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Multicriteria Sustainability Evaluation of Transport Networks for Selected European Countries

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***Abstract*—As an essential economic activity, transportation has complex interactions with the environment and society. Since the concept of sustainable development has become one of the top priorities for nations, there has been a growing interest in evaluating the performance of transport systems with respect to sustainability issues. The main purpose of this study is to introduce a decision making framework to assess the sustainability of the transport networks in a multidimensional setting and a technique to identify non-compromise alternatives. We also propose an elucidation technique to identify according to which criteria a system needs to be improved and how much improvement is required to attain a certain level of sustainability. The proposed methods are applied to a set of selected European countries within a case study.**

***Index Terms*—sustainable transportation, multicriteria decision making (MCDM), non-compromise solution, Choquet integral, TOPSIS.**

I. Introduction

DURING the last decade, sustainable development has emerged as a concept with global priority. It presents a huge challenge for sectors of society and the need for new analytical tools to deal with this challenge is tremendous [1]. As transportation has immense economic, social and environmental effects, it plays a significant role in maintaining sustainable development. Despite this fact, a fewer number of studies pay particular attention to the applications in the transport sector compared to a large number of studies focusing on sustainable development in general. This paper aims at contributing to the relatively scarce literature particularly related to sustainable transport by introducing a method for evaluating the sustainability of the country-wide transport systems.

Although there is no consensus, various definitions are proposed for sustainable transportation. The most cited and globally recognized definition is given in the Brundtland Commission's Report [2]: satisfying current transport and mobility needs without compromising the ability of future generations to meet these needs. Later, the Council of the European Union proposed a more comprehensive definition: a sustainable transport system allows the basic access and development needs of individuals, companies and societies to be met safely and in a manner consistent with human and ecosystem health, and promises equity within and between successive generations; is affordable, operates fairly and efficiently, offers choice of transport mode, and supports a competitive economy as well as balanced regional development; limits emissions and waste within the planet's ability to absorb them, uses renewable resources at or below their rates of generation, and uses nonrenewable resources at or below the rates of development of renewable substitutes while minimizing the impact on land and the generation of noise [3]. Along these lines, we can state that the central idea is to build a transportation system which supports a balanced development by integrating economic, social and environmental objectives while considering the needs of different interest groups.

To quantify the progress towards the objectives of sustainable transportation, it is crucial to define the proper indicators. In a simple way, indicators can be defined as selected, targeted, and compressed variables that reflect public concerns and are of use to decision makers [4]. It is then possible to construct a composite index by aggregating a selected set of indicators. Such indices to evaluate sustainable development are abundant in the literature [5]–[9]. While there are no well-defined selection rules to identify the appropriate indicator sets associated with the specified sustainability objectives, there are several such lists of indicators proposed in the literature [6], [10]–[12]. It can be argued that sets constructed according to the available data and of smaller sizes are more convenient to use but may fail to include important impacts. In contrast, larger sets can be more comprehensive but the costs associated with the data-collection process can be prohibitive [13].

In the transportation literature, existing indicators mainly reflect the economic, social and environmental effects of a system, thus sustainability indicators are generally categorized in these three dimensions. There are also additional dimensions mentioned in some studies such as technical, operational or institutional [6], [14], [15] . Alternatively, the indicators can be classified based on the transportation goals and objectives as in the TERM project [16] or the STPI project [17]. Note that some indicators can be related to more than one category. For example, accessibility can be classified as a social or economic indicator, since the accessibility to public services and the accessibility to employment opportunities correspond to social and economic aspects, respectively. Similarly, the energy consumed by the transport means can be associated with the environmental or economic dimension. When the number of indicators is large, being able to identify an indicator as a member of a single category simplifies any decision making analysis. Such a categorization is employed in our case study.

Sustainability is characterized by very different indicators and a system would be evaluated as sustainable if it performs reasonably well with respect to all of the specified

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indicators. The compensation of values across indicators could be converse to the sustainability premise. Thus, one shall seek for non-compromise alternatives. For example, a system having average indicator values may be evaluated as more sustainable than a system with the highest values for most of the indicators and the lowest values for some of the indicators. In the sustainability- evaluation context, the existing aggregations lead to various well-known composite indices like the Index of Sustainable Economic Welfare (ISEW), the Genuine Progress Indicator (GPI), the Human Development Index (HDI), the Environmental Sustainability (ESI) and Environmental Performance (EPI) Indices, etc. However, these indices are not sufficient to deal effectively with all the information contained in different indicators and we need to address here a more elaborative aggregation method. In this study, a weight (or measure) is assigned not to a single criterion only, but to any desired coalitions of criteria. According to this approach the importance of a pair of criteria is not necessarily the weighted sum of the individual importance of those criteria; it would be greater in the case of a positive interaction or lower in the case of a negative interaction. In order to take the effects of the interactions between the criteria into account while obtaining an aggregate score associated with an alternative, we propose a suitable method based on the Choquet integral.

The contributions of this study are (i) developing a framework to assess the sustainability of the transport networks in a multidimensional setting, (ii) specifying a set of sustainability indicators for transport systems, (iii) proposing a method to aggregate the sustainable transportation indicators by considering the interactions between them, (iv) constructing a detailed case study.

II. Evaluation Framework

Considering the conflicting natures of indicators, developing an overall sustainability measure emerges as a difficult but required task. Divers indicators are proposed by many researchers but they are generally not studied in a unified manner. Another difficulty is to provide practical implementation of these indicators. Nonetheless, several efforts have been made to provide economic, social and environmental indicators for practical implementations. In the context of the SUMMA project the researchers identify eighteen outcomes related to the objectives and goals that are mentioned in the definition of the sustainable transportation provided by the Council of EU [18]. Related to those outcomes, sixty indicators are proposed and evaluated based on monetary values. The STPI project of the Canadian Center for Sustainable Transportation considers fourteen indicators based on the data extracted from the Canadian databases [19]. Similarly, some indicators related to the environmental performance of the European member countries transport systems are identified, the annually collected related data have been presented in the form of fact sheets and reports within the scope of the TERM project of the European Environment Agency [16]. In another study, Black considers nine transport sustainability measures among which the vehicle kilometer traveled is the most representative [20]. Together with this indicator, fuel consumption and gross domestic product (GDP) are combined into a single Sustainable Transport and Potential Mobility (STPM) index. Yevdokimov and Han use the GPI as an aggregate sustainability criterion within a system dynamics approach to analyze the potential changes in the sustainability of the transport systems with respect to the policy variables [21]. Rassafi and Vaziri construct composite indices from a selected set of economic, environmental and social indicators [22]. Then the proposed composite indices are aggregated by the Concordance Analysis Technique to obtain comprehensive sustainability indices which are used to rank, compare and classify the selected countries according to the sustainability level of their transport systems. Campos and Ramos propose the Sustainable Mobility Index in urban areas which is in fact a simple weighted linear combination of sustainability related transport and land-use indicators [23]. The indicator weights are derived with a widely applied multi-criteria decision making (MCDM) method known as the Analytic Hierarchy Process (AHP) [24]. Amekudzi et al. present a sustainability footprint framework that may be used in analyzing the impacts of transportation and other infrastructure systems on regional sustainable development [25]. Bojkovic et al. introduce a MCDM outranking approach, namely the ELECTRE method for evaluating the transport sustainability at the macro level [26]. Jeon et al. evaluate three transport and land-use scenarios at the urban level using the simple weighted average method in conjunction with composite sustainability indices and a range of performance measures [15]. Most of the studies mentioned above consider composite indices to evaluate the sustainability of the transport systems. We note that considering composite indices enables us to obtain a full comparison of alternate systems and we also prefer to focus on constructing a composite index from multiple indicators. Sustainability is based on the balanced development concept and therefore, the non-compromise alternatives are of special importance. In order to identify such preferred alternatives it is crucial to consider the interaction between sustainability indicators. However, the proposed composite indices are based on the weighted average aggregation method, which ignores the interactions between sustainability indicators. In order to fill this gap in the literature, we propose a method that takes the indicator dependencies into account to identify the non-compromise alternatives.

It is crucial to select appropriate indicators in order to more accurately measure the sustainability of a transportation system. The set of indicators selected in this study captures economic, social and environmental objectives, relies on existing data from the European statistical databases, and are easy to understand by potential users. The selected indicators are related to most of the transportation sectors but they mainly concentrate on the road transport which is mostly held responsible for unsustainable trends. We have expressed indicators in units that would allow comparing countries objectively; for example, some indicators are expressed relative to the GDP or the population size. The GDP is the best known measure of macro-economic activity and a standard benchmark used by policy makers. For some indicators, we have taken into account their change towards sustainability over a certain time period. Some indicators are based on the statistical data and some are based on the survey results and the perception of network users. In summary, we have identified five environmental, five economic and seven social indicators as given in Table I. Environmental

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TABLE I
DETAILS ABOUT THE INDICATORS SELECTED TO EVALUATE THE TRANSPORT NETWORK SUSTAINABILITY

Dimension	Indicator	Description	Measurement Unit	Source	Prefered Direction
Environmental	CEN1	Energy consumption relative to GDP	Terajoules/Euro	Eurostat	⇑
	CEN2	Greenhouse gases emission from all transport modes	% change	Eurostat	⇓
	CEN3	Greenhouse gases emission from road transport	Tones/1000psgr-km	Eurostat	⇓
	CEN4	Total acidifying potential from road transport	% change	Eurostat	⇓
	CEN5	Particulate formation from road transport	% change	Eurostat	⇓
Economical	CEC1	Car share of inland passenger transport	% share	Eurostat	⇓
	CEC2	Share of non-motorized individual transport	% share	Eurobarometer	⇑
	CEC3	Road share of inland freight transport	% share	Eurostat	⇓
	CEC4	Contribution of transport sector to GDP	% share	Eurostat	⇑
	CEC5	Contribution of the transport sector to employment	% share	Eurostat	⇑
Social	CSC1	Number of injuries	% change	Eurostat	⇓
	CSC2	Number of fatalities	% change	Eurostat	⇓
	CSC3	Total household consumption for transport	% share	Eurostat	⇓
	CSC4	Quality of public transport	% 1-10	EurLIFE	⇑
	CSC5	Time to the next public transport stop	% share	EurLIFE	⇑
	CSC6	Time to get to work/training place	% share	Eurobarometer	⇑
	CSC7	Car ownership	% share	EurLIFE	⇓

indicators are related to energy usage and emission data, economic indicators are more related to transportation habits and consumption, and social indicators reflect accidents (with injuries or fatalities), quality of transport or time spend for transportation.

III. METHODOLOGY

Let us consider a finite set of alternatives $\mathcal{A} = \{a_1, \ldots, a_m\}$ and a finite set of criteria $\mathcal{N} = \{c_1, \ldots, c_n\}$ for a multicriteria decision problem. In our setup, an alternative represents the transport system of a country and a criterion corresponds to a sustainability indicator. Each alternative $a_j \in \mathcal{A}$ is associated with a profile $\mathbf{x}^j = (x_1^j, \ldots, x_n^j) \in [0,1]^n$, where x_i^j denotes the partial score of a_j associated with the criterion c_i. Defining the scores on the interval $[0,1]$ does not detract from the generality of our analysis; it is only required to define all the partial scores on the same interval scale, i.e. up to the same linear transformation [27].

A. TOPSIS

The Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method is presented in [28], with reference to [29]. The basic principle is that the chosen alternative should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution. The TOPSIS procedure consists of the following steps:

1) Assuming that x_i^j values are normalized, the weighted normalized value v_i^j is calculated as

$$v_i^j = w_i x_i^j, \quad i = 1, \ldots, n, \; j = 1, \ldots, m \qquad (1)$$

where $w_i \geq 0$ is the weight of the criterion c_i, $i = 1, \ldots, n$, and $\sum_{i=1}^n w_i = 1$.

2) Let us denote the set of benefit type of criteria and the set of cost type criteria by $\mathcal{N}'$ and $\mathcal{N}''$, respectively. Basically, $\mathcal{N}'$ and $\mathcal{N}''$ form a partition of the set of criteria $\mathcal{N}$, i.e. $\mathcal{N}' \cup \mathcal{N}'' = \mathcal{N}$ and $\mathcal{N}' \cap \mathcal{N}'' = \emptyset$. Without loss of generality, we assume that the first $|\mathcal{N}'|$ indicators are of benefit type, where $|\mathcal{N}'|$ denotes the cardinality of $\mathcal{N}'$. Then the ideal and negative-ideal solutions are defined as

$$\begin{aligned}\mathbf{v}^+ &= (v_1^+, \ldots, v_n^+) \\ &= \Big(\max_j v_1^j, \ldots, \max_j v_{|\mathcal{N}'|}^j, \\ &\qquad \min_j v_{|\mathcal{N}'|+1}^j, \ldots, \min_j v_n^j\Big)\end{aligned} \qquad (2)$$

and

$$\begin{aligned}\mathbf{v}^- &= (v_1^-, \ldots, v_n^-) \\ &= \Big(\min_j v_1^j, \ldots, \min_j v_{|\mathcal{N}'|}^j, \\ &\qquad \max_j v_{|\mathcal{N}'|+1}^j, \ldots, \max_j v_n^j\Big)\end{aligned} \qquad (3)$$

3) The distance of each alternative to the ideal and the negative-ideal solutions are calculated using the Euclidian norm:

$$d_+^j = \sqrt{\sum\nolimits_{i=1}^n (v_i^j - v_i^+)^2}, \quad j = 1, \ldots, m, \qquad (4)$$

and

$$d_-^j = \sqrt{\sum\nolimits_{i=1}^n (v_i^j - v_i^-)^2}, \quad j = 1, \ldots, m. \qquad (5)$$

4) The relative closeness of each alternative to the negative-ideal solution is given by

$$C^j = d_-^j / (d_+^j + d_-^j) \qquad (6)$$

The best alternative is considered to be the one with the highest C^j value.

B. The Choquet integral

As emphasized before, we consider the interaction among criteria and propose to model it using a discrete fuzzy measure. Let $\mathcal{P}(\mathcal{N})$ denote the power set of $\mathcal{N}$. A discrete fuzzy measure on $\mathcal{N}$ is a set function $\mu : \mathcal{P}(\mathcal{N}) \to [0,1]$ satisfying the following conditions: (*i*) $\mu(\emptyset) = 0$, $\mu(\mathcal{N}) = 1$ and (*ii*) $\mu(\mathcal{N}_1) \leq \mu(\mathcal{N}_2)$ whenever $\mathcal{N}_1 \subseteq \mathcal{N}_2 \subseteq \mathcal{N}$ (monotonicity condition). For each subset of indicators $\widetilde{\mathcal{N}} \subseteq \mathcal{N}$, $\mu(\widetilde{\mathcal{N}})$ can be interpreted as the weight of the importance of the coalition $\widetilde{\mathcal{N}}$. Basically, the monotonicity of μ means that the weight of a subset of criteria cannot decrease when a new criterion is added to it. The discrete Choquet integral of the profile $\mathbf{x}^j$ with respect to the fuzzy measure μ is defined by

$$C_\mu^j = C_\mu(\mathbf{x}^j) = \sum_{i=1}^{n} \mu\left(\mathcal{N}_{[i]}^j\right) - \left(x_{[i]}^j - x_{[i-1]}^j\right) \quad (7)$$

where $[\cdot]$ indicates a permutation such that $0 \leq x_{[1]}^j \leq \ldots \leq x_{[n]}^j \leq 1$ with the convention that $x_{[0]}^j = 0$ and $\mathcal{N}_{[i]}^j = \{c_{[i]}, \ldots, c_{[n]}\}$ for all $i = 1, \ldots, n$. When μ is additive, that is, when the criteria are independent, the Choquet integral is equivalent to the weighted arithmetic mean, i.e. $C_\mu^j = \sum_{i=1}^n \mu(\{c_i\}) x_i^j$.

In real-life applications, it is really hard to estimate the higher order interactions between the multiple sustainability indicators. Therefore, we focus only on the pairwise interactions and use a special case of the Choquet integral, which is known as the 2-additive Choquet integral [30] and expressed in the following interpretable form.

$$C_\mu^j = \sum_{i=1}^{n} \left(w_i - \frac{1}{2} \sum_{k \neq i} |u_{ik}| \right) x_i^j \quad (8)$$
$$+ \sum_{u_{ik}>0} u_{ik} \min\{x_i^j, x_k^j\} + \sum_{u_{ik}<0} u_{ik} \max\{x_i^j, x_k^j\}.$$

Here u_{ik} represents the interaction between the criteria c_i and c_k and takes values it the interval $[-1; 1]$. The u_{ik} parameters satisfy the conditions that $w_i - (1/2)\sum_{k \neq i} |u_{ik}| \geq 0$ for all $i = 1, \ldots, n$. This condition is always smaller that the weight if that criterion. The interpretation of the interaction terms can be summarized as follows:

- u_{ik} takes a positive value for a pair of criteria (c_i, c_k) if the alternative with higher scores of both criteria s preferable by the decision maker. In order to reflect the importance of having higher scores on both criteria, the overall performance is calculated based on the lower score and the level of importance is quantified by specifying the value of u_{ik}.
- u_{ik} takes a negative value if the decision maker is satisfied with the alternative which has a reasonably high score in at least one if the criteria c_i and c_k. When U_{ik} takes a larger negative value, the effect of the lower score gets less significant.
- the value of zero implies that there is no interaction between the two criteria considered and it leads to the classical weighted sum based on the w_i parameters.

The coefficients of importance w_i and u_{ik} are specified according to the decision makers's preferences.

IV. Case Study

Recall that Table I presents our proposed indicators. Based on these indicators we construct a case to apply the described methods for the following selected European countries: Austria (AT), Belgium (BE), Czech Republic (CZ), Finland (FI), France (FR), Germany (DE), Hungary (HU), Italy (IT), Netherlands (NL), Poland (PL), Romania (RO), Spain (ES), Sweden (SE), Turkey (TR) and United Kingdom (UK). The idea behind selecting this set of countries is to contrast the countries with large, moderate and small economic activities, and to assure a geographic dispersion. To transform the values of the indicators into scores, a scale from 0.2 to 1.0 with 0.2 increments was used and a higher value means a preferable score. The scaled values are given in Table II.

Determining the weights to quantify the relative importance of the sustainability criteria is an integral part of the analysis. In our study, 17 indicators are taken into account due to the data availability. The sustainability dimensions and also the indicators within each dimension are evaluated in a pairwise fashion using the Analytical Hierarchy Process [24] technique based on consultations with a group of experts in the field. If more sustainability indicators are considered in such an analysis, it would be more challenging to specify the importance weight associated with each criterion. In such cases, assigning equal weights to all the criteria can be an option [31].

Emissions of the greenhouse gases, energy consumption and safety issues are identified as the most important criteria in the context of sustainable transport, and the motivation behind this outcome can be explained without much difficulty. Transport accounts for more than a one-fifth of the greenhouse-gas emissions and around a one-third of all final energy consumption in the European countries. Although the transport sector of the new EU Member States contributes to the total GHG emissions less than the older EU Member States, the increase rate of their contributions is higher due to their developing transportation systems. The major concern is related to the fact that between 1990 and 2006, the GHG emissions in the European area decreased in all main emitting sectors except in the transport sector. As with emissions, the increase in passenger- and freight-transport demand has resulted in a rapid growth in the total energy consumption. As transport mainly depends on the fossil fuels, the energy consumption and the GHG emissions are closely related. To reflect the economic aspect of the energy consumption and distinguish it from the environmental indicator of GHS emissions, the energy consumption is scaled by the GDP. Finally, safety is also regarded as an important factor. The main consequences of traffic accidents are not only social but economic as well. Although the annual number of road fatalities is gradually falling on the average for the EU countries, significant effort is needed especially for the east European countries.

The interaction parameters reflect the level of conservativeness of the decision makers preferences. That is, a pessimistic (conservative) decision maker prefers that the scores of all (or most) of the criteria are satisfactory, while an optimistic one is satisfied if a satisfactory performance is observed for at least one criterion. In fact, when dealing with sustainability evaluation, the conservative approach is more suitable, since attaining reasonable scores in most of the sustainability criteria is preferable. This discussion explains why the specified values of the interaction parameters are in general positive.

We obtain the country scores by using the Choquet integral method and provide the respective rankings in Table III. That table also presents the results obtained by the TOPSIS method. According to both of these techniques DE turns out to have the most sustainable system among the selected countries. The countries FI, FR, BE, NL, SE, UK, RO and HU have different rankings depending on the method applied. The rankings of the remaining countries (AT, IT, ES, TR, CZ, PL) obtained by two methods do not differ. The

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TABLE II
INDICATORS AND ASSOCIATED SCALED SCORES FOR THE SELECTED COUNTRIES

	CEN1	CEN2	CEN3	CEN4	CEN5	CEC1	CEC2	CEC3	CEC4	CEC5	CSC1	CSC2	CSC3	CSC4	CSC5	CSC6	CSC7
AT	1.0	0.6	1.0	0.4	0.2	0.4	0.4	1.0	0.2	0.6	0.6	1.0	0.6	1.0	1.0	0.6	0.2
BE	0.8	0.8	1.0	0.8	0.6	0.4	0.4	0.8	0.4	1.0	0.6	0.8	0.8	0.8	0.6	1.0	0.4
CZ	0.2	0.2	1.0	1.0	1.0	0.4	0.4	0.6	0.6	1.0	0.8	0.6	0.8	0.6	1.0	0.4	0.6
FI	1.0	0.8	1.0	0.8	0.8	0.2	0.6	0.8	0.6	0.8	0.6	0.4	0.8	0.8	1.0	1.0	0.4
FR	1.0	1.0	1.0	0.8	0.8	0.2	0.2	0.6	0.2	0.6	1.0	1.0	0.4	0.6	1.0	0.6	0.2
DE	1.0	1.0	1.0	1.0	1.0	0.2	0.6	1.0	0.2	0.4	0.8	1.0	0.6	1.0	1.0	0.8	0.2
HU	0.2	0.2	0.4	0.2	0.2	0.8	0.8	0.6	0.4	1.0	0.4	0.2	0.4	0.8	0.2	0.2	0.6
IT	1.0	0.8	0.2	0.8	0.8	0.2	0.4	0.4	0.2	0.4	0.6	0.8	0.6	0.2	1.0	1.0	0.2
NL	1.0	0.8	1.0	0.8	0.8	0.2	1.0	1.0	0.2	0.6	0.8	1.0	0.8	0.2	1.0	0.4	0.4
PL	0.4	0.4	0.2	0.6	0.6	0.2	0.6	0.8	0.2	0.4	0.8	0.6	1.0	0.6	1.0	0.4	0.6
RO	0.2	0.2	0.2	0.4	0.2	0.4	0.8	0.8	0.6	0.4	0.4	0.2	0.4	0.6	1.0	0.2	1.0
ES	0.6	0.6	1.0	0.6	0.6	0.2	0.4	0.2	0.2	0.6	0.6	1.0	0.8	0.6	0.6	0.8	0.6
SE	1.0	0.8	1.0	0.8	0.8	0.2	0.6	1.0	0.2	0.6	0.4	0.8	0.6	0.8	1.0	0.6	0.4
TR	0.8	0.4	1.0	0.4	0.4	1.0	0.4	0.2	1.0	0.2	0.2	0.6	0.2	0.4	0.2	1.0	1.0
UK	1.0	0.8	1.0	0.8	0.8	0.2	0.4	0.4	0.2	0.8	1.0	0.6	0.4	0.6	1.0	0.2	0.4

TABLE III
AGGREGATE SCORES AND RANKINGS

	TOPSIS		Choquet Integral	
	Score	Rank	Score	Rank
AT	0.67	8	0.58	8
BE	0.71	7	0.67	4
CZ	0.40	12	0.47	12
FI	0.73	4	0.69	2
FR	0.78	2	0.69	3
DE	0.79	1	0.70	1
HU	0.16	14	0.23	15
IT	0.62	9	0.53	9
NL	0.75	3	0.65	5
PL	0.33	13	0.35	13
RO	0.16	15	0.24	14
ES	0.57	10	0.53	10
SE	0.71	6	0.59	6
TR	0.55	11	0.47	11
UK	0.72	5	0.59	7

TABLE IV
RELATIVE POTENTIALS

	ENV	ECO	SOC
R(DE, AT)	-0.1022	-0.0201	0.2449
R(DE, BE)	0.0661	-0.0786	0.0413
R(DE, CZ)	-0.0075	0.0807	0.1554
R(DE, FI)	0.0378	-0.0974	0.0705
R(DE, FR)	0.0170	-0.0052	0.0008
R(DE, HU)	0.1484	0.0813	0.2352
R(DE, IT)	0.1082	0.0083	0.0525
R(DE, NL)	0.0378	-0.0185	0.0277
R(DE, PL)	0.0967	0.0020	0.2475
R(DE, RO)	0.1552	0.0824	0.2206
R(DE, ES)	-0.0756	0.0027	0.2428
R(DE, SE)	0.0378	-0.0138	0.0818
R(DE, TR)	0.0465	0.0813	0.0996
R(DE, UK)	0.0378	-0.0131	0.0847

differences between the two ranking lists clearly indicate that the interactions play an important role in the analysis.

In order to investigate the rationale behind the obtained rankings, we closely examine the relative potentials given in Table IV. It can be observed that the success of DE can be attributed to its high score in environmental and social dimensions. There are other countries such as AT, ES or CZ for which the contribution of environmental dimension is higher compared to DE, but the contribution of the social dimension is the highest for DE. As the environmental and social dimensions have higher weights in our decision model, DE is selected as the best even with its average score on the economic dimension. Apart from this result, the rankings of FI and BE require special attention to demonstrate the effectiveness of our approach. FI and BE are ranked the fourth and the seventh according to the TOPSIS method, respectively, and the second and the fourth using the Choquet Integral method, respectively. The absolute potentials of these countries show that they have moderate and balanced scores on all dimensions and thus their transport networks are evaluated as being more sustainable according to our proposed method. Considering their scores on the economic dimension, it is clear that FI and BE can be ranked even higher if the weight of the economic dimension is increased to a sufficiently large value.

In this study, we assume that the cost of improving the scores of any two criteria by the same amount is identical. Based on this assumption and the relative potentials in Table V, we identify the required improvement amount for each country and criterion to attain the same performance with the most sustainable transport system. In Table V, the required improvement amount is denoted by S, M, I and C if it is small, moderate, imperative, and critical, respectively. It is not difficult to deduce that relatively new members of the EU and the candidate countries such as PL, RO, HU and TR have a long way to follow to make their systems more sustainable. Especially, HU and ES should focus on the energy efficiency and the emission reduction by implementing the policies that motivate individuals and companies to update their existing vehicles with EURO compliant ones, and also implement new regulations to tightly control the driving behavior of network users and decrease the number of injuries and fatalities.

V. CONCLUSIONS

In this study, we propose a multicriteria decision making framework to evaluate the sustainability of transport networks of countries and a methodology that takes into account criteria dependencies. Sustainability is based on the balanced development concept and therefore, the non-compromise alternatives are of special importance. We show that the proposed technique enables us to identify such preferred alternatives as opposed to the classical weighted mean based approaches. Moreover, the proposed elucidation process points out according to which criteria a system needs to be improved and specifies the required level of improvements.

TABLE V
IMPROVEMENT REQUIRED TO ATTAIN THE SAME SUSTAINABILITY PERFORMANCE WITH DE

	CEN					CEC					CSC						
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	6	7
AT		S							I		S						
BE									S								
CZ	M	M							S			S					
FI												S					
FR									S								
HU	C	C	S						S		I	C					
IT		S	I						M	S	S						
NL									M								
PL	M	M	M						I	M		S					
RO	C	C	M						S	S	I	C					
ES	M	S							M		S						
SE									M		M						
TR	S	I								S	I	S					
UK									M			M					

There exist some indicators for which there is no available data for some countries. There are also some other indicators for which the data is available but the collection methods differ for some countries. Therefore, such indicators are not included in our analysis. When appropriate data on additional sustainability indicators are made available, one can apply the proposed methods considering a larger set of indicators. Another important subject is the determination of the weights associated with the indicators. Here, we use a simple voting mechanism to specify the importance weights and interactions, but more elaborated group decision making techniques can be incorporated into the proposed framework. Finally, the cost of improvement should differ for different indicators. If it would be possible to estimate such costs accurately, then we may try to build an optimization model to properly identify the required improvement level for each indicator.

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