	18	2.8152	18	0.9033	18	1.7018	18
A22	New Zealand	0.0349	23	2.7570	23	0.8783	23	1.6623	23
A23	Poland	0.0379	10	2.9586	6	0.9540	10	1.7916	6
A24	Slovak Republic	0.0350	22	2.7686	22	0.8814	22	1.6689	22
A25	Slovenia	0.0334	25	2.6761	25	0.8392	25	1.6045	25
A26	Sweden	0.0365	13	2.8587	13	0.9193	13	1.7295	13
A27	Turkey	0.0380	8	2.9403	7	0.9552	8	1.7854	9
A28	United States	0.0258	27	2.4301	27	0.6484	27	1.3785	27

4.4. Sensitivity Analysis

Sensitivity analysis is conducted to demonstrate the robustness and stability of the presented model in the decision-making process. In this paper, the coefficient value (λ) was considered to be 0.5 ($\lambda = 0.5$) for the beginning analysis. Then, in the sensitivity analysis stage, the respect outcome values are analyzed by changing the range of coefficient value (λ) from 0 to 1, which can change the results as expected. The final performance score of the CoCoSo model with different λ values is presented in Table A3 (Appendix A) and visualized in Figure 5. The result displays that no matter how the λ changes, we can find that the final performance score of the top five countries with the highest performance score (Japan, Germany, France, United Kingdom, and Canada) is unchanged. Iceland still has the lowest performance in the evaluation process. Therefore, the reliability and effectiveness of the proposed model are demonstrated.

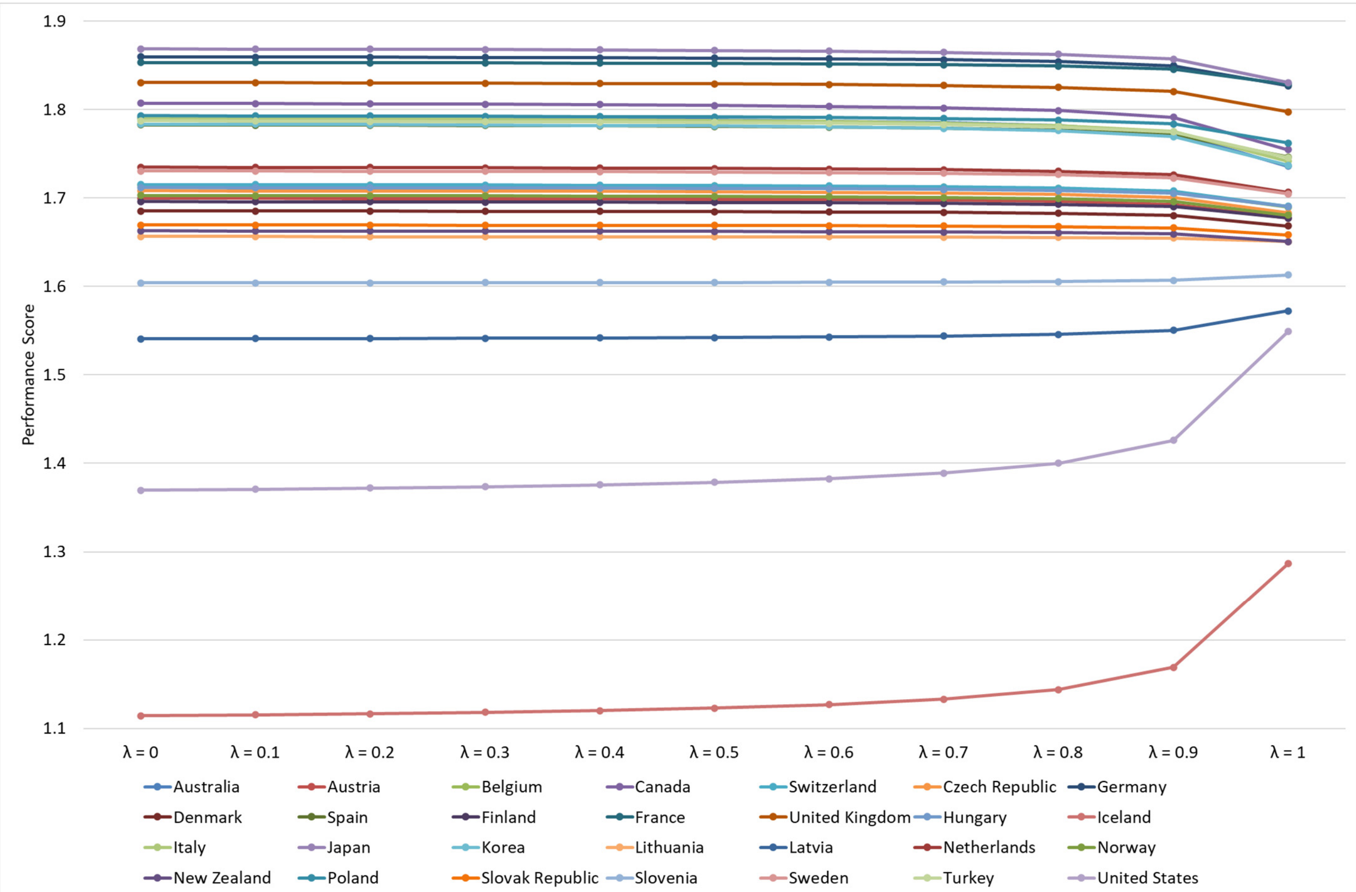

Figure 5. The final ranking of alternatives with different λ value.

5. Discussion

Economic, social, and environmental sustainability are important targets in transportation development sectors in countries. This research aims to evaluate the sustainability performance of road transportation systems in OECD countries by using an integrated MCDM method. The entropy approach is applied to obtain the weights of the criteria used to evaluate sustainability. This research reveals that fuel consumption is the most significant transport sustainability with the highest weight value. Road accidents and air pollution emissions obtain the second and third places, respectively. Previous studies have also presented that fuel consumption greatly influences the sustainability performance of transportation systems [64,67]. According to the CoCoSo approach, the top three countries' sustainability performance are Japan, Germany, and France. These are countries with developed infrastructure and transportation services. Findings also indicate that Iceland, the United States, and Latvia are ranked last. The findings are novel and might be interesting to both scholars and policyholders dealing with the development of the national road transportation systems.

6. Conclusions

The road haulage solutions are also very flexible, with the ability to connect domestically and overseas. Road transportation promises a greener, more efficient, and safer future through advanced technology. The multi-criteria decision-making (MCDM) model proposed in this research can help stakeholders comprehend the present status of transportation systems and plan the sustainability strategies in the future. Four major indicators and 12 criteria related to road transportation sustainability are identified for a comprehensive evaluation. The integrated entropy–CoCoSo methods are applied to measure the sustainability performance of OECD countries as a real-life case study. In this approach of the analysis, we initially identify transport sustainability indicator system based on four sustainability categories (system effectiveness and economic, social and environmental sustainability). Then, the weight of the sustainability criteria is computed by using the entropy method. The sustainable performance of the road transportation system in 28 OECD countries is obtained by the CoCoSo methods. Finally, the sensitivity analyses are conducted based on the comparison of the final performance score derived for different coefficient values.

In the future studies, several important aspects deserve more studies. For example, the proposed model for sustainable transportation systems evaluation can be extended beyond 12 criteria. Future studies can apply various methods in assessing sustainability performance and compare the results in this study, such as WASPAS, DEMATEL, and VIKOR, to name a few, under uncertain decision-making processes using gray theory or fuzzy systems. Future studies should combine the objective and subject weighting methods to obtain the knowledge and vision of experts. Moreover, we will try to apply and improve the proposed model to other similar industries.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. The weighted comparability sequence matrix of the CoCoSo model.

Alternative	C11	C12	C13	C14	C21	C22	C23	C31	C32	C41	C42	C43
A1	0.0106	0.0046	0.0067	0.0040	0.0116	0.0662	0.0050	0.0045	0.0974	0.0985	0.0780	0.0756
A2	0.0015	0.0013	0.0008	0.0010	0.0004	0.0844	0.0015	0.0015	0.0964	0.1033	0.0836	0.0872
A3	0.0018	0.0017	0.0010	0.0015	0.0006	0.0848	0.0019	0.0017	0.0962	0.1033	0.0832	0.0874
A4	0.0127	0.0062	0.0084	0.0074	0.0063	0.0777	0.0063	0.0070	0.0927	0.0946	0.0746	0.0751
A5	0.0007	0.0013	0.0005	0.0013	0.0034	0.0814	0.0026	0.0016	0.0973	0.1035	0.0841	0.0880
A6	0.0014	0.0015	0.0012	0.0011	0.0011	0.0839	0.0008	0.0018	0.0971	0.1036	0.0831	0.0865
A7	0.0076	0.0126	0.0095	0.0130	0.0140	0.0816	0.0140	0.0148	0.0822	0.0964	0.0733	0.0808
A8	0.0007	0.0007	0.0004	0.0008	0.0009	0.0836	0.0012	0.0010	0.0981	0.1040	0.0843	0.0878
A9	0.0018	0.0072	0.0076	0.0047	0.0014	0.0826	0.0050	0.0078	0.0927	0.0998	0.0806	0.0841
A10	0.0011	0.0007	0.0008	0.0009	0.0012	0.0848	0.0009	0.0009	0.0980	0.1040	0.0841	0.0875
A11	0.0131	0.0102	0.0055	0.0108	0.0082	0.0815	0.0098	0.0103	0.0953	0.0980	0.0795	0.0826
A12	0.0049	0.0101	0.0049	0.0089	0.0081	0.0815	0.0102	0.0117	0.0901	0.0985	0.0787	0.0838
A13	0.0025	0.0009	0.0011	0.0011	0.0019	0.0850	0.0005	0.0015	0.0974	0.1038	0.0840	0.0875
A14	0.0000	0.0000	0.0000	0.0001	0.0000	0.0856	0.0000	0.0000	0.0982	0.1045	0.0847	0.0880
A15	0.0028	0.0111	0.0039	0.0107	0.0025	0.0696	0.0072	0.0087	0.0891	0.0994	0.0792	0.0834
A16	0.0151	0.0203	0.0065	0.0114	0.0249	0.0557	0.0183	0.0233	0.0779	0.0990	0.0659	0.0796
A17	0.0012	0.0057	0.0044	0.0050	0.0111	0.0812	0.0059	0.0096	0.0860	0.0982	0.0743	0.0845
A18	0.0009	0.0003	0.0016	0.0004	0.0002	0.0855	0.0001	0.0004	0.0981	0.1043	0.0846	0.0880
A19	0.0006	0.0001	0.0004	0.0000	0.0001	0.0854	0.0000	0.0003	0.0981	0.1044	0.0846	0.0881
A20	0.0015	0.0025	0.0013	0.0025	0.0008	0.0838	0.0032	0.0031	0.0975	0.1030	0.0822	0.0868
A21	0.0010	0.0008	0.0006	0.0009	0.0032	0.0816	0.0014	0.0009	0.0981	0.1039	0.0841	0.0874
A22	0.0010	0.0010	0.0007	0.0000	0.0008	0.0837	0.0007	0.0009	0.0976	0.1038	0.0842	0.0866
A23	0.0049	0.0068	0.0121	0.0035	0.0020	0.0848	0.0021	0.0062	0.0966	0.1013	0.0796	0.0827
A24	0.0004	0.0006	0.0010	0.0004	0.0006	0.0852	0.0003	0.0009	0.0980	0.1042	0.0842	0.0877
A25	0.0003	0.0002	0.0000	0.0001	0.0001	0.0853	0.0001	0.0003	0.0979	0.1043	0.0845	0.0881
A26	0.0024	0.0013	0.0013	0.0016	0.0020	0.0839	0.0018	0.0018	0.0975	0.1036	0.0842	0.0875
A27	0.0028	0.0043	0.0082	0.0043	0.0060	0.0853	0.0027	0.0113	0.0889	0.1004	0.0782	0.0797
A28	0.0814	0.0702	0.0879	0.0852	0.0794	0.0000	0.0779	0.0568	0.0000	0.0000	0.0000	0.0000

Table A2. The exponentially weighted comparability sequence matrix of the CoCoSo model.

Alternative	C11	C12	C13	C14	C21	C22	C23	C31	C32	C41	C42	C43
A1	0.8472	0.8265	0.7972	0.7700	0.8586	0.9782	0.8072	0.8660	0.9992	0.9938	0.9930	0.9865
A2	0.7217	0.7572	0.6599	0.6844	0.6559	0.9988	0.7361	0.8134	0.9981	0.9988	0.9989	0.9991
A3	0.7344	0.7690	0.6766	0.7080	0.6758	0.9993	0.7471	0.8185	0.9980	0.9988	0.9984	0.9993
A4	0.8599	0.8439	0.8137	0.8123	0.8178	0.9918	0.8215	0.8877	0.9943	0.9896	0.9892	0.9860
A5	0.6787	0.7542	0.6346	0.7001	0.7786	0.9957	0.7665	0.8169	0.9991	0.9990	0.9994	0.9998
A6	0.7184	0.7649	0.6836	0.6918	0.7113	0.9984	0.7013	0.8213	0.9989	0.9991	0.9983	0.9983
A7	0.8243	0.8866	0.8225	0.8520	0.8713	0.9960	0.8746	0.9266	0.9827	0.9915	0.9877	0.9924
A8	0.6817	0.7230	0.6185	0.6731	0.7010	0.9980	0.7216	0.7928	0.9999	0.9994	0.9995	0.9997
A9	0.7338	0.8522	0.8065	0.7813	0.7246	0.9970	0.8071	0.8935	0.9943	0.9952	0.9958	0.9959
A10	0.7067	0.7201	0.6650	0.6794	0.7171	0.9993	0.7056	0.7882	0.9998	0.9994	0.9993	0.9994
A11	0.8618	0.8732	0.7841	0.8386	0.8352	0.9958	0.8507	0.9073	0.9970	0.9933	0.9946	0.9943
A12	0.7951	0.8728	0.7757	0.8250	0.8340	0.9959	0.8535	0.9142	0.9915	0.9939	0.9937	0.9956
A13	0.7523	0.7376	0.6802	0.6877	0.7421	0.9995	0.6752	0.8147	0.9991	0.9993	0.9992	0.9994
A14	0.0000	0.0000	0.0000	0.5498	0.0000	1.0000	0.0000	0.0000	1.0000	1.0000	1.0000	0.9999
A15	0.7611	0.8788	0.7598	0.8378	0.7589	0.9825	0.8306	0.8988	0.9904	0.9947	0.9943	0.9952
A16	0.8718	0.9167	0.7956	0.8427	0.9122	0.9639	0.8934	0.9507	0.9775	0.9944	0.9789	0.9911
A17	0.7078	0.8387	0.7688	0.7847	0.8553	0.9956	0.8178	0.9041	0.9870	0.9935	0.9889	0.9963
A18	0.6906	0.6749	0.7029	0.6311	0.6252	0.9999	0.5989	0.7574	0.9999	0.9997	0.9998	0.9999
A19	0.6686	0.6390	0.6255	0.0000	0.5907	0.9998	0.5466	0.7366	0.9998	0.9999	0.9999	1.0000
A20	0.7218	0.7904	0.6895	0.7408	0.6942	0.9983	0.7799	0.8479	0.9992	0.9985	0.9974	0.9987

Table A2. *Cont.*

Alternative	C11	C12	C13	C14	C21	C22	C23	C31	C32	C41	C42	C43
A21	0.6982	0.7306	0.6445	0.6767	0.7755	0.9960	0.7305	0.7896	0.9998	0.9994	0.9994	0.9992
A22	0.6988	0.7408	0.6572	0.4863	0.6940	0.9982	0.6903	0.7889	0.9994	0.9992	0.9994	0.9985
A23	0.7954	0.8489	0.8399	0.7620	0.7454	0.9993	0.7539	0.8814	0.9984	0.9967	0.9947	0.9944
A24	0.6453	0.7160	0.6749	0.6347	0.6813	0.9996	0.6470	0.7882	0.9998	0.9996	0.9995	0.9996
A25	0.6353	0.6728	0.5020	0.5677	0.5829	0.9998	0.5982	0.7389	0.9997	0.9998	0.9998	1.0000
A26	0.7511	0.7578	0.6890	0.7108	0.7476	0.9983	0.7469	0.8214	0.9993	0.9990	0.9994	0.9994
A27	0.7599	0.8226	0.8115	0.7746	0.8145	0.9998	0.7690	0.9121	0.9903	0.9958	0.9932	0.9912
A28	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000

Table A3. The final performance score of the CoCoSo model with different λ value.

Country	Final Performance Score										
	$\lambda = 0$	$\lambda = 0.1$	$\lambda = 0.2$	$\lambda = 0.3$	$\lambda = 0.4$	$\lambda = 0.5$	$\lambda = 0.6$	$\lambda = 0.7$	$\lambda = 0.8$	$\lambda = 0.9$	$\lambda = 1$
A1	1.7907	1.7904	1.7901	1.7896	1.7890	1.7882	1.7871	1.7852	1.7819	1.7742	1.7360
A2	1.6997	1.6996	1.6994	1.6992	1.6990	1.6987	1.6982	1.6974	1.6961	1.6929	1.6772
A3	1.7147	1.7146	1.7144	1.7142	1.7139	1.7135	1.7130	1.7122	1.7106	1.7071	1.6896
A4	1.8072	1.8069	1.8066	1.8061	1.8055	1.8048	1.8036	1.8019	1.7987	1.7913	1.7547
A5	1.7151	1.7150	1.7149	1.7147	1.7144	1.7140	1.7135	1.7127	1.7112	1.7077	1.6907
A6	1.7082	1.7081	1.7079	1.7077	1.7074	1.7070	1.7065	1.7057	1.7041	1.7006	1.6831
A7	1.8596	1.8594	1.8592	1.8589	1.8586	1.8581	1.8574	1.8563	1.8543	1.8497	1.8269
A8	1.6854	1.6853	1.6852	1.6850	1.6848	1.6846	1.6842	1.6836	1.6826	1.6803	1.6685
A9	1.7826	1.7824	1.7822	1.7819	1.7815	1.7809	1.7802	1.7790	1.7768	1.7717	1.7466
A10	1.6959	1.6958	1.6957	1.6955	1.6953	1.6950	1.6946	1.6940	1.6929	1.6902	1.6772
A11	1.8532	1.8530	1.8529	1.8527	1.8524	1.8520	1.8515	1.8507	1.8492	1.8458	1.8288
A12	1.8306	1.8304	1.8302	1.8299	1.8296	1.8291	1.8284	1.8273	1.8253	1.8206	1.7976
A13	1.7117	1.7116	1.7115	1.7113	1.7111	1.7107	1.7103	1.7096	1.7083	1.7052	1.6903
A14	1.1145	1.1154	1.1166	1.1182	1.1202	1.1229	1.1268	1.1330	1.1439	1.1690	1.2866
A15	1.7898	1.7895	1.7892	1.7888	1.7883	1.7875	1.7865	1.7849	1.7820	1.7752	1.7416
A16	1.8686	1.8684	1.8681	1.8678	1.8674	1.8669	1.8660	1.8648	1.8625	1.8571	1.8306
A17	1.7836	1.7833	1.7830	1.7826	1.7821	1.7814	1.7804	1.7789	1.7761	1.7695	1.7370
A18	1.6564	1.6564	1.6563	1.6563	1.6562	1.6561	1.6560	1.6558	1.6555	1.6547	1.6507
A19	1.5408	1.5409	1.5411	1.5414	1.5418	1.5422	1.5429	1.5440	1.5459	1.5504	1.5724
A20	1.7347	1.7346	1.7344	1.7341	1.7338	1.7334	1.7328	1.7319	1.7302	1.7262	1.7065
A21	1.7028	1.7027	1.7025	1.7024	1.7021	1.7018	1.7013	1.7005	1.6992	1.6960	1.6805
A22	1.6628	1.6628	1.6627	1.6626	1.6625	1.6623	1.6620	1.6616	1.6609	1.6592	1.6509
A23	1.7931	1.7929	1.7927	1.7924	1.7921	1.7916	1.7910	1.7899	1.7881	1.7837	1.7622
A24	1.6695	1.6694	1.6693	1.6692	1.6691	1.6689	1.6687	1.6683	1.6676	1.6661	1.6583
A25	1.6041	1.6041	1.6042	1.6042	1.6043	1.6045	1.6047	1.6050	1.6055	1.6068	1.6130
A26	1.7306	1.7305	1.7303	1.7301	1.7298	1.7295	1.7289	1.7280	1.7265	1.7228	1.7048
A27	1.7873	1.7871	1.7868	1.7865	1.7860	1.7854	1.7845	1.7831	1.7806	1.7747	1.7456
A28	1.3697	1.3707	1.3720	1.3736	1.3757	1.3785	1.3825	1.3889	1.4002	1.4262	1.5491

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