Measuring Sustainability, Metrics and Metrology

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OUTLINE

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3. Sustainability and Quality Infrastructure
4. Sustainability and Metrology
5. Sustainability definitions
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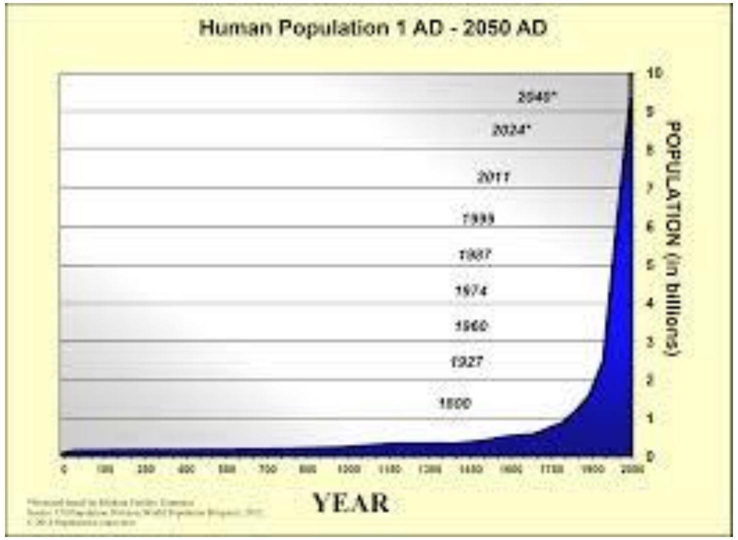
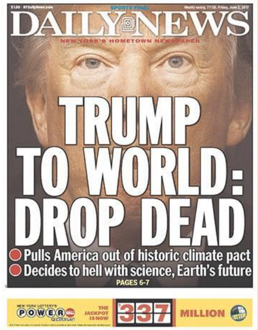
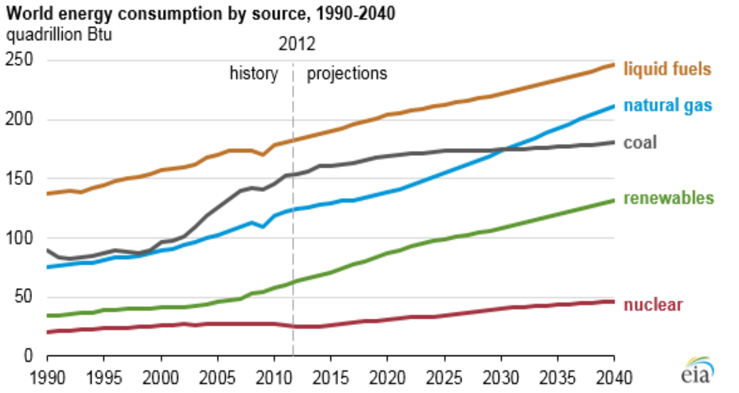
7. Sustainability framework
8. Examples- Similarity, multivariate analyses, uncertainty , normalization, aggregation,, weighting and Modern Portfolio Theory.
9. Remarks

Inmetro
the Brazilian National Metrology Institute

Why to be concerned ?





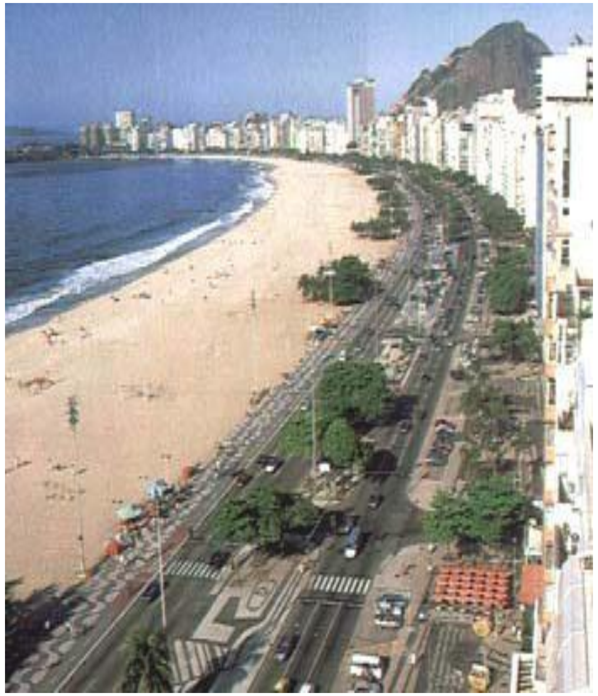


Source: http://www.valmet.com/sustainability/sustainability-agenda/environmental-concerns/

World's eight richest people have same wealth as poorest 50%

The Guardian 16/01/2017

Why to be concerned ?



Praia de Copacabana, vista do sopé do Morro do Leme até o atual Posto 6, c. 1890

Copacabana – Rio de Janeiro
1980´s – 1880´s

Barra da Tijuca - Rio de Janeiro
1970´s - 1990´s

"I dream of having a specific measure of ecosystem value in the same way we value crude oil labor (...) Why can't I have the same for water or pollination?"

Mark Weick, Director of Sustainability for Dow Chemical

Certification

CERTIFICATION SEALS: IMPACT ON PURCHASING

How often do you look for each of the following seals or labels when shopping for various products or services—always, most of the time, sometimes, rarely or never? *Note: Respondents are only shown visual representations of certification seals that they have seen before.* (% Responding)

	Always	Most of the time	Sometimes	Rarely	Never	Never seen
(Energy Star)	31%	26%	18%	7%	6%	13%
(Recyclable)	20%	25%	25%	10%	9%	11%
(USDA Organic)	8%	15%	21%	12%	7%	38%
(Smart Choice)	7%	11%	15%	7%	5%	55%
(Green-e)	3%	5%	8%	3%	2%	79%
(Whole Trade Guarantee)	3%	4%	7%	3%	2%	81%
(Fair Trade Certified)	2%	4%	7%	3%	2%	82%
(Certified Humane Raised and Handled)	2%	3%	5%	2%	1%	86%
(Rainforest Alliance Certified)	2%	3%	6%	3%	2%	83%
(LEED or Green Building Certified)	1%	3%	4%	2%	1%	88%
(Cruelty Free/Leaping Bunny Certified)	2%	3%	3%	1%	2%	89%
(Marine Stewardship Council Certified)	1%	3%	4%	2%	1%	89%
(Forest Stewardship Council Certified)	1%	1%	2%	1%	1%	94%

CERTIFICATION SEALS: FAMILIARITY

Now you are going to see some seals or labels that could appear on the packaging of products you buy. Please indicate if you have seen that label or seal before. *Note: Respondents are only shown visual representations of certification seals.* (% Responding "yes, have seen")

	All
(Recyclable)	89%
(Energy Star)	87%
(USDA Organic)	62%
(Smart Choice)	45%
(Green-e)	21%
(Whole Trade Guarantee)	19%
(Fair Trade Certified)	18%
(Rainforest Alliance Certified)	17%
(Certified Humane Raised and Handled)	14%
(LEED or Green Building Certified)	12%
(Cruelty Free/Leaping Bunny Certified)	11%
(Marine Stewardship Council Certified)	11%
(Forest Stewardship Council Certified)	6%

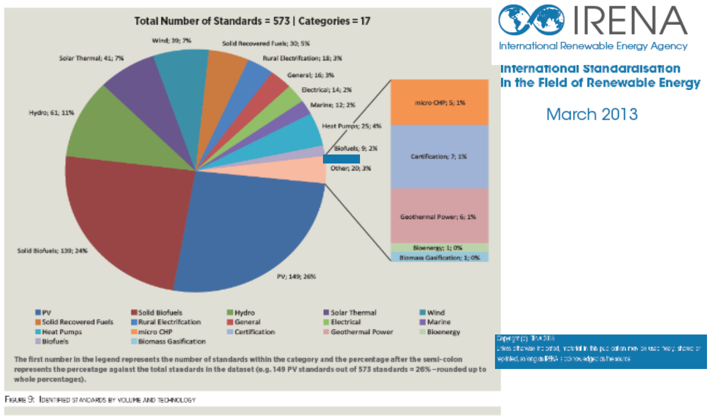
Labelling

Labelling lamps and refrigerators generated USD 14 billions for the Brazilian economy

How to implement sustainability?

- A documentary standard is a **repeatable**, **harmonized**, **agreed** and **documented** way of doing something. Documentary standards contain technical specifications or other precise criteria designed to be used consistently as a rule, guideline, or definition.
- Sustainability may be introduced through standards and regulations that guide the sustainable development of a product, a service or a process, demanding reliable and widely accepted measurements
- Standards may be used by policy makers to implement sustainability policies

Standards for Energy Efficiency



QUALIDADE-ABNT-AMBIENTAL

Global Reporting Initiative™

RAINFOREST ALLIANCE CERTIFIED

INTERNATIONAL CERTIFICATIONS ISO 14001

Quality Infrastructure

Pillars of sustainable development: Technical basis of Quality and Development

Express what is wanted	➢ Standardization – Documentary standards
Deliver what is what is expressed	➢ Conformity Assessment
Measure what is delivered	➢ Metrology – Measurement standards

Standards – Important tools to implement sustainability

What must be incorporated into any Standard?

- **Be measurable**
- Consensus of expert opinions
- Assurance for a fair competition of products and services
- Assurance to users and consumers of comparability of products, materials and services
- Coherence and credibility
- Core requirements, terminology, definitions
- Harmonized across borders with other standards
- Friendly and flexible
- Transparency & accountability

Klemes (2015)
Has brought attention to the need of assessing and measuring sustainability and the importance of increasing the efforts to address sustainability problems:

- 0.1% of 96,260 publications in Scopus deal with “sustainability and measurement” issues.

Brandi and Santos (2015)
Among 102,773 publications in the Scopus database containing the word “sustainability”:

- 113 publications (0.1%) contained the expression “sustainability AND uncertainty AND measurement"
- ZERO publication containing the acronym “GUM”.

Measurements and Metrology

“Metrology is the science of measurement”

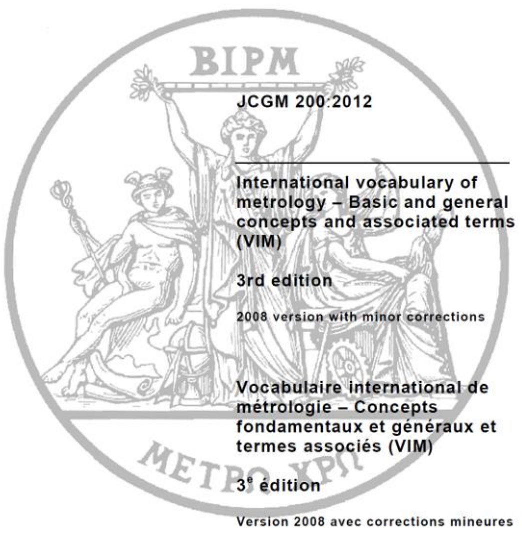
International Vocabulary of Metrology (VIM)

Metrology includes all aspects both theoretical and practical with reference to measurements, whatever their uncertainty, and in whatever fields of science or technology they occur.

Metrology is the only science based in a international agreement: The Meter Convention -1875

Focus on the quality, uniformity and confidence of measurements

Metrology



measurand
quantity intended to be measured
VIM

- Principles of measurements may be applied to different fields.
- The conceptual requirements from physics and chemistry are being extended to materials, biology, medicine, food science, and others fields
- Application to sustainability can incorporate internationally recognized tools.
- Harmonizes sustainability measurements.
- Brings to sustainability recognized measurements required by sustainability standards and international directives.
- Identify and quantify uncertainties and risks.

How to define sustainability?

- The development that meets the needs of the present without compromising the ability of future generations to meet their own needs

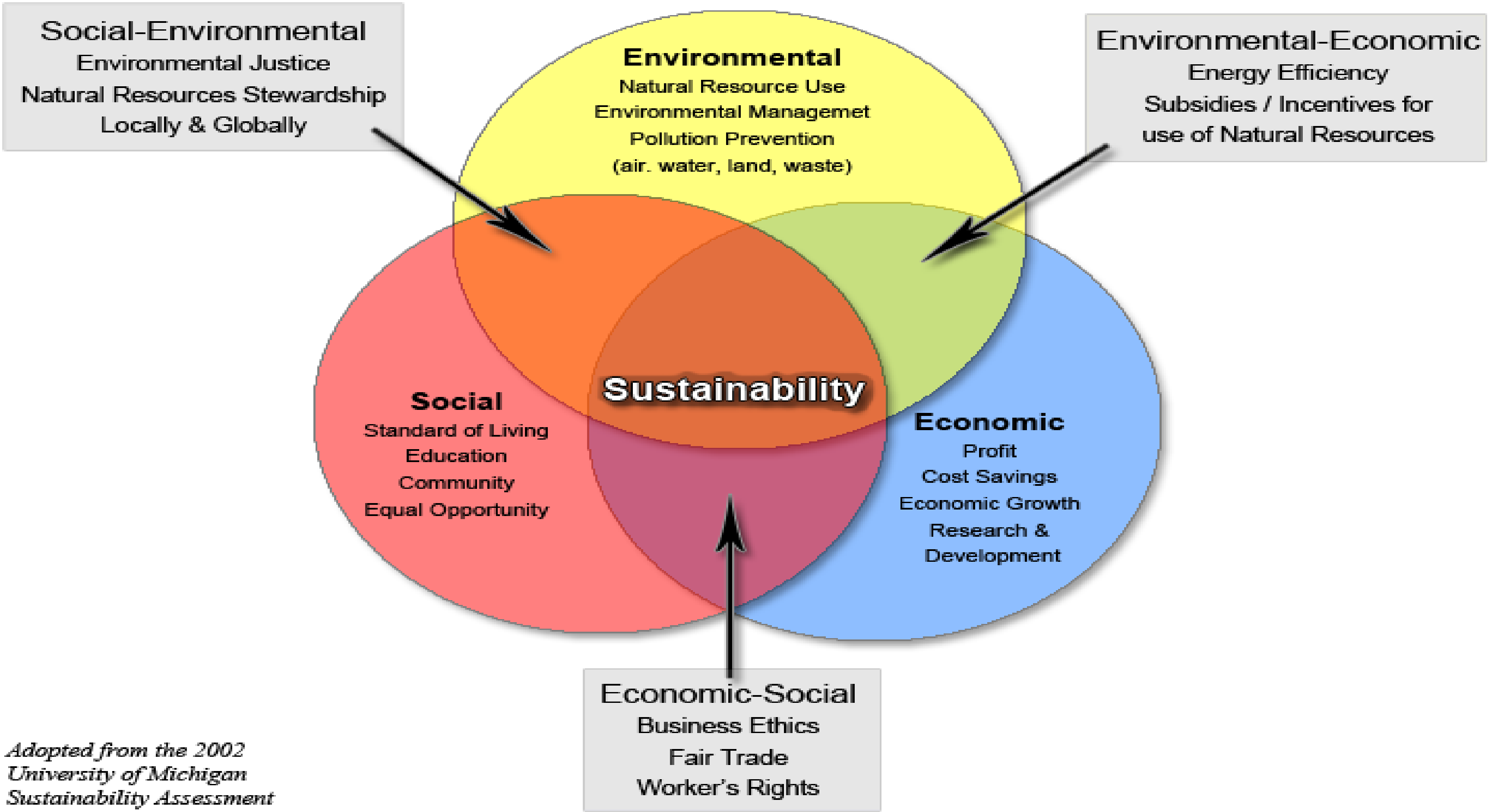
Our Common Future – Gro Harlem Brundtland, Brundtland Report 1987

- The level of human consumption and activity, which can continue into the foreseeable future, so that the systems that provide goods and services to the humans, persists indefinitely

US National Research Council

➢ Problem: if we cannot foresee the future, we cannot define the measurand precisely

Sustainable development involves the three dimensions Environmental, Economics, and Social



Measuring Sustainability

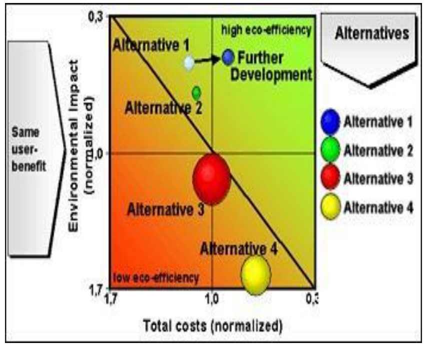
- Sustainability is always comparative. A reference system with similar attributes is required
- Sustainability systems are forms to express sustainability
- Metric or indicator are a quantified measure of a chosen aspect of a system.
- A collection of metrics is required to determine the status of a system
- Choosing the right set of indicators is very important to well represent the system
- Sustainability systems are complex systems and currently there is no standard method of measuring it

Sikdar, et al (2017), Measuring Progress Towards Sustainability ,2017

Displaying metrics for sustainability analysis

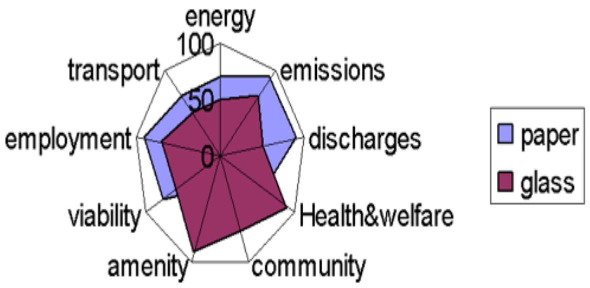
Diagrams are an attempt to provide in a single diagram an appreciation of the sustainable development attributes two states of a system

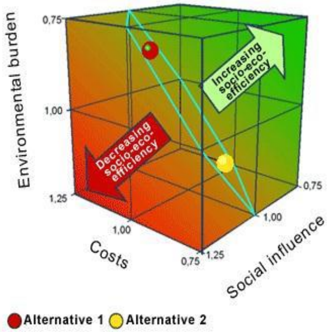
- Not pratical for large number of metrics
- Difficult to visually compare and to communicate



BASF Eco-efficiency analysis

Combines Environmental and Economic Dimensions of Sustainability





BASF Sustainability Analysis

Combines all three dimensions of sustainability

Metrics, distances and similarities

Mathematics: Metric or distance function is a function that defines a distance between each pair of elements of a set.
A set with a metric is called a metric space.

A metric, d, satisfies five properties:
(i) non-negativity $d(a; b) \geq 0$;
(ii) symmetry $d(a; b) = d(b; a)$;
(iii) identification mark $d(a; a) = 0$;
(iv) definiteness $d(a; b) = 0$ if and only if $a = b$;
(v) triangle inequality $d(a; b) + d(b; c) \geq d(a; c)$.

Pairwise distances, are functions satisfying the first three properties of a metric, only.
Distances are mathematical representations of close or similar.

A similarity function $\sum$ has a less precise definition, satisfying three properties:
(i) nonnegativity $\sum(x; y) \geq 0$;
(ii) Symmetry $\sum(x; y) = \sum(y; x)$;
(iii)The more *similar* the objects x and y the greater $\sum(x;y)$

Measuring Sustainability: A Theoretical Framework

System definition

Various roughly equivalent definitions of systems. To **ISO**, a *"system is a set of interrelated or interacting elements"*. A system **S** can be described by a set of characteristic indicators, X_i , *i= 1, n:*

$$\mathbf{S} \approx f(X_i)$$

System boundaries

The boundaries help define the system indicators and must include space and time horizon.

Choice of indicators

i) An indicator is a (measurable) *quantity.* The property of a phenomenon with magnitude that can be expressed as a number and a reference. ii) The indicators have to represent one or more of the three domains of sustainability. iii) The initial set of indicators must incorporate an adequate description of the sustainability conditions of a particular system. Use well recognized data basis

Multivariate statistical methods

Assess reliability, validity, and dimensionality of sustainability data expressed by their measurements to select the number and the quality of the indicators representing sustainability

Normalization

Normalization is required to any a sustainability analysis as the indicators in a data set often have different measurement units.Examples of normalization procedures are: ranking, standardization, re-scaling, distance to reference, categorical scales, cyclical indicators, balance of opinions.

Normalization	Normalization is required to any a sustainability analysis as the indicators in a data set often have different measurement units.Examples of normalization procedures are: ranking, standardization, re-scaling, distance to reference, categorical scales, cyclical indicators, balance of opinions.
Uncertainty	Uncertainty of measurement is an expression of the fact that, for a given measurand and a given result of measurement of it. There is not one value but an infinite number of values dispersed about the result that are consistent with all of the observations and data and one's knowledge of the physical world, and that with varying degrees of credibility can be attributed to the measurand. (VIM 2012)
Metrics	Standards of measurement by which efficiency, performance, progress, or quality of a plan, process, or product can be assessed (Business Dictionary)
Aggregation	Arrow's impossibility theorem shows that no perfect aggregation convention can exist. (Arrow, 1963, OECD, 2008)). A fundamental point in measurement theory is that of the *uniqueness of scale*, *i.e.* which admissible transformations of scale allow for the truth or falsity of the statement involving numerical scales to remain unchanged • (*problem of meaningfulness*) (OECD,2008)
Weighting	Non-aggregators main objection to aggregation (Sharpe, 2004). Use statistical models, such as Factor Analysis (FA), Data Envelopment Analysis (DEA) and Unobserved Components Models (UCM), or from participatory methods like Budget Allocation Processes (BAP), Analytic Hierarchy Processes (AHP) and Conjoint Analysis (CA).

Arrow imposibility theorem: Borda X Condorcet debate

		Voters' choices			
Arbitrary Borda's weights	Rank	3	5	7	6
3	1º	A	A	B	C
2	2º	B	C	D	B
1	3º	C	B	C	D
0	4º	D	D	A	A

Source-, Tables adapted from Nardo et al,(OECD) 2008

- **Borda weigthing**

A = 8 *x* 3 = 24
B = 7 *x* 3 + 9 *x* 2 + 5 *x* 1 = 44
C = 6 *x* 3 + 5 *x* 2 = 28
D = 7 *x* 2 + 6 *x* 1 = 20

This rule leads to the following order: **B – C – A – D**

- **Condorcet rule**

Is based in a pairwise comparison among all candidates by counting how many voters are in favour of each candidate.

This rule leads to the following order: **C – B – D – A**

- **Most voted candidate**

This rule leads to the following order: **A** – B – C – D

Metrics

Composite Sustainability Index - Similarity to a reference state [1]

$$I_j^S \equiv 1 - \frac{1}{n}\sum_{i=1}^{n} d(v_i, r_i);\ 0 \leq\ I_j^S \leq 1$$

Multivariate statistical methods

Determinant factors [2]

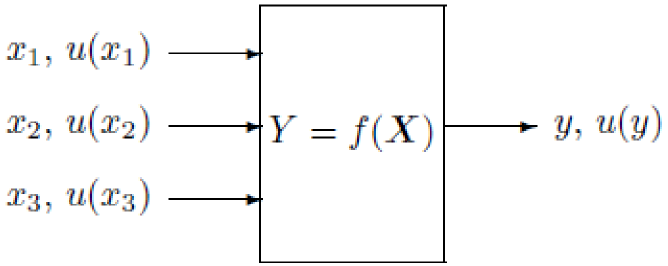
- Multivariate statistic techniques relate the indicators in organized dimensions [3]
- Assign weights to the indicators and dimensions
- The resulting dimensions have a minimum of correlation between each other and the maximum possible correlation among their indicators

[1] Santos and Brandi, 2015b; [2] (Santos (2014); [3](Hair et al. 2005)

Uncertainty evaluation: short remarks on the GUM methods

A. The GUM uncertainty framework (GUF)

The GUF relies on the law of propagation of uncertainty, characterizing the output quantity by a Gaussian distribution or a scaled and shifted *t*-distribution



Source: (BIPM 2008b)

The law of propagation of uncertainties has limitations such as the truncation of the Taylor´s series and the validity of the central theorem

GUF methodology

The methodology presented by the GUM may be summarized as in the following steps (BIPM 2008a):

1-Mathematical expression of the measurand y and the input quantities x_i:

$$y = f(x_1, x_2, \ldots, x_N)$$

2- Determination of x_i, the estimate value of X_i. This determination can be made on the basis of statistical analysis of a series of observations (Type A) or determined from other sources of information (Type B).

3- Evaluation of the standard uncertainty $u(x_i)$ of each estimate x_i. Input estimates obtained from statistical analysis of a series of observations should be estimated through the standard deviation, $s(\bar{x})$ (Type A evaluation). For input estimates obtained from other means $u(x_i)$ must be evaluated taking into account all available information about the measurement input sources (Type B evaluation). $u(x_i) = s(\bar{X}_i) = \frac{s(X_i)}{\sqrt{n}} = \frac{1}{\sqrt{n}}\frac{1}{n-1}\sum_{i=1}^{n}(X_i - \bar{X}_i)^2$

4- Evaluation of the covariances associated with the input estimates that are correlated (see step 6).

5-Calculation of the result of the measurement, i. e., the estimate y of the measurand Y applying the functional relationship f using the estimates x_i.

6-Determination of the combined standard uncertainty $u_c(y)$ of the result y.

As the GUF is based on the law of propagation of uncertainty, the model of the measurand ($y = f(x_1, x_2, \ldots, x_n)$) is expanded in a Taylor's series simplified to take just the first order terms. This approach leads to the following expression for propagation of uncertainties:

$$u_c^2(y) = \sum_{i=1}^{N}\sum_{j=1}^{N}\frac{\partial f}{\partial x_i}\frac{\partial f}{\partial x_j}u(x_i, x_j)$$

$$= \sum_{i=1}^{N}\left(\frac{\partial f}{\partial x_i}\right)^2 u^2(x_i) + 2\sum_{i=1}^{N-1}\sum_{j=i+1}^{N-1}\frac{\partial f}{\partial x_i}\frac{\partial f}{\partial x_j}u(x_i, x_j)$$

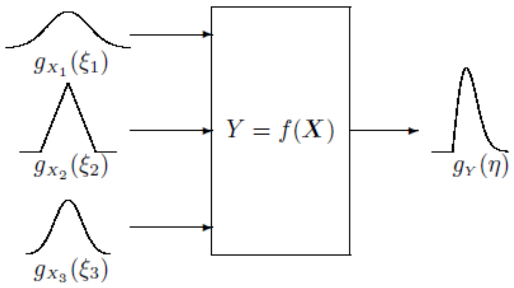
B. The Monte Carlo simulation methodology: propagation of distributions

Monte Carlo Method (MCM) is based on simulations with pseudo random numbers and propagation of distributions of the input quantities.

Once defined the input PDFs for each X_i, they are propagated through the mathematical model by a series of Monte Carlo trials to obtain the PDF for Y

It can be used *to provide (a representation of) the PDF for the output quantity from which can obtained:*

a) an estimate of the output quantity,
b) the standard uncertainty associated with this estimate, and
c) a coverage interval for that quantity, corresponding to a specified coverage probability



Source: (BIPM 2008b)

GUM-MCM methodology

MCM as an implementation of the propagation of distribution can be performed according to the following procedure (BIPM 2008b):

- selection of a predetermined number M of Monte Carlo random trials;
- generation of M vectors, by sampling from the assigned PDFs to each input quantities (indicators in the present work);
- formation of corresponding model value of Y for each of the M vectors, yielding M model values;
- sort of the M model values into an increasing order and use the values to obtain G;
- use G to form an estimate y of Y and the standard uncertainty $u(y)$ associated with y;
- use G to form a coverage interval for Y, for a given coverage probability p.

Application of the framework to a sustainability system (biodiesel supply chain)

Comparison of sustainability index of six countries using different metrics

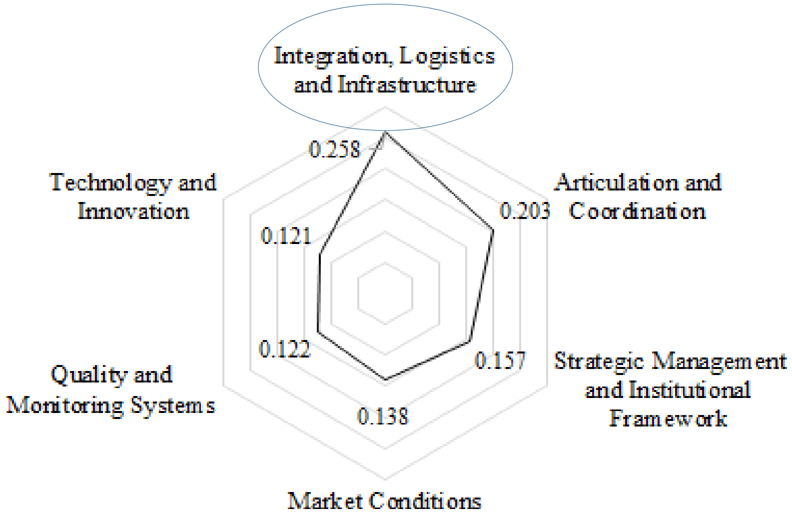
The Integration, Logistic and Infrastructure (ILI) dimension

Indicators (x_i)	Germany	Argentina	Brazil	China	USA	France	Reference state (r_i)
x_1 Road sector diesel fuel consumption per capita	346	185	170	74	404	478	316.60 [(a)]
x_2 Quality of railroad infrastructure	5.72	1.70	1.76	4.70	4.89	6.29	6.29
x_3 Quality of port infrastructure	5.85	3.67	2.71	4.48	5.67	5.41	5.85
x_4 Quality of roads	6.01	3.07	2.77	4.50	5.68	6.40	6.40
x_5 Child mortality [(b)]	100	85.07	68.59	76.23	95.33	100	100
x_6 Wastewater treatment	95.18	11.75	10.87	18.18	63.66	83.8	95.18
x_7 Value chain breadth	6.05	3.53	3.75	4.08	5.32	5.50	6.05
x_8 Level of energy dependency	60	4	8	11	19	46	4
x_9 Individuals using Internet	84.00	55.80	49.85	42.30	81.03	83.00	84

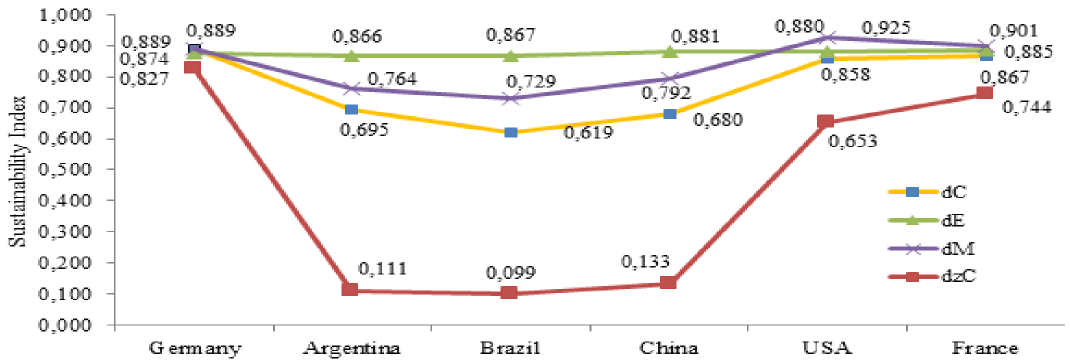
WEF 2015; World Bank 2014b; EPI/Yale 2014; Yale 2012)

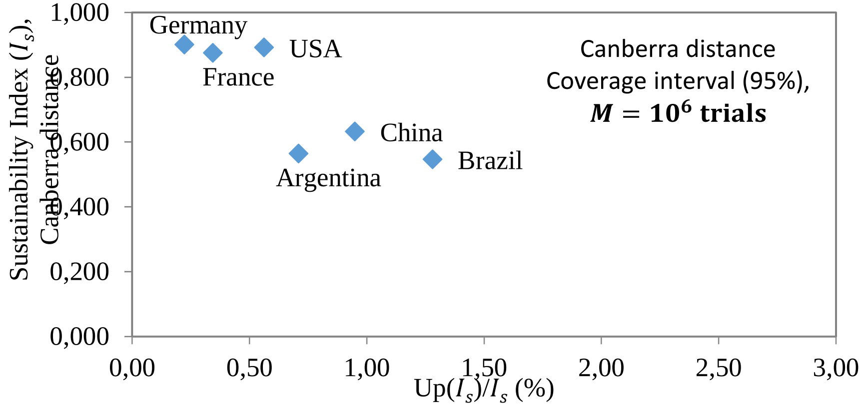
Compared Metrics

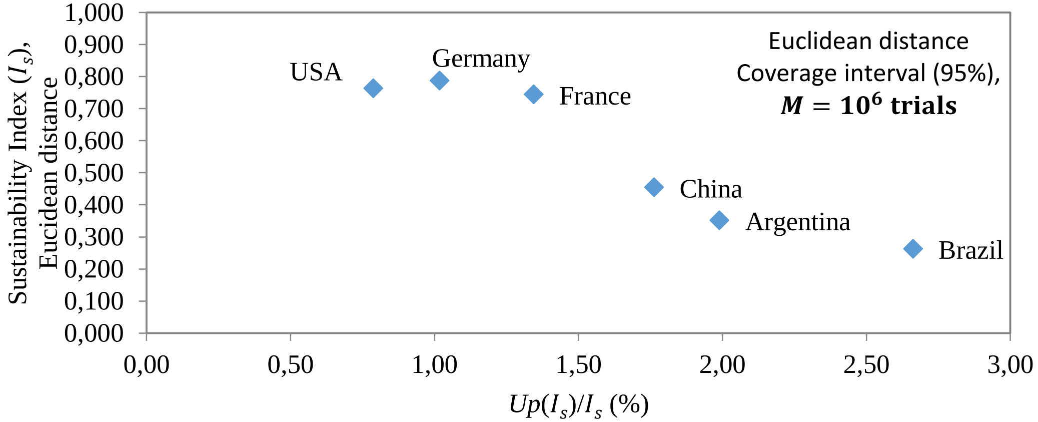
Euclidean distance	$d_E(x,r) = \frac{1}{n}\sqrt{\sum_{i=1}^{n}\frac{(X_i - r_i)^2}{{s_i}^2}}$
Mahalanobis distance	$d_M(x,r) = \sqrt{\sum_{i=1}^{n}\left[\frac{(x_i - r_i)}{s_i}\right]^2}$
Canberra distance	$d_c(x,r) = \sum_{i=1}^{n}\frac{\lvert x_i - r_i\rvert}{\lvert x_i - x_{i0}\rvert + \lvert r_i - x_{i0}\rvert}$
z-score normalized Canberra distance z-score ($x \to \frac{x-\bar{x}}{s}$)	$d_{zC}(x,r) = \sum_{i=1}^{n}\frac{\lvert x_i - r_i\rvert}{\lvert x_i - \bar{x}_i\rvert + \lvert r_i - \bar{x}_i\rvert}$



Some results







Comparing metrics

- Close to the reference state, the results for the sustainability index obtained with the zCanberra distance approach the values of the other three metrics.
- Far, the sustainability index of Argentina, Brazil and China are very small as compared with the other three metrics due to the indicators "cutoff" behavior associated to this distance. The values of many indicators are not in the range between r_i and $\bar{x}_i$ and do not contribute to the sustainability index.

- The results with uncertainty, suggest that the Euclidean distance better separates the countries than the Canberra distance. Therefore, this result could be an indication that the Euclidean is more appropriate than Canberra distance to represent the single sustainability indicator of the *ILI* dimension of the biodiesel supply chain.

Calculations rank Brazil the least sustainable ILI biodiesel supply chain, among the six countries

This result demonstrate that the indicators reflect the poor situation of the Brazilian infrastructure and social and environmental challenges

MPT: a Method for Weighting

- Modern Portfolio Theory (MPT), is a very successful method used in economics. The mathematical framework established by Markowitz (Marling and and Emanuelsson 2012)

- Its key insight is that an asset's risk and return should not be assessed by itself, but by how it contributes to a portfolio's overall risk and return

- According to MPT, it is possible to construct an *efficient frontier* of optimal portfolios offering the maximum possible expected return for a given level of risk. The expected return of the portfolio is calculated as a weighted sum of the individual assets' returns.

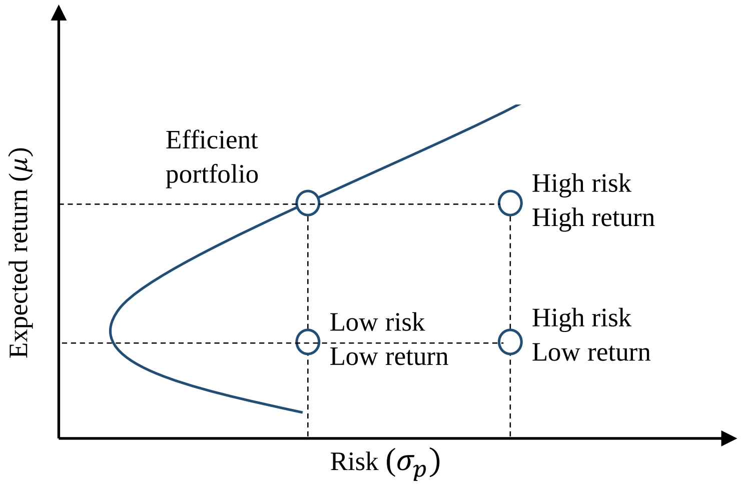
- In economics, MPT considers that given possible choices for investments, some investors may prefer fewer risks but others can accept riskier investments to obtain larger returns. Thus, a trade-off exists and its analysis depends on the investors risk aversion.

- The correspondence between economics and the following application is straightforward: the portfolios are associated to the competitiveness indexes, the assets with the indicators and the weights of the return of investments correspond to the weights of the indicators in the composite competitiveness indexes

Attainable set - The set of all possible (μ_p, σ_p) combinations

Efficient frontier (or efficient portfolio set) - Those (μ_p, σ_p) with minimum or more, σ_p, for a given μ_p, and with maximum μ_p or less, for a given σ_p

The preferred portfolio of an investor, because its risk/reward characteristics approximate the investor's utility function, may not be an efficient portfolio. It is a portfolio that maximizes the investor preferences with respect to expected return and risk.



The efficient frontier and portfolios

Marling and and Emanuelsson, 2012.

According to MPT, the return of a portfolio at a time t (R_t) is defined as:

$$R_t = \frac{x_t}{x_{t-1}} - 1$$

Where x_t is the value of the asset at a time t and $x_{t-1}$is the value of the same asset in the immediately previous time t – 1.

For a portfolio of n different assets, the expected return of the portfolio μ_p is defined as:

$$\mu_p = E[R_p] = \sum_{i=1}^{n} w_i E[R_i] = \sum_{i=1}^{n} w_i \mu_i = \boldsymbol{R^T w}$$

Where R_p is the return on the portfolio; R_i is the return on the asset i; $\boldsymbol{R^T}$ is the transpose matrix of the expected returns; w_i is the weighting of the asset i or the proportion of the asset i in the portfolio and $\boldsymbol{w}$ is the matrix of the portfolio weights, with the constraint:

$$\sum_{i=1}^{n} w_i = 1$$

The variance of the portfolio is defined as:

$${\sigma_p}^2 = Var[R_p] = \sum_{i=1}^{n}\sum_{j=1}^{n} \sigma_{i,j} w_i w_j = \boldsymbol{w^T \Sigma w}$$

Where $\sigma_{i,j}$ is the covariance of the returns on the assets i and j ($\sigma_{i,j} = \sigma_i \sigma_j \rho_{i,j}$); $\rho_{i,j}$ is the correlation coefficient between the return on assets i and j and $\boldsymbol{\Sigma}$ is the covariance matrix of the returns on the assets portfolio. The portfolio risk (volatility or uncertainty) is defined by the (sample) standard deviation

$$\sigma_p = \sqrt{{\sigma_p}^2}$$

In matrix form, the efficient frontier can be obtained by optimizing:

$$min\left(\boldsymbol{w^T \Sigma w} - A\boldsymbol{R^T w}\right) = min\,({\sigma_p}^2 - A\mu_p)$$

The factor A ($0 \leq A \leq \infty$) is the so-called risk aversion factor. $A = 0$ results in the portfolio with the smallest variance. Increasing A corresponds to the investor to be more willing to accept greater risk in order to get a higher expected return. $A = \infty$ corresponds to the investor aiming a large expected return no matter the risk involved (Marling and Emanuelsson 2012)

Applying MPT to analyze BRICS countries´ competitiveness-

Santos and Brandi, 2017, CTEP

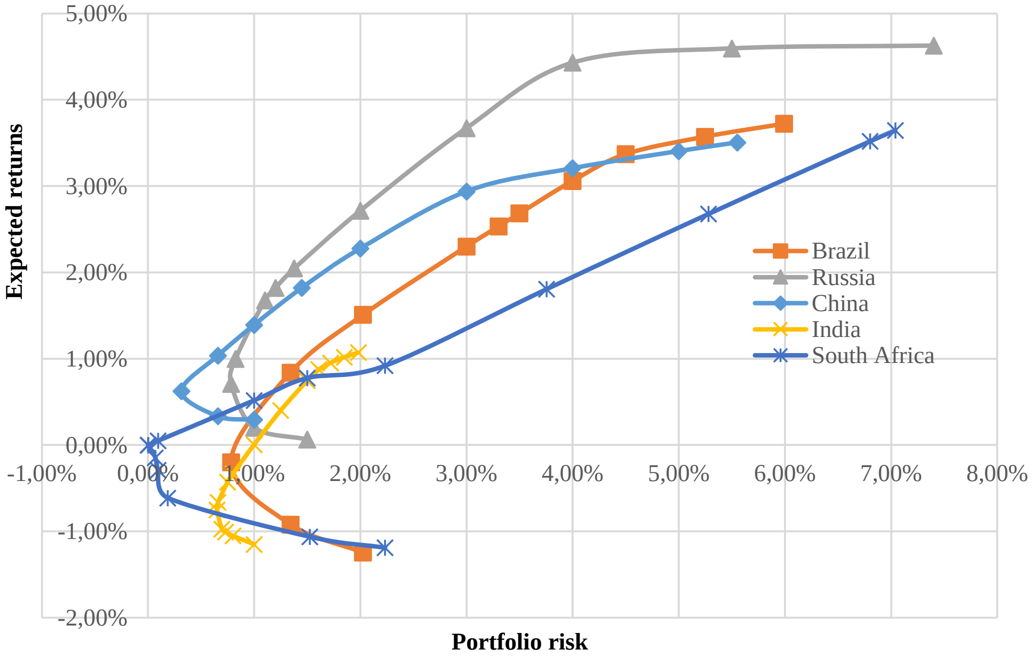
The Global Competitiveness Index indicators are grouped into 12 pillars scored from 1 to 7:
***Institutions, Infrastructure, Macroeconomic environment, Health and primary education, Higher education and training, Goods market efficiency, Labor market efficiency, Financial market development, Technological readiness, Market size, Business sophistication, and Innovation*.**

They are aggregated in three subindexes used to group the countries depending on the economy’s stage of development (World Economic Forum 2016) (Table 1).

The GCI includes statistical data from internationally recognized organizations, as the International Monetary Fund (IMF), the World Bank and various United Nations’ specialized agencies, including the International Telecommunication Union, UNESCO, World Health Organization.
The index also includes indicators derived from the World Economic Forum’s Executive Opinion Survey (World Economic Forum 2016).

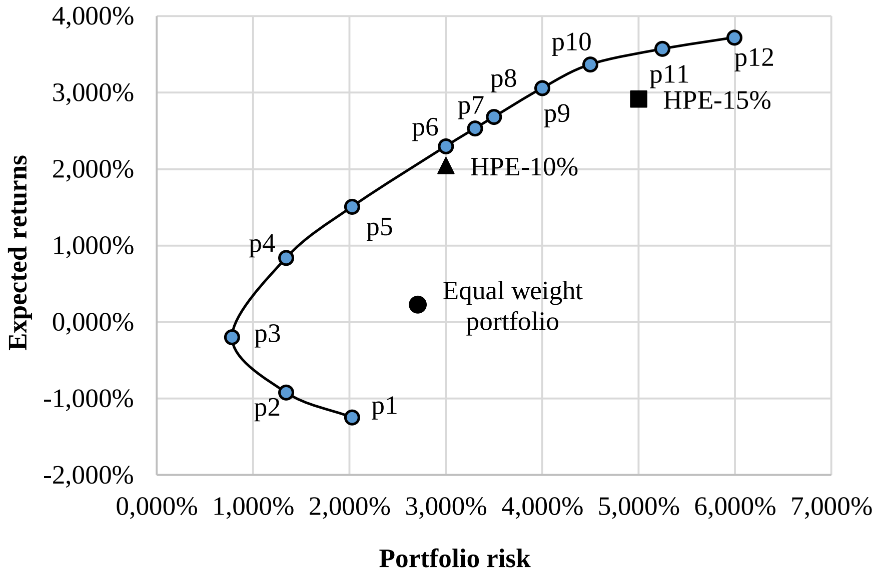
- In general, for risks greater than 1.00%, Russia has relatively larger expected returns. Easier for Russia to increase its indexes (and so its position in the GCI ranking) than the other BRICS countries.
- For risks greater than 4.00% the expected returns roughly reach a plateau.
- For risks greater than 1.50%, South Africa is the country with lesser returns.
- In the case of India, the efficient portfolios are restricted to a small range of risks. Its level of returns is relatively small comparing to the other four countries and therefore it will be harder to this country to improve its level of competitiveness.
- Brazil and China are in an intermediate region. Brazil surpasses China only in the region of risks greater than ≈ 4.25%.

Efficient frontier profiles for the BRICS



Brazil, a case study

- The optimal portfolio has three indicators :
- *Technological readiness (TER), Infrastructure (INF)* and *Market size (MKS)* weights are 42.61%, 32.22% and 25.17%, respectively.
- A policy maker may choose a different set in order to implement specific policies as to estimulate Health and Primary Education (HPE).
- Including in the optimal set10% and 15% in Health and Primary Education (HPE) indicator.



Efficient frontier and portfolios

Remarks

- Standardization is an efficient tool to implement sustainability policies.
- Measurements are necessary to implement sustainability standards
- The metrological approach brings to sustainability internationally adopted methodologies
- Aggregation is a tool that allows policy makers to have na overview of sustainability policies
- Aggregation is a tool to communicate sustainability results
- Uncertainty, sensitivity and risk analysis give relevant information on the sustainability indicators

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Thank you!
Obrigado

Other issues

Risk analysis

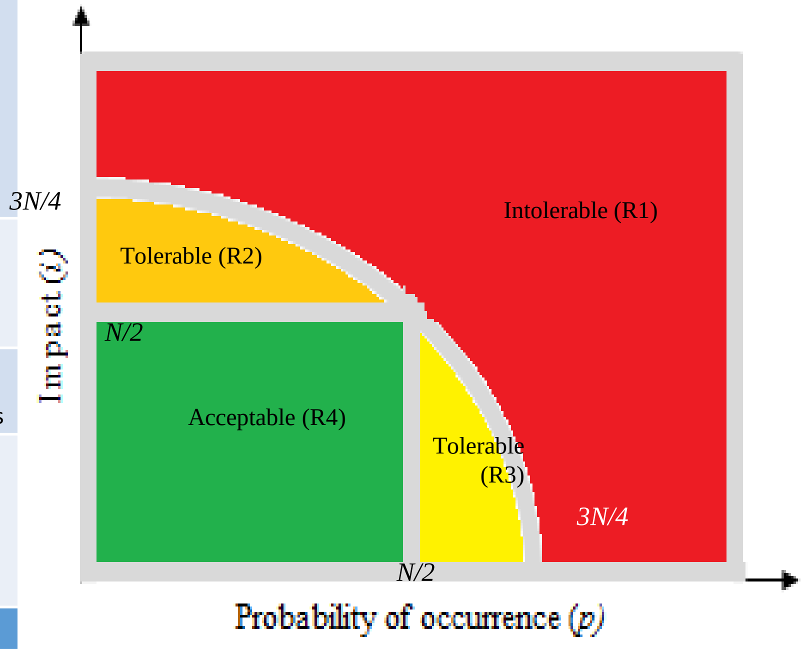
Application to sustainability of the *Logistic and Infrastructure* and T*echnology and Innovation* dimensions of the biodiesel supply chain (Santos et al. 2017).

- Risk can be defined as: "*the effect of uncertainty on objectives*" (ABNT/ISO 2009)
  "*uncertain consequence of an event or an activity with respect to something that humans value*" (Renn and Graham 2005).
  "*the probability that a certain kind of damage will be realized*"(Ball and Watt 2001).
- Despite the variety of definitions of risk, it is common sense that "*taking on risks is necessary to pursue opportunities for development. The risk of inaction may well be the worst option of all*" (World Bank 2013).
- The effect of uncertainties can be mediated by the actions to prepare for and confront risk.
- Although risk is not a physical entity that can be directly measured, it can be estimated from the effects that it produces (for instance, in the stock market one of the most commonly used absolute risk metrics is standard deviation).
- This requires risks to be identified, assessed and controlled, i.e. managed to avoid its repetition.
- There are many similar approaches related to risk management in the literature
- Classifying risks is the most controversial step of the process for their identification and prioritization.
- In general, risks can be classified in "*acceptable*" (very low risks; additional efforts to reduce are not perceived as necessary), "*tolerable*" (risks that demand limited additional efforts) and "*intolerable*" (risks with large probability of occurrence and strong impacts) (Renn and Graham 2005)

Short remarks on evaluating risks

Vulnerability is an important concept in the context or risk management. **It is defined as the combination of the impact of a risk (*i*) on the objectives and the probability of occurrence of the risk (*p*)**. The largest the vulnerability, the largest the risk (UNESCO 2010). The functional relation among the parameters i and p is arbitrary.

Limits/Regions	Categories of risks (Regions)	Procedures to be adopted
$v \geq \frac{3}{4}N$	Intolerable (R1)	Immediate actions are required More resources are required Additional controls are required
$\frac{N}{2} \leq v < \frac{3}{4}N$ and $i \geq \frac{N}{2}$	Tolerable (R2)	Contingency plan to approach treats Consider more resources
$\frac{N}{2} \leq v < \frac{3}{4}N$ and $p \geq \frac{N}{2}$	Tolerable (R3)	Monitor; Maintain existing resources
$p < \frac{N}{2}$ and $i < \frac{N}{2}$	Acceptable (R4)	Maintain routine treatment Release resources Release controls
In the present work we assume a scale ranging from 0 to $N = 4$		



1- Construct a matrix of distances $D = (d_{jk})$

2- The probability of occurrence, p_{jk}, associated with an indicator j of country k, i.e, x_{jk}, may be obtained by comparing the distance d_{jk} with the sum of all distances of a given country k ($j = 1$ to m).

$$p_{jk} = \frac{d_{jk}}{\sum_{i=1}^{m} d_{ik}}$$

3- The estimation of the impact i_{jk} is obtained by comparing the same distances d_{jk} with the result of the sum of all distances of a given indicator j ($k = 1$ to n)

$$i_{jk} = \frac{d_{jk}}{\sum_{t=1}^{n} d_{jt}}$$

4- This procedure results in two matrices used to estimate vulnerability: one of probabilities of occurrence, $P = (p_{jk})$, and another of impacts, $I = (i_{jk})$, .

5-The concept of vulnerability is defined as the combination of probability of occurrence (i) and impacts (p) of risks (UNESCO 2010). The functional relation among the parameters i and p is arbitrary (examples: $v = i\,x\,p$; $v = \sqrt{i\,x\,p}$). In the present work, we define vulnerability as the radius of the part of a circle in the first quadrant of the Cartesian plane, centered in origin of the $i\,x\,p$ plane

$$v_{jk} = \sqrt{p_{jk}^2 + i_{jk}^2}; \qquad p_{jk}, i_{jk} \geq 0$$

6- Normalized in a scale from 0 to N ($N > 0$):

$$v_{jk} = N\sqrt{\left(\frac{p_{jk}}{p_{jk_{máx}}}\right)^2 + \left(\frac{i_{jk}}{i_{jk_{máx}}}\right)^2}$$

7- The total vulnerability of a country k is estimated as $v_k = \sum_{j=1}^{m} v_{jk}$. The vulnerability can be normalized into a scale from 0 to N through

$$v_{jk}^N = N\frac{v_{jk}}{v_{jk_{máx}}}$$

8- In order to compare the total vulnerability to risk, it is necessary to consider the different weights associated to each dimension, related to the supply chain. In the present work, we use the factor loadings, c_i

$$V_k = \sum_{i=1}^{p} c_i v_{ik}^N$$

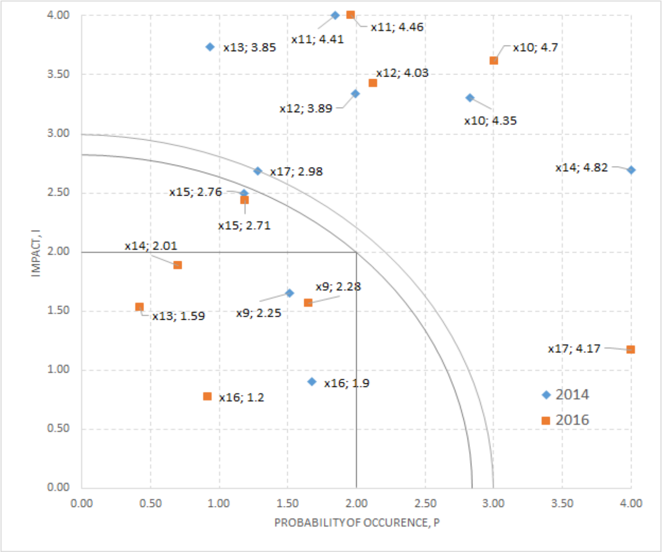
Results for probability of occurrence, impact and vulnerability: *Technology and Innovation*. Brazilian case

(a)

Codes	Indicators (year)	Units	Database
x_1	Availability of latest technology	1-7 (best)	(WEF 2014; WEF 2016)
x_2	Capacity for innovation	1-7 (best)	
x_3	Quality of scientific research institutions	1-7 (best)	
x_4	University-industry collaboration in R&D	1-7 (best)	
x_5	Availability of scientists and engineers	1-7 (best)	
x_6	Number of policies for R&D related to biodiesel	Number	(IEA/IRENA 2014)
x_7	Production process sophistication	1-7 (best)	(WEF 2014; WEF 2016)
x_8	Number of patents on biodiesel production per million inhabitants	Patents/millions of inhabitants [(a)]	(WIPO 2014); (Cepal 2011)

Codes	2014						2016				
	p^N	i^N	v^N	Category	Risk Region		p^N	i^N	v^N	Category	Risk Region
x_6	4.00	2.25	4.59	Intolerable	R1		4.00	2.61	4.77	Intolerable	R1
x_5	0.89	4.00	4.10	Intolerable	R1		0.97	3.98	4.09	Intolerable	R1
x_8	2.59	2.25	3.43	Intolerable	R1		2.59	2.29	3.46	Intolerable	R1
x_3	0.66	3.02	3.09	Intolerable	R1		1.03	4.00	4.13	Intolerable	R1
x_4	0.72	2.71	2.80	Tolerable	R2		0.83	2.94	3.05	Intolerable	R1
x_2	0.66	2.65	2.73	Tolerable	R2		0.87	3.28	3.40	Intolerable	R1
x_7	0.67	2.30	2.39	Tolerable	R2		0.86	3.08	3.20	Intolerable	R1
x_1	0.48	2.11	2.17	Tolerable	R2		0.73	2.71	2.81	Tolerable	R2

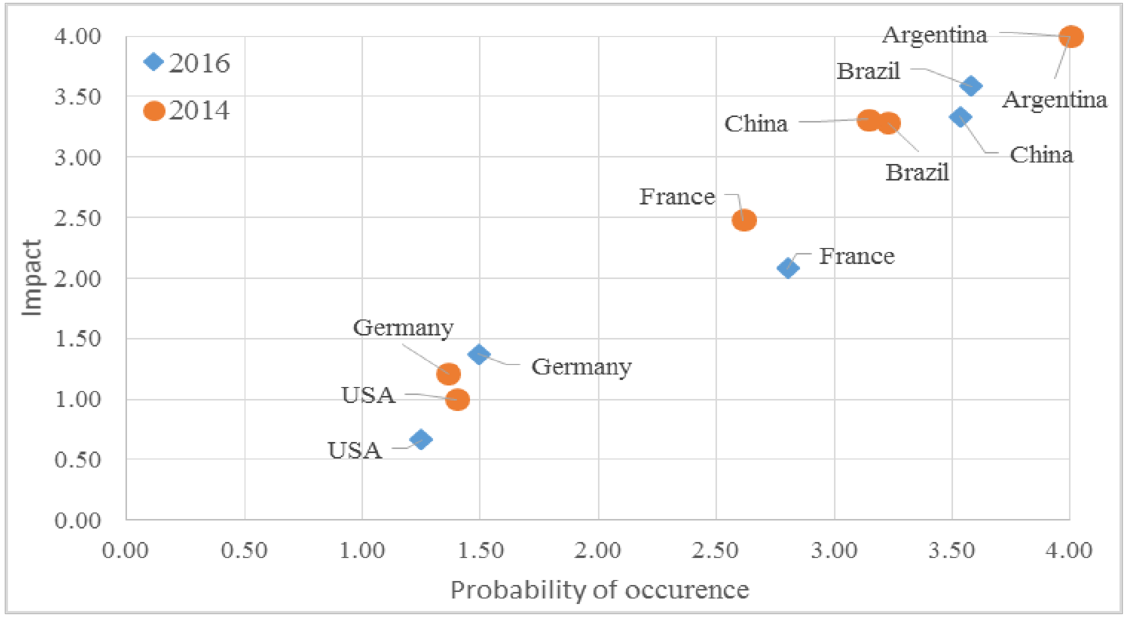
The lack of innovation is one of the most important problems of the Brazilian industry (World Bank 2016) with influence on the sustainability of the biodiesel supply chain, in particular and in the whole Brazil's productivity. According to World Bank, the nature of innovation in Brazilian companies is mostly "*catch-up*" (incremental) rather than "*frontier*" (or radical) innovation and characterized by more process innovation than product innovation. The main obstacles to more investment in innovation in Brazilian's companies are scarcity of financial resources, high costs of innovation, and lack of qualified personnel performing innovation activities (World Bank 2016) "



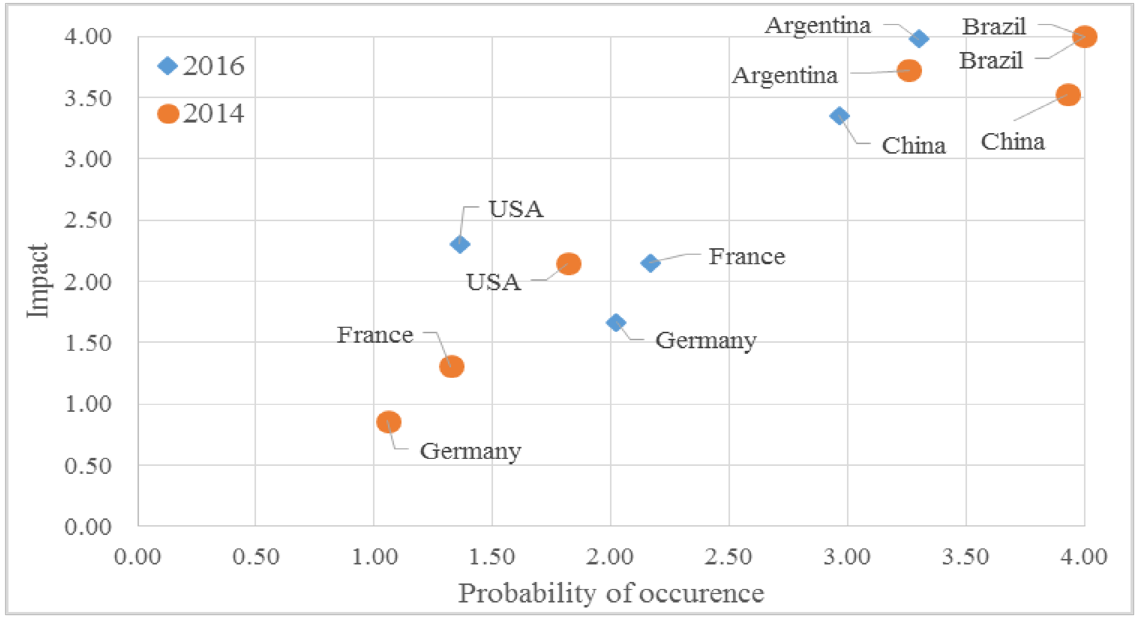
Matrix of vulnerability to risks associated to the *Integration, Logistics and Infrastructure* dimension of the Brazilian biodiesel chain. The distances between the origin to each point represents vulnerability to risk.

An example of a risk situation that should be subject of the analyses of decision makers concerns the indicator x_{17} (Individuals using Internet) shows that in 2014 it was situated in a grey region, near to the *R1* region, characterizing it as an escalating point. However, the results of 2016 indicate that no action has been taken in order to mitigate this risk: its vulnerability has increased about 40%, from $x_{17} = 2.98$ to 4.17.

(a)



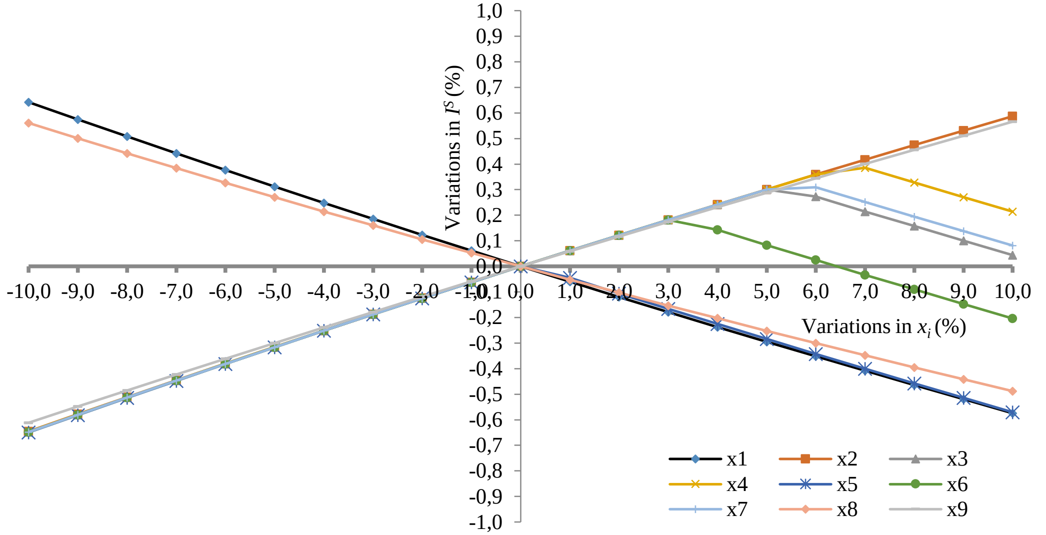
(b)



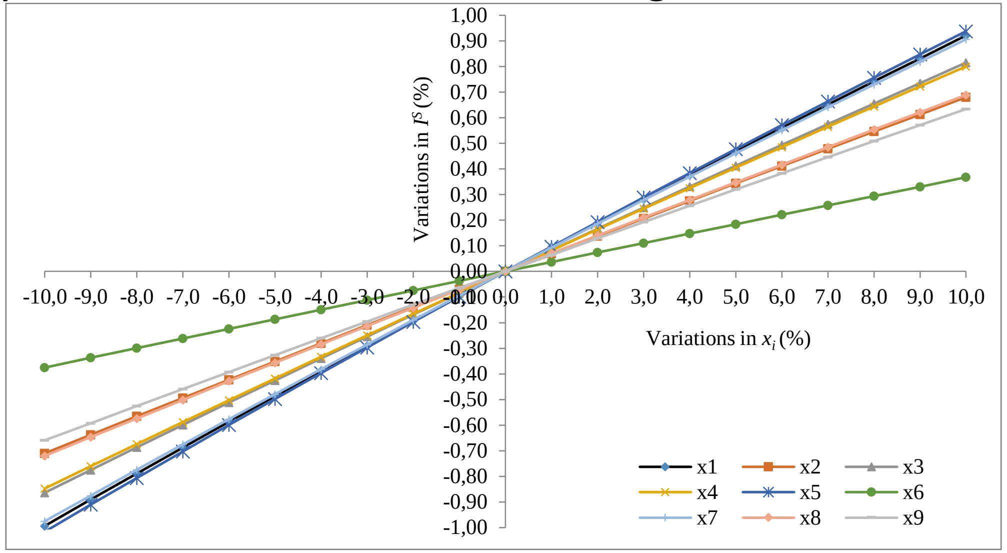
Variation of the total vulnerability to risks from 2014 to 2016 for the six selected countries:
(a) *Technology and Innovation*, (b) *Integration, Logistics and Infrastructure*

Sensitive analysis

- Figures show how the variation of each individual indicator contributes to the change in sustainability index.
- These results indicate how uncertainty and sensitivity analysis may provide a tool for a policy maker to choose the adequate indicators to act to improve or correct sustainability policies. presents
- Situations where the nonlinear behavior, may play an important role. For Germany, relative to indicators $x_i,\ i = 3,4,6,7$, there is a limit of benefits that may be obtained increasing the performance of these indicators. This limit is their reference values. Reaching this limit, increasing the value of the indicator decreases the sustainability index. the sensitivity coefficient involves the change in the sustainability index due to the chance in a single indicator



Variation in the Germany´s indicators affecting the Sustainability Index



Variation in the Brazil´s indicators affecting the Sustainability Index

The GUF methodology requires the knowledge of the first partial derivatives of the measurand I_j^S, the change, ΔI_j^S in the sustainability index,I_j^S, caused by a variation Δx_{ij} in the indicator. They correspond to sensitivity coefficients ($c_{ij} = \partial I_j^S / \partial x_{ij}$). GUM suggests that *"by holding all input quantities but one fixed at their best estimates, Monte Carlo simulation can be used to provide the probability density function for the output quantity value for the model having just that input quantity as a variable".* However, simply by holding all input quantities but one we obtain an exact expression for the nonlinear situation

$$\Delta I_{ij}^S = I_j^S(x_{ij}) - I_j^S(x_{ij}^0)$$