Scandinavian SD – The SAFE Way

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Abstract

People of various interests talk about Sustainable Development (SD) and in their talks they understand SD very differently. A lexicographer for example may define SD according to Oxford Advanced Learner's Dictionary as "the use of natural products and energy in a way that does not harm the environment". While a passer-by may happily dub her society as sustainable if it is providing her with her life needs while considering the needs of generations to come over a very long time. To take it to an extreme edge, the philosopher Luc Ferry [1] defines SD by saying: "I know that this term is obligatory, but I find it also absurd, or rather so vague that it says nothing!".
In this paper we try to define and measure SD in Scandinavian countries using a novel mathematical approach. We rely on a non-concrete model for this purpose; namely the SAFE model, which is based on concepts derived from fuzzy logic. It is widely believed that the application of fuzzy logic brings powerful reasoning abilities in disciplines where concrete mathematical models do not exist; and SD is one such discipline. In fact, fuzzy logic is an outstanding tool for mimicking human thinking and foresight. Based on the SAFE model, we give a careful assessments of sustainability in each of the Scandinavian countries. We also undergo a trend monitoring combined with a sensitivity analysis in order to stand on the most important sustainability factors in each of these countries.

1. Introduction

The environmental crisis has become obvious to almost everybody, therefore people are increasingly talking about sustainability. In essence, a society is a highly complex system, and when a problem arises in it, its solution depends on awareness, knowledge, values, will and perseverance. In days gone by, sustainability was not an issue because human actions were not a hazard to the terrestrial, aquatic or atmospheric ecosystems – the size of human population was small. At present, humans have already exceeded the Earth's capacity to supply food, absorb pollution and regenerate – the human populations are engaged in an endless cycle of consumption of the ecosystems to support their growth, often in an irreversible way. A question thus arises as a consequence of the strain we are putting on the environment: How sustainable is our way of living? Such a question gropes for definitions, methods and indicators for assessing sustainability. Mathematically speaking, sustainability is a composition of functions of several eco-variables. Deterministic evaluation of these functions is not possible because sustainability is inherently a blurred concept and cannot be represented through traditional mathematics. Fuzzy evaluation, on the other hand, is applicable to sustainability because it can model complex systems whose structure is not known, or of which the knowledge of dynamics is limited.
The remainder of this paper is organized as follows: first, in Section 2, we briefly discuss available sustainability indicators other than the SAFE and their downsides. Then, in Section 3, we introduce a comprehensive description of the mathematical foundations of the SAFE model. Thereafter, in Section 4, we describe the notion of sensitivity analysis. Last but not least, in Section 5, we give and discuss our assessment results.

2. Sustainability Indicators Other Than The SAFE

Sustainability Indicators (SIs) consider certain sustainability attributes quantitatively to provide an idea of the state of each attribute. The concept behind SIs is illustrated in Figure 1 [2].

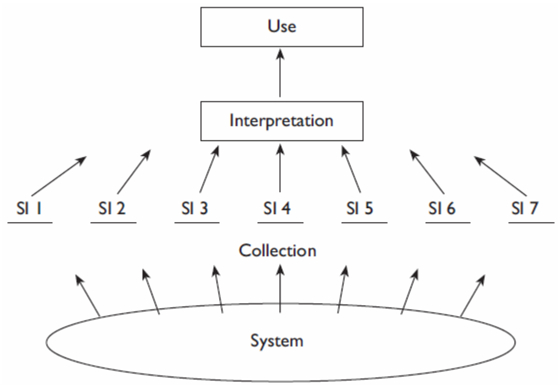

Figure 1. The Concept Behind Sustainability Indicators (SIs) – The Number Of Collected Indicators Is Arbitrary

In Figure 1, we see how seven apropos SIs (SI1 through SI7) are gathered from a given ecosystem and calculated. The results of the calculation are then interpreted and used to draw sustainable acts. SIs can be grouped in discrepant ways. The simplest division is into five groups [2]:

1) Driving Forces SIs. These describe economic and social development and its impact on the lifestyles of individuals e.g. the population growth in a country.
2) Pressure SIs. These describe development in use of natural resources and release of physical and biological agents e.g. the amount of land used for roads.
3) State SIs. These describe the quality and quantity of physical, biological or chemical phenomena in a certain area e.g. the noise level in an airport neighborhood.
4) Impact SIs. These describe the reflection of changes in the state of the environment e.g. the frequency of fish kills.
5) Response SIs. These describe the responses of a society to alleviate changes in the state of the environment e.g. the recycling rates of domestic waste.

There is an amplitude of SIs; in the UN list [3], we can count over 130. The larger the number of SIs we include in a study, the broader is the scope we are considering of sustainability. In the following sections, we elucidate some of the SIs before we elaborate on the SAFE model.

2.1. The Shannon-Wiener Index Of Biodiversity

Shannon–Wiener define the Index Of Biodiversity [2] as: $H = -\sum_{i=1}^{i=s}(p_i)(\log_2 p_i)$, where s is the number of species in a sample taken from an ecosystem, and p_i denotes sample portion that belongs to species i. The higher the value of H, the greater is the biodiversity of the sample. Shannon-Wiener Index Of Biodiversity has a number of downsides [2]. One of which is that the number of species in the ecosystem sample must be known beforehand, although this number may not be available in practice. Another downside is that the index measures biodiversity without respecting the differences in the species that contribute to that diversity; this may lead to an extravagant loss of information.

2.2. Total Factor Productivity (TFP)

Lynam and Herdt (1989) define the TFP as [2]: $TFP = \frac{\text{value of outputs from a farming system}}{\text{value of inputs into a farming system}}$.

Lynam and Herdt (1989) suggest that an increase in TFP means sustainability and vice versa. One disadvantage of TFP is that it does not account for environmental and social factors that may be central to sustainability. It further cannot handle complex biological processes. As a result, a high TFP is not an eminent guarantor of sustainability. Other disadvantages include the difficulty in linking TFP across multiple periods [4], the difficulty in measuring inputs, the complexity of data obtained [5], the inability to decompose TFP into different efficiency types (e.g. technical and economic) [6] and the inability to consider quality changes [7]. As a matter of fact, Chen [8] pointed out that China's TFP growth rate is disappointing despite the high-speed economic growth in the country!

2.3. Maximum Sustainable Yield (MSY)

The Maximum Sustainable Yield (MSY) [2] is the maximum number of individuals that can be harvested from an ecosystem without attenuating the population. Note in Figure 2 that population change in an ecosystem is driven by four major factors; birth, immigration, deaths, and emigration.

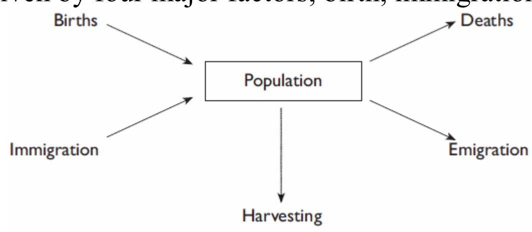

Figure 2. Population Change And The MSY

The difference Harvesting = (Births + Immigration) – (Deaths + Emigration) is the MSY. If harvesting over a year is at or below MSY, then harvesting is supposed to be safe and sustainable. The classic story of the Peruvian anchovy fishery confutes this claim. Anchovy fishery was at the MSY in the 1960's and the capture was about 10 million ton per year. Ten years later, the Peruvian anchovy fishery unexpectedly collapsed. Thus, MSY did not truly reflect reality and did not ensure sustainability. The reason for this is that population change is strongly dynamic in nature and subject to factors that cannot be expressed algebraically. In the Peruvian story for example, the El Niño event in 1972 could not be accounted for. El Niño started to bring warmer water into the fishery and this warmer water had a negative effect on the anchovy population, because it encouraged an increased number of anchovy predators.

3. The SAFE Model

The SAFE model was introduced in 2001 by Phillis and Andriantiatsaholiniaina [9] to assess the suitability of nations or geographic regions. This model uses a collection of indicators of economic efficiency and social welfare as inputs and applies fuzzy inference to output a sustainability measure. The overall sustainability (OSUS) in the SAFE model [10][11] is composed of two components, ecological sustainability (ECOS) and human sustainability (HUMS). ECOS and HUMS are also known as the primary indicators (see Figure 3).

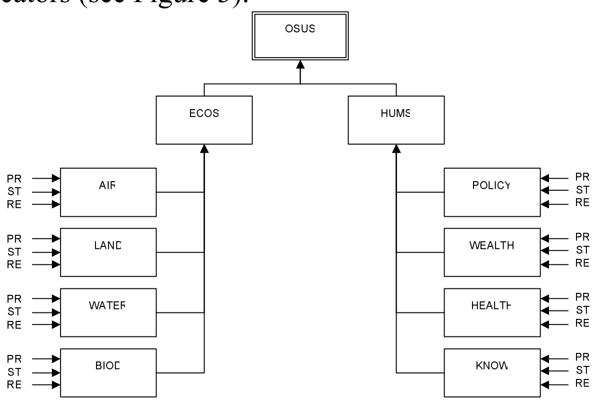

Figure 3. Sustainability Components Of The SAFE Model

ECOS is composed of four secondary indicators; air quality (AIR), land integrity (LAND), water quality (WATER) and biodiversity (BIOD). In a similar way, HUMS is composed of four secondary indicators; political aspects (POLICY), economic welfare (WEALTH), health (HEALTH) and education (KNOW). The evaluation of each secondary indicator is done using three more tertiary indicators; pressure (PR), state (ST) and response (RE). The evaluation of each tertiary indicator is done using a bundle of basic indicators that can be adapted in compliance with environmental, economic, and social changes. This makes the SAFE model very acclimatizable to emerging and evolving conditions while measuring sustainability.

3.1. Model Configuration

The configuration steps of the SAFE model are outlined below and illustrated in Figure 4.
1) We start with a series of values for each basic indicator over a time period e.g. two series ($Z_{c,1}$, $Z_{c,2}$,…, $Z_{c,n}$) and ($Z_{c',1}$, $Z_{c',2}$,…, $Z_{c',n}$) for two basic indicators c and c' respectively.
2) Each value in a series is normalized on the interval [0, 1] using linear interpolation between the most desirable and the least desirable values e.g. we get two normalized series ($X_{c,1}$, $X_{c,2}$,…, $X_{c,n}$) and ($X_{c',1}$, $X_{c',2}$,…, $X_{c',n}$) from ($Z_{c,1}$, $Z_{c,2}$,…, $Z_{c,n}$) and ($Z_{c',1}$, $Z_{c',2}$,…, $Z_{c',n}$) respectively.
3) We transform each normalized series into a single value using exponential smoothing e.g. we get two values X_c and $X_{c'}$ from ($X_{c,1}$, $X_{c,2}$,…, $X_{c,n}$) and ($X_{c',1}$, $X_{c',2}$,…, $X_{c',n}$) respectively.
4) For each exponentially smoothed value, we compute the membership grade to selected fuzzy sets that form complete ordered partition of the interval [0, 1]. This step is referred to as fuzzification. The output of this step is the fuzzy values of basic indicators.
5) We input the fuzzy values of basic indicators to a fuzzy inference engine of the type Takagi-Sugeno-Kang (TSK) to get the fuzzy values of the tertiary indicators.
6) We repeat steps 4 and 5 inputting the fuzzy values of tertiary indicators to a second TSK inference engine to get the fuzzy values of the secondary indicators.
7) Once more, we repeat steps 4 and 5 inputting the fuzzy values of the secondary indicators to a third TSK inference engine to get the fuzzy values of the primary indicators.
8) Again, we repeat steps 4 and 5 inputting the fuzzy values of the primary indicators to a fourth TSK inference engine to get the fuzzy value of OSUS.
9) We use defuzzification to obtain a single value of OSUS.

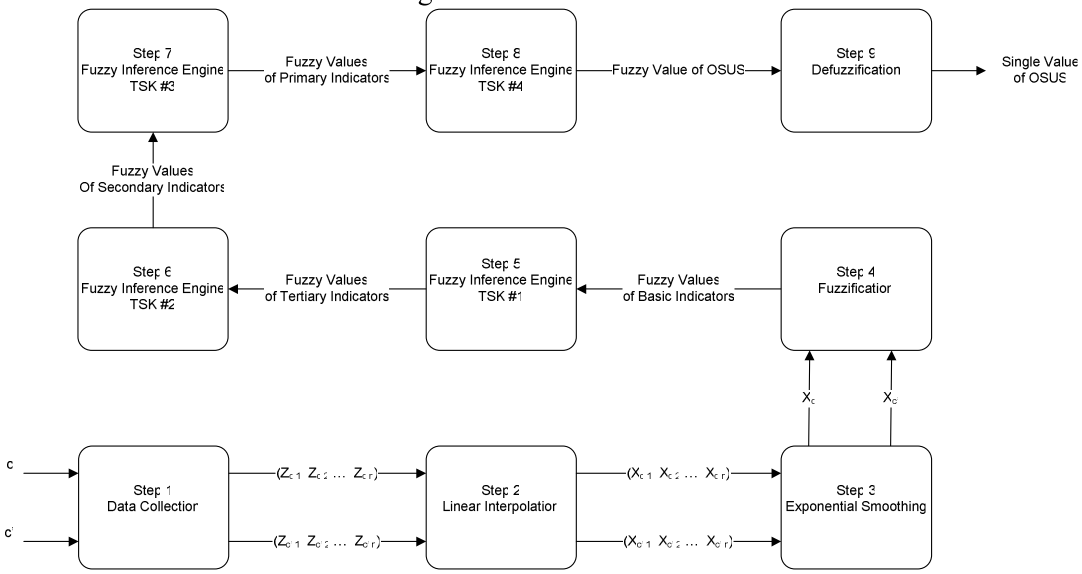

Figure 4. Configuration Steps Of The SAFE Model

3.2. Basic Indicators

In this section, we define (some) of the basic indicators we used in our country-level sustainability assessment. Our definitions are taken from multiple sources of which we mention the World Bank, the World Health Organization (WHO) and the Food and Agricultural Organization (FAO).

ECOS Indicators

AIR Indicators

- PR. Greenhouse Gas (GHG) emissions per capita: Emissions of total GHG (CO_2, CH_4, N_2O, HFCs, PFCs and SF_6) excluding land-use, land-use change and forestry.
- ST. Mortality from respiratory diseases: These diseases reduce lung function and are common in young children.
- RE. Renewable resources production: The higher this indicator, the less a country is exhausting damaging energy sources such as nuclear energy.

LAND Indicators

- PR. Nuclear waste: It comes from nuclear power plants and it has negative repercussions on land sustainability.
- ST. Forest area: The land under natural or planted trees. Productivity of trees is irrelevant. The higher this indicator, the greater is land sustainability.
- RE. Protected area: The land dedicated to the maintenance of biodiversity. Protected area ensures land sustainability.

WATER Indicators

- PR. Total water withdrawals: The amount of water withdrawal per amount of water resources. Hyper-usage adulterates water sustainability.
- ST. Phosphorous concentration: It measures eutrophication which cripples aquatic resources.
- RE. Waste water treatment plants: Only publicly held plants are counted when estimating this indicator.

BIOD Indicators

- PR. Threatened mammals: They include critically endangered, endangered and vulnerable species of mammals.
- ST. Forest area described above can also be used to evaluate the BIOD indicator.
- RE. Protected area described above can also be used to evaluate the BIOD indicator.

HUMS Indicators

POLICY Indicators

- PR. Ratio of refugees from a country to the total population of that country.
- ST. Gini index: It measures the deviation of individuals' income from perfectly uniform distribution. Perfect equality gives a Gini index of zero, while perfect inequality gives a Gini index of 100.
- RE. Tax revenue: Tax is any payment made to the government of a country for public purposes.

WEALTH Indicators

- PR. Unemployment: The portion of labor force that is without a job. Unemployment contradicts with wealth.
- ST. Poverty rate: The percentage of population living below the national poverty line.
- RE. Exports: The value of goods exported by a country to the rest of the world. Exports increase wealth.

HEALTH Indicators

- PR. Infant mortality rate: The infants who die before reaching one year of age.
- ST. Life expectancy: The number of years an infant would live if mortality patterns at its birth time were to remain the same throughout her life.
- RE. Public health expenditure: The amount spent from capital budget on public health.

KNOW Indicators

- PR. Ratio of students to teaching staff in secondary education: Teaching staff do not include nonprofessionals who support the educational process.
- ST. Literacy rate: The percentage of people aged 15 and above who can read and write a short statement on their daily life.
- RE. Internet users: The number of computers directly connected to the Internet. Internet access facilitates learning and knowledge acquisition.

3.3. Linear Interpolation

Basic indicators described in the previous section are measured in a variety of ways, using a variety of units. In order to facilitate the comparison of these indicators, it is essential to normalize their values on the interval [0, 1] using linear interpolation by assigning 0 to the least desirable value and 1 to the most desirable value. Let c be a basic indicator and Z_c the value of c for a given country. A normalized value X_c of Z_c is calculated as follows:

$$X_c = \begin{cases} 0 & Z_c \le v_c \\ \dfrac{Z_c - v_c}{\tau_c - v_c} & v_c < Z_c < \tau_c \\ 1 & \tau_c \le Z_c \le T_c \\ \dfrac{U_c - Z_c}{U_c - T_c} & T_c < Z_c < U_c \\ 0 & Z_c \ge U_c \end{cases}$$

where v_c is the minimum value of Z_c for all countries (or a set of courtiers we are studying) and U_c its maximum. The range $[\tau_c, T_c]$ is the range of equally desirable values of c.

Let us example with Norway and two basic indicators used to evaluate the AIR secondary indicator. The first indicator is the Consumption of Ozone Depleting Substances (ODSs) and the second one is the Greenhouse Gas (GHG) emissions per capita. Table 1 shows the target and least desirable values for each indicator, the original values over a number of years and the corresponding normalized values. Because the smaller the normalized value X_c, the better, we need to apply the formula $\dfrac{U_c - Z_c}{U_c - T_c}$. For example, $X_{c1}^{1990} = \dfrac{U_{c1} - Z_{c1}}{U_{c1} - T_{c1}} = \dfrac{1.1301 - 0.000517}{1.1301 - 0} = 0.999542$.

Table 1. Normalizing Two Basic Indicators For Norway

Basic Indicator	c_1 = Consumption of Ozone Depleting Substances (ODSs)		c2 = Greenhouse Gas (GHG) emissions per capita	
Target Value	$T_{c1} = 0$		$T_{c2} = 0.0000079$	
Least Desirable Value	$U_{c1} = 1.1301$		$U_{c2} = 0.0000262$	
Year	Original Value Z_{c1}	Normalized Value X_{c1}	Original Value Z_{c2}	Normalized Value X_{c2}
1990	0.000517	0.999542	0.0000117	0.792349
1991	0.000341	0.999698	0.0000111	0.825136
1992	0.000197	0.999825	0.0000107	0.846994
1993	0.000128	0.999886	0.0000111	0.825136
1994	0.000617	0.999454	0.0000115	0.803278
1995	0.000021	0.999981	0.0000114	0.808743
1996	0.000016	0.999985	0.0000120	0.775956
1997	0.000015	0.999986	0.0000119	0.781420
1998	0.000011	0.999990	0.0000119	0.781420
1999	0.00000033	0.999999	0.0000120	0.775956
2000	0.00000407	0.999996	0.0000118	0.786885

3.4. Exponential Smoothing

Obtaining accurate data on each basic indicator is often arduous, therefore, we need to improve the quality of information we are using to assess sustainability. This is done through exponential smoothing by assigning weights to past and present values of basic indicators.

Let c be a basic indicator, $X_{c,1}, X_{c,2}, \ldots, X_{c,n}$ the normalized values of c in years $t_1, t_2, \ldots, t_n$, and $w_1, w_2, \ldots, w_n$ their weights. The aggregate value of indicator c can be gauged using the formula:

$$X_c(n) = w_1X_{c,1} + w_2X_{c,2} + \ldots + w_nX_{c,n};\ w_1 + w_2 + \ldots + w_n = 1$$

Logically, recent values of a basic indicator are more important than past ones, therefore, we should give recent values higher weights. We can achieve this through single exponential smoothing for time series in which the smoothed values are given by the formula:

$$X_c(k) = \frac{X_{c,k} + X_{c,k-1}\beta^{t_k - t_{k-1}} + \ldots + X_{c,1}\beta^{t_k - t_1}}{1 + \beta^{t_k - t_{k-1}} + \ldots + \beta^{t_k - t_1}} \quad (*)$$

where β is a smoothing parameter taken from the range [0, 1]. If we used standard exponential smoothing, then the smoothed values become:

$$X_c(k) = (1 - \beta)X_{c,k} + \beta(1 - \beta)X_{c,k-1} + \beta^{k-1}(1 - \beta)X_{c,1}$$

Note that the total sum of weights, in this type of smoothing, is not one; However, when n grows unboundedly, both types of smoothing give similar results. We define the smoothing error as the difference between the observations at time t_k and at time t_{k-1}:

$$e_k = X_{c,k} - X_c(k-1)$$

We set $X_c(0) = 0$ and $X_c(1) = X_{c,1}$, so $e_1 = X_{c,1} - 0$ and $e_2 = X_{c,2} - X_{c,1}$. We also define the sum of squared errors (SSE) as:

$$SSE = e_1^2 + e_2^2 + \ldots + e_n^2$$

The best value of β is the one that minimizes SSE. To facilitate computations, we can put formula (*) recursively as follows:

$$X_c(k) = \frac{N(K)}{D(k)};\ N(k) = X_{c,k} + N(k-1)\beta^{t_k - t_{k-1}},\ D(k) = 1 + D(k-1)\beta^{t_k - t_{k-1}}$$

with $N(1) = X_{c,1}$ and $D(1) = 1$.
Table 2 shows the exponential smoothing of indicator c1 (Consumption of Ozone Depleting Substances) for Norway assuming β = 0.29.

Table 2. Exponential Smoothing Of Indicator c1 For Norway Assuming β = 0.29

k	t_k	$X_{c1,k}$	$t_k - t_{k-1}$	$\beta^{t_k - t_{k-1}}$	N(k)	D(k)	$X_{c1}(k)$	$e_k = X_{c1,k} - X_{c1}(k-1)$
1	1990	0.999542	NA	NA	0.999542	1.000000	0.999542	0.999542
2	1991	0.999698	1	0.29	1.289565	1.290000	0.999662	0.000147
3	1992	0.999825	1	0.29	1.373798	1.374100	0.999780	0.000163
4	1993	0.999886	1	0.29	1.398287	1.398489	0.999855	0.000106
5	1994	0.999454	1	0.29	1.404957	1.405561	0.999570	-0.000401
6	1995	0.999981	1	0.29	1.407418	1.407612	0.999862	0.000411
7	1996	0.999985	1	0.29	1.408136	1.408207	0.999949	0.000123
8	1997	0.999986	1	0.29	1.408345	1.408380	0.999975	0.000037
9	1998	0.999990	1	0.29	1.408410	1.408430	0.999985	0.000015
10	1999	0.999999	1	0.29	1.408437	1.408444	0.999995	0.000014
11	2000	0.999996	1	0.29	1.408442	1.408448	0.999995	0.000001

Finally we set X_{c1} equal to the most recent estimate $X_{c1}(11) = 0.999995$.

3.5. Fuzzification

As we saw in section 3.1, we have to compute the membership grade of each exponentially smoothed value of basic indicators to selected fuzzy sets that form complete ordered partition of the interval [0, 1]. This step is referred to as fuzzification. For this purpose, we will define three fuzzy sets with three linguistic values "weak" (W), "medium" (M) and "strong" (S) as shown in Figure 5.

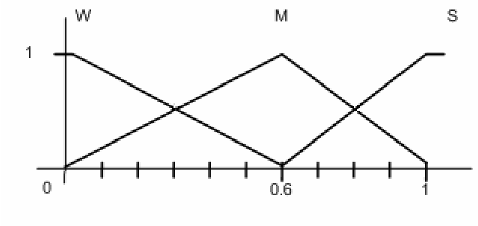

Figure 5. Three Fuzzy Sets With Three Linguistic Values To Fuzzify Basic Indicators

The linguistic value W is assigned to low exponentially smoothed basic indicator values. Normally, we assign three integer values 0, 1 and 2 to these three linguistic values such that 0 corresponds to W, 1 corresponds to M and 2 corresponds to S. Let us illustrate computing membership grades with an example. We found in section 3.4 that the exponentially smoothed value of the basic indicator c1 for Norway is $X_{c1} = 0.999995$. Similar computations reveal that the exponentially smoothed value of the basic indicator c2 for Norway is $X_{c2} = 0.888588$. The membership grades to fuzzy sets W, M and S are:

$$\mu_W(c_1) = 0,\ \mu_M(c_1) = \frac{0.999995 - 1}{0.6 - 1} = 0.0000125,\ \mu_S(c_1) = \frac{0.999995 - 0.6}{1 - 0.6} = 0.9999875$$

$$\mu_W(c_2) = 0,\ \mu_M(c_2) = \frac{0.888588 - 1}{0.6 - 1} = 0.27853,\ \mu_S(c_2) = \frac{0.888588 - 0.6}{1 - 0.6} = 0.72147$$

To fuzzify composite indicators, we need more fuzzy sets, therefore, we will define five more fuzzy sets with five linguistic values "very bad" (VB), "bad" (B), "average" (A), "good" (G), and "very good" (VG). In the same way, we assign five integer values 0, 1, …, 4 to these five linguistic values such that 0 corresponds to VB, 1 corresponds to B and so on.

3.6. Rules

Rules For OSUS

The two major components of OSUS are ECOS and HUMS (see Figure 3), each of which has five linguistic values. This means that we have $5^2 = 25$ possible combinations for OSUS rules. Knowing that OSUS can be written as OSUS = ECOS + HUMS, we discover that the minimum value of OSUS is 0 + 0 = 0, and the maximum value is 4 + 4 = 8. Therefore, we will need nine fuzzy sets with nine linguistic values to describe OSUS. The linguistic values are "extremely low" (EL), "very low" (VL), "low" (L), "fairly low" (FL), "intermediate" (I), "fairly high" (FH), "high" (H), "very high" (VH) and "extremely high" (EH). Now we can list the 25 different rules for OSUS in Table 3.

Table 3. Rules For OSUS

Ri	ECOS	HUMS	OSUS	Ri	ECOS	HUMS	OSUS
R1	VB	VB	EL	R14	A	G	FH
R2	VB	B	VL	R15	A	VG	H
R3	VB	A	L	R16	G	VB	FL
R4	VB	G	FL	R17	G	B	I
R5	VB	VG	I	R18	G	A	FH
R6	B	VB	VL	R19	G	G	H
R7	B	B	L	R20	G	VG	VH
R8	B	A	FL	R21	VG	VB	I
R9	B	G	I	R22	VG	B	FH
R10	B	VG	FH	R23	VG	A	H
R11	A	VB	L	R24	VG	G	VH
R12	A	B	FL	R25	VG	VG	EH
R13	A	A	I				

As an example, contemplate rule R10, the integer value of ECOS is 1 and the integer value of HUMS is 4. Thus, the integer value of OSUS is 4 + 1 = 5 which corresponds to FH.

Rules For ECOS And HUMS

Each of ECOS and HUMS has four inputs (see Figure 3), each of which has five linguistic values. This means that we have $5^4 = 625$ possible combinations for ECOS and HUMS rules. Knowing that ECOS can be written as ECOS = AIR + LAND + WATER + BIOD, we discover that the minimum value of ECOS is 0 + 0 + 0 + 0 = 0, and the maximum value is 4 + 4 + 4 + 4 = 16. Therefore, we will need 17 fuzzy sets with 17 linguistic values to describe ECOS. This is inconvenient and would lead to an explosion in the number of linguistic values. To avoid that, we will keep on using the same five linguistic values for ECOS; however, we will map each value to a range this time:

$$ECOS = \left\{ \begin{matrix} VB & 0 \le SUM \le 3 \\ B & 4 \le SUM \le 7 \\ A & 8 \le SUM \le 11 \\ G & 12 \le SUM \le 15 \\ VG & SUM = 16 \end{matrix} \right\} where\ SUM = AIR + LAND + WATER + BIOD$$

Same reasoning applies to HUMS which can be written as HUMS = POLICY + WEALTH + HEALTH + KNOW.

Rules For Secondary Indicators

Following the same approach above, we can determine the linguistic value of each secondary indicator using:

$$Secondary\ Indicator = \left\{ \begin{matrix} VB & 0 \le SUM \le 1 \\ B & 2 \le SUM \le 4 \\ A & 5 \le SUM \le 7 \\ G & 8 \le SUM \le 10 \\ VG & 11 \le SUM \le 12 \end{matrix} \right\} where\ SUM = PR + ST + RE$$

Rules For Tertiary Indicators

Each of the tertiary indicators has n basic indicators as inputs, each of which has three linguistic values. This means that we have 3^n possible combinations for tertiary indicators. Knowing that each tertiary indicator can be written as Tertiary Indicator = L1 + L2 + … + Ln, we discover that the minimum value of a tertiary indicator is 0 + 0 + … + 0 = 0, and the maximum value is 2 + 2 + … + 2 = 2n. Suppose n = 2, then we have $3^2 = 9$ rules listed in Table 4.

Table 4. Rules For Tertiary Indicators With Two Basic Indicators

Ri	Basic Indicator 1	Basic Indicator 2	Tertiary Indicator
R1	W	W	VB
R2	W	M	B
R3	W	S	A
R4	M	W	B
R5	M	M	A
R6	M	S	G
R7	S	W	A
R8	S	M	G
R9	S	S	VG

Let us apply rule R5 to a numeric example. We found in section 3.5 that the membership grades of the basic indicator c1 for Norway are: 0 to fuzzy set W, 0.0000125 to fuzzy set M and 0.9999875 to fuzzy set S. We further found that the membership grades of the basic indicator c2 for Norway are: 0 to fuzzy set W, 0.27853 to fuzzy set M and 0.72147 to fuzzy set S. Applying rule R5 gives the partial membership grade of the tertiary indicator (PR on AIR) to fuzzy set A:

R5: c1 is M(0.0000125) and c2 is M(0.27853) → PR on AIR is A(0.0000125 * 0.27853 = 0.000003481625).

To get the overall membership grade of the tertiary indicator (PR on AIR) to fuzzy set A, we have to apply rules R5 and R7, and then sum up partial membership grades we get. Of course, applying one rule (R1) is enough to compute the membership grade to fuzzy set VB.

4. Sensitivity Analysis

Sensitivity analysis [10] is a superior tool in decision making and formulating sustainable policies. It entails monitoring the values of sustainability indicators as they change over a period of time. This largely helps in determining the most important indicators that contribute to sustainable development. To perform sensitivity analysis, we go through the following steps:

1) We gauge OSUS following the procedures we saw in section 3.
2) We randomly choose a basic indicator c, perturb its normalized value X_c by an amount γ so that it becomes $X_c + \gamma$. We truncate the resulting value as necessary to make sure that it falls within the range [0, 1].
3) We re-gauge overall sustainability $OSUS(X_c + \gamma)$.
4) We compute OSUS gradient using the formula $\Delta_c = OSUS(X_c + \gamma) - OSUS$.
5) We repeat steps 2 and 3 with all basic indicators.
6) The maximum gradient we get corresponds to the most important basic indicator.

5. Assessment Results

A gigantic amount of calculations lists Scandinavian countries in decreasing sustainability in Table 5. The data dates back to 2005 and was accumulated from the sources mentioned in section 3.2.

Table 5. Scandinavian Countries Listed In Decreasing Sustainability

Country	ECOS	HUMS	OSUS
Sweden	0.7400	0.9370	0.8431
Finland	0.7412	0.9105	0.8301
Denmark	0.7458	0.8871	0.8145
Norway	0.7477	0.8752	0.8042

Applying sensitivity analysis showed that the most important basic indicators for Scandinavian countries are those related to ecology or environment e.g. renewable energy production, greenhouse gas emissions and forest change.

6. Conclusions

In this paper, we gave a fuzzy measurement of SD in Scandinavian countries using the SAFE model. We started with a brief discussion of common sustainability indicators other than the SAFE, then we shed the light on the mathematical foundations of the SAFE model, elucidating its configuration and steps; starting with data collection, moving to linear interpolation, exponential smoothing and multi-stage fuzzification, and ending with defuzzification. Thereafter, we demonstrated the notion of sensitivity analysis and how it can be combined with the SAFE model in order to determine the most influential factors in sustainability. We ended by reflecting on our assessment results.

The environmental conscious in Scandinavia is quite awoke, although some experts argue that the Scandinavians first enriched themselves by destroying enough of their environment and now they are using their wealth to protect the remaining. In either event and based on our study results, renewable energy production, greenhouse gas emissions and forest change were found to be the major factors Scandinavians should consider when articulating future sustainable acts.

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