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Measuring Tools for Quantifying Sustainable Development

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Abstract
This work reviews the tools and methods used for quantifying sustainable development. The paper first reviews categorization of the tools based on weak and strong sustainability. It then provides critical review of the UN review of sustainability indicators and the methods for calculating the indicators, which include the environmental footprint, capital approach to measuring sustainable development, green national net product, genuine savings, genuine progress indicator, indicator of sustainable economic welfare and human development indicator on sustainable development. The benefits of standardizing the assessment tools for sustainable development would be seen through well directed policy leading to a balance between economy, environment and society where none is compromised to achieve greater results in the other. However, there is still no single method of assessing the sustainability of development that is widely accepted as suitable and all methods developed have inadequacies that prevent a true measure of sustainable development from being determined.

Keywords: Sustainability indicators, environmental footprint, genuine savings, sustainable economic welfare, human development indicator.

1. Introduction

Sustainable development is a concept first suggested during the Brundtland Commission (formerly known as the World Commission on Environment and Development) (1987) and developed through subsequent meetings and publications such as Agenda 21.

Sustainable development, as understood in the technical context, is currently defined as "balancing the fulfilment of human needs with the protection of the natural environment so that those needs can be met not only in the present, but in the indefinite future" (Larson et al., 1986). The UN (2008) defines development as "an increase in well-being across the members of a society between two points in time". Well-being and welfare are often used interchangeably, however well-being is a more complex notion than welfare, which is easily defined as "the benefit an individual derives from consuming goods and services over time". There is no single accepted definition of well-being as it is not just the health, but rather a complex combination of physical, mental, emotional and social health factors.

Sustainable development cannot be measured by the traditional economic model of increasing per capita income or gross domestic product (GDP) as this can mask situations where the poor are getting poorer despite increasing average GDP (UN, 2008). Any assessment of sustainable development should also take into consideration that sustainable is not always synonymous with desirable and so a measure of social desirability should also be considered.

Some critical assets to be accounted in measuring sustainable development include clean air, clean and available water, climate stability and unaffected natural biodiversity. A difficulty is encountered with the need to account for the contribution of capital assets to well-being outside the market place when discussing natural, human and social capital.

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There have been many and varied approaches to measuring sustainable development. Many involve the identification of indicators of sustainable development and methods for collating these values, which are often indexed to allow for comparison. A commonality to all methods is addressing the 3 aspects of our living, the environment, economy and society. For development to be identified as sustainable, it must address sustainability under each category.

Following is a review and comparison of many different approaches to measuring sustainable development. These include ecological footprinting, multi-criteria decision analysis, United Nations Human Development Index, green national net product, indicators of sustainable economic welfare, genuine savings, genuine progress indicator, pollution-sensitive human development indicator, sustainable human development indicator, French dashboard on sustainable development, United Nations commission on sustainable development, consultative group on sustainable development indicators, wellbeing index, environmental sustainability index, global scenario group. Other measures not discussed in detail include the living planet index, city development index, environmental performance index, environmental vulnerability index, wellbeing index and environmental adjusted domestic product.

Nourry (2008) compared the results of eight different methods of assessing sustainable development. The overall findings were that every method had limitations. Therefore the methods for sustainable development assessment require critical analysis as the final conclusions are specific and can be different for each method. Alfsen and Greaker (2007) state that most indicators fail due to the large number of indicators, often representing measurements without theory, only focusing, to a limited extent, on parameters of critical importance for sustainable development. Rather than focusing on critical parameters, these indicators often attempt to measure all aspects of development. Conversely, with single aggregate indicators it is difficult to determine the methodology for weighing and individual areas of importance. Alfsen and Greaker (2007) suggest a balanced measure of sustainable development should have:

- A clear plan for the utilisation of natural resources and environmental accounts.
- A broad theoretical framework based on comprehensive national wealth supported by capital accounts of relevant assets, conversion and end use accounts for analysis of policy impacts.
- A common framework is needed among countries of the world based upon a resource or capital approach.
- Authoritative national and global indicators based on the concept of national wealth are desirable.

The aim of this paper is to review the tools developed for measuring and quantifying sustainable development and provide critical assessment of their suitability as standard indicators for measuring sustainable development.

2. Weak and Strong Measures of Sustainable Development

Measures are categorised as weak or strong indicators of sustainable development. The difference between weak and strong indicators relates to the substitutability between natural capital and manufactured capital (Ayres et al., 1998). Weak measures of sustainable development were developed from the 1970's, with foundations in classical economic accounting models, adding a non-renewable natural resources as a factor of production component to economic growth. Specific rules were needed for stable welfare over time, with maintenance of economic and natural capital. This lead to the creation of the Hartwick (1977) rule which states that the economic gain from non-renewable resource depletion should be reinvested in produced capital, which has been generalised into a rule of weak sustainability, where the total net capital investment, or rate of change of total net capital wealth, is not allowed to be persistently negative. *Where total net capital investment is the gross investment in all forms of capital that are feasibly able to be*

measured, less depreciation or consumption of capital (Dietz and Neumayer, 2007). Another feature of weakly sustainable models is the elasticity of substitution between factors of production, based on the assumption that natural capital is similar to produced capital, which can be easily substituted.
Strongly sustainable models take the differing approach of natural capital being more or less non-substitutable. For this to apply, natural capital is broken down into four component functions of natural capital,
1. The provision of raw materials for production and direct consumption including food, timber and fossil fuels
2. The assimilation of waste products of consumption and production
3. The provision of amenity services including visual amenities of landscape
4. The provision of basic life support functions which human life and the first 3 capital functions all depend.
Therefore it is the fourth form on natural capital that is of the primary value and components 1-3 are of secondary values (Dietz and Neumayer, 2007). Accordingly, there may be some substitution allowable among the first 3 components, but no substitution with regard to life support systems. Brand (2009) explores the concept of critical natural capital and its relationship to ecological resilience, finding that ecological resilience can help to specify the ecological criticality of natural resources, which would be of benefit in understanding critical natural capital when seeking to assess strongly sustainable development.

3. Measuring Sustainable Development through Indicator Sets

3.1 Ecological/Environmental footprinting

The objective of ecological footprinting (also known as environmental footprinting) is to determine the area of required resources and for waste management to be able to sustain the human activity. The indication of ecological sustainability is calculated according to the agricultural land area and water required to support a given population at its level of consumption and resource efficiency and comparing this footprint value to the available biocapacity. Ecological footprint is a physical measure, using the unit global hectare, where 1 global hectare is 1 hectare of land with world average productivity. Since the Earth is a planet with fixed and finite resources, as the world population grows, the bioproductive area available per person is reduced (Nourry, 2008).
The ratio of the national per capita footprint to the globally available biocapacity per capita measures the minimum number of Earth-equivalent planets required to support the current human population if global consumption was at the country level. The number of required Earth-equivalent planets increases with global population and per capita consumption and decreases with increasing efficiency in resource application and total available biocapacity. A ratio less than or equal to one is a necessary minimum condition for sustainability.
Moran et al. (2008) measured sustainable development by applying environmental footprinting. In 2003, the average global per capita footprint was 2.2gha with a range from 0.5gha/cap in Bangladesh to 11.9gha/cap in the United Arab Emirates. In this same year the globally available biocapacity was 1.8gha/cap, a significant reduction from the 1961 biocapacity of 3.4gha/cap. Applying the ratio described above to the data from 2003 shows that the consumption was unsustainable, with 1.2 Earth-equivalents needed.
The indicator for calculating sustainable development based on ecological footprinting is appealing and its use widespread, but it is imperfect for the following reasons (Nourry, 2008):

- The construction of ecological footprint is criticised because multiple data are converted to land units and some of the economical activity is difficult to incorporate in this physical conversion
- The ecological footprint is assessed as a measure of weak sustainability because this measure

does not involve irreversibility or environmental promotion, while the proponents present it as a measure of strong sustainability.

• The positive ecological footprint indicates positive environmental performance, even when exceeding some critical ecological thresholds.

Dietz and Neumayer (2007) argue that it is inevitable for cities and highly urbanised areas to give a footprint greater than their actual size as such areas could never live within their own ecological carrying capacity. The same reasoning may also be applied to whole countries and regions. They argue then, in this sense that the only meaningful boundary for measuring ecological footprint is the global one.

Ecological footprint is an indicator of environmental load given as a support area. Other similar methods include embodied energy and emergy accounting (Agostinho and Pereira, 2013). Comparing the 3 methods, Agostinho and Pereira (2013) showed that the results of the environmental load varied widely according to the methodology used in its calculation, from 0.04 ha to 4.32 ha in the case studied. Emergy accounting showed the highest values and the authors conclude it gave a more eligible representation of the load given its global scale view.

Bastianoni et al., (2012) suggests a method for calculating the ecological footprint (EF) as:

$$EF_{TOT} = EF_{DIR} + EF_{INDIR}$$

Where EF_{TOT} is the total ecological footprint and the term EF_{DIR} is related to direct occupation of land for crop cultivation, as given by:

$$EF_{DIR} = \left(\frac{Q}{Y_W}\right) \times EQF_{cropland}$$

Where :

Q is the amount of a generic crop harvested (in tonnes);

Y_W is the average yield of production of product in question in the world as a whole (in tonnes) and

EQF (equivalence factor) is a scaling factor needed to convert a specific land-use type into a universal unit of biologically productive area (global hectare). EQF is evaluated annually as the ratio of maximum potential ecological productivity of world-average land of a specific type to the average productivity of all biologically productive land on Earth. A set of EQFs for each land type is published by the Global Footprint Network every year. In this instance, the Y_W and EQF of cropland are used.

The term EF_{INDIR} takes into account all indirect land uses and is the contribution of the n inventoried inputs required for crop production (like fuels, fertilisers, chemicals). It is given as:

$$EF_{INDIR} = \sum_{i=1}^{n} EF_i$$

$$EF_i = \sum_{j=1}^{6} ({}^{R}A)_i \times YF_j \times EQF_j = \sum_{j=1}^{6} \left(\frac{Q_i}{Y_i}\right) \times YF_j \times EQF_j$$

Where:

${}^{R}A$ is the total area required (in physical hectares, ha) given by the ratio of the quantity (Q_i) of a generic input (i) to the yield (Y_i);

The subscript I (=1, …, n) refers to the inputs inventoried;

The subscript j (=1, …, 6) indicates the six land-use types of national footprint accounts (i.e. cropland, grazing land, finishing grounds, forest, built-up land and carbon footprint);

YF_j is the yield factor for specific country and j-land type and

EQF_j is the equivalence factor specific for each j-land type.

3.2 Capital approach to measuring sustainable development

A capital approach to measuring sustainable development says that "sustainable development can be defined as non-declining per capita wealth over time" (Smith, 2008). To do so, it seeks to identify a set of indicators which best reflect the value, defined as the welfare effects, of the various components of national wealth (Alfsen and Greaker, 2007). Alfsen and

Greaker (2007) outline a set of 16 issues that the indicators are designed to address with 1 or more indicators per issue. This set actively sought to avoid controversial data where non-transparent judgments are necessary, however it is not possible to entirely avoid this.
The notion of a capital approach requires an extended notion of capital from an intergenerational perspective (Smith, 2008). It is accepted that human well-being is a function of the consumption of goods and services produced within the market, however many environmental goods and services and social interactions significantly impact well-being but are consumed at no cost. To widen the view of capital, five individual capital stocks are identified:
1. Financial capital- stocks, bonds and currency deposits
2. Produced capital- machinery, buildings, telecommunications and other infrastructure
3. Natural capital-natural resources, land and ecosystems
4. Human- an educated and healthy workforce
5. Social capital- functioning social networks and institutions

Of these, social capital is the least understood and controversial, with no single definition universally accepted.
Smith (2008) outlines a measurement framework to provide guidelines for expressing theoretical and possibly abstract variables from the conceptual framework into a set of quantitative statistical measures. Smith (2008) argues that while stable or growing wealth per capita is not a guarantee of sustainable development, it is a necessary minimum condition as declining per capita stocks will deteriorate over time meaning that sustainable development is not possible.
The most controversial aspect of a capital approach is that a single unit of measurement must be applied, with the only obvious choice being financial unit value. This is problematic as it is difficult to comprehensively define all of the ways capital contributes to well-being. For those that can be defined, translating their values into dollar terms is difficult. The capital approach to measuring sustainable development is also subject to debate as to the ethics of valuation. A third consideration arises from the limited degree of substitutability among different types of capital. Where capital services are identified for which no substitute can be found, these are said to come from critical capital stocks. As it ***would not make sense to monetize*** all stocks into a single measure, a practical implementation of a capital approach cannot be based on money alone and separate measures must be given of critical capital stocks in physical units (Smith, 2008). Examples of agreed critical capital assets include:

- Stable and predictable climate
- Clean air
- High-quality water in sufficient quantities and
- Natural landscapes suitable for supporting a diversity of plant and animal life.

3.3 Green national net product

The green national net product (GNNP) is a measure used to calculate economic performance and indicates on the performance of national development and welfare. This indicator gives a value for the domestically produced goods and services. However, this measure does not account for the natural capital, while the human capital is only partially accounted (Nourry, 2008).
GNNP is calculated by estimating the national net products (NNP) by subtracting the depreciation of physical capital from gross national product (GNP). Then, adjustments are applied to take into account the specific environmental variables such as exhaustible, resources, renewable natural resources, pollution flows and discoveries. However, there is a disagreement on the rationale for the modifications and techniques used for these adjustments, as well as for the interpretation of GNNP. According to some, GNNP measures the maximum amount of possible consumption during a period that does not reduce the possibilities of future consumption.

Arguments against GNNP include:

- The instantaneous nature of the measure as GNNP does not indicate if the economic growth is sustainable.
- GNNP applies the current prices in the empirical work, which are neither optimal nor sustainable.
- Often average costs are used as marginal costs are unavailable.
- Few pollution flows are included due to lack of data on abatement costs.

Therefore GNNP is considered to be an indicator of weak sustainability. Repetto (2007) developed methods of estimating GNNP, using the following equations:

$$GNNP = GNP - Dp - Dn$$

$$Dn = RD + ED$$

Where:
GNP is gross national product;
Dp is depreciation of produced capital;
Dn is the depreciation of natural capital
RD is resource depletion and
ED is environmental degradation.

3.4 Genuine savings

Genuine savings is an index developed by the World Bank to assess sustainability of an economy by taking into consideration the human and environmental factors of the national economic accounting. Genuine savings is an extension of the Hartwick rule, which states that an economy is sustainable if savings are greater than the aggregated depreciation of human, man-made and natural capital.

The World Bank method for calculating genuine savings, which is now referred to as 'adjusted net saving' is:

GS = investment in produced capital – net foreign borrowing + net official transfers – depreciation of produced capital – net depreciation of natural capital + current education expenditures

Where net depreciation of natural capital is the sum of resource depletion and environmental degradation. Estimates of environmental degradation have been typically based solely on carbon dioxide emissions, with the recent addition of particulate emissions (Dietz and Neumayer, 2007).

According to genuine savings, most developing countries, dependent on natural resource exploitation, are unsustainable whereas results for developed nations do not indicate unsustainability. Genuine savings is a measure of weak sustainability (Nourry, 2008) because no limitations are imposed on the ability to substitute human, man-made capital for environmental capital, therefore it does not allow for threshold effects or irreversibility. There are also problems with the switch from theoretical to operational as the theoretical model assumes efficient growth path of the economy. Therefore the used prices must be optimal and sustainable, however, the current prices that are available for empirical work, but these are considered neither optimal nor sustainable. These limitations suggest that cautious conclusions should be drawn for the national sustainability based on genuine savings.

Methods to calculate natural resources depletion and damages from pollution are often criticised. Genuine savings is over-estimated as only the damage from carbon dioxide and particulate matter are subtracted, while other important environmental effects, such as biodiversity, water and soil are excluded.

4. Measures of Welfare

4.1 Genuine progress Indicator and Indicator of Sustainable Economic Welfare

There were some attempts in the past to correct GDP to a sustainable development indicator by integrating the environmental, social and governance variables. The gross progress indicator (GPI) and indicator of sustainable economic welfare (ISEW) are two examples of these efforts. The general concept is to include contributions to sustainability or welfare (for example household labour, volunteer work, personal consumption expenditures adjusted for income inequality) and subtract losses (such as the cost of environmental damages). GPI and ISEW differ based on the calculation methods and expenditures on health, education and the incorporation of cost estimates of welfare losses, such as the loss of leisure time or cost of underemployment. These two indictors are not strictly indicators of sustainable economic welfare as the cost of environmental degradation is not sufficiently incorporated.

A rise in the value of GPI or ISEW shows that national economic welfare is improving. Estimates for GPI and ISEW have decreased significantly in the last 20-30 years despite the GDP increasing. This shows that economic growth can reach a threshold beyond which it no longer supports, but contrary, it deteriorates the economic welfare.

The two primary limitations of these indicators are:

- There is no theoretical basis that supports them. The environmental and social adjustments do not seem to come from theoretical models but depend on ad-hoc justifications. Therefore, like GNNP and GS, empirical results depend upon the choice of valuation method.
- A sustainable development indicator should enable for the assessment of whether a country is on a sustainable growth path. ISEW and GPI do not give this since no benchmark value for a sustainable state exists.

GPI and ISEW give an indication of environmental and social conditions, while accounting for national development and welfare.

Other indicators of economic welfare are the sustainable net benefit index and the measure of domestic progress. A generalised calculation of sustainable economic welfare is given by Dietz and Neumayer (2007) as:

Sustainable economic welfare = personal consumption weighted by income + domestic labour + non-defensive public expenditure - defensive private expenditure – difference between expenditure on consumer durables – cost of environmental degradation - depreciation of natural resources + capital adjustments

Dietz and Neumayer (2007) question whether or not these sustainable economic welfare indicators actually measure sustainability adequately as what affects welfare does not affect sustainability and vice versa.

4.2 A "green" extension of human development indicator

So-called "green" extensions of the human development indicator (HDI) constitute a second indicator of welfare. HDI is compromised of the measures of human development, equally weighted; GDP per capita, life expectancy at birth and education level measured by adult literacy rates and enrolment rates in education. The validity of HDI as a measure of human development and well-being is criticised, either due to the fact that HDI is not reflecting human development accurately or to the construction and technical properties of the index. Such criticisms also carry over to the 'green' HDI.

The HDI already includes economic and social variables, an environmental measure is needed to allow HDI to be an indicator of sustainable development. Methods of environmental accounting include carbon dioxide emissions per capita, or an equally weighted "sustainable HDI" composed of 3 measures of environmental quality, namely air, water and soil quality. Whilst "green" HDI seems to assess sustainable development, there are limits of its computation and interpretation due to:

- The choice of environmental variable and its exhaustiveness is essential, it must represent all environmental threats. Therefore it is more relevant to use and aggregated and weighted ecological index.
- The choice of weighting affects empirical results, however this step is arbitrary.
- Inclusion of environmental degradation is not sufficient to indicate the level of achieved sustainability. No benchmark for a sustainable state exists. However, it is still better at measuring sustainability than GDP since ecological and social elements are considered.

Neumayer (2001) cristicises adding a green component to the HDI, suggesting the ability to incorporate assessment of sustainable development is already included in the index. He proposes the formula for an index (X):

$$X\ Index = \frac{(actual\ value - minimum\ value)}{(maximum\ value - minimum\ value)}$$

$$X = (Income, Longevity, Education)$$

$$HDI = \frac{1}{3}(Income\ index + Longevity\ index + Education\ index)$$

Constantini and Manni (2005) offer a different calculation method, taking into account education, social stability, access to resources (GNNP) and quality of the natural environment. The four values are added and averaged to give a single index, as shown:

$$SHDI = \frac{1}{4}\left[\left(\frac{x_1 - 0}{80 - 0}\right) + \left(\frac{1}{3}x_2 + \frac{2}{3}x_3\right) + \left(\frac{\log(x_4) - \log(100)}{\log(4000) - \log(100)}\right) + \left(\frac{x_5 + x_6 + x_7 + x_8}{4}\right)\right]$$

Where:

x_1 is the Tertiary gross enrolment rate;

$x_2 = (y_1 - 25)/(85 - 25)$, the Health index ($y_1$ is the life expectancy at birth in years);

$x_3 = 1 - [(y_2 - 0)/(25 - 0)]$, the Unemployment index (y_2 is the unemployment rate in percentage);

x_4 is the GNNP current purchasing power parity ($PPP) per capita;

$x_5 = 1 - [(y_3 - 0)/(0.015 - 0)]$, the Air pollution index (y_3 is tonnes per day per worker of NO_x, SO_2, NH_3, NMVOC, CO);

$x_6 = 1 - [(y_4 - 0)/(0.35 - 0)]$, the Water pollution index (y_4 is BOD emissions, in kg/day per worker).

$x_7 = 1 - [(y_5 - 0)/(1000 - 0)]$, the Soil pollution from agriculture index (y_5 is fertilisers, herbicides and insecticides used on arable land, kg per hectare) and

$x_8 = 1 - [(y_6 - 0)/(10 - 0)]$, the Energy index ($y_6$ is tonnes of oil equivalent consumed per year).

5. Conclusion

A significant amount of work has been invested in attempts to accurately measure sustainable development. The benefits of achieving this would be seen through well directed policy leading to a balance between economy, environment and society where none is compromised to achieve greater results in the other. Unfortunately, due to the all-encompassing definition of sustainable development, it is presently difficult and confusing as to where energy should be focused. There is not, as yet, a single method of assessing the sustainability of development that is widely accepted as suitable and all methods developed have inadequacies that prevent a true measure of sustainable development from being determined.

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