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A multicriteria evaluation methodology for assessing the impact of COVID-19 in EU countries

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A B S T R A C T

Our purpose in this paper is to develop an integrated multicriteria evaluation methodology for assessing the impact of COVID-19 in the 27 countries of the European Union. Initially, a specialized and comprehensive set of normalized criteria metrics that capture several dimensions of the pandemic, such as infection, mortality, recovery and testing rates, is carefully specified. Then, by means of a well-established and intuitive weighting system, which directly takes into consideration the experts’ preferences, the gravity of each criterion is determined properly. Next, two of the most popular multicriteria ranking techniques, i.e. the TOPSIS and the PROMETHEE II, are simultaneously exploited in order to derive and integrate the obtained evaluations. Moreover, the value of the suggested decision support system is enriched through the introduction of a novel element in the field of multicriteria analysis, i.e. the “2-dimensions evaluation plane”, a data visualization concept which provides rich information to the decision maker, by fruitfully blending the ranking results of the utilized multicriteria methods. The validity of the proposed approach is verified through an indicative illustrative application on Coronavirus data for the European Union countries, deriving a wide spectrum of insightful conclusions. Finally, the flexibility of the suggested framework is also stressed, since it can be fully customized, both in terms of the selected criteria and its weights, and run repetitively under a specific time-step frequency, according to the evolution dynamics and implications of the underlying pandemic.

1. Introduction & problem setting

The Coronavirus outbreak is first and foremost a human tragedy, affecting millions of people [1]. It is the most infectious disease pandemic, taking into consideration the numbers infected, the mortality rate and the demand for healthcare services [2]. Globally, according to the World Health Organization, as of August 19, 2022, there have been 591,683,619 confirmed cases of COVID-19, including 6,443,306 deaths [3]. But the Coronavirus pandemic is also having a growing impact on the global economy, since the consequences from the organizational shutdowns and other measures are unprecedented.

Under these disastrous circumstances, contributions from the field of operations research and management science (ORMS) have played a critical role [4,5]. Choi [6] and Queiroz and Wamba [7] highlight and set the pace on the interconnection of ORMS and COVID-19. Interesting applications on the relevant conjoint field are the ones of Abdin et al. [8], Amaratunga et al. [9], Sinha et al. [10], and Baveja et al. [11]. And in general, the application of operations research techniques, like simulation, optimization and system dynamics, in the healthcare sector is very broad; see Eldabi et al. [12], Kotiadis et al. [13], Viana et al. [14] and Tako and Kotiadis [15]. The ORMS quantitative framework is also very useful for the specialized containment of pandemics, across various dimensions, such as policy decision analysis [16], global supply chains [17] and modeling protocols [18]. In terms of an even more elaborate level of analysis, ORMS modeling frameworks applied in healthcare can be identified in the field of blood supply chain [19,20] or in the flow-arrivals optimization of acute patients and intensive care unit management [21–24].

Apart from the conventional operations research techniques that have been applied in the healthcare field, and more specifically in pandemics decision making, some more alternative and disruptive methodologies have also been utilized, such as the multicriteria decision making (MCDM) framework [25–27], combined with visualization and evaluation analytics. See for example Araz [28] who integrate complex system dynamics of pandemic influenza with a MCDM model for evaluating public health strategies; see also Araz et al. [29] who propose a bi-criteria simulation modeling case study for pandemic decision making. Moreover, Brennan et al. [30] suggest a taxonomy of model structures for economic evaluation of health technologies; also, Araz et al. [31] present a method of exercising pandemic preparedness through an interactive simulation and visualization. Indeed, MCDM provides a very sound and robust methodological basis for modeling...
the inherent complexity of problems with multiple conflicting criteria, in which the decision maker’s (DM) preferences must be taken into consideration and incorporated in the decision process. For modern treatments of the MCDM, the interested reader should see Greco et al. [32] and Papathanasiou and Ploskas [33].

Our purpose in this paper is to develop an integrated multicriteria evaluation methodology for assessing the impact of COVID-19 in the 27 countries of the European Union (EU). Initially, a specialized and comprehensive set of normalized criteria metrics that capture several dimensions of the pandemic, such as infection, mortality, recovery and testing rates, is carefully specified. Then, by means of a well-established and intuitive weighting system, which directly takes into consideration the experts’ preferences, the gravity of each criterion is determined properly. Next, two of the most popular MCDM ranking techniques, i.e. the TOPSIS and the PROMETHEE II, are simultaneously exploited in order to derive and integrate the obtained evaluations. Moreover, the value of the suggested decision support system is enriched through the introduction of a novel element in the field of MCDM, i.e. the ‘2-dimensions evaluation plane’, a data visualization concept which provides rich information to the DM, by fruitfully blending the ranking results of the utilized multicriteria methods. The validity of the proposed approach is verified through an indicative illustrative application on Coronavirus data for the EU countries, deriving a wide spectrum of insightful conclusions. Finally, the flexibility of the suggested framework is also stressed, since it can be fully customized, both in terms of the selected criteria and its weights, and run repetitively under a specific time-step frequency, according to the evolution dynamics and implications of the underlying pandemic. To the best of our knowledge, this is the first time a methodology is presented for assessing the impact of COVID-19 in the 27 countries of the EU. We also stress at this point that, MCDM has come about because of the need for powerful tools to analyze problems with complex structures. With this work as an example, another purpose of the paper is to encourage all with an in-depth knowledge of the arsenal of MCDM tools, that have been built up over the past half-century, to work on effective applications, as now is the time they are needed most.

The paper proceeds as follows: In Section 2, we present the proposed methodological framework and all the technical aspects of the adopted theoretical modeling. In Section 3, we elaborately discuss the testing procedure. Finally, the concluding remarks are given in Section 4.

2. Proposed methodology

In this section, we provide a general description of the suggested framework, we develop the mathematical formulation of the employed multicriteria evaluation methods, i.e. TOPSIS and PROMETHEE II, and finally we briefly present the theoretical background of the weighting system chosen to the methodology’s criteria.

2.1. General description

The aim of the proposed methodology is to assess the impact of COVID-19 in EU countries. The logical diagram of the approach is graphically depicted in Fig. 1.
The basic steps of the methodology are summarized as follows (see Sections 2.2–2.4 for the whole spectrum of the underlying technical implications):

**Step 1:** Firstly, an elaborate set of ratios, i.e. evaluation criteria, that capture all the pandemic aspects, such as infection, mortality, recovery and testing rates, is determined by the DMs.

**Step 2:** In the next step, by utilizing a specialized and intuitive weighting method, which fully takes into account the DMs’ preference system, the importance of each criterion is specified.

**Step 3:** Then, two MCDM ranking algorithms, the TOPSIS and the PROMETHEE II, are simultaneously applied for producing two discrete evaluation rankings, based on the selected criteria and weights.

**Step 4:** Next, the ‘2-dimensions evaluation plane’ is introduced, so as to visualize and integrate the ranking results of the 2 MDCM methods and provide the DM with comprehensive insights.

**Step 5:** The proposed approach is applied on Coronavirus data for the 27 EU countries under a rolling period of 4 consequent weeks and the results are validated by the DMs.

**Step 6:** The suggested approach is fully customizable, either regarding the criteria and its weights or the set of evaluation alternatives, i.e. countries, considering the pandemic dynamics of each time.

The methodology is proposed for use by epidemiologists, health care officials, and other experts. People like the authors, that is, people with professional backgrounds in OR-MS and MCDM, would then carry out the roles of ‘analyst’ and ‘facilitator’ in the decision making process (as in [25]). In operation, one set of criteria is as laid in Table 1 with six criteria clustered along three major dimensions: (a) the infection dimension, (b) the mortality dimension, and (c) the recovery & testing dimension.

| No | Criterion | Description | Direction | Dimension | Unit          |
|----|-----------|-------------|-----------|-----------|---------------|
| G1 | AC/TC     | Active Cases/Total Cases | Max       | Infection | Percentage %  |
| G2 | TC/MP     | Total Cases/1M Population | Max       | Infection | Number        |
| G3 | TD/TC     | Total Deaths/Total Cases  | Max       | Mortality | Number        |
| G4 | TD/MP     | Total Deaths/1M Population | Max       | Mortality | Percentage %  |
| G5 | SCC/TC    | Serious-Critical/Total Cases | Max       | Mortality | Percentage %  |
| G6 | TR/TC     | Total Recoveries/Total Cases | Min     | Recovery & Testing | Percentage % |
| G7 | TT/MP     | Total Testing/1M Population | Min     | Recovery & Testing | Number |

| Table 1

Set of criteria.

The methodology is proposed for use by epidemiologists, health care officials, and other experts. People like the authors, that is, people with professional backgrounds in OR-MS and MCDM, would then carry out the roles of ‘analyst’ and ‘facilitator’ in the decision making process (as in [25]). In operation, one set of criteria is as laid in Table 1 with six criteria clustered along three major dimensions: (a) the infection dimension, (b) the mortality dimension, and (c) the recovery & testing dimension.

There is no doubt that the assignment of importance weightings to each criterion is a crucial issue for the application of multicriteria methods. For example, outranking methods are non-compensatory, thus the interpretation of weights is different than for a compensatory MAUT-based system [34]. Rogers et al. [35] distinguish four methods which can be employed to weight criteria for use within multicriteria methods: (a) the direct weighting system [36], (b) the Mousseau system [37], (c) the allocation system [38,39], and (d) the ‘resistance to change grid’ weighting method [40]. The method chosen for the determination of weights in the proposed framework is the allocation of Simos [38,39]. This method concentrates many advantages [41]. First, it is relatively simple and straightforward. Second, the weights obtained can be directly connected to the DM’s concept of personal importance. And third, this method has been widely in a very large number of real-world applications. The underlying technical details of the Simos weighting system, along with its step-by-step implementation for the COVID-19 impact assessment application, appear in Section 2.4.

Finally, we stress that the main reason for utilizing the TOPSIS and PROMETHEE II methods in the current study has to do with their conformity to the nature of the evaluation problem, which calls for a ranking of the alternatives; also, it is associated with the fact that these methods are easy to perceive by the DM. The second reason for exploiting the above methods is connected with the ease of their implementation; no assignment of parameters is necessarily required by the DM, such as indifference, preference and veto thresholds. Improper determination of these parameters may lead to inconsistent results, that actually do not reflect the DM’s preference system. Finally, the choice of these methods is also based on their quite extended applicability, regarding various types of modern decision support problems. The TOPSIS and the PROMETHEE methods can be considered as classical MCDM techniques that have received a lot of attention, not only from scholars, researchers and practitioners [32,42–44].

### 2.2. The TOPSIS method

TOPSIS is the product of Hwang and Yoon [45] and Chen and Hwang [46]. TOPSIS stands for Technique for Order of Preference by Similarity to Ideal Solution. Representative applications in a number of areas can be found in the reviews of Palczewska and Salabun [43] and Salih et al. [44].

Consider a problem with m alternatives numbered 1 to m, and k criteria numbered 1 to k. Let each alternative be evaluated with respect to each criterion. This yields a decision matrix $X = (x_{ij})_{m \times k}$, where $x_{ij}$ is the value assigned to alternative i by criterion j. According to TOPSIS, the first step is to make the criteria dimensionless. This is done by normalization, which is accomplished by re-scaling the columns of X, that is, by converting each $x_{ij}$ value into an $r_{ij}$ as follows:

$$
 r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{q=1}^{m} x_{ij}^2}}, \quad i = 1, \ldots, m, \quad j = 1, \ldots, k
$$

Then each $r_{ij}$ is converted into a $v_{ij}$ value as follows:

$$
 v_{ij} = w_j r_{ij}, \quad i = 1, \ldots, m, \quad j = 1, \ldots, k
$$

where the $w_j$ are the criterion weights obtained from the weighting system. In this way, the i-th row of $V = (v_{ij})_{m \times k}$ is the weighted normalized criterion vector of the i-th alternative.

The next task of TOPSIS is to construct the ideal (zenith) and anti-ideal (nadir) solutions of the problem. The simplest case is that the ideal and anti-ideal points are fixed by the DM, but this should be avoided as it would imply that the DM can actually make a credible elicitation of the two points and it would add more subjectivity to the procedure. A better approach is to construct the components of the ideal solution $v^+ = (v^+_1, \ldots, v^+_k)$ by means of:

$$
 v^+_j = \begin{cases} 
\max \{v_{ij} \mid i = 1, \ldots, m\} & \text{if } j \text{ is a benefit criterion} \\
\min \{v_{ij} \mid i = 1, \ldots, m\} & \text{if } j \text{ is a cost criterion} 
\end{cases}
$$

and the components of the anti-ideal solution $v^- = (v^-_1, \ldots, v^-_k)$ by means of:

$$
 v^-_j = \begin{cases} 
\min \{v_{ij} \mid i = 1, \ldots, m\} & \text{if } j \text{ is a benefit criterion} \\
\max \{v_{ij} \mid i = 1, \ldots, m\} & \text{if } j \text{ is a cost criterion} 
\end{cases}
$$

Now it is necessary to calculate how far the weighted normalized criterion vector of each alternative is from the ideal solution. This is done by computing:

$$
 D_i^+ = \sqrt{\sum_{j=1}^{k} (v_{ij} - v^+_j)^2}, \quad i = 1, \ldots, m
$$
Similarly, it is necessary to calculate how far the weighted normalized criterion vector of each alternative is from the anti-ideal solution. This is done by computing:

\[
D_i^2 = \sum_{j=1}^{k} \left( p_{ij} - v_{ij} \right)^2, \quad i = 1, \ldots, m, \quad j = 1, \ldots, m
\]  

(6)

Using these two distances, we compute each alternative’s relative closeness to the ideal solution:

\[
C_i^+ = \frac{D_i^2}{D_i^2 - D_i^-}
\]  

(7)

After reordering the alternatives from best relative closeness to worst, the alternative at the top of the list is the problem’s solution.

2.3. The PROMETHEE method

PROMETHEE is the product of Brans and Vincke [47] and Brans et al. [48]. Insightful applications of PROMETHEE are found in the review of Behzadzian et al. [42]. One of the creators of PROMETHEE, Bertrand Mareschal, maintains a list of references on his website (www.promethee-gaia.net), which as of January 2020 contained over 2200 references.

Once again, consider a problem with \( m \) actions or alternatives, \( A = \{a_1, \ldots, a_m\} \), which are to be evaluated on a set of \( k \) criteria, \( F = \{f_1, \ldots, f_k\} \). Suppose, without loss of generality, that all criteria are to be maximized. For each criterion \( j \) and for each pair of actions \( (a, b) \), assume the DM is able to express his or her degree of preference in the form of \( P_j(a, b) \in [0, 1] \), where the order of notation is that action \( a \) is preferred to \( b \) based upon the difference \( d_j(a, b) = f_j(a) - f_j(b) \). The degree of preference is obtained using a preference function chosen by the DM. The preference functions that have been proposed are: (a) the usual criterion, (b) the U-shaped criterion, (c) the V-shaped criterion, (d) the level criterion, (e) the V-shaped criterion with indifference region, and (f) the Gaussian criterion. These six types are easy to define and have a clear intuition for the DM.

Depending on the function chosen, threshold values may be required. For example, if the DM selects a V-shaped criterion with indifference region, the DM is then required to specify the threshold values of \( p_j \) (strict preference) and \( q_j \) (indifference). If the difference between the evaluation of \( a \) and \( b \) on the \( j \)-th criterion is smaller than the indifference threshold \( q_j \), then neither action is preferred. If the difference between the evaluations of \( a \) and \( b \) is greater than the preference threshold, \( p_j \), \( d_j(a, b) > p_j \), then action \( a \) is preferred to action \( b \).

In order to evaluate how much action \( a \) is preferred to \( b \) over all criteria, the preference index \( \pi(a, b) \) is calculated using a weighted sum of the degrees of preference \( P_j(a, b) \). The weights, \( w_j > 0 \), are to reflect the importance of each criterion in the decision. That is, the greater the weight, the more important is the criterion. The preference indices are:

\[
\pi(a, b) = \sum_{j=1}^{k} w_j \times P_j(a, b)
\]  

(8)

and

\[
\pi(b, a) = \sum_{j=1}^{k} w_j \times P_j(b, a)
\]  

(9)

where \( \pi(a, b) \) expresses the degree to which \( a \) is preferred over \( b \) for all criteria, and \( \pi(b, a) \) represents how much \( b \) is preferred to \( a \). As each action is compared with other \( m - 1 \) actions, positive \( \varphi^+ \) and negative \( \varphi^- \) outranking flows can be defined as follows:

\[
\varphi^+(a) = \frac{1}{m-1} \sum_{x \in A} \pi(a, x)
\]  

(10)

\[
\varphi^-(a) = \frac{1}{m-1} \sum_{x \in A} \pi(x, a)
\]  

(11)

The positive flow \( \varphi^+(a) \) expresses how much alternative \( a \) outranks all other \( m - 1 \) alternatives, thus it represents the global preference for action \( a \) in comparison to all the other actions. The higher the value of \( \varphi^+(a) \), the better the alternative is. The negative flow, \( \varphi^-(a) \), expresses how alternative \( a \) is outranked by all other \( m - 1 \) alternatives, thus it represents the global weakness of \( a \) in comparison to all the other actions. The smaller \( \varphi^-(a) \), the better the alternative is. Based on the positive and negative outranking flows, the PROMETHEE I partial ranking is defined as follows:

\[
a P b \iff \begin{cases} \varphi^+(a) = \varphi^+(b) \quad \text{and} \quad \varphi^-(a) < \varphi^-(b) \\ or \\ \varphi^+(a) > \varphi^+(b) \quad \text{and} \quad \varphi^-(a) = \varphi^-(b) \end{cases}
\]  

(12)

\[
a P b \iff \begin{cases} \varphi^+(a) = \varphi^+(b) \quad \text{and} \quad \varphi^-(a) < \varphi^-(b) \\ or \\ \varphi^+(a) > \varphi^+(b) \quad \text{and} \quad \varphi^-(a) = \varphi^-(b) \end{cases}
\]  

(13)

\[
a R b \iff \begin{cases} \varphi^+(a) > \varphi^+(b) \quad \text{and} \quad \varphi^-(a) > \varphi^-(b) \\ or \\ \varphi^+(a) > \varphi^+(b) \quad \text{and} \quad \varphi^-(a) < \varphi^-(b) \end{cases}
\]  

(14)

The positive and the negative flows can be combined to obtain the net outranking flow, defined as follows:

\[
\varphi(a) = \varphi^+(a) - \varphi^-(a)
\]  

(15)

PROMETHEE II exploits the above net flow in order to provide a complete ranking of actions, from best to worst; the higher the value of \( \varphi(a) \), the better the alternative is:

\[
\begin{cases} a P b \iff \varphi(a) > \varphi(b) \\ a I b \iff \varphi(a) = \varphi(b) \\ a R b \iff \varphi(a) < \varphi(b) \end{cases}
\]  

(16)

2.4. The Simos weighting system

Simos [38, 39] proposed a technique allowing any DM (not necessarily familiarized with multicriteria decision aiding) to think about and express the way in which he or she wishes to hierarchize a set of criteria in a given context. This procedure aims to communicate to the analyst the information needed in order to attribute a numerical value to each criterion when used in ranking-type methods [49]. The system has been used in research and practice [40] and seems eminently suitable to the study at hand. Certain shortcomings in the method have led to a revised approach being proposed by Figueira and Roy [50].

The distinguishing feature of this weighting method lies in the linkage between allocation cards and the criteria. The name of each criteria is inscribed on a card, and then given to the DM in random order. The DM is asked to physically manipulate these cards in order to rank them and insert blank cards where appropriate in order to reinforce ranking differences when necessary. The active participation by DMs in the procedure gives them an understanding of the approach. The Simos method is summarized as follows [40]:

i. Allocation cards are handed to the person being questioned, with the name of each criterion on a separate card. Thus, if there are \( k \) criteria in total being considered in the decision problem, \( k \) cards are initially handed out. In order to avoid influencing the DM, it is advisable not to assign any number to each of the individual cards. Blank cards are also available but are generally not handed out until step iii.

ii. The person being questioned is then asked to order the cards from 1 to \( k \) in order of importance, with the criterion ranked first being the least important and the one ranked last deemed the most important. If certain criteria are, in the opinion of the DM, of the same importance (and therefore the same weighting), their cards are grouped together. This physical procedure results in a complete ordering of the \( k \) criteria.

iii. Finally, the person being questioned is asked to consider whether the difference in importance between any two successively ranked criteria (or groups of criteria graded equally) should,
upon reflection, be more or less pronounced. For the weight-
ing process to suitably reflect this greater or smaller gap in
importance, one can ask for blank cards for use between two
successively ranked cards (or group of cards), with the number
of blanks used for reflecting the size of the gap.

The step-by-step implementation of the Simos weighting system ap-
pears in Table 2, while final weights as determined by experts, both per
criterion and dimension appear in Table 3. Apparently, the mortality
related dimension, i.e. the criteria associated with deaths and inten-
sive care unit patients, are associated with the highest significance,
following the infection dimension and finally the recovery and testing
one.

3. Indicative application

The proposed methodology has been applied on data concerning the
27 countries of the EU. The EU, a political and economic union of 27
member states that are located primarily in Europe has an estimated to-
total population of about 447 million. Its nominal GDP estimate for 2022
is 17.9 trillion Euros, while the GDP per capita is 45,567 Euros [51].
It is critical to note that the usefulness of the proposed methodology is
not affected by the fact that it is applied only to the EU area, since it
can be considered for any region, upon data availability.

The type of data that are employed in this application are also
available to all researchers and scientists, through the Worldometer
database (https://www.worldometers.info/coronavirus), in which data
are collected from official reports, directly from government’s com-
munication channels or indirectly, through local media sources when
deemed reliable. The study period includes 4 consecutive weeks, with
the data sets, i.e. EU countries and their corresponding values in the
selected criteria, to be recorded on April 6, 13, 20 and 27, 2020.
Indicatively, the corresponding performance matrix, for the first run of
April 6, 2020, is shown in Table 4. The obtained evaluation results,
i.e. country rankings, according to the TOPSIS and PROMETHEE II

| Table 2 |
| Weights by individual criterion and criterion level. |
| --- |
| Grouping | Cards | Position | Weights | norm-Weights | Total |
| Cr1, Cr6 | 2 | 1.2 | (1+2)/2 = 1.5 | 1.5/39 ≈ 4% | 2 × 4% = 8% |
| Blank | 1 | (3) | – | 4/39 ≈ 10% | 1 × 10% = 10% |
| Cr2, Cr4 | 2 | 6.7 | (6+7)/2 = 6.5 | 6.5/39 ≈ 17% | 2 × 17% = 34% |
| Blank | 1 | (8) | – | 9.5/39 ≈ 24% | 2 × 24% = 48% |
| Sum | 10 | 39 | 100% |

| Table 3 |
| Weights accumulated by dimension. |
| --- |
| No | Dimension | Criterion | Description | Criterion weight | Dimension weight |
| Cr1 | Infection | AC/TC | Active Cases/ Total Cases | 4% | 21% |
| Cr2 | TC/MP | Total Cases/ 1M Population | 17% | 65% |
| Cr3 | Mortality | TD/TC | Total Deaths/ Total Cases | 17% | 65% |
| Cr4 | TD/MP | Total Deaths/ 1M Population | 17% | 65% |
| Cr5 | Recovery & Testing | SCC/TC | Serious-Critical/ Total Cases | 24% | 65% |
| Cr6 | TR/TC | Total Recoveries/ Total Cases | 4% | 14% |
| Cr7 | TT/MP | Total Testing/ 1M Population | 10% | 14% |
| Sum | | | 100% | 100% |

| Table 4 |
| Performance matrix as of April 6, 2020. |
| --- |
| Country | Cr1 | Cr2 | Cr3 | Cr4 | Cr5 | Cr6 | Cr7 |
| Austria | 69.52% | 1,342 | 1.82% | 24 | 2.07% | 28.66% | 12,357 |
| Belgium | 73.01% | 1,796 | 7.84% | 141 | 6.04% | 19.15% | 6,040 |
| Bulgaria | 88.91% | 78 | 3.88% | 3 | 4.07% | 7.21% | 9,066 |
| Croatia | 88.16% | 288 | 1.27% | 4 | 3.30% | 10.58% | 2,649 |
| Cyprus | 96.34% | 429 | 1.57% | 7 | 1.83% | 2.09% | 7,939 |
| Czechia | 67.59% | 802 | 3.85% | 31 | 3.10% | 28.56% | 8,503 |
| Denmark | 92.69% | 835 | 1.71% | 14 | 1.26% | 5.60% | 7,939 |
| Estonia | 84.93% | 393 | 2.12% | 5 | 3.30% | 13.79% | 5,724 |
| Finland | 73.87% | 1,422 | 8.70% | 124 | 7.37% | 17.43% | 3,436 |
| France | 69.76% | 1,195 | 1.58% | 19 | 3.93% | 28.66% | 10,962 |
| Germany | 91.30% | 1,011 | 3.16% | 32 | 3.30% | 0.50% | 6,119 |
| Greece | 96.72% | 1,106 | 2.62% | 29 | 2.37% | 0.67% | 8,470 |
| Hungary | 73.01% | 1,796 | 7.84% | 141 | 6.04% | 19.15% | 6,040 |
| Ireland | 92.69% | 835 | 1.71% | 14 | 1.26% | 5.60% | 7,939 |
| Italy | 88.16% | 288 | 1.27% | 4 | 3.30% | 10.58% | 2,649 |
| Latvia | 99.63% | 287 | 0.18% | 0.5 | 0.92% | 0.18% | 11,374 |
| Lithuania | 97.39% | 310 | 1.66% | 5 | 1.30% | 0.95% | 9,403 |
| Luxembourg | 97.39% | 310 | 1.66% | 5 | 1.30% | 0.95% | 9,403 |
| Malta | 88.71% | 1,042 | 9.89% | 103 | 7.76% | 1.40% | 4,401 |
| Poland | 93.81% | 1,115 | 1.58% | 19 | 3.93% | 28.66% | 10,962 |
| Portugal | 91.30% | 1,011 | 3.16% | 32 | 3.30% | 0.50% | 6,119 |
| Romania | 96.72% | 1,106 | 2.62% | 29 | 2.37% | 0.67% | 8,470 |
| Slovakia | 87.07% | 491 | 2.94% | 14 | 2.94% | 9.99% | 13,590 |
| Spain | 69.76% | 1,195 | 1.58% | 19 | 3.93% | 28.66% | 10,962 |
| Sweden | 91.13% | 676 | 5.87% | 40 | 7.92% | 3.00% | 3,654 |
methods are presented in Tables 5a–5b, which contain the closeness percentages (%) to the ideal solution for each country and each run. Also, Tables 6a–6b contain a heat-map representation of the TOPSIS and PROMETHEE II results, in alphabetical order of the EU countries.

It is stressed that after the first run of April 6, 2020, no information regarding the recoveries in Netherlands was provided by the Worldometer© database. Neither were such data available from the Dutch National Institute for Public Health at the time (see https://www.rivm.nl/en/en/novel-coronavirus-covid-19). For these reasons, and in order not to completely exclude Netherlands from the analysis, we approximated that specific figure taking into account the corresponding growth rate of neighboring countries with similar pandemic characteristics.

Next, the 2-dimensions MCDM evaluation planes, as of April 6, 13, 20 and 27, 2020 are shown in Figs. 2a–2d, while the typical TD/TC versus SCC/TC evaluation planes for the same dates are presented in Figs. 3a–3d. The 2-dimensions MCDM evaluation planes can be very helpful when analyzing the obtained results, since they provide a very straightforward and intuitive visualization. The major findings derived from them (see Figs. 2a–2d) have been fully validated by experts and can be summarized as follows:

i. In both the 4 four runs, a subset of 6 countries, i.e. Belgium, France, Italy, Netherlands, Spain and Sweden, appear to have suffered the worst consequences from the pandemic crisis, in
a consistent manner. As an example, according to the TOPSIS method, Spain’s range of closeness to the ideal solution, spans from 22.96% to 30%, while according to PROMETHEE II method, Netherland’s range of net flow spans from −0.63 to 0.68. These two countries appear to have suffered the most (see also Tables 5a–5b). The same subset of countries appears isolated at the top-right area of the simple TD/TC versus SCC/TC evaluation plane (see Figs. 3a–3d).

ii. In contrast, 3 countries, i.e. Latvia, Malta and Slovakia have minimized the underlying consequences, during the horizon of the analysis. As an example, according to the TOPSIS method, Malta’s range of closeness to the ideal solution, spans from 86.32% to 93.3%, while according to PROMETHEE II method, Latvia’s range of net flow spans from +0.65 to +0.72. These two countries are ranked at the top of the rankings. Again, the same subset of countries appears isolated at the top-left area of the simple TD/TC versus SCC/TC evaluation plane (see Figs. 3a–3d).

iii. A set of 5 countries, Croatia, Cyprus, Czechia, Estonia & Lithuania, are consistently ranked fairly high in the rankings. On the other hand, a set of 3 countries, Hungary, Ireland and Romania, are ranked fairly low in the obtained rankings. As an example, according to the TOPSIS method, Lithuania’s average range of closeness to the ideal solution is 80.06%, while according to PROMETHEE II method, Hungary’s average net flow is −0.54.

Also, Tables 6a–6b may provide additional helpful information regarding the dynamics of the underlying evaluations. As mentioned, these tables contain a heat-map representation of the TOPSIS and PROMETHEE II results, in alphabetical order of the EU countries. Some examples:

i. During the specified period of analysis, the position of Belgium is also worsening, reporting a 42.73% closeness to the ideal solution on April 6 and 24.64% on April 27, according to the TOPSIS results. Similarly, according to the PROMETHEE II results, its net flows on April 6 and April 27, are −0.59 and −0.7 correspondingly.

ii. The position of France is worsening, reporting a 41.91% closeness to the ideal solution on April 6 and a 33.17% on April 27, according to the TOPSIS results. Similarly, according to the PROMETHEE II results, its net flows on April 6 and April 27, are −0.64 and −0.73 correspondingly.

iii. The position of Greece is improving, reporting a 64.86% closeness to the ideal solution on April 6 and 69.3% on April 27, according to the TOPSIS results. Similarly, according to the PROMETHEE II results, its net flows on April 6 and April 27, are +0.15 and −0.2 correspondingly.

iv. The position of Hungary is worsening, reporting a 69.02% closeness to the ideal solution on April 6 and 59.82% on April 27, according to the TOPSIS results. Similarly, according to the PROMETHEE II results, its net flows on April 6 and April 27, are +0.15 and −0.2 correspondingly.

v. The position of Ireland is improving, reporting a 68.22% closeness to the ideal solution on April 6 and 60.61% on April 27, according to the TOPSIS results. Similarly, according to the PROMETHEE II results, its net flows on April 6 and April 27, are −0.29 and −0.12 correspondingly.

vi. The position of Italy is improving, reporting a 33.07% closeness to the ideal solution on April 6 and 41.46% on April 27, according to the TOPSIS results. Similarly, according to the PROMETHEE II results, its net flows on April 6 and April 27, are −0.43 and −0.33 correspondingly.
Table 6b
PROMETHEE II heat-map evaluation results in alphabetical order.

| Country  | April 6, 2020 | April 13, 2020 | April 20, 2020 | April 27, 2020 |
|----------|---------------|----------------|----------------|----------------|
| Austria  | 0.14          | 0.11           | 0.16           | 0.2            |
| Belgium  | -0.59         | -0.63          | -0.65          | -0.7           |
| Bulgaria | -0.01         | -0.1           | -0.01          | -0.06          |
| Croatia  | 0.28          | 0.34           | 0.44           | 0.34           |
| Cyprus   | 0.19          | 0.39           | 0.33           | 0.28           |
| Czechia  | 0.27          | 0.15           | 0.26           | 0.27           |
| Denmark  | -0.07         | 0.01           | 0.03           | 0.1            |
| Estonia  | 0.24          | 0.33           | 0.32           | 0.31           |
| Finland  | 0.19          | 0.19           | 0.25           | 0.06           |
| France   | -0.64         | -0.64          | -0.68          | -0.73          |
| Germany  | 0.01          | 0              | -0.03          | -0.01          |
| Greece   | -0.21         | 0              | 0              | 0.01           |
| Hungary  | 0.15          | -0.17          | -0.32          | -0.2           |
| Ireland  | -0.29         | -0.22          | -0.33          | -0.12          |
| Italy    | -0.43         | -0.39          | -0.35          | -0.33          |
| Latvia   | 0.65          | 0.68           | 0.72           | 0.68           |
| Lithuania| 0.34          | 0.37           | 0.39           | 0.4            |
| Luxembourg| 0.24        | 0.17           | 0.15           | 0.26           |
| Malta    | 0.61          | 0.56           | 0.7            | 0.77           |
| Netherlands| -0.68       | -0.66          | -0.63          | -0.66          |
| Poland   | 0.34          | 0.09           | 0.14           | 0.06           |
| Portugal | -0.12         | 0.02           | -0.02          | 0.02           |
| Romania  | -0.17         | -0.15          | -0.21          | -0.23          |
| Slovakia | 0.63          | 0.75           | 0.66           | 0.7            |
| Slovenia | 0.1           | -0.04          | -0.14          | -0.18          |
| Spain    | -0.6          | -0.58          | -0.6           | -0.6           |
| Sweden   | -0.56         | -0.58          | -0.59          | -0.62          |

Fig. 2a. The 2-dimensions MCDM evaluation plane as of April 6, 2020.
Fig. 2b. The 2-dimensions MCDM evaluation plane as of April 13, 2020.

Fig. 2c. The 2-dimensions MCDM evaluation plane as of April 20, 2020.
Fig. 2d. The 2-dimensions MCDM evaluation plane as of April 27, 2020.

Fig. 3a. Typical TD/TC versus SCC/TC evaluation plane as of April 6, 2020.
Fig. 3b. Typical TD/TC versus SCC/TC evaluation plane as of April 13, 2020.

Fig. 3c. Typical TD/TC versus SCC/TC evaluation plane as of April 20, 2020.
4. Conclusions

The world is facing a very aggressive pandemic of a magnitude and speed that are almost unprecedented. Under these circumstances, evaluation frameworks for measuring the impact in each country might be extremely helpful decision support tools. The critical features of the approach presented are outlined as follows: (a) Incorporation in the evaluation process of several criteria, which in a realistic basis capture the pandemic impact, (b) Incorporation of the experts’ preference system, regarding both the choice of these criteria and their significance, and (c) Incorporation of multicriteria methods, i.e. the TOPSIS and PROMETHEE II, which are well adapted to the nature of the problem, as they provide complete rankings of the alternatives, i.e. the 27 EU countries.

More specifically, we developed an integrated multicriteria evaluation methodology for assessing the impact of COVID-19 in the EU region. A comprehensive set of normalized ratios that capture the main dimensions of the pandemic, such as infection, mortality, recovery and testing rates, is carefully specified, in close collaboration with epidemiologists. By means of a well-established weighting system, which directly takes into consideration the experts’ preferences, the gravity of each criterion is determined properly. Further, two MCDM ranking techniques, are simultaneously exploited in order to derive and integrate the obtained evaluations. The value of the suggested decision analytics system is enriched through the introduction of an innovative element in the field of MCDM, i.e., the ‘2-dimensions evaluation plane’, a data visualization concept which provides effective information to the DM, by fruitfully blending the ranking results of the utilized multicriteria methods. The results obtained are fully compatible with the experts’ heuristic and qualitative assessment and have been fully validated by them. Finally, the flexibility of the suggested framework is a critical benefit, since it can be fully customized, both in terms of the selected criteria and its weights, and run repetitively under a specific time-step frequency.

In closing, further work that may be considered for broadening the suggested framework can be related to the expansion of its focus, by assessing more dimensions, such as the financial and/or social impact of the COVID-19 pandemic, thus including additional criteria or criteria of not only quantitative, but also qualitative nature. Moreover, the suggested approach might be enriched in the future with a new methodological component, beyond the epidemiological data. Expanding analysis with such information as unemployment, drop in GDP, etc., will provide additional insights to the decision makers, with focus on policy alternatives and courses of action.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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