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Short Communication

SAFE 2013: Sustainability of countries updated

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ABSTRACT

Sustainability Assessment by Fuzzy Evaluation (SAFE) is a model that measures the overall sustainability of countries by combining indicators of ecological sustainability and human sustainability. The model provides country rankings and performs sensitivity analysis which reveals key indicators that each country should improve. This note presents the most recent country rankings and policy recommendations based on the most recent data. A comparison with past rankings shows the relative progress of each country over the last decade.

1. Introduction

After the 1992 Rio Earth Summit, sustainability has become an important topic of study by scientists in several disciplines. Agenda 21, the main outcome of the Summit, stressed the need of developing indicators of sustainability "to provide solid bases for decision-making at all levels and to contribute to a self-regulating sustainability of integrated environment and development systems" (UN, 1993, Section 40.4).

Developing an integrated and widely accepted measuring scheme of sustainability is a challenging task. SAFE (Phillis and Andriantiatsaholiniaina, 2001; Andriantiatsaholiniaina et al., 2004; Kouloumpis et al., 2008; Phillis et al., 2011) is one such a scheme that also serves as a decision support tool for policymaking. SAFE is a hierarchical, fuzzy rule-based system, which aggregates basic indicators of sustainability into a single numerical value for the overall sustainability of a country. Fuzzy logic is a convenient approach to handling such a vague and complex concept as sustainability. The model has undergone three main revisions. The latest version (Phillis et al., 2011) has the following improvements over the original one (Phillis and Andriantiatsaholiniaina, 2001):

- A refined set of basic indicators, which are the inputs of the model, refined rule bases, and a compact rule base representation.
- A fuzzy inference scheme that ensures monotonicity, i.e., the overall sustainability of a country increases when a basic indicator is improved.
- A smoothing filter which takes into account past environmental pressures and other factors affecting the sustainability of a country in a given year.
- An improved sensitivity analysis scheme for policymaking.
- An imputation algorithm that generates appropriate numerical inputs whenever some indicator data are not available.

This model was used in Phillis et al. (2011) for the assessment of sustainability of countries using data for the period 1990–2005. In this note we present results using data up to 2011 and display the relative progress of each country over its previous ranking.

2. Outline of SAFE

The model encompasses two broad components, ecological sustainability (ECOS) and human sustainability (HUMS). ECOS comprises four indicators: water quality (WATER), land integrity (LAND), air quality (AIR), and biodiversity (BIOD). HUMS comprises another four indicators: political aspects (POLICY), economic welfare (WEALTH), health (HEALTH), and education (KNOW). Each of these eight indicators is evaluated by means of more elementary variables: Pressure (PR), State (ST), and Response (RE) indicators. State is the present state of a component such as the size of forested land. Pressure is a force tending to change the state such as the deforestation rate. Response is the reaction taken to bring pressure to a level that will guarantee a better state as, for example, protecting a given area. All these variables are functions of the basic indicators, which are provided by the user. For

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Table 1
Components and basic indicators of the SAFE model.

Component	Basic indicator	Type[a]	Thresholds[b,c]
PR(LAND)	Municipal waste (kg per capita per year)	SB	$T = 300.0$, $U = 817.5$
PR(LAND)	Nuclear waste (tons per capita per year)	SB	$T = 0$, $U = 0.0593$
PR(LAND)	Hazardous waste (tons per capita per year)	SB	$T = 0$, $U = 1.0881$
PR(LAND)	Population growth rate (percent)	SB	$T = 0$, $U = 1.2$
PR(LAND)	Pesticide consumption (kg per hectare)	SB	$T = 3.22$, $U = 8.00$
PR(LAND)	Fertilizer consumption (kg per hectare)	SB	$T = 162.471$, $U = 477.333$
ST(LAND)	Desertification of land (percent of dryland area)	SB	$T = 0$, $U = 100$
ST(LAND)	Forest area (percent of what existed in 2000)	LB	$\upsilon = 0$, $\tau = 100$
RE(LAND)	Forest change (annual rate)	LB	$\upsilon = -0.0690$, $\tau = 0.0257$
RE(LAND)	Protected area (percent of total land area)	LB	$\upsilon = 0.2592$, $\tau = 53.7527$
RE(LAND)	Glass recycling (percent of apparent consumption)	LB	$\upsilon = 0$, $\tau = 100$
RE(LAND)	Paper recycling	LB	$\upsilon = 0$, $\tau = 100$
PR(WATER)	Pesticide consumption (kg per hectare)	SB	$T = 3.22$, $U = 8.00$
PR(WATER)	Fertilizer consumption (kg per hectare)	SB	$T = 162.471$, $U = 477.333$
PR(WATER)	Water withdrawals (percent of internal resources)	SB	$T = 22.7287$, $U = 90.8123$
ST(WATER)	BOD emissions (kg per capita per day)[d1]	SB	$T = 0.0090$, $U = 0.0146$
ST(WATER)	Phosphorous concentration (mg per liter of water)	SB	$T = 0.1764$, $U = 0.6700$
ST(WATER)	Metals concentration (micro-Siemens per centimeter)	SB	$T = 438.8$, $U = 2.247.4$
RE(WATER)	Public wastewater treatment plants (percent of population connected)	LB	$\upsilon = 0$, $\tau = 86.64$
PR(BIOD)	Threatened mammals (percentage)	SB	$T = 0$, $U = 35.46$
PR(BIOD)	Threatened birds (percentage)	SB	$T = 0$, $U = 33.16$
PR(BIOD)	Threatened plants (percentage)	SB	$T = 0$, $U = 8.45$
PR(BIOD)	Threatened fishes (percentage)	SB	$T = 0$, $U = 55.10$
PR(BIOD)	Threatened amphibians (percentage)	SB	$T = 0$, $U = 20.72$
PR(BIOD)	Threatened reptiles (percentage)	SB	$T = 0$, $U = 20.75$
ST(BIOD)	Desertification of land (percent of dryland area)	SB	$T = 0$, $U = 100$
ST(BIOD)	Forest area (percent of what existed in 2000)	LB	$\upsilon = 0$, $\tau = 100$
RE(BIOD)	Forest change (annual rate)	LB	$\upsilon = -0.0690$, $\tau = 0.0257$
RE(BIOD)	Protected area (percent of total land area)	LB	$\upsilon = 0.2592$, $\tau = 53.7527$
PR(AIR)	Ozone depleting substances (metric tons per capita)	SB	$T = 0$, $U = 0.1475$
PR(AIR)	Greenhouse gas emissions (tons of CO_2 equivalent per capita)	SB	$T = 0.0057$, $U = 0.0368$
ST(AIR)	Mortality from poor air quality (deaths per 100,000 population)	SB	$T = 12.8$, $U = 1,805.2$
ST(AIR)	Urban NO_2 concentration ($\mu g/m^3$ of air)	SB	$T = 18.20$, $U = 109.16$
ST(AIR)	Urban SO_2 concentration ($\mu g/m^3$ of air)	SB	$T = 1.33$, $U = 97.07$
ST(AIR)	Urban TSP (total suspended particulates) concentration ($\mu g/m^3$ of air)	SB	$T = 18.92$, $U = 320.00$
RE(AIR)	Renewable energy production (percent of total primary energy supply)	LB	$\upsilon = 0$, $\tau = 20$
PR(POLICY)	Military spending (percent of GDP[d2])	SB	$T = 1.5471$, $U = 8.4135$
PR(POLICY)	Refugees per capita (country of origin)	SB	$T = 0.00025$, $U = 0.01000$
PR(POLICY)	Poverty (percent of population below national poverty line)	SB	$T = 0$, $U = 29.6$
ST(POLICY)	Political rights (values in [1,7])[d3]	SB	$T = 1$, $U = 3$
ST(POLICY)	Civil liberties (values in [1,7])[d3]	SB	$T = 1$, $U = 3$
ST(POLICY)	Gini index[d4]	SB	$T = 25.79$, $U = 50.00$
ST(POLICY)	Corruption Perceptions Index (values in [0,10])[d5]	LB	$\upsilon = 3$, $\tau = 8$
RE(POLICY)	Environmental laws and enforcement (values in [0,1])[d6]	LB	$\upsilon = 0.1774$, $\tau = 0.5974$
RE(POLICY)	Tax revenue (percent of GDP)	LB	$\upsilon = 9.4523$, $\tau = 21.3757$
PR(WEALTH)	GDP implicit deflator (annual percent growth rate)	SB	$T = 1.3221$, $U = 3.0871$
PR(WEALTH)	Imports (percent of GDP)	SB	$T = 47.9642$, $U = 84.2983$
PR(WEALTH)	Unemployment (percent of total labor force)	NB	$\upsilon = 0.7$, $\tau = 4.0$, $T = 7.0$, $U = 12.0$
PR(WEALTH)	Unemployment gender gap (percent)	SB	$T = 0$, $U = 6.5$
ST(WEALTH)	Poverty (percent of population below national poverty line)	SB	$T = 0$, $U = 29.6$
ST(WEALTH)	Central government debt (percent of GDP)	SB	$T = 77.9$, $U = 176.2$
ST(WEALTH)	GNI per capita PPP[d7]	LB	$\upsilon = 24,620$, $\tau = 36,091$
RE(WEALTH)	Exports (percent of GDP)	LB	$\upsilon = 5.4856$, $\tau = 50.3272$
RE(WEALTH)	Foreign direct investment (percent of GDP)	LB	$\upsilon = -2.8982$, $\tau = 3.3123$
PR(HEALTH)	Mortality from poor air quality (deaths per 100,000 population)	SB	$T = 12.8$, $U = 1,805.2$
PR(HEALTH)	Infant mortality rate (deaths per thousand)	SB	$T = 2.63$, $U = 98.20$
PR(HEALTH)	Maternal mortality rate (deaths per 100,000 live births)	SB	$T = 6.83$, $U = 690.00$
PR(HEALTH)	HIV/AIDS prevalence rate (percent of population aged 15-49)	SB	$T = 0$, $U = 1.8$
PR(HEALTH)	Tuberculosis prevalence rate (per 100,000 population)	SB	$T = 0$, $U = 993$
PR(HEALTH)	Malaria cases (per thousand people)	SB	$T = 0$, $U = 0.0012$
ST(HEALTH)	Life expectancy (years)	LB	$\upsilon = 47.7764$, $\tau = 80.9659$
ST(HEALTH)	Immunization against measles (percent of population)	LB	$\upsilon = 76$, $\tau = 100$
ST(HEALTH)	Immunization against DPT (percent of population)[d8]	LB	$\upsilon = 83$, $\tau = 100$
ST(HEALTH)	Daily per capita calorie supply	LB	$\upsilon = 1,604$, $\tau = 3,486$
RE(HEALTH)	Number of doctors (per thousand people)	LB	$\upsilon = 0.0080$, $\tau = 3.7843$
RE(HEALTH)	Hospital beds (per thousand people)	LB	$\upsilon = 0.1000$, $\tau = 3.1767$
RE(HEALTH)	Public health expenditure (percent of GDP)	LB	$\upsilon = 0.2589$, $\tau = 8.2798$
RE(HEALTH)	Access to improved water sources (percent of population)	LB	$\upsilon = 40$, $\tau = 100$
RE(HEALTH)	Access to improved sanitation (percent of population)	LB	$\upsilon = 9$, $\tau = 100$
PR(KNOW)	Primary education ratio of students to teaching staff	SB	$T = 12.8785$, $U = 76.0736$
PR(KNOW)	Secondary education ratio of students to teaching staff	SB	$T = 10.9696$, $U = 66.8171$
PR(KNOW)	Tertiary education ratio of students to teaching staff	SB	$T = 14.88$, $U = 45.50$
ST(KNOW)	Male expected years of schooling	LB	$\upsilon = 5.8829$, $\tau = 12.0000$
ST(KNOW)	Female expected years of schooling	LB	$\upsilon = 4.0826$, $\tau = 12.0000$
ST(KNOW)	Primary net school enrollment (percent of children)	LB	$\upsilon = 33.0700$, $\tau = 98.2542$
ST(KNOW)	Secondary net school enrollment (percent of children)	LB	$\upsilon = 8.70$, $\tau = 93.16$