# *Fahrenheit 59*

## An environmental decision support system for benchmarking global warming at Johnson Space Center

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**Abstract**

**Purpose** – The overwhelming majority of scientists agree the earth's temperature has risen during the past century. Nature maintains a balance to keep the earth's average surface temperature at 59 degrees Fahrenheit. About 59 degrees is to earth what 98.6 degrees is to our body. Although, the fact that the earth's temperature has risen is generally not in dispute by scientists, environmental decisions remain among the most difficult facing policy makers. *Fahrenheit 59* is an environmental decision support system developed at Johnson Space Center for benchmarking global warming. This paper aims to present the details of the benchmarking model embedded in *Fahrenheit 59*.

**Design/methodology/approach** – The model attempts to establish benchmark scores that are weighted sum measures of subjective and intrinsic weights and performance scores associated with a series of global warming opportunities and threats. *Fahrenheit 59* has the potential to monitor continuous progress towards countering the threat of global warming worldwide.

**Findings** – The European Union (EU) is at the forefront of international efforts to combat global warming. The EU has been taking serious steps to address its own greenhouse gas emissions and climate changes. A pilot study conducted resulted in a benchmarking scheme that shows of the 27-member EU states, seven were global protectors, four were global remediators, 12 were global defectors, and four were global predators.

**Originality/value** – *Fahrenheit 59* assists policy makers concerned about global warming to compare environmental performance with "best-in-class" achievements. The proposed system bridges the gap between technology and decision making to stimulate environmental awareness and activism.

**Keywords** Benchmarking, Decision support systems, Global warming, European Union

**Paper type** Research paper

## 1. Introduction

A Native American proverb says, "We do not inherit the Earth from our ancestors – we borrow it from our children." Environmental problems, from urban and industrial pollution to natural and technological hazards, are deeply embedded in the socioeconomic fabric of all nations. In the past decade, environmental decision support system (EDSS) have emerged to manage these problems characterized by multiple and usually conflicting objectives, data and perceptions, beliefs and fears, and hidden agenda and plural rationalities (Fedra, 2000). In general, environmental awareness has grown sharply in response to global population growth and ever growing consumption of energy. Environmental information is now an important

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element of the policy-making process in a civic society. Guariso and Werthner (1989) argue that environmental problems are complex and multi-disciplinary in nature requiring integrated EDSS with quantitative, socio-political, and economic components. Paggio *et al.* (1999) also argue the necessity of integrated EDSS and show that EDSS are often associated with complex problems with multiple criteria and conflicting objectives requiring several tools and techniques.

EDSS are interactive, flexible, and adaptable information systems used to assess environmental alternatives and solutions. Matthies *et al.* (2007), Poch *et al.* (2004), Cortes *et al.* (2000) and Avouris (1995) report on several EDSS designed for managing weather, water, forest, emergencies and environmental. Weather management systems include STORMCAST for forecasting storm over the Scandinavian Peninsula, MEDEX for forecasting Mediterranean gale force winds, SLCPS for clouds prediction, and FRAME and DUSTRO for air quality control. Water management systems include OASIS for ground water containment modeling and DAI-DEPUR for wastewater treatment plant operations. Forest management systems include INFORMS-R8 for analyzing ecosystem conditions and alternatives, PHOENIX for managing forest fires and CHARADE for preventing catastrophic wild fires. Emergency management systems include DCHEM for managing chemical emergencies and RODOS for managing nuclear accidents. Environmental management systems include (Quah *et al.*, 1996) for environmental situational analysis and (Stylios and Groumpos, 1999; Ozyurt *et al.*, 1998) for process industry environmental systems. Global warming is an environmental concern that has a plethora of contributory factors. EDSS can play a significant role in tracking these dynamic environmental factors. Massive data and complex multiple criteria decision analysis models can be used in EDSS for benchmarking and developing solutions to reduce the impact of today's ongoing environmental issues.

The concept of benchmarking has become synonymous with achieving successful performance. The original meaning of the word "benchmark" refers to a metric unit on a scale of measurement. Benchmarking is the systematic comparison of performance elements in a company against those best practices of relevant companies and obtaining information that will help the observing company to identify and implement improvement (Lau *et al.*, 2001). While a number of definitions for benchmarking can be found in the literature, they all essentially share the same theme. Benchmarking is a framework within which indicators and best practices are examined in order to identify areas where performance can be improved.

Environmental benchmarking has been the subject of numerous studies. Matthews (2003) used critical analysis to present a framework for extending environmental management systems for corporate environmental benchmarking. Veleva *et al.* (2003) used a five-level indicator hierarchy to analyze the environmental sustainability indicators voluntarily-reported by six pharmaceutical companies. Their study reflected the current state-of-the-art in terms of developing more sustainable production systems. Boks and Stevels (2003) developed a benchmarking system that integrated product-related environmental matters into an overall strategy considering the interests of all internal and external stakeholders. Schvaneveldt (2003) proposed an environmental benchmarking framework and examined a case study for improving the environmental performance of various products. Matthews and Lave (2003) introduced a screening level benchmarking model that could accomplish much of the benchmarking goals quickly and inexpensively. They also suggested ways this type of benchmarking information could be used broadly within a firm for decision-making purposes.

Although, most benchmarking frameworks consider financial metrics and management issues, environmental benchmarking focused on environmentally related practices and indicators which will lead to superior environmental performance. *Fahrenheit 59* is an EDSS designed at Johnson Space Center to classify global warming factors into opportunities (factors that prevent global warming) and threats (factors that contribute to global warming) and process them with a complex multiple criteria benchmarking model. The benchmarking system embedded in *Fahrenheit 59* helps policy makers concerned about global warming achieve good environmental performance by learning from "best-in-class" achievements. The proposed system bridges the gap between technology and decision-making to stimulate environmental awareness and activism. Based on the rankings developed by *Fahrenheit 59*, each state in a region can be identified as a global protector, remediator, defector or a global predator. This ranking results in spatially disbursed global warming benchmarks for specific geographical regions from which decision makers (DMs) can run scenarios and perform sensitivity analysis. The details of the benchmarking model are presented in the next section followed by the benchmarking data in Section 3 and the conclusion and future research directions in Section 4.

## 2. Benchmarking model

To formulate an algebraic model of *Fahrenheit 59*, consider a general problem with $n$ states, $m$ opportunities, and $l$ threats. Let $A_j$ represent state $j$ ($j = 1, \ldots, n$), $\mathrm{O}_i$ represent opportunity $i$ ($i = 1, \ldots, m$), and $\mathrm{T}_i$ represent threat $i$ ($i = 1, \ldots, l$). Let us further assume that $z_{\mathrm{O}_{ij}}$ represents the score of the $j$th state for the $i$th opportunity and $z_{\mathrm{T}_{ij}}$ represents the score of the $j$th state for the $i$th threat. The higher scores of opportunities are preferable ($z_{\mathrm{O}_{im}} > z_{\mathrm{O}_{in}}$ implies that state $m$ has a better score on opportunity $i$ than state $n$) and the lower scores of threats are preferable ($z_{\mathrm{T}_{im}} > z_{\mathrm{T}_{in}}$ implies that state $m$ has a worse score on threat $i$ than state $n$).

We further assume $w_{\mathrm{O}'_i}$ is the importance weight of opportunity $i$, where $\sum_{i=1}^{n} w_{\mathrm{O}'_i} = 1$, and $w_{\mathrm{T}'_i}$ is the importance weight of threat $i$, where $\sum_{i=1}^{l} w_{\mathrm{T}'_i} = 1$. The importance weight associated with each opportunity or threat can be elicited by different weighting procedures. The simplest approach is weighting each opportunity and threat directly by point allocation. Other weighting methods include SMART and SMARTER (Barron and Barnett, 1996; Edwards and Barron, 1994), SWING (von Winterfeldt and Edwards, 1986), and analytic hierarchy process (AHP) (Saaty, 1977, 1983, 1994). Using SMART, ten points are given to the least important opportunity and threat. Then, more points are given to the other opportunities and threats, depending on their relative importance. In SMARTER, the weights are elicited with the centroid method of Solymosi and Dombi (1986). The SWING method is similar, but the procedure starts from the most important opportunity and threat, keeping it as the reference.

AHP is used in *Fahrenheit 59* to develop the importance weights of the opportunities and threats. AHP has been widely used in benchmarking for technology management (Tavana, 2004), supplier selection (Chen and Huang, 2007), logistics management (Chan *et al.*, 2006), project evaluation and management (Liang, 2003; Dey, 2002), quality management (Shen *et al.*, 2000, Tavana *et al.*, 2003). The DMs identify $m$ opportunities and $l$ threats to be used as the evaluation factors in the model. Assuming that the DM believes, $O_1, O_2, \ldots, O_m$ are the $m$ opportunities (or $l$ threats) that contribute to the importance of a state, the DM's goal is to assess the relative importance of these opportunities and threats.

Saaty's AHP (Saaty and Vargas, 1998; Forman and Gass, 2001) is a method of deriving the importance weights associated with each of the $m$ opportunities (or $l$ threats). Initially, the DMs are asked to compare each possible pair $O_p$, $O_q$ of opportunities and provide judgments about which opportunities are more important and by how much. AHP quantifies these judgments and represents them in an $m \times m$ matrix, $\mathbf{B} = (b_{pq})$, where $p, q = 1, 2, \ldots, m$. If $O_p$ is judged to be of equal importance as $O_q$, then $b_{pq} = 1$; if $O_p$ is judged to be more important than $O_q$, then $b_{pq} > 1$; and if $O_p$ is judged to be less important than $O_q$, then $b_{pq} < 1$. $b_{pq} = 1/b_{qp}$ for $b_{pq} \neq 0$. Because the entry $b_{pq}$ is the inverse of the entry $b_{qp}$, the matrix $\mathbf{B}$ is a reciprocal matrix. $b_{pq}$ reflects the relative importance of $O_p$ compared with criterion $O_q$. For example, $b_{12} = 1.25$ indicates that $O_1$ is 1.25 times as important as $O_2$.

Then, the vector $\mathbf{w}_O$ representing the relative weights of each of the $m$ opportunities can be found by computing the normalized eigenvector corresponding to the maximum eigenvalue of matrix $\mathbf{B}$. An eigenvalue of $\mathbf{B}$ is defined as $\lambda$ which satisfies the following matrix equation: $\mathbf{B}\mathbf{w}_O = \lambda \mathbf{w}_O$, where $\lambda$ is a constant, called the eigenvalue, associated with the given eigenvector $\mathbf{w}_O$. Saaty (1994) has shown that the best estimate of $\mathbf{w}_O$ is the one associated with the maximum eigenvalue ($\lambda_{\max}$) of the matrix $\mathbf{B}$. Because the sum of the weights should be equal to 1.00, the normalized eigenvector is used. Saaty's algorithm for obtaining this $\mathbf{w}_O$ is incorporated in the Expert Choice (2006) software.

One of the advantages of AHP is that it encourages DMs to be consistent in their pairwise comparisons. Saaty suggests a measure of consistency for the pairwise comparisons. When the judgments are perfectly consistent, the maximum eigenvalue, $\lambda_{\max}$, should equal $m$, the number of opportunities that are compared. In general, the responses are not perfectly consistent. The larger the $\lambda_{\max}$, the greater is the degree of inconsistency. Saaty defines the consistency index as $(\lambda_{\max} - m)/(m - 1)$, and provides a random index table for matrices of order 3-10.

This random index is based on a simulation of a large number of randomly generated weights. Saaty recommends the calculation of a consistency ratio, which is the ratio of consistency index to the random index for the same order matrix. A consistency ratio of 0.10 or less is considered acceptable. When the consistency ration is unacceptable, the DM is made aware that his or her pairwise comparisons are logically inconsistent, and he or she is encouraged to revise them.

There has been some criticism of AHP in the operations research literature. Harker and Vargas (1987) show that AHP does have an axiomatic foundation, the cardinal measurement of preferences is fully represented by the eigenvector method, and the principles of hierarchical composition and rank reversal are valid. On the other hand, Dyer (1990a) has questioned the theoretical basis underlying AHP and argues that it can lead to preference reversals based on the alternative set being analyzed. In response, Saaty (1990) explains how rank reversal is a positive feature when new reference points are introduced. We use the geometric aggregation rule to avoid the controversies associated with rank reversal (Dyer, 1990a, b; Saaty, 1990; Harker and Vargas, 1990).

Next, we normalize the scores by defining $z_{\mathrm{O}'_{ij}}$ as the normalized score of the *j*th state for the *i*th opportunity, $z_{\mathrm{O}'_{ij}} = z_{\mathrm{O}_{ij}} / \max_{j=1,\ldots,n} z_{\mathrm{O}_j}$, and $z_{\mathrm{T}'_{ij}}$ as the normalized score of the *j*th state for the *i*th threat, $z_{\mathrm{T}'_{ij}} = z_{\mathrm{T}_{ij}} / \min_{j=1,\ldots,l} z_{\mathrm{T}_j}$. Following this normalization, we use $z_{\mathrm{T}''_{ij}} = z_{\mathrm{T}'_{ij}} / \max_{j=1,\ldots,l} z_{\mathrm{T}'_{ij}}$ to further normalize the $z_{\mathrm{T}'_{ij}}$ scores. This secondary normalization step is necessary to ensure that the lower $z_{\mathrm{T}''_{ij}}$ scores are preferable to the higher $z_{\mathrm{T}''_{ij}}$ scores and to ensure that $0 \leq z_{\mathrm{T}''_{ij}} \leq 1$. However, the secondary normalization step is not necessary for the $z_{\mathrm{O}'_{ij}}$ scores because higher $z_{\mathrm{O}'_{ij}}$ scores are naturally preferable to lower $z_{\mathrm{O}'_{ij}}$ scores and $1 \leq z_{\mathrm{O}'_{ij}} \leq 0$. Therefore, $z_{\mathrm{O}''_{ij}} = z_{\mathrm{O}'_{ij}}$.

We then revise the importance weight of the opportunities ($\mathbf{w}_{\mathrm{O}'_i};\ i = 1, \ldots, m$) and threats ($\mathbf{w}_{\mathrm{T}'_i};\ i = 1, \ldots, l$) using the entropy concept. Each opportunity or threat is an information source; therefore, the more information an opportunity or threat reveals, the more relevant it is to the decision analysis. Zeleny (1982) argues that this intrinsic information must be used in parallel with the subjective weights the DMs assigned to various opportunities and threats. In other words, the overall importance weight of an opportunity ($\mathbf{w}_{\mathrm{O}_i}$), is directly related to the intrinsic weight, ($\mathbf{w}_{\mathrm{O}''_i}$), reflecting the average intrinsic information developed by the score of the states, and the subjective weight, ($\mathbf{w}_{\mathrm{O}'_i}$), reflecting the DM's subjective assessment of its importance. Similarly, the overall importance weight of a threat ($\mathbf{w}_{\mathrm{T}_i}$), is directly related to the intrinsic weight, ($\mathbf{w}_{\mathrm{T}''_i}$), and the subjective weight, ($\mathbf{w}_{\mathrm{T}'_i}$).

The more different, the scores of an opportunity or threat are for a set of states, the larger is the contrast intensity of the opportunity or threat, and the greater is the amount of information transmitted by that opportunity or threat. Assuming that vector $\mathbf{Z}_{\mathrm{O}''_i} = (z_{\mathrm{O}''_{ij}})$ characterizes the set $\mathbf{Z}$ in terms of the *i*th opportunity and the *j*th state ($\mathbf{Z}_{\mathrm{O}''_i} = \sum_{j=1}^{n} z_{\mathrm{O}''_{ij}}$; where $i = 1,\ 2, \ldots,\ m$ and $j = 1,\ 2, \ldots,\ n$), the entropy measure of the *i*th opportunity is:

$$e(z_{\mathrm{O}''_i}) = -K \sum_{j=1}^{n} \frac{z_{\mathrm{O}''_{ij}}}{\mathbf{Z}_{\mathrm{O}''_i}} \ln \frac{z_{\mathrm{O}''_{ij}}}{\mathbf{Z}_{\mathrm{O}''_i}} \tag{1}$$

where $K \rangle 0$, ln is the natural logarithm, $0 \leq z_{\mathrm{O}''_{ij}} \leq 1$, and $e_{\mathrm{O}''_i} \geq 0$. When all $z_{\mathrm{O}''_{ij}}$ are equal for a given *i* and *j*, then $z_{\mathrm{O}''_{ij}} / \mathbf{Z}_{\mathrm{O}''_i} = 1/n$, and $e(z_{\mathrm{O}''_i})$ assumes its maximum value, which is $e_{\max} = \ln n$. By setting $K = 1/e_{\max}$, we achieve $0 \leq e(z_{\mathrm{O}''_i}) \leq 1$. This normalization is necessary for meaningful comparisons. The smaller $e(z_{\mathrm{O}''_i})$ is, the more information the *i*th opportunity transmits, and the larger $e(z_{\mathrm{O}''_i})$ is, the less information it transmits. When $e(z_{\mathrm{O}''_i}) = e_{\max} = \ln n$, the *i*th opportunity transmits no useful information. In addition, the total entropy for the opportunities is defined as $E_{\mathrm{O}} = \sum_{i=1}^{m} e(z_{\mathrm{O}''_i})$.

The intrinsic weight of opportunity $i$ is calculated as $\mathbf{w}_{\mathrm{O}''_i} = (1/(1 - E_{\mathrm{O}}))\left[1 - e(z_{\mathrm{O}''_i})\right]$. Because $\mathbf{w}_{\mathrm{O}''_i}$ is inversely related to $e(z_{\mathrm{O}''_i})$, entropy uses $1 - e(z_{\mathrm{O}''_i})$ instead of $e(z_{\mathrm{O}''_i})$ and normalize it to make sure $0 \leq \mathbf{w}_{\mathrm{O}''_i} \leq 1$ and $\sum_{j=1}^{n} \mathbf{w}_{\mathrm{O}''_i} = 1$. The more different the score of an opportunity ($z_{\mathrm{O}''_{ij}}$) is, the larger $\mathbf{w}_{\mathrm{O}''_i}$ is and the more important the opportunity is. When all the scores for an opportunity are equal, then $\mathbf{w}_{\mathrm{O}''_i} = 0$. Entropy multiplies the intrinsic weight ($\mathbf{w}_{\mathrm{O}''_i}$) by the subjective weight ($\mathbf{w}_{\mathrm{O}'_i}$)

and normalizes the product to calculate the overall importance weight of an opportunity:

$$\mathbf{w}_{\mathrm{O}_i} = \frac{\mathbf{w}_{\mathrm{O}'_i}\mathbf{w}_{\mathbf{O}''_i}}{\sum_{i=1}^{n}\mathbf{w}_{\mathrm{O}'_i}\mathbf{w}_{\mathrm{O}''_i}} \tag{2}$$

Assuming that vector $\mathbf{Z}_{\mathrm{T}''_i} = (z_{\mathrm{T}''_{ij}})$ characterizes the set $\mathbf{Z}$ in terms of the $i$th threat and the $j$th state ($\mathbf{Z}_{\mathrm{T}''_i} = \sum_{j=1}^{n} z_{\mathrm{T}''_{ij}}$; where $i = 1, 2, \ldots, l$ and $j = 1, 2, \ldots, n$), the entropy measure of the $i$th threat is:

$$e(z_{\mathrm{T}''_i}) = -K\sum_{j=1}^{n}\frac{z_{\mathrm{T}''_{ij}}}{\mathbf{Z}_{\mathrm{T}''_i}}\ln\frac{z_{\mathrm{T}''_{ij}}}{\mathbf{Z}_{\mathrm{T}''_i}} \tag{3}$$

Similarly, the total entropy for the threats is defined as $E_{\mathrm{T}} = \sum_{i=1}^{m} e(z_{\mathrm{T}''_i})$ and the intrinsic weight of threat $i$ is calculated as $\mathbf{w}_{\mathrm{T}''_i} = 1/(1 - E_{\mathrm{T}})\left[1 - e(z_{\mathrm{T}''_i})\right]$. Again, because $\mathbf{w}_{\mathrm{T}''_i}$ is inversely related to $e(z_{\mathrm{T}''_i})$, entropy uses $1 - e(z_{\mathrm{T}''_i})$ instead of $e(z_{\mathrm{T}''_i})$ and normalize it to make sure $0 \leq \mathbf{w}_{\mathrm{T}''_i} \leq 1$ and $\sum_{j=1}^{n}\mathbf{w}_{\mathrm{T}''_i} = 1$. The more different the score of a threat ($z_{\mathrm{T}''_{ij}}$) is, the larger $\mathbf{w}_{\mathrm{T}''_i}$ is and the more important the threat is. When all the scores for a threat are equal, then $\mathbf{w}_{\mathrm{T}''_i} = 0$. Entropy multiplies the intrinsic weight ($\mathbf{w}_{\mathrm{T}''_i}$) by the subjective weight ($\mathbf{w}_{\mathrm{T}'_i}$) and normalizes the product to calculate the overall importance weight of a threat:

$$\mathbf{w}_{\mathrm{T}_i} = \frac{\mathbf{w}_{\mathrm{T}'_i}\mathbf{w}_{\mathrm{T}''_i}}{\sum_{i=1}^{l}\mathbf{w}_{\mathrm{T}'_i}\mathbf{w}_{\mathrm{T}''_i}} \tag{4}$$

A tabular representation of our general problem with $n$ states, $m$ opportunities and their revised importance weights, $l$ threats and their revised importance weights, $m \times n$ revised opportunity scores, and $l \times n$ revised threat scores is shown in Table I.

Next, we develop a weighted sum overall measure of performance for each state by integrating different measures reflecting multiple objectives driven by problem situation and not by a particular method. The weighted sum (also called weighted average sum or linear-weighted attribute) is a very popular and simple aggregation method (Triantaphyllou, 2000). Each objective is assigned a weighting value representing the relative importance of that objective. The method transforms multiple

**Table I.**
A tabular representation of the general problem

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | *Opportunities* | | | | |
| $\mathrm{O}_i$ | $\mathbf{w}_{\mathrm{O}'_i}$ | $\mathbf{w}_{\mathrm{O}''_i}$ | $\mathbf{w}_{\mathrm{O}_i}$ | $A_1$ | $A_2$ | $\ldots$ | $A_n$ |
| $\mathrm{O}_1$ | $\mathbf{w}_{\mathrm{O}'_1}$ | $\mathbf{w}_{\mathrm{O}''_1}$ | $\mathbf{w}_{\mathrm{O}_1}$ | $z_{\mathrm{O}''_{11}}$ | $z_{\mathrm{O}''_{12}}$ | $\ldots$ | $z_{\mathrm{O}''_{1n}}$ |
| $\mathrm{O}_2$ | $\mathbf{w}_{\mathrm{O}'_2}$ | $\mathbf{w}_{\mathrm{O}''_2}$ | $\mathbf{w}_{\mathrm{O}_2}$ | $z_{\mathrm{O}''_{21}}$ | $z_{\mathrm{O}''_{22}}$ | $\ldots$ | $z_{\mathrm{O}''_{2n}}$ |
| $\ldots$ | $\ldots$ | $\ldots$ | $\ldots$ | $\ldots$ | $\ldots$ | $\ldots$ | $\ldots$ |
| $\mathrm{O}_m$ | $\mathbf{w}_{\mathrm{O}'_m}$ | $\mathbf{w}_{\mathrm{O}''_m}$ | $\mathbf{w}_{\mathrm{O}_m}$ | $z_{\mathrm{O}''_{m1}}$ | $z_{\mathrm{O}''_{m2}}$ | $\ldots$ | $z_{\mathrm{O}''_{mn}}$ |
| | | | *Threats* | | | | |
| $\mathrm{T}_i$ | $\mathbf{w}_{\mathrm{T}'_i}$ | $\mathbf{w}_{\mathrm{T}''_i}$ | $\mathbf{w}_{\mathrm{T}_i}$ | $A_1$ | $A_2$ | $\ldots$ | $A_n$ |
| $\mathrm{T}_1$ | $\mathbf{w}_{\mathrm{T}'_1}$ | $\mathbf{w}_{\mathrm{T}''_1}$ | $\mathbf{w}_{\mathrm{T}_1}$ | $z_{\mathrm{T}''_{11}}$ | $z_{\mathrm{T}''_{12}}$ | $\ldots$ | $z_{\mathrm{T}''_{1n}}$ |
| $\mathrm{T}_2$ | $\mathbf{w}_{\mathrm{T}'_2}$ | $\mathbf{w}_{\mathrm{T}''_2}$ | $\mathbf{w}_{\mathrm{T}_2}$ | $z_{\mathrm{T}''_{21}}$ | $z_{\mathrm{T}''_{22}}$ | $\ldots$ | $z_{\mathrm{T}''_{2n}}$ |
| $\ldots$ | $\ldots$ | $\ldots$ | $\ldots$ | $\ldots$ | $\ldots$ | $\ldots$ | $\ldots$ |
| $\mathrm{T}_l$ | $\mathbf{w}_{\mathrm{T}'_l}$ | $\mathbf{w}_{\mathrm{T}''_l}$ | $\mathbf{w}_{\mathrm{T}_l}$ | $z_{\mathrm{T}''_{l1}}$ | $z_{\mathrm{T}''_{l2}}$ | $\ldots$ | $z_{\mathrm{T}''_{ln}}$ |

objectives into an aggregated objective function by multiplying the performance score of each objective by the weighting values and summing up all weighted scores. Many weighted sum models have been developed to help DMs deal with the strategy evaluation process (Gouveia *et al.*, 2008; Leyva-Lopez and Fernandez-Gonzalez, 2003). Triantaphyllou and Baig (2005) have examined the use of four key weighted sum MCDA methods when benefits and costs (opportunities and threats) are used as conflicting criteria. They compared the simple weighted sum model, the weighted-product model, and the AHP along with some of its variants, including the multiplicative AHP. Their extensive empirical analysis revealed some ranking inconsistencies among the four methods, especially, when the number of alternatives was high. Although, they were not able to show which method results in the "correct" ranking, they did prove multiplicative AHP is immune to ranking inconsistencies.

The weights used in the weighted sum method are selected by the DMs prior to determination of the solution. Often, experienced DMs have difficulty reliably selecting specific values even if they are intimately familiar with the problem domain. The solutions in weighted sum method are strongly dependent on how the weights were chosen. Using the weighted sum method, the expected opportunity value ($d_{\mathrm{O}_j}$) and the expected threat value ($d_{\mathrm{T}_j}$) of state $j$ are:

$$d_{\mathrm{O}_j} = \sum_{i=1}^{m} \mathbf{w}_{\mathrm{O}_i}(z_{\mathrm{O}''_i}) \quad (0 \leq d_{\mathrm{O}_j} \leq 1) \tag{5}$$

$$d_{\mathrm{T}_j} = \sum_{i=1}^{l} \mathbf{w}_{\mathrm{T}_i}(z_{\mathrm{T}''_i}) \quad (0 \leq d_{\mathrm{T}_j} \leq 1) \tag{6}$$

Next, we find the mean expected opportunity value ($\bar{d}_{\mathrm{O}_j}$) and the mean expected threat value ($\bar{d}_{\mathrm{T}_j}$) for all of the $n$ states considered in the study as:

$$\bar{d}_{\mathrm{O}_j} = \frac{\sum_{j=1}^{n} d_{\mathrm{O}_j}}{n} \tag{7}$$

$$\bar{d}_{\mathrm{T}_j} = \frac{\sum_{j=1}^{n} d_{\mathrm{T}_j}}{n} \tag{8}$$

The value determination procedure in *Fahrenheit 59* has been specified so that the "ideal state" with the most preferred opportunity and threat scores will have a value of one for $d_{\mathrm{O}_j}$ and zero for $d_{\mathrm{T}_j}$. Typically, there will not be any actual state with $d_{\mathrm{O}_j} = 1$ and $d_{\mathrm{T}_j} = 0$.

The states are next plotted on a matrix similar to Figure 1 along with the mean opportunity value ($\bar{d}_{\mathrm{O}_j}$) and the mean threat value ($\bar{d}_{\mathrm{T}_j}$). The horizontal dimension ($x$-axis) indicates $d_{\mathrm{O}_i}$, while the vertical dimension ($y$-axis) shows $d_{\mathrm{T}_j}$. The mean opportunity value and the mean threat value divide the matrix into four quadrants: global protectors, remediators, defectors, and predators.

1. Global protectors are states that do a lot to help the environment (high opportunities preventing global warming, $d_{\mathrm{O}_j} > \bar{d}_{\mathrm{O}_j}$) and do little to harm the environment (low threats contributing to global warming, $d_{\mathrm{T}_j} \leq \bar{d}_{\mathrm{T}_j}$).

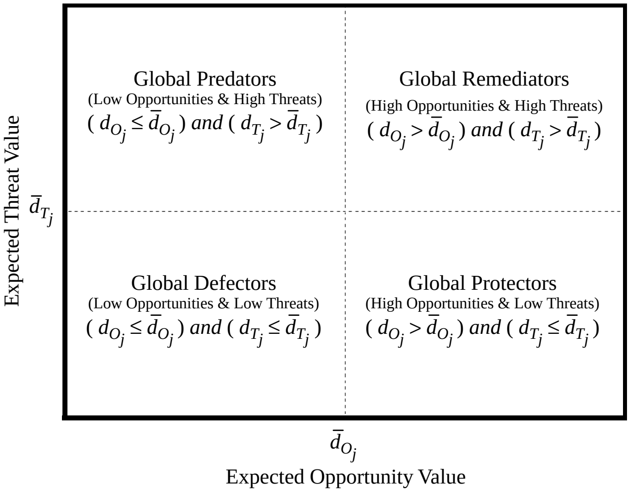

**Figure 1.**
The four quadrants and their characteristics

(2) Global remediators are states that do a lot to help the environment (high opportunities preventing global warming, $d_{\mathrm{O}_j} > \bar{d}_{\mathrm{O}_j}$) and do a lot to harm the environment (high threats contributing to global warming, $d_{\mathrm{T}_j} > \bar{d}_{\mathrm{T}_j}$).

(3) Global defectors are states that do little to help the environment (low opportunities preventing global warming, $d_{\mathrm{O}_j} \leq \bar{d}_{\mathrm{O}_j}$) and do little to harm the environment (low threats contributing to global warming, $d_{\mathrm{T}_j} \leq \bar{d}_{\mathrm{T}_j}$).

(4) Global predators are states that do little to help the environment (low opportunities preventing global warming, $d_{\mathrm{O}_j} \leq \bar{d}_{\mathrm{O}_j}$) and do a lot to harm the environment (high threats contributing to global warming, $d_{\mathrm{T}_i} > \bar{d}_{\mathrm{T}_j}$).

The weighted sum scores in *Fahrenheit 59* are used to compare a group of states among themselves and with an ideal state. The concept of ideal, unattainable ideas, serving as a norm or rationale facilitating human choice problem is not new. See, for example, the stimulating work of Schelling (1960), introducing the idea. Subsequently, Festinger (1964) showed that an external, generally non-accessible alternative assumes the important role of a point of reference against which choices are measured. Zeleny (1974, 1982) demonstrated how the highest achievable scores on all currently considered decision criteria form the ideal alternative. Zeleny (1982, p. 144) shows that the Euclidean measure can be used as a proxy measure of distance. The overall Euclidean distance of each state from the ideal state $\widehat{D}_j$ is:

$$\widehat{D}_j = \sqrt{(d_{\mathrm{O}_j} - \widehat{d}_{\mathrm{O}_j})^2 + (d_{\mathrm{T}_j} - \widehat{d}_{\mathrm{T}_j})^2} \quad \text{where} \quad \widehat{d}_{\mathrm{O}_j} = 1 \quad \text{and} \quad \widehat{d}_{\mathrm{T}_j} = 0. \tag{9}$$

Consider hypothetical state 1 with $d_{\mathrm{O}_1} = 0.40$ and $d_{\mathrm{T}_1} = 0.30$. No specific meaning can be given to value numbers without considering the ranges of the evaluation measures that are being used ($0 \leq d_{\mathrm{O}_j} \leq 1$ and $0 \leq d_{\mathrm{T}_j} \leq 1$). State 1 can be compared with the "best-in-class" using the above classification. The total Euclidean score provides a reference point to the ideal state. In this context, the value of 0.40 means that state 1 is 40 percent away from the best possible opportunity score ($\widehat{d}_{\mathrm{O}_j} = 1$) and 60 percent away from the best possible threat score ($\widehat{d}_{\mathrm{T}_j} = 0$). Equation (9) calculates the overall Euclidean distance of state 1 from the ideal state ($\widehat{D}_1 = \sqrt{(0.40 - 1)^2 + (0.30 - 0)^2} = 0.67$).

Once the model is developed, sensitivity analyses can be performed to determine the impact on the ranking of states for changes in various model assumptions. Some sensitivity analyses that are usually of interest are on the weights the opportunity and threat factors.

## 3. Benchmarking data

The global warming benchmarking problem in this pilot study considered 27 European Union (EU) states ($n = 27$) and 75 opportunities and threats. Opportunities are those factors that prevent global warming, whereas, threats are those factors that contribute to global warming. About 40 opportunities ($m = 40$), and 35 threats ($n = 35$) were identified by a group of nine DMs (global warming experts and scientists) at Johnson Space Center who agreed to participate in this pilot study. Each DM was asked to develop his/her list of opportunities and threats relevant to the global warming problem in the EU. All individual responses were collated into a comprehensive list which was shared with the DMs. After several rounds, the nine DMs agreed to a list of 40 opportunities and 35 threats presented in Tables II and III[1].

The importance weight of each opportunity and threat was captured and measured with AHP using the Expert Choice (2006) software. The DMs were asked to provide their subjective assessment of each pairwise comparison and those with inconsistency ratios greater than 0.10 were asked to reconsider their judgments as suggested by Saaty. The mean importance weights were calculated for the DM after the necessary adjustments were made to inconsistent responses. Only, homogeneous judgments were aggregated to ensure the meaningful representation of group judgments. Each DM was presented with his/her individual score along with the group judgments. DMs were given the opportunity to revisit their judgments and make revisions to their pairwise comparison scores based on this feedback. Some DMs took advantage of this opportunity and revised their judgments in the second round. The subjective weights (the second round mean importance weights) of the opportunities ($\mathbf{w}_{\mathrm{O}'_i}$) and threats ($\mathbf{w}_{\mathrm{T}'_i}$) used in this study are presented in Tables II and III.

Next, we used the subjective weights presented in Tables II and III to revise the initial weight of the opportunities and threats using the entropy concept. Each opportunity and threat is an information source and the more information an opportunity or threat reveals, the more relevant it is to the decision analysis. We use this intrinsic information in parallel with the subjective weights the DMs assigned to various opportunities and threats. The intrinsic weight of the opportunities ($\mathbf{w}_{\mathrm{O}''_i}$) and threats ($\mathbf{w}_{\mathrm{T}''_i}$) and the overall importance weight of the opportunities ($\mathbf{w}_{\mathrm{O}_i}$) and threats ($\mathbf{w}_{\mathrm{T}_i}$) used in this study are presented in Tables II and III.

Next, we present the opportunity scores ($z_{\mathrm{O}_{mn}}$) and the threat scores ($z_{\mathrm{T}_{ln}}$) identified by the DMs for each of the 27 EU states in Tables III and IV. The opportunity and threat scores are normalized using the procedure described in Section 2 to identify the normalized opportunity scores ($z_{\mathrm{O}''_{mn}}$) and the normalized threat scores ($z_{\mathrm{T}''_{ln}}$). This normalization is necessary to assure $0 \leq z_{\mathrm{O}''_{mn}} \leq 1$ and $0 \leq z_{\mathrm{T}''_{ln}} \leq 1$ (Table V).

Next, we calculate the expected opportunity values ($d_{\mathrm{O}_j}$) and the expected threat values ($d_{\mathrm{T}_j}$) for each of the EU states. As described earlier, higher expected

**Table II.**
The opportunities and their weights

| $O_i$ | Description | $\mathbf{w}_{O'_i}$ | $\mathbf{w}_{O''_i}$ | $\mathbf{w}_{O_i}$ |
|---|---|---|---|---|
| O-01 | Wind energy | 0.053 | 0.009 | 0.060 |
| O-02 | Solar energy | 0.042 | 0.010 | 0.056 |
| O-03 | Geothermal energy | 0.047 | 0.021 | 0.127 |
| O-04 | Biogas energy | 0.041 | 0.012 | 0.063 |
| O-05 | Biodiesel energy | 0.029 | 0.012 | 0.045 |
| O-06 | Nuclear energy | 0.039 | 0.011 | 0.055 |
| O-07 | Biomass energy | 0.033 | 0.005 | 0.022 |
| O-08 | Hydro energy | 0.027 | 0.005 | 0.019 |
| O-09 | Sustainable energy | 0.032 | 0.005 | 0.019 |
| O-10 | Renewable energy | 0.037 | 0.004 | 0.020 |
| O-11 | Hydro electric units | 0.031 | 0.007 | 0.029 |
| O-12 | Solar panels | 0.131 | 0.011 | 0.182 |
| O-13 | Liquid biofuels | 0.024 | 0.012 | 0.038 |
| O-14 | Permanent crops land | 0.023 | 0.012 | 0.036 |
| O-15 | Land use – Arable land | 0.028 | 0.008 | 0.028 |
| O-16 | Area – water | 0.022 | 0.008 | 0.024 |
| O-17 | Waste treatment facilities | 0.033 | 0.004 | 0.018 |
| O-18 | Public sector environmental investment | 0.015 | 0.001 | 0.003 |
| O-19 | Paper and cardboard recycling | 0.026 | 0.001 | 0.004 |
| O-20 | Rail transport | 0.014 | 0.005 | 0.010 |
| O-21 | Public transportation | 0.036 | 0.002 | 0.007 |
| O-22 | Forest land | 0.013 | 0.005 | 0.008 |
| O-23 | Trees undamaged by demolition | 0.012 | 0.001 | 0.001 |
| O-24 | Tree density | 0.023 | 0.004 | 0.013 |
| O-25 | Wild areas protected | 0.011 | 0.003 | 0.005 |
| O-26 | Protected area (national reserves, parks, etc.) | 0.012 | 0.005 | 0.007 |
| O-27 | Biosphere reserves area | 0.010 | 0.016 | 0.021 |
| O-28 | Wilderness percentage | 0.026 | 0.010 | 0.034 |
| O-29 | Environmental agreement compliance | 0.009 | 0.000 | 0.000 |
| O-30 | Population connected to wastewater treatment | 0.009 | 0.000 | 0.001 |
| O-31 | Total literacy rate | 0.030 | 0.005 | 0.019 |
| O-32 | Education spending | 0.007 | 0.001 | 0.001 |
| O-33 | Environmental protection expenditure | 0.006 | 0.005 | 0.004 |
| O-34 | Organic farming | 0.011 | 0.003 | 0.004 |
| O-35 | Carbon efficiency | 0.022 | 0.002 | 0.006 |
| O-36 | Municipal recycling | 0.005 | 0.004 | 0.002 |
| O-37 | Emission reductions | 0.007 | 0.002 | 0.002 |
| O-38 | Particulate matter reductions | 0.014 | 0.002 | 0.003 |
| O-39 | Thermal power station efficiency | 0.003 | 0.000 | 0.000 |
| O-40 | Water resource availability | 0.005 | 0.003 | 0.002 |
| Total | | 1.000 | 1.000 | 1.000 |

opportunity value increases desirability, whereas, higher expected threat value decreases the desirability of a state. We further determine the mean expected opportunity and threat values for all 27 states of the EU. The mean expected opportunity and threat values are the benchmark scores used in *Fahrenheit 59* to classifying the participating states into those who achieve or fail to achieve these benchmark scores. The numerical expected values of the 27-member EU states and their classification are presented in Table VI and Figure 2, respectively.

| $\mathrm{T}_i$ | Description | $\mathbf{w}_{\mathrm{T}'_i}$ | $\mathbf{w}_{\mathrm{T}''_i}$ | $\mathbf{w}_{\mathrm{T}_i}$ |
|---|---|---|---|---|
| T-01 | Carbon dioxide emissions | 0.046 | 0.010 | 0.059 |
| T-02 | Methane emissions | 0.036 | 0.012 | 0.054 |
| T-03 | Nitrous oxide emissions | 0.018 | 0.024 | 0.055 |
| T-04 | Perfluorocarbon emissions | 0.042 | 0.013 | 0.073 |
| T-05 | Hydrofluorocarbon emissions | 0.038 | 0.014 | 0.068 |
| T-06 | Sulphur hexafluoride emissions | 0.011 | 0.012 | 0.018 |
| T-07 | Fugitive emissions | 0.037 | 0.006 | 0.029 |
| T-08 | Anthropogenic emissions | 0.030 | 0.006 | 0.024 |
| T-09 | Solid waste emissions | 0.044 | 0.005 | 0.030 |
| T-10 | Population | 0.039 | 0.005 | 0.024 |
| T-11 | Urbanized land | 0.034 | 0.008 | 0.037 |
| T-12 | Number of cars per 1,000 in habitants | 0.039 | 0.012 | 0.062 |
| T-13 | Oil consumption | 0.026 | 0.014 | 0.047 |
| T-14 | Electricity consumption | 0.045 | 0.013 | 0.079 |
| T-15 | Natural gas consumption | 0.032 | 0.009 | 0.036 |
| T-16 | Coal consumption | 0.040 | 0.009 | 0.049 |
| T-17 | Pesticide consumption | 0.015 | 0.005 | 0.009 |
| T-18 | Chemical fertilizers consumption | 0.042 | 0.002 | 0.009 |
| T-19 | Commercial energy consumption | 0.014 | 0.001 | 0.003 |
| T-20 | Energy consumption per capita | 0.010 | 0.006 | 0.008 |
| T-21 | Nox pollution | 0.015 | 0.002 | 0.003 |
| T-22 | Fossil fuel | 0.019 | 0.005 | 0.014 |
| T-23 | Airplanes departure | 0.024 | 0.001 | 0.003 |
| T-24 | Air passengers | 0.019 | 0.005 | 0.013 |
| T-25 | Civil aviation traffic | 0.026 | 0.004 | 0.013 |
| T-26 | Forest trees damaged by defoliation | 0.032 | 0.006 | 0.024 |
| T-27 | Municipal waste | 0.027 | 0.018 | 0.065 |
| T-28 | Total power plants | 0.030 | 0.011 | 0.045 |
| T-29 | Carbon dioxide intensity | 0.022 | 0.000 | 0.000 |
| T-30 | GDP per capita | 0.028 | 0.001 | 0.002 |
| T-31 | Wildfires area | 0.017 | 0.006 | 0.012 |
| T-32 | Heavy industry | 0.047 | 0.001 | 0.005 |
| T-33 | Paved highways | 0.023 | 0.006 | 0.018 |
| T-34 | Refinery output | 0.012 | 0.003 | 0.005 |
| T-35 | Hazardous waste | 0.022 | 0.002 | 0.007 |
| Total | | 1.000 | 1.000 | 1.000 |

**Table III.**
The threats and their weights

As shown in Figure 2, those states whose expected opportunity values are greater than the average expected opportunity value ($d_{\mathrm{O}_j} > 0.122$) and their expected threat value is less than or equal to the average-expected threat value ($d_{\mathrm{T}_j} \leq 0.261$) are called "Global protectors." DEN, SWE, AUT, NED, ESP, BEL, and FIN are the global protectors identified in this study. Those states whose expected opportunity values are greater than the average expected opportunity value ($d_{\mathrm{O}_j} > 0.122$) and their expected threat values are greater than the average expected threat value ($d_{T_j} > 0.261$) are called "Global remediators." ITA, GER, FRA, and GBR are the global remediators identified in this study. Those states whose expected opportunity values are less than or equal to the average expected opportunity value ($d_{\mathrm{O}_j} \leq 0.122$) and their expected threat values are less than or equal to the average expected threat value ($d_{\mathrm{T}_j} \leq 0.261$) are called "Global defectors." GRE, POR, LTU, LAT, LUX, MLT, SLO, SVK, CYP, BUL,

**Table IV.**
The opportunity scores ($z_{O_{ij}}$)

| | AUT | BEL | BUL | CYP | CZE | DEN | EST | FIN | FRA | GER | GRE | HUN | IRL | ITA | LAT | LTU | LUX | MLT | NED | POL | POR | ROM | SVK | SLO | ESP | SWE | GBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| O-01 | 965 | 193 | 32 | 0 | 50 | 3,136 | 32 | 86 | 1,567 | 2,622 | 746 | 61 | 745 | 2,123 | 27 | 56 | 35 | 0 | 1,560 | 153 | 1,716 | 3 | 5 | 0 | 11,615 | 572 | 1,963 |
| O-02 | 1,987 | 87 | 0 | 392 | 81 | 265 | 1 | 13 | 812 | 6,002 | 2,301 | 35 | 6 | 606 | 3 | 2 | 11 | 17 | 452 | 115 | 102 | 0 | 51 | 78 | 477 | 209 | 177 |
| O-03 | 35 | 1 | 33 | 0 | 0 | 3 | 0 | 0 | 130 | 138 | 1 | 87 | 0 | 4,791 | 0 | 3 | 0 | 0 | 0 | 9 | 66 | 82 | 8 | 0 | 8 | 0 | 1 |
| O-04 | 410 | 237 | 0 | 0 | 175 | 285 | 7 | 22 | 501 | 7,338 | 579 | 22 | 108 | 1,234 | 0 | 0 | 33 | 0 | 286 | 241 | 33 | 0 | 4 | 32 | 675 | 54 | 4,997 |
| O-05 | 123 | 25 | 4 | 0 | 107 | 80 | 0 | 0 | 743 | 2,662 | 42 | 0 | 4 | 447 | 7 | 10 | 0 | 2 | 18 | 116 | 91 | 10 | 82 | 11 | 199 | 13 | 192 |
| O-06 | 0.0 | 12.3 | 4.5 | 0.0 | 6.7 | 0.0 | 0.0 | 5.9 | 114.9 | 43.0 | 0.0 | 2.9 | 0.0 | 0.0 | 0.0 | 4.1 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 1.3 | 4.7 | 1.4 | 16.1 | 17.6 | 23.1 |
| O-07 | 3.5 | 0.5 | 0.0 | 0.0 | 1.5 | 1.3 | 0.6 | 6.6 | 9.7 | 7.9 | 1.0 | 1.1 | 0.2 | 1.0 | 1.4 | 0.7 | 0.0 | 0.0 | 1.1 | 4.3 | 2.7 | 0.0 | 0.4 | 0.5 | 4.2 | 7.9 | 0.7 |
| O-08 | 67.2 | 0.6 | 8.1 | 0.0 | 2.9 | 0.1 | 0.1 | 18.7 | 14.0 | 4.2 | 3.8 | 0.5 | 2.3 | 18.4 | 70.9 | 5.7 | 25.2 | 0.0 | 1.0 | 1.5 | 31.3 | 27.6 | 16.0 | 27.3 | 18.2 | 50.8 | 0.9 |
| O-09 | 24.8 | 0.7 | 2.5 | 0.1 | 1.2 | 9.2 | 0.2 | 16.3 | 5.7 | 3.8 | 4.3 | 0.2 | 1.9 | 6.8 | 14 | 0.8 | 0.9 | 0.1 | 1.3 | 0.7 | 16.4 | 9.7 | 4.4 | 10.8 | 9.4 | 28.1 | 1.2 |
| O-10 | 6.77 | 0.96 | 1.01 | 0.10 | 1.50 | 2.73 | 0.69 | 8.86 | 17.38 | 13.76 | 1.56 | 0.97 | 0.32 | 11.88 | 2.14 | 0.74 | 0.07 | 4.25 | 2.36 | 4.32 | 3.89 | 4.66 | 0.74 | 0.82 | 8.98 | 14.13 | 3.48 |
| O-11 | 2,828 | 21 | 260 | 0 | 119 | 2 | 1 | 825 | 5,088 | 1,657 | 410 | 15 | 51 | 2,906 | 195 | 28 | 7 | 0 | 6 | 144 | 1,352 | 1,140 | 299 | 255 | 3,531 | 4,604 | 278 |
| O-12 | 3,009 | 77 | 0 | 730 | 85 | 321 | 0 | 87 | 635 | 7,197 | 3,047 | 45 | 13 | 0 | 0 | 0 | 4 | 0 | 620 | 0 | 289 | 0 | 0 | 0 | 797 | 371 | 583 |
| O-13 | 65 | 725 | 0 | 0 | 127 | 71 | 0 | 0 | 546 | 2,527 | 0 | 0 | 1 | 0 | 2 | 14 | 1 | 0 | 60 | 145 | 0 | 0 | 35 | 0 | 339 | 311 | 71 |
| O-14 | 78 | 20 | 2 | 0 | 5 | 170 | 0 | 5 | 988 | 2,139 | 77 | 6 | 30 | 1,215 | 1 | 2 | 0 | 0 | 256 | 59 | 170 | 1 | 0 | 0 | 4,599 | 51 | 1,181 |
| O-15 | 11 | 3 | 3 | 0 | 16 | 4 | 3 | 176 | 213 | 636 | 12 | 7 | 6 | 413 | 2 | 0 | 0 | 0 | 125 | 316 | 4 | 155 | 0 | 0 | 207 | 349 | 194 |
| O-16 | 1.4 | 0.3 | 0.4 | 0.0 | 1.6 | 0.7 | 2.0 | 33.7 | 3.4 | 7.8 | 1.1 | 0.7 | 1.4 | 7.2 | 1.0 | 0.0 | 0.0 | 0.0 | 7.6 | 8.2 | 0.4 | 7.2 | 0.0 | 0.1 | 5.2 | 39.0 | 3.2 |
| O-17 | 500 | 212 | 300 | 8 | 347 | 146 | 261 | 359 | 452 | 2,926 | 2 | 729 | 126 | 789 | 550 | 200 | 200 | 200 | 38 | 1,401 | 120 | 765 | 277 | 168 | 195 | 274 | 200 |
| O-18 | 0.1 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.4 | 0.3 | 0.2 | 0.0 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.4 | 0.3 | 0.4 | 0.1 | 0.1 | 0.0 |
| O-19 | 68.0 | 18.0 | 18.0 | 18.0 | 33.0 | 51.0 | 18.0 | 46.0 | 43.0 | 72.0 | 27.0 | 0.0 | 13.0 | 29.0 | 12.0 | 12.0 | 12.0 | 50.0 | 65.0 | 47.0 | 45.0 | 45.0 | 34.0 | 45.0 | 40.0 | 67.0 | 43.0 |
| O-20 | 8.7 | 8.7 | 2.6 | 2.4 | 6.6 | 5.9 | 5.6 | 5.6 | 5.6 | 72.9 | 1.7 | 10.2 | 1.6 | 49.3 | 0.8 | 0.3 | 0.3 | 5.6 | 14.1 | 18.4 | 3.7 | 8.5 | 2.2 | 0.7 | 20.3 | 8.7 | 43.3 |
| O-21 | 1,043 | 873 | 309 | 0 | 648 | 1,008 | 184 | 663 | 1,269 | 880 | 167 | 707 | 428 | 808 | 389 | 125 | 596 | 0 | 903 | 439 | 323 | 368 | 402 | 388 | 485 | 629 | 731 |
| O-22 | 3.9 | 0.7 | 3.6 | 0.2 | 2.6 | 0.5 | 2.3 | 22.5 | 15.6 | 11.1 | 3.8 | 2.0 | 0.7 | 10.0 | 2.9 | 2.1 | 0.1 | 0.0 | 0.4 | 9.2 | 3.8 | 6.4 | 1.9 | 1.3 | 17.9 | 27.5 | 2.8 |
| O-23 | 13.1 | 14.9 | 33.7 | 12.2 | 57.3 | 11.8 | 5.3 | 9.8 | 31.7 | 31.4 | 30.0 | 21.5 | 17.4 | 35.9 | 12.5 | 13.9 | 15.0 | 22.5 | 27.5 | 34.6 | 16.6 | 31.2 | 26.7 | 29.3 | 15.0 | 16.5 | 26.5 |
| O-24 | 2.1 | 5.6 | 1.5 | 4.8 | 5.3 | 2.9 | 1.1 | 0.6 | 0.8 | 1.3 | 0.9 | 15.0 | 0.1 | 0.6 | 3.1 | 2.9 | 14.0 | 4.8 | 22.3 | 3.7 | 1.3 | 20.2 | 2.2 | 0.9 | 0.9 | 7.7 | 4.1 |
| O-25 | 5.5 | 0.3 | 6.8 | 21.7 | 25.5 | 10.7 | 5.8 | 21.7 | 6.4 | 0.9 | 3.7 | 19.3 | 3.2 | 11.0 | 3.4 | 4.4 | 0.1 | 0.1 | 3.8 | 1.8 | 10.5 | 16.8 | 4.4 | 0.1 | 16.7 | 12.8 | 26.0 |
| O-26 | 3.1 | 0.1 | 1.1 | 0.1 | 1.3 | 1.1 | 0.9 | 3.0 | 6.2 | 11.7 | 0.4 | 0.8 | 0.2 | 3.4 | 1.0 | 0.6 | 0.0 | 0.0 | 1.0 | 7.3 | 0.5 | 0.6 | 1.1 | 0.1 | 4.7 | 3.2 | 2.6 |
| O-27 | 0.0 | 3.9 | 0.0 | 3.9 | 0.4 | 97.2 | 1.6 | 0.8 | 0.9 | 1.6 | 0.0 | 0.1 | 0.0 | 0.2 | 0.5 | 3.9 | 3.9 | 3.9 | 0.3 | 0.4 | 0.0 | 0.7 | 0.2 | 3.9 | 1.2 | 0.1 | 0.0 |
| O-28 | 0.0 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.9 | 30.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 70.9 | 70.9 | 70.9 | 2.6 | 2.6 | 0.8 | 2.6 | 2.6 | 2.6 | 3.4 | 31.4 | 0.2 |
| O-29 | 6.33 | 5.46 | 3.88 | 5.34 | 5.26 | 6.67 | 5.42 | 6.72 | 5.67 | 6.27 | 5.34 | 4.97 | 4.83 | 5.37 | 4.46 | 4.33 | 5.34 | 5.34 | 6.18 | 4.59 | 4.50 | 4.12 | 5.34 | 5.34 | 4.87 | 6.54 | 5.69 |
| O-30 | 75.0 | 29.0 | 36.0 | 61.2 | 56.0 | 87.0 | 72.0 | 77.0 | 77.0 | 88.0 | 55.0 | 21.0 | 58.0 | 63.0 | 61.2 | 61.2 | 88.0 | 13.0 | 97.0 | 42.0 | 61.2 | 61.2 | 48.0 | 61.2 | 48.0 | 93.0 | 61.2 |
| O-31 | 8 | 10 | 7 | 1 | 10 | 5 | 1 | 5 | 63 | 82 | 10 | 10 | 4 | 57 | 2 | 4 | 0 | 0 | 16 | 38 | 10 | 22 | 5 | 2 | 40 | 9 | 60 |
| O-32 | 5.7 | 6.3 | 3.5 | 6.3 | 4.4 | 8.5 | 5.7 | 6.4 | 5.6 | 4.6 | 4.0 | 5.5 | 5.5 | 4.7 | 5.8 | 5.9 | 0.1 | 0.0 | 5.1 | 5.6 | 5.8 | 3.5 | 4.4 | 6.1 | 4.5 | 7.7 | 5.3 |
| O-33 | 1.9 | 3.3 | 0.3 | 0.1 | 0.8 | 2.2 | 0.1 | 1.2 | 5.5 | 3.0 | 3.0 | 1.0 | 3.0 | 21.1 | 0.0 | 0.1 | 3.0 | 3.0 | 3.0 | 2.4 | 1.1 | 0.7 | 0.5 | 0.4 | 4.8 | 1.8 | 13.2 |
| O-34 | 11.0 | 1.8 | 0.0 | 1.0 | 7.2 | 5.1 | 3.6 | 6.3 | 2.0 | 4.3 | 7.3 | 3.0 | 0.6 | 8.2 | 6.5 | 2.1 | 2.2 | 0.1 | 2.3 | 0.0 | 6.2 | 0.0 | 4.4 | 4.5 | 0.0 | 6.1 | 3.9 |
| O-35 | 0.9 | 1.1 | 3.2 | 0.0 | 2.4 | 1.1 | 3.9 | 1.3 | 0.8 | 1.2 | 1.5 | 1.5 | 1.2 | 0.9 | 1.5 | 1.7 | 0.0 | 0.0 | 1.2 | 2.8 | 1.0 | 1.8 | 0.0 | 1.3 | 1.0 | 0.7 | 1.2 |
| O-36 | 58.0 | 50.0 | 0.0 | 0.0 | 16.0 | 32.0 | 0.0 | 25.0 | 25.0 | 53.0 | 9.0 | 0.0 | 13.0 | 24.0 | 0.0 | 43.0 | 36.0 | 0.0 | 59.0 | 0.0 | 4.0 | 23.0 | 0.0 | 0.0 | 28.0 | 39.0 | 23.0 |
| O-37 | 16.0 | 31.0 | 41.0 | 4.0 | 43.0 | 33.0 | 46.0 | 36.0 | 39.0 | 56.0 | 0.0 | 21.0 | 19.0 | 38.0 | 40.0 | 56.0 | 33.0 | 0.0 | 42.0 | 37.0 | 0.0 | 41.0 | 50.0 | 4.0 | 0.0 | 40.0 | 50.0 |
| O-38 | 4.0 | 31.0 | 51.0 | 3.0 | 69.0 | 42.0 | 55.0 | 35.0 | 32.0 | 70.0 | 0.0 | 56.0 | 21.0 | 44.0 | 60.0 | 67.0 | 40.0 | 28.0 | 43.0 | 45.0 | 0.0 | 41.0 | 66.0 | 45.0 | 5.0 | 38.0 | 56.0 |
| O-39 | 57.2 | 44.5 | 41.7 | 35.0 | 46.5 | 71.0 | 43.3 | 76.6 | 35.5 | 46.1 | 37.2 | 50.3 | 42.2 | 42.0 | 81.6 | 80.1 | 57.7 | 33.2 | 56.2 | 48.3 | 46.7 | 52.3 | 51.2 | 44.2 | 46.7 | 83.8 | 42.7 |
| O-40 | 6.4 | 1.2 | 2.0 | 1.2 | 1.5 | 2.5 | 7.4 | 18.0 | 3.3 | 1.4 | 3.0 | 1.2 | 12.5 | 2.0 | 6.3 | 5.1 | 10.0 | 1.1 | 0.7 | 1.5 | 3.3 | 1.5 | 2.2 | 8.0 | 2.3 | 15.9 | 3.1 |

**Table V.**
The threat scores ($z_{T_{ij}}$)

| | AUT | BEL | BUL | CYP | CZE | DEN | EST | FIN | FRA | GER | GRE | HUN | IRL | ITA | LAT | LTU | LUX | MLT | NED | POL | POR | ROM | SVK | SLO | ESP | SWE | GBR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T-01 | 64.4 | 125.0 | 44.7 | 7.0 | 124.1 | 51.3 | 14.9 | 56.6 | 363.5 | 837.4 | 92.2 | 56.8 | 42.8 | 446.6 | 6.5 | 11.6 | 8.4 | 2.1 | 174.8 | 303.8 | 64.8 | 90.7 | 36.9 | 15.1 | 304.9 | 48.8 | 558.2 |
| T-02 | 7.1 | 7.8 | 10.3 | 0.7 | 11.0 | 5.6 | 1.9 | 4.5 | 56.9 | 47.6 | 9.3 | 7.8 | 13.1 | 39.8 | 1.8 | 3.3 | 0.3 | 0.3 | 16.7 | 38.3 | 11.4 | 25.7 | 4.2 | 2.1 | 37.3 | 5.6 | 49.5 |
| T-03 | 5.3 | 11.0 | 4.4 | 0.7 | 8.0 | 7.0 | 0.8 | 6.9 | 72.3 | 66.5 | 9.1 | 9.7 | 8.8 | 40.5 | 1.5 | 5.0 | 0.4 | 0.3 | 17.6 | 31.1 | 6.1 | 16.8 | 3.7 | 1.3 | 29.6 | 7.7 | 39.6 |
| T-04 | 118 | 141 | 90 | 10 | 10 | 14 | 16 | 10 | 1,801 | 718 | 128 | 209 | 174 | 361 | 3 | 41 | 6 | 5 | 265 | 261 | 129 | 570 | 20 | 124 | 244 | 296 | 351 |
| T-05 | 912 | 1,454 | 387 | 91 | 594 | 805 | 8 | 864 | 10,958 | 9,363 | 1,162 | 518 | 431 | 5,267 | 19 | 19 | 83 | 42 | 1,354 | 2,750 | 391 | 4 | 175 | 95 | 5,011 | 777 | 9,221 |
| T-06 | 287 | 43 | 4 | 16 | 86 | 22 | 6 | 20 | 1,354 | 4,740 | 210 | 201 | 96 | 460 | 8 | 1 | 4 | 8 | 337 | 24 | 10 | 0 | 17 | 19 | 272 | 142 | 1,143 |
| T-07 | 644 | 1,250 | 447 | 70 | 1,241 | 513 | 149 | 566 | 3,635 | 8,374 | 922 | 568 | 428 | 4,466 | 65 | 116 | 84 | 21 | 1,748 | 3,038 | 648 | 907 | 369 | 151 | 3,049 | 488 | 5,582 |
| T-08 | 782 | 1,126 | 480 | 82 | 779 | 988 | 120 | 558 | 9,533 | 6,354 | 1,045 | 846 | 1,845 | 3,721 | 192 | 405 | 38 | 38 | 1,817 | 3,488 | 824 | 2,028 | 322 | 202 | 4,476 | 857 | 4,489 |
| T-09 | 228 | 133 | 648 | 26 | 291 | 137 | 53 | 244 | 1,410 | 1,369 | 328 | 394 | 178 | 1,933 | 76 | 154 | 3 | 12 | 664 | 1,221 | 647 | 740 | 211 | 65 | 1,296 | 215 | 2,208 |
| T-10 | 832 | 1,046 | 764 | 86 | 1,033 | 546 | 134 | 530 | 6,410 | 8,231 | 1,115 | 1,005 | 430 | 5,921 | 23 | 337 | 47 | 41 | 1,639 | 3,813 | 1,062 | 2,144 | 539 | 202 | 4,512 | 915 | 6,059 |
| T-11 | 305 | 11 | 112 | 8 | 125 | 109 | 89 | 297 | 619 | 1,166 | 43 | 83 | 16 | 338 | 97 | 59 | 4 | 1 | 95 | 732 | 47 | 58 | 110 | 15 | 466 | 319 | 255 |
| T-12 | 501 | 467 | 314 | 448 | 373 | 354 | 350 | 448 | 491 | 546 | 348 | 280 | 385 | 581 | 297 | 384 | 659 | 525 | 429 | 314 | 572 | 149 | 222 | 456 | 454 | 456 | 463 |
| T-13 | 282 | 641 | 131 | 53 | 203 | 171 | 60 | 220 | 1,970 | 2,650 | 436 | 132 | 182 | 1,881 | 47 | 56 | 62 | 19 | 947 | 446 | 332 | 212 | 74 | 53 | 1,573 | 362 | 1,827 |
| T-14 | 65.2 | 82.4 | 37.4 | 4.5 | 58.8 | 36.4 | 6.8 | 80.8 | 482.4 | 524.6 | 53.5 | 37.1 | 23.2 | 303.8 | 6.3 | 9.4 | 6.1 | 2.1 | 102.4 | 124.1 | 46.1 | 49.6 | 28.6 | 13.7 | 241.8 | 137.8 | 345.2 |
| T-15 | 9.00 | 17.06 | 3.47 | 0.01 | 9.60 | 4.82 | 1.44 | 4.86 | 45.41 | 102.00 | 2.34 | 14.46 | 4.30 | 80.61 | 1.91 | 2.92 | 1.36 | 0.00 | 51.30 | 15.67 | 4.30 | 18.00 | 6.00 | 1.10 | 27.01 | 0.98 | 98.47 |
| T-16 | 3.00 | 3.10 | 7.40 | 0.00 | 19.40 | 5.50 | 0.00 | 5.20 | 13.10 | 82.40 | 8.80 | 2.90 | 0.00 | 17.40 | 0.00 | 0.20 | 3.10 | 0.00 | 7.50 | 58.40 | 3.70 | 7.60 | 3.80 | 0.00 | 18.30 | 2.20 | 43.80 |
| T-17 | 369 | 989 | 98 | 89 | 389 | 385 | 8 | 77 | 10,979 | 3,463 | 999 | 770 | 233 | 16,980 | 53 | 60 | 55 | 30 | 1,492 | 950 | 1,246 | 270 | 280 | 950 | 3,402 | 179 | 3,313 |
| T-18 | 227 | 289 | 157 | 23 | 395 | 317 | 42 | 297 | 4,178 | 2,612 | 420 | 323 | 573 | 1,681 | 64 | 162 | 0 | 1 | 409 | 1,557 | 228 | 327 | 120 | 72 | 2,183 | 287 | 1,909 |
| T-19 | 3.5 | 5.8 | 2.3 | 3.2 | 3.9 | 3.6 | 3.3 | 6.4 | 4.4 | 4.1 | 2.6 | 2.4 | 3.9 | 3.0 | 1.5 | 2.0 | 8.4 | 2.1 | 4.8 | 2.3 | 2.5 | 1.6 | 3.2 | 3.3 | 3.1 | 5.4 | 4.0 |
| T-20 | 6.9 | 7.7 | 3.3 | 5.3 | 5.4 | 6.2 | 4.5 | 15.5 | 6.8 | 6.3 | 4.6 | 3.2 | 5.9 | 2.3 | 1.7 | 1.3 | 13.5 | 1.3 | 6.4 | 1.5 | 1.8 | 1.1 | 2.0 | 2.4 | 2.3 | 3.7 | 2.5 |
| T-21 | 0.46 | 3.43 | 0.19 | 0.00 | 0.43 | 1.01 | 0.09 | 0.19 | 0.99 | 1.82 | 0.47 | 0.23 | 0.45 | 1.00 | 0.04 | 0.21 | 0.00 | 0.00 | 1.51 | 0.28 | 0.22 | 0.27 | 0.27 | 0.17 | 0.44 | 0.27 | 2.76 |
| T-22 | 29 | 38 | 48 | 100 | 76 | 83 | 100 | 39 | 8 | 62 | 95 | 60 | 96 | 79 | 29 | 17 | 57 | 100 | 90 | 98 | 65 | 63 | 30 | 35 | 50 | 4 | 74 |
| T-23 | 133 | 178 | 7 | 13 | 44 | 111 | 8 | 129 | 786 | 782 | 103 | 32 | 164 | 395 | 11 | 10 | 38 | 15 | 227 | 72 | 96 | 20 | 2 | 13 | 518 | 234 | 985 |
| T-24 | 804 | 334 | 65 | 192 | 471 | 1,034 | 58 | 708 | 5,248 | 9,079 | 945 | 274 | 4,287 | 3,612 | 103 | 51 | 85 | 137 | 2,613 | 355 | 1,014 | 171 | 71 | 76 | 4,986 | 902 | 9,360 |
| T-25 | 130 | 103 | 7 | 0.00 | 53 | 78 | 7 | 97 | 860 | 1,070 | 80 | 46 | 197 | 398 | 7 | 10 | 74 | 22 | 429 | 68 | 128 | 26 | 5 | 13 | 473 | 129 | 977 |
| T-26 | 0.13 | 0.19 | 0.10 | 0.12 | 0.57 | 0.12 | 0.05 | 0.10 | 0.32 | 0.31 | 0.10 | 0.22 | 0.17 | 0.36 | 0.13 | 0.14 | 0.19 | 0.10 | 0.28 | 0.35 | 0.17 | 0.10 | 0.27 | 0.29 | 0.15 | 0.17 | 0.27 |
| T-27 | 630 | 464 | 463 | 739 | 289 | 737 | 436 | 468 | 543 | 601 | 438 | 459 | 740 | 542 | 310 | 378 | 705 | 611 | 624 | 245 | 446 | 382 | 289 | 423 | 597 | 482 | 584 |
| T-28 | 46 | 17 | 4 | 5 | 4 | 8 | 0 | 47 | 59 | 17 | 6 | 4 | 27 | 47 | 0 | 1 | 0 | 0 | 19 | 31 | 15 | 7 | 26 | 16 | 85 | 31 | 62 |
| T-29 | 521 | 828 | 1,004 | 3,711 | 1,359 | 843 | 1,254 | 697 | 162 | 1,140 | 2,247 | 976 | 2,423 | 1,473 | 362 | 139 | 1,707 | 2,856 | 1,575 | 1,501 | 1,377 | 744 | 798 | 851 | 1,248 | 41 | 1,170 |
| T-30 | 347 | 330 | 107 | 230 | 220 | 371 | 203 | 335 | 312 | 319 | 240 | 175 | 445 | 302 | 160 | 153 | 714 | 213 | 321 | 144 | 198 | 91 | 186 | 234 | 274 | 322 | 318 |
| T-31 | 0.0 | 0.0 | 20.2 | 4.8 | 0.6 | 7.0 | 0.6 | 0.2 | 20.5 | 0.1 | 18.3 | 1.3 | 0.5 | 76.4 | 1.0 | 0.1 | 0.1 | 0.1 | 0.2 | 49.5 | 111.8 | 1.6 | 0.1 | 0.7 | 92.4 | 1.3 | 0.2 |
| T-32 | 24.7 | 20.1 | 34.1 | 13.3 | 34.3 | 21.6 | 24.1 | 28.8 | 16.4 | 26.3 | 0.0 | 29.6 | 26.7 | 22.6 | 18.3 | 30.1 | 9.7 | 20.2 | 20.8 | 29.5 | 20.9 | 36.1 | 32.5 | 29.7 | 21.1 | 25.4 | 18.4 |
| T-33 | 134 | 117 | 34 | 8 | 127 | 72 | 13 | 51 | 951 | 231 | 107 | 70 | 96 | 480 | 28 | 69 | 5 | 2 | 105 | 249 | 59 | 98 | 37 | 20 | 657 | 167 | 372 |
| T-34 | 9.2 | 37.0 | 6.3 | 0.0 | 8.1 | 7.5 | 0.0 | 12.8 | 86.3 | 122.7 | 21.2 | 8.4 | 3.1 | 100.6 | 0.0 | 9.2 | 0.0 | 0.0 | 84.7 | 18.5 | 13.6 | 14.9 | 6.2 | 0.0 | 60.3 | 19.8 | 86.0 |
| T-35 | 1.0 | 5.2 | 0.5 | 0.1 | 1.4 | 0.3 | 7.3 | 2.5 | 7.6 | 20.0 | 0.3 | 1.4 | 0.7 | 6.1 | 0.0 | 0.1 | 0.1 | 0.0 | 1.9 | 1.6 | 2.3 | 2.2 | 0.4 | 0.1 | 3.1 | 1.2 | 8.0 |

**Table VI.**
The overall results

| State | $d_{O_j}$ | $d_{T_j}$ |
|---|---|---|
| AUT | 0.210 | 0.219 |
| BEL | 0.053 | 0.212 |
| BUL | 0.033 | 0.148 |
| CYP | 0.036 | 0.142 |
| CZE | 0.058 | 0.186 |
| DEN | 0.096 | 0.178 |
| EST | 0.027 | 0.109 |
| FIN | 0.131 | 0.196 |
| FRA | 0.262 | 0.713 |
| GER | 0.601 | 0.791 |
| GRE | 0.136 | 0.176 |
| HUN | 0.046 | 0.158 |
| IRL | 0.025 | 0.208 |
| ITA | 0.291 | 0.548 |
| LAT | 0.058 | 0.081 |
| LTU | 0.062 | 0.106 |
| LUX | 0.065 | 0.161 |
| MLT | 0.051 | 0.129 |
| NED | 0.094 | 0.299 |
| POL | 0.092 | 0.360 |
| POR | 0.080 | 0.203 |
| ROM | 0.085 | 0.193 |
| SVK | 0.038 | 0.116 |
| SLO | 0.041 | 0.130 |
| ESP | 0.245 | 0.478 |
| SWE | 0.219 | 0.206 |
| GBR | 0.163 | 0.615 |
| Mean | 0.122 | 0.261 |

EST, and IRL are the global defectors identified in this study. Those states whose expected opportunity values are less than or equal to the average expected opportunity value ($d_{O_j} \leq 0.122$) and their expected threat value are greater the average expected threat value ($d_{T_j} > 0.261$) are called "Global predators." POL, ROM, CZE, and HUN are the global predators identified in this study. These classifications allow the states to compare themselves to the "best-in-class."

Next, we calculate the total Euclidean distance of each EU member state from the ideal state with $\widehat{d}_{O_j} = 1$ and $\widehat{d}_{T_j} = 0$. These Euclidean distances ($\widehat{D}_j$) provides an overall rankings of the 27-member EU states. Those states with a lower Euclidean distance are closer the ideal state, whereas, those states with a higher Euclidean distance are further away from the ideal state. The Euclidean distances of the EU member states are presented in an ascending order in Table VII.

## 4. Conclusions and future research directions

*Fahrenheit 59* is an EDSS developed at Johnson Space Center to benchmark and monitor the progress towards the elimination of global warming. In this research, a pilot study was conducted for the 27-member EU. The unification of the EU has generated a consolidation of nations with varying technological levels. Some EU-member states such as Germany, France and the UK are technologically advanced

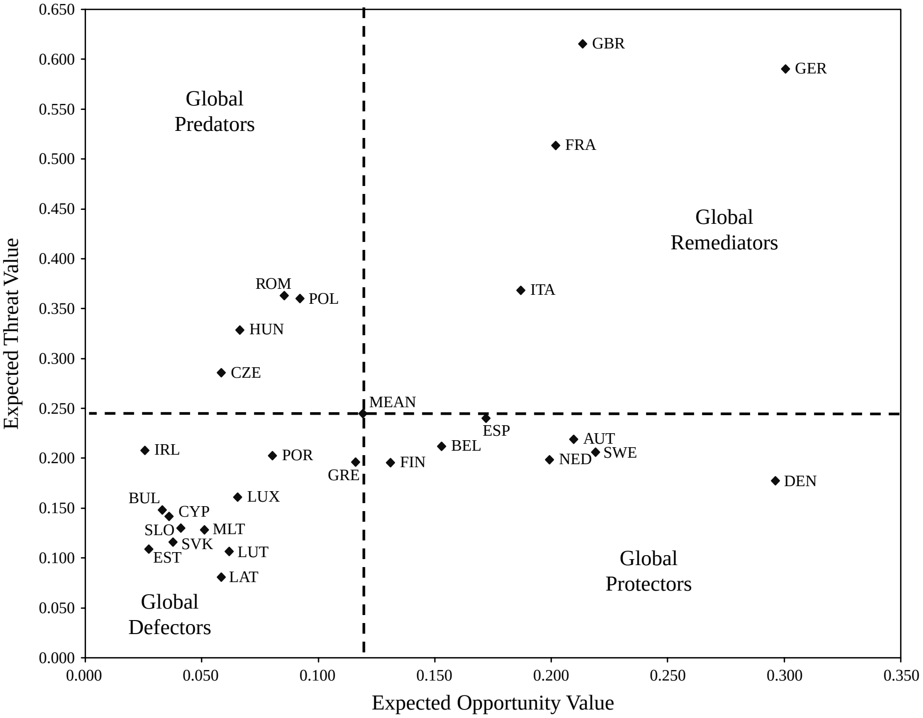

**Figure 2.**
A graphical classification of the 27-member EU states

in comparison with developing states such as Hungary and Romania, whom recently joined the EU nations. As a unified conglomerate, the EU is directly influenced by actions in every state that has signed on to its constitution. The benchmarking scheme developed in this study shows that of the 27 states, seven were identified as global protectors, four were global remediators, 12 were global defectors, and four were identified as global predators. *Fahrenheit 59* is a benchmarking system designed to monitor continuous progress towards countering the threat of global warming worldwide. It is not a reward or punishment system. However, global protectors, remediators, defectors, and predators can use the system to compare their progress towards fighting global warming with the "best-in-class" or "the ideal" and focus on strategies to limit their negative impact on the environment.

The results from this pilot study suggest that Western European nations with the most resources and capacity to invest in energy production from environmentally friendly sources will continue to be the most successful in fighting global warming. These states are able to spend more on research and development than smaller developing nations. In addition, larger states are better positioned to support themselves than smaller states such as Estonia, Slovenia, and Luxembourg.

The model can also point to the strengths and weaknesses of a state in fighting global warming. The strengths and weaknesses can be in the opportunities, threats, or both. For example, Germany is identified as a global remediator in this study. A detailed scrutinizing of the data shows that while Germany has a high opportunity

**Table VII.**
The Euclidean distances

| State | $\widehat{D}_j$ |
|---|---|
| DEN | 0.726 |
| SWE | 0.808 |
| AUT | 0.820 |
| NED | 0.825 |
| ESP | 0.862 |
| BEL | 0.873 |
| FIN | 0.891 |
| ITA | 0.893 |
| GRE | 0.905 |
| GER | 0.915 |
| POR | 0.942 |
| LTU | 0.944 |
| LAT | 0.945 |
| LUX | 0.948 |
| FRA | 0.949 |
| MLT | 0.958 |
| SLO | 0.968 |
| SVK | 0.969 |
| CYP | 0.974 |
| POL | 0.977 |
| BUL | 0.978 |
| EST | 0.979 |
| ROM | 0.984 |
| CZE | 0.984 |
| HUN | 0.990 |
| IRL | 0.996 |
| GBR | 0.999 |

score, they also score high in contributing to global warming. Germany is the most populated state in the EU, and as a result needs to consume more energy. However, the Germans have become very conscientious about the effects of fossil fuel consumption on the environment. While only a few states could be identified as the global protectors, it is encouraging to see that states that present the biggest threats are also providing the most opportunities.

Environmental decision making is a complex and difficult task. *Fahrenheit 59* uses environmental opportunities and threats with the theory of displaced ideal to reduce these complexities by decomposing the complex environmental assessment process into manageable steps. This decomposition is achieved without simplifying the problem. Previous environmental assessment models tend to be either intuitive or highly analytical. While intuition is still favored by DMs, it may be dangerously unreliable when used to solve complex environmental problems. On the other hand, highly analytical models are often avoided or misused because of their technical difficulties. *Fahrenheit 59* has several attractive features that address many of the limitations inherent in the existing models:

(1) *Analytical.* The value analysis model utilized in *Fahrenheit 59* is considered a multiple criteria decision analysis approach.

(2) *Intuitive*. *Fahrenheit 59* captures the intuitive preferences of DMs by using methods such as AHP.

(3) *Flexible*. *Fahrenheit 59* does not limit the number of states or environmental opportunities and threats to be examined.

(4) *Structured*. *Fahrenheit 59* decomposes the complex environmental assessment process into manageable steps and then integrates the results from each step to develop a benchmark and classification scheme.

(5) *Visual*. *Fahrenheit 59* allows DMs to visually examine the opportunities and threats associated with a state to the "best-in-class" and the ideal state.

(6) *Sensitivity analysis*. *Fahrenheit 59* can be used in an interactive mode to perform "goal seeking" and "what-if" analyzes.

Using a step-by-step and structured approach like *Fahrenheit 59* does not imply a deterministic approach to environmental decision making. While *Fahrenheit 59* enables DMs to crystallize their thoughts and organize their beliefs, it should be used very carefully. Personal and group judgment is an integral component of *Fahrenheit 59*; therefore, the effectiveness of the model relies heavily on the DM's cognitive abilities to provide sound judgments. Potentially, DMs could make poor judgments as they do with any approach. Such judgments can generate misleading results and ultimately poor decisions. As with any decision calculus model, the researchers and policy-makers must be aware of the limitations of subjective estimates. *Fahrenheit 59* should not be used to plug-in numbers and crank-out solutions. In summary, global warming is a complex environmental, social, political, economical, and scientific phenomenon needing more time and research. *Fahrenheit 59* is an EDSS capable of providing a benchmarking springboard for further study of global warming.

## Note

1. The data presented in this study is significantly reduced to allow a meaningful illustration of the model. The actual study considered 112 opportunity and 128 threat factors.

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