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A review on existing sustainable indices on efficient energy.

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Abstract.

This paper reviews the set of existing sustainability indices which are related to energy efficiency a critical factor in the actual moment, unveiling the main differences between indices, focusing the attention on those indices more adequate to policy making, finding the most adequate sources for indicators to compose the indices from a European perspective, showing the inconsistencies and limitations of most indices and the need of a simple index based on several complementary indices.

Keywords

Energy Efficiency, Sustainable, Index, Indicators, Economic, Energy intensities, Policy making.

1. Introduction

Energy efficiency has taken a crucial importance in recent times due to the need for adapting generation capacity to consumption needs. The European Commission recommended in March 2007 to promote energy efficiency worldwide and to set the goal 20-20-20: 20% energy savings, 20% of energy generation from renewable sources, 20% reduction in carbon dioxide emissions, all for 2020[1]

Efficiency must be combined with sustainable resources and processes in order to avoid the creation of new unrealistic solutions to the existing energetic challenges. Unsustainability and undesired effects will be found otherwise according to Jevons paradox [2].

Sustainability has been defined as the level of human activity and consumption which can continue into the foreseeable future, so that the systems which provide goods and services could persist indefinitely [3].

The first attempt to achieve a complex quantitative sustainability macro analysis, after Malthus catastrophic forecasts two centuries before, was carried out by the Club of Rome in 1970 and as a result "The limits of growth" was published. This study analysed a group of variables: population, industrial and agricultural production, pollution and the known reserves of some minerals establishing the limits of growth for the planet in 2070 decade if trends continue in the future.[4] These limits have been reviewed repeatedly along last years by the authors[5], and they provide a guideline for predicting the future in terms of sustainability. However it is already under discussion when would be the limit of growth mainly due to the unpredictability of new energetic crisis.

Moreover, Hubbert forecast that the global oil extraction limit was going to be reached on 2000. This limit has moved to a point close to our days due to the new oil extraction techniques and to the discovery and exploitation of new oil fields. However since the current global oil extraction level is close to the limit higher levels of pressure are detected in protected zones such as polar and marine deposits.[6-8]

The Brundtland report [3], written under the UN umbrella, emphasised the need to set policies for a sustainable development. These guidelines have to be defined by means of the use of quantitative indices.

Sustainability models study different dimensions of sustainability. Usually more important are social, economic and environmental dimensions [9]. However, other horizontal dimensions like technological progress and efficiency may be involved in the redefinition of the limits and the performance of the rest of the dimensions.

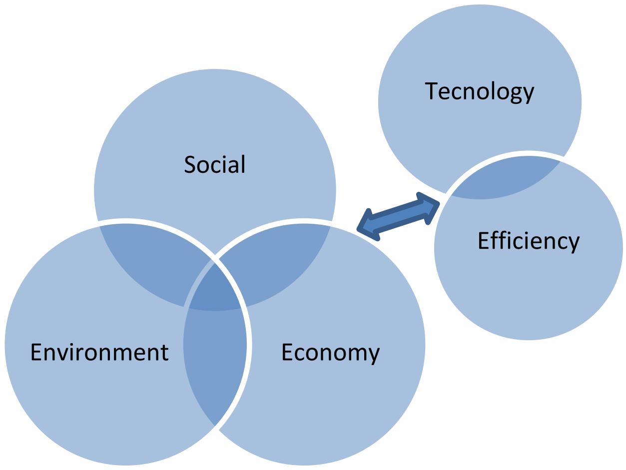

Figure 1. – Dimensions of sustainability

Nowadays, sustainability investigations have become more quantitative and include multiple simultaneous sustainability dimensions. As a general rule, a system will be sustainable if it is sustainable in all of its studied dimensions.[10]

Complex indices might look more precise at a first glance, however they could lead to contradictory results. Some of the key aspects for each index are its objective or subjective nature, the biases, the choice of the system boundaries, the data processing and measurement and the aggregation method that is utilised.

2. Sustainability indices

An impressive number of sustainability indices have been developed, with different dimensions [11-12] and different models [13].

As different as the indices may seem, many of them incorporate the same underlying data because of the small number of available global sustainability datasets. Most of the available data are collected by the United Nations and other international organisations [14].

Especially those indexes that are based on a predetermined set of data are difficult to find suitable for the determination of sustainability from an energy perspective. Although economic indicators, present in most existing indices, can be converted to equivalent energy and energy efficiency improvements in products or processes can be compared with existing products or processes provided that they take into account the damage caused to the environment and the life cycle of the product, these conversions are impractical when the input data cannot accurately be modified as they belong to nonlinear systems. Therefore, it will be in the interest to our study only those indexes of sustainability with a strong energy component, and of those, only the ones flexible enough from the point of view of the input data. Taking into account the last criterion it can be distinguished.

A. Satellite imagery-based Sustainability Index

The Satellite imagery-based Sustainability Index is built by analysing artificial night-time illumination as an indicator of the degree of modification of the environment and as an indirect emission measure of the greenhouse effect. This index is affected by improvements in artificial light production technologies. It makes sense if their results are accompanied with a study of the technologies used for night-time illumination and if the energy generation mix is known. It provides datasets to study sustainability in countries that do not provide another source of information (e.g. North Korea).[15-16]

B. Sparse Principal Component Analysis

Principal Components Analysis (PCA) is based on data reduction techniques and can be used to aggregate sustainability indicators at different scales. The main advantage of this index is that it could be a good base to aggregate indices focused on aspects of our interest. Moreover, it provides a dimension reduction as showed by Barrios and Komoto [17] works with a resulting reduction from 18 to 3 dimensions. This allows output data to be easily understandable.

C. Fisher Information Index

Fisher Information Index allow indicators aggregation, and is particularly focused on the measurement of stability along time. The index is calculated using the following equation:

$$I(<s>) = \int \frac{ds}{p_0(s|<s>)} \left[\frac{dp_0(s|<s>)}{d<s>} \right]^2 \quad (1)$$

In this equation, $\mathbf{p_0(s|<s>)}$ is the probability density,or the likelihood of observing regime *s* given $<s>$, which is the mean of s over time T.[18]

Processes or services that are measured using Fisher Information Index will be positively affected when implementing efficiency improvement policies (e.g. adapting existing power plants to combined cycles). The index allows the determination of the positive or negative influence of sustainability policies in cases that are not as evident as the previous example and therefore it helps to discover erroneous solutions.

D. Genuine Savings Index

Genuine Savings Index includes CO_2 emissions and resources depletion. These two variables are related to energy efficiency and the use of energy generation technology, which make it relevant to our review.

$$GENSAV = \frac{GDS - D_P + EDU - \sum R_{n,i} - CO_2 emissions}{GDP} \quad (2)$$

GDS is gross domestic savings, D_p is depreciation on physical capital, EDU is education expenditure, $R_{n,i}$is the rent from all sources of natural capital , minus damages from CO_2 emissions.[19]

However, this index is still under discussion as it does not take into account diverse effects such as import resources. As a result it provides a poor measurement of sustainability in the long term.

E. Sustainable National Income

The Sustainable National Income (SNI) aggregates resource consumption by different production sectors applying a general equilibrium model. Its main drawback is the leak of sufficient and accurate data to build the estimation. Although, it becomes an adequate instrument to measure the effects caused by efficiency improvements when datasets are available. [20].

F. Emergy analysis

Much of the available indicators of sustainability are redesigned in order to be used by economists. They perform the energy analysis by converting general resources consumption, goods and waste into economic values.

The emergy analysis is based on the study of energy converted to all goods, services, processes and waste that are involved in a particular activity. It is also based in the energy that is suitable for assessing the sustainability from an engineering perspective [21].

The emergy analysis fundamental unit is the emJ, a unit that represents the "Embodied energy" in Joules contained in a service or product. The emergy analysis does not represent the amount of energy consumed but its quality, . As a result it is able to accurately calculate the result of energy efficiency policies.

G.Ecological Footprint Index

The Ecological Footprint Index (EFI) assumes that the availability of natural resources and services provided by the ecosystem (e.g. pollution absorption) are the final limit on human consumption.

This index calculates the amount of energy used or consumed by a system. The resulting energy is represented as the area required by living organisms that hold the solar energy using photosynthesis (plants) to absorb the waste.[22]

Emergy analysis provides similar results in a modified version of Ecological Footprint Index named the carrying capacity-based Ecological Footprint Index.

Both indices are adequate to evaluate the impact of energy efficiency policies and to extract useful information from an engineering perspective since they are both based in energetic values.

3. Source of indicators for sustainability indices

In terms of policy-making from an energy efficiency perspective, the International Energy Agency developed and maintains since 1996 several indicators suitable to describe the most relevant energy consuming sectors: buildings, manufacture and transport. The IEA indicators consider the fuel mix energy generation to be able to find out if CO_2 reductions come from renewables or from a higher efficiency in any particular sector.

In 2002 an international partnership initiative on ISED was conducted by the IAEA in cooperation with UNDESA, the International Energy Agency (IEA), the Statistical Office of the European Communities (Eurostat) and the European Environment Agency (EEA), This initiative had the objective of achieving an optimization of efforts by leading international organizations to provide users with a single set of energy indicators that are applicable worldwide.

IEA indicators are complementary and included since 2002 in the ISED indicators. In ISED, indicators evolved and kept the IEA original idea of sectorial indicators and a high level of disaggregation.

In 2005, the ISED initiative achieved two mayor outcomes; development and publication of a set of energy indicators and corresponding guidelines and methodologies that can be used worldwide by countries in tracking development goals. They also perform a set of national case studies for testing and analysing the applicability, relevance and utility of these indicators in a number of selected countries.

The publication “Energy Indicators for Sustainable Development: Guidelines and Methodologies” is a multi-agency report representing a unique collaboration between five major international organizations with expertise in the field of energy indicators [23].

The ISED set of indicators is not easily comprehensive but addresses the most important energy-related issues of interest to countries worldwide. The energy indicators (Table 1) were selected based on consensus reached by the international organizations participating in this partnership.

Table 1. – Energy indicators for sustainable development

Theme/sub-theme	Indicator	Description
Equity/Accessibility	SOC1	Share of households without electricity or commercial energy, or heavily dependent or non-commercial energy
Equity/Affordability	SOC2	Share of household income spent on fuel and electricity
Equity/Disparities	SOC3	Household energy use for each income group and corresponding fuel mix
Health/Safety	SOC4	Accident fatality per energy produced by fuel chain
Use and production patterns/Overall use	ECO1	Energy use per capita
UPP/Overall productivity	ECO2	Energy use per unit of GDP
UPP/Supply efficiency	ECO3	Efficiency of energy conversion and distribution
UPP/Production	ECO4	Reserves-to-production ratio
UPP/Production	ECO5	Resources-to-production ratio
UPP/End Use	ECO6	Industrial energy intensities
UPP/End Use	ECO7	Agricultural energy intensities
UPP/End Use	ECO8	Service/commercial energy intensities
UPP/End Use	ECO9	Household energy intensities
UPP/End Use	ECO10	Transport energy intensities
UPP/Fuel mix	ECO11	Fuel shares in energy
UPP/Fuel mix	ECO12	Non-carbon energy share in energy and electricity
UPP/Fuel mix	ECO13	Renewable energy share in energy and electricity
UPP/Prices	ECO14	End-use energy prices by fuel and by sector
Security/Imports	ECO15	Net energy import dependency
Security/Strategic fuel stocks	ECO16	Stocks of critical fuels per corresponding fuel consumption
Atmosphere/Climate change	ENV1	GHG emissions from energy production and use per capita and per unit of GDP
Atmosphere/Air quality	ENV2	Ambient concentrations of air pollutants in urban areas
Atmosphere/Air quality	ENV3	Air-pollutant emissions from energy systems
Water/Water quality	ENV4	Contaminant discharges in liquid effluents from energy systems
Land/Soil quality	ENV5	Soil area where acidification exceeds critical load
Land/Forest	ENV6	Rate of deforestation attributed to energy use
Land/Solid-waste generation and management	ENV7	Ratio of solid waste generation to units of energy produced
Land/SWG&M	ENV8	Ratio of solid waste properly disposed of to total generated solid waste
Land/SWG&M	ENV9	Ratio of solid radioactive waste to units of energy produced
Land/SWG&M	ENV10	Ratio of solid radioactive waste awaiting disposal to total generated solid radioactive waste

The ISED set of indicators should be of reference to a macro analysis of the principal dimensions of sustainability. Economic indicators are highly correlated to energy generation, transportation and consumption as social and environmental dimensions depend highly on different forms of energy waste and disasters.

Eurostat produces a monitoring report, based on the EU set of sustainable development indicators (SDIs) that should be a complementary tool to ISED set when working or comparing exclusively between European countries [24].

ODYSSEE MURE is a project coordinated by ADEME (Agence de l'Environement et de la Mabrise de l'Energie) and supported under the Intelligent Energy Europe Programme of the European Commission. This project gathers representatives such as energy Agencies from the 27 EU Member States plus Norway and Croatia and it aims at monitoring energy efficiency trends and policy measures in Europe [25] using the same methodology and definitions as Eurostat.

The ODYSSEE-MURE project has 3 main objectives:

A. *Evaluate and compare energy efficiency progress by sector for EU countries and for the EU as a whole, and relate the progress to the observed trend in energy consumption.*
B. *Evaluate energy efficiency policy measures in the EU countries.*
C. *Monitor EU and national targets on energy efficiency.*

4. Problems with sustainability indices

Aggregation methods, as we have seen, are the basis of all available indices of sustainability. These methods cannot be scaled without ambiguity or losing consistency. This creates a different case mix of accumulated errors that cause the indices disagree among themselves or generate anomalous results [10].

The main causes of these problems must be known to understand the results provided by the indices and how to interpret and compare them. These are:

A. System boundaries.

1) Leakage of data amongst different countries.

2) Fluxes of goods between countries.

3) Fluxes of pollution through ecosystem between countries.

B. Data Inclusion.

1) The subjective choice of indicators included in the index defines what information is relevant and which not.

2) Some characteristics of a defined indicator may be overweighed if present in another indicator.

C. Standardization and weighting methods.

1) Standardization process defines the importance of indicators.

2) Weighting methods may differ between expert knowledge and community knowledge leading to different conclusions.

D. Aggregation methods.

1) Summing up does not reflect real sustainability conditions especially when adding indicators highly correlated.

2) When correlating instead of summing up systems may have very high sensitivity to changes in a few indicators while low sensitivity to big changes in others resulting in differences when comparing in an absolute manner.

E. Comparisons across indices.

1) There is low consistency when different countries are rated.

2) Indices are more useful if they contain information regarding the result of applied policies.

5. Conclusions and recommendations

This paper has identified the most representative indices for the study of sustainability from an energy perspective, studying the limits of indices.

The main characteristics of the indices are condensed in Table 2. The most relevant characteristics for our analysis are a high level of flexibility, dynamic perspective and to have the possibility of be based in energy efficiency. This criterion highlights several indices over the rest: Sparse Principal Component Analysis, Fisher Information Index, Emergy Analysis and Ecological Footprint Index.

The usual strategy for the measurement of sustainability has been to evaluate different indices and to generate a report based on the different results obtained from a qualified expert.

Although this strategy is viable for macro analysis, most of the micro analysis at a municipal or small corporate level makes it impractical as there is usually not a qualified expert available to draw conclusions from the results.

It is urgent to implement an easy highly comprehensible and intuitive sustainability index, created by combining several complementary indices and indicators. This will greatly help in policy making at macro and especially at micro level. The main goal will be that any private or public policy maker will be able to understand the results provided by this index.

Table 2. –Energy efficiency related sustainability indices

Index	Macro	Micro	Econ. based	Ener. Effic. based	Static/ Dinam
Satellite imagery-based Sustainability Index	Yes	Yes	No	No	S
Sparse Principal Component Analysis	Yes	Yes	Yes	Yes	S
Fisher Information Index	Yes	Yes	Yes	Yes	D
Genuine Savings Index	Yes	No	Yes	No	S
Sustainable National Income	Yes	No	Yes	No	S
Emergy analysis	Yes	Yes	No	Yes	D
Ecological Footprint Index	Yes	Yes	No	Yes	S

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