The role of policy for a more sustainable path: economic effects of sustainability indicators

Fabrizia Manzo

University of Naples 'Parthenope',
via Ammiraglio Ferdinando Acton,
38, Naples, Italy
Email: fabriziamanzo07@icloud.com

Abstract: The main aim of this paper is to focus the attention on the state of the art of the so-called *sustainability indicators*, i.e., that group of data, statistic values and guidelines useful to the qualitative or quantitative evaluation of environmental, social and economical conditions of a system under examination. In particular, we will try to establish the links between the effective application of these indicators in modern society and the role of policy in the development and assessment of laws to actualise the effective application. The structure of the paper has been made in three steps. First, we start from the concept of sustainable development. Second, we explain the main aspects of the most important sustainability. Finally, we tackle the limits of the actual application of the sustainability indicators and the implication of policy in this application.

Keywords: sustainable development; sustainability indicators; governance.

Reference to this paper should be made as follows: Manzo, F. (2022) 'The role of policy for a more sustainable path: economic effects of sustainability indicators', *Int. J. Technology Transfer and Commercialisation*, Vol. 19, No. 1, pp.45–68.

Biographical notes: Fabrizia Manzo graduated in Economical and Financial Sciences. She has a PhD in Economy, Statistics and Sustainability.

1 Introduction

In the modern world, the environmental protection cannot be more considered as a prerogative of the governments, or the symbol of ecologist groups, or the interest of restricted researcher groups.

We have to understand that environmental sustainability represents a radical mutation of everyday behaviour which involves each of us, at different levels, in all aspects of our life.

To achieve this goal, it is necessary to establish new behaviour criteria and new civic regulations, which can allow us to reach what is known for the last decades as the 'sustainable development'.

In this direction, scientists and governments of the most advanced nations are establishing a number of criteria to achieve this model, the so called 'sustainability indicators'.

The main goal of the sustainable development is thus represented by the possibility to encourage the governments of the most developed countries to face with the improvement of people living conditions respecting a wide range of environmental limits (Hak et al., 2007).

Some interesting data are explanatory of the present situation.

As for example, the average per capita consumption is 60,000 kg of natural resources per year, the weekly equivalent of 300 shopping bags filled with materials, or the weight of a luxury car (Hak et al., 2007).

To avoid more problems, due also to the population growth, we should make the use of the resources much more efficient by 2030, just to maintain the level of environmental degradation at present levels (Daly, 1997; McGlade, 2002).

In this way, we have caused many dramatic ecological changes in environment, which have led to the severe decline in the ecosystem services on which we rely (Ayensu et al., 1999; EEA, 2004; Gewin, 2002; Millennium Ecosystem Assessment, 2003).

For example, in Carpenter et al. (1985), is reported that in the lakes and the Sea of Azov, the increasing use of freshwater from rivers for domestic, industrial, and agricultural purposes made the salinity more and more intensified, causing a dramatic collapse of many fishing activities (Mee, 2001).

Many changes can occur without early warning signals.

That is why predicting which types of change will occur and over what time and space scales is fundamental to protect our environment.

Sentinel indicators – which could capture the dynamics of change – are essential in this context and may not coincide with any keystone species (Hak et al., 2007).

Another important aspect in the detection of the signals of environmental degradation are those related to different time and space scales.

In fact, long-term data series can help in predicting which responses are most likely to occur, but often they are represented by phenomena occurring at the margins or on local scales that give us the first clues of a critical situation.

Unfortunately, many models used to forecast and organise management intervention are not able to allow us to have a predictable framework, but they have only a limited number of future outcomes.

That is why it is so extremely important to understand which indicators can best provide early and maturing signals of change.

It is well-known that in the past environmental decision making was made on an ad hoc basis, solving each particular problem in isolation from others.

Overexploitation and misuse of resources must be limited or prohibited if they cause fundamental harm to environmental processes, but we need indicators of change to guide us along the way (McGlade, 2001).

In this perspective, it is clear that sustainability policies need to be supported by information flows from heterogeneous sources.

Whether these relate to economic, social, or environmental processes, they will need to be monitored in a transparent way, through electronic transactions across a wide range of communication media (Hak et al., 2007).

With the aim to deal with the main aspects of these problems, in this paper, we tried to collect the most important efforts made during the last decades in the perspective to achieve the possibility to build a better world, from a sustainable point of view, by means of the use of the indicators of sustainability.

To achieve this target, we have collected the most important articles regarding this subject written during the last years, attempting to sum up which are the most effective indicators of sustainability, in various contexts (both local and international) and which could be their best fields of applicability.

To depict this last aspect, it is clear that a fundamental rule is that played by the policy, which has the task of regulating the laws regarding these indictors.

In this way, we can finally claim that the indicators of sustainability represent an approach designed to meet the most important challenges of the sustainable development, especially because they derive principally from different frameworks, such as economic, natural and social analysis processes, which can, in some cases, be integrated among themselves.

Today, what is needed is an indicator framework in which to successfully monitor, learn, decide, and act, to be able to obtain a clear view of where current and proposed policies are taking society.

The main aim of this article is to assess the features of the existing indicators in order to assist those who need to apply indicators now and later.

Progress in sustainability indicator development is reviewed in the next sections in the following three domains: conceptual aspects, depiction and methodological applications and policy relevance.

We focus in particular on the connections between sustainability indicators and the sustainable development, in the framework of social, economic and environmental dimension, and in their application at national and international levels.

Finally, it is important to underline the fact that no one recommended indicator set, but different approaches that may be appropriate for particular uses.

2 The sustainable development

Expanding urbanisation is one of the leading problems of rapid population growth today (Dizdaroglu, 2017).

According to the United Nations' world urbanisation prospects report, 54% of the world's population resided in urban areas in 2014 and this number is expected to reach 66% by 2050 (UNDESA, 2014).

Naturally, in this prospect, the governments and the environmental societies have to develop a new concept of 'sustainability'.

As one of them, sustainability assessment (SA) is a methodology that aims to (Waas et al., 2014):

1 contribute to a better understanding of the sustainability and its contextual interpretation

2 integrate sustainability issues into decision making by identifying and assessing sustainability impacts

3 foster sustainable development policies.

Over the past decades, various methodologies were developed to perform SA focusing on different scopes (i.e., four pillars of sustainability) and scales (i.e., local, national and international) (Cinelli et al., 2014).

Many studies in literature point out the potential of this approach as well as emphasise a need for further research to gather reliable and accessible data at different geographical scales (Adinyira et al., 2007; Dahl, 2012; Dizdaroglu, 2015; Fredericks, 2014; Mayer, 2008; Moldan et al., 2012; Shen et al., 2011; Tanguay et al., 2010; Turcu, 2013; Yigitcanlar et al., 2015).

As it is widely recognised, the role of the sustainable development must be central, due to its vision and practice.

We can think to the concept of sustainability as the ability of a system to maintain itself permanently, in harmony with the surrounding environment; its main goal is to guarantee to everyone a dignified life in a dignified society.

It is essentially an anthropocentric concept of sustained intergenerational and intragenerational justice (Grunwald et al., 2001), claiming for humans the right to a dignified life (Littig, 2001).

As elaborated in Agenda 21, and as confirmed by the World Summit on Sustainable Development, the sustainable development rests on three fundamental pillars, i.e., social, environmental and economic, to which a fourth pillar, represented by the institutional one, was later added.

The best thing to do, in the management of the sets of indicators for the sustainable development, should be to use a minimum number of sets, but with strong inter-linkages among themselves, because in this way, they could be more effective in the communication of suitable information for policy and governments.

The ultimate test of any indicator effort is its suitability for a specific use and the impact the indicators have on policies and public awareness (Hak et al., 2007).

The economic, social, and environmental dimensions of sustainable development have different characteristic time scales, ranging from a long-term view of sustainability in general to the short-term perspective of policy and economic measures.

In fact, the economic systems evolve more fastly than the environmental systems, which instead have longer time ranges between their start and their effects on the society.

It is evident that it is very difficult to render acceptable the pillars of sustainability to the policy, who take in consideration only problem already present, and not only predicted; in this prospective, obviously, the main difficulty for the sustainability indicators is to present in a clear and undoubtable way the time scales of their application and effectiveness.

A similar effort has to be made in the presentation of the sustainability indicators at different spatial scales.

A local community can appear sustainable if it exports its unsustainable consumption or waste disposal, but the main challenge in this framework is that to make an average application of the sustainability indicators both on local and regional scales.

Frameworks may help to interrelate indicators from the natural and social sciences, to position both stock and rate indicators, and to identify inter-linkages (Hak et al., 2007).

According to the previous observations, it is clear that the main goal of the sustainable development it to establish a number of variables able to define an *ideal city*, namely a city built starting from the main pillars of the sustainable development.

A *sustainable city* can be defined by integrating four pillars: social development, economic development, environmental management and urban governance (Dujon et al., 2013; UNDESA, 2016).

Cities that are considered to be sustainable are those which (Dizdaroglu, 2017):

1. are socially inclusive in their growth
2. are environmentally responsible (i.e., have positive or at least minimal adverse impacts on the environment)
3. have a sustainable economy
4. are based on good governance principles (i.e., accountable, responsive, transparent, efficient and effective to the citizens, follow the rules of law, consensus oriented on policies and create opportunities for participation in decision making) (Graham et al., 2017).

The inter-linkages among the four pillars of sustainable development are evident in cities, which function as integrated systems (European Investment Bank, 2016).

As reported for example in Dizdaroglu (2017), during the last years, many countries began to construct new projects and manage new planning principles on the basis of the sustainable development indications.

There are a number of different principles which have helped different communities in developing their guides to build cities on the basis of the sustainable development.

These principles can be summarised under the main headings as follows (Dizdaroglu, 2017):

1. Sustainable urban form and design

   Good urban design contributes to sustainability by (Dizdaroglu, 2017):

   - using resources more efficiently
   - creating a sense of place identity
   - enhancing diversity of housing forms
   - developing different spaces for public and private services.

   In these ways, urban design and land use strategies work together to create a sustainable city (Burton et al., 2003; Dempsey, 2005; Frey, 2003; Milder, 2012; Williams et al., 2000).

2. Sustainable transportation

   According to many authors (Black, 2010; Dubey and Gunasekaran, 2015; Gudmundsson et al., 2015; Taniguchi, 2014; Tolley, 2003; Williams, 2005), it is possible to create more livable cities by means of the improvement of the urban transport system.

   As reported by Nathanail et al. (2016), some of these improvements include:

   - restriction of traffic zones
   - low emission traffic zones
   - low or light traffic zones
   - development of green transport model for freight, such as electric vehicles (vans, bicycles and so on)
   - use of information systems for enforcement.

3 Environmental protection and restoration

One of the principles of sustainable development is to protect and restore the existing species, habitats and ecosystems by creating ecologically valuable green spaces, designing green buildings and architecture (Dizdaroglu, 2017).

Green infrastructure is a valuable planning tool for protecting biodiversity, ecosystem functioning and services, promoting societal well-being and supporting green economy, sustainable land and water management (Ahern, 2007; EU Working Group on Green Infrastructure, 2016; European Commission, 2016; Haq, 2015; Mell, 2015; Sinnett et al., 2015).

4 Renewable energy and waste management

A sustainable city should use renewable energy resources, in an efficient way of land managing (Dizdaroglu, 2017).

Additionally, waste management practices such as landfill, incineration, biological treatment, zero waste, recycling-orientated eco-industrial parks, environmental taxes, law and policies are necessary for the achievement of sustainability (Davidson, 2011; Ekström, 2014; Goswami and Kreith, 2007; Maczulak, 2009; Twidell and Weir, 2015; UNIDO, 2016).

5 Social equity and environmental justice

The strategies for creating well-balanced and sustainable communities concern equitable and accessible transportation services for all residents, affordable and quality smart growth housing choices for people, benefits of a healthy environment, education and workforce training opportunities, public facilities and the involvement of a wide range of residents (Bullard, 2007; Campbell et al., 2015; Haughton, 1999; Wolch et al., 2014).

6 Economic development

Sustainable economy initiatives include cleantech business cluster, green business, sustainable real estate development, green investment, green jobs, green and cleantech business attraction and retention, green underserved communities and sustainability community engagement (Nixon, 2016).

7 Healthy urban planning

The guiding principles for planning healthy cities can be summarised, among the other things, in the access to fresh, nutritious and affordable food, incidental physical activity, housing supporting human and environmental health, improvement of public transport services, improvement of location of jobs to housing and commuting options, crime prevention, providing access to green spaces and natural areas, access to a range of facilities to attract and support a diverse population, environments that will encourage social interaction and connection amongst people, enhancing air quality (Barton and Tsourou, 2013; Barton et al., 2015; New South Wales Department of Health, 2016; Sarkar et al., 2014).

3 Sustainability indicators

In the framework of the environmental management, we can distinguish between *environmental indicators* and *sustainability indicators*: the *environmental indicators* are considered as measurable parameters showing the main conditions of an environmental system; while the *sustainability indicators* are considered as particular environmental indicators, which help to understand if the environmental conditions are part of fixed expectations and satisfy the main goals of the sustainable development.

Thanks to the environmental sustainability indicators, we are able to identify potential criticalities and make hypothesis about their solutions, for example using the greenhouse gas global emission data we can hypothesise a future scenario about climate-humankind interactions and allow the sustainability of policies regarding the hydrocarbon usage.

Each of the sustainability indicators can be considered as a meaningful variable of the examined system: this means that more complex the system is, more complex are the indicators used to describe it; the sustainability indicators are also connected to the main objectives of the sustainable development.

One of the main aims of the sustainability indicators frameworks is to obtain a set of information useful for the policy and understandable by the most part of society, in such a way to help people on deciding for what is the best for themselves and for the surrounding environment.

To achieve this goal, the sustainability indicators must reflect changes across significant areas of interest to society; indeed, they should be easy to communicate to the different users, to quickly interpret the different forms of information and better organise future policy actions.

Finally, we need a modular approach to this framework of sustainability indicators, introducing new types of modules, in such a way to take advantages from core infrastructures, to reduce the costs of application, to identify the risks and to integrate different processes into the cycle (Hak et al., 2007).

No one of the sustainability indicators could be considered as the best in respect of the others, but the most shared opinion is that different approaches could be appropriate for the different particular uses, also because most part of the sustainability indicators are broadly related to sustainable development, especially from the economical, social and environmental points of view.

Generally, sustainability indicators can be represented under the form of symbols (e.g., numbers, graphics, symbols, colours) designed to communicate a particular trend or property in a complex system.

Originally, the sustainability indicators were introduced from the necessity to provide information about a variety of factors, such as environment, economy, society and so on, factors which influence the environmental quality and the sustainable development; in this way, the sustainability indicators could lead political, social and economical analysis and decisional processes, in the direction of a more eco-compatible view.

The main characteristics of sustainability indicators are *accessibility*, *availability* and *scientific accuracy*, because they must be easily understood by everyone, and not only by technical users; in this way, they can be comprehensible, easily found from their sources and built on accurate scientific criteria.

During last years, several categories of indicators were assessed.

At present, hundreds of different indicators and indices have been suggested and are used in many varied contexts, by different users, for diverse purposes (Hak et al., 2007).

The sustainability indicators can be both quantitative and qualitative.

At the moment, most existing sustainability indicators are quantitative, because they are based on quantitative measurements of variables from which indicators and indices are derived; on the other side, this characteristic of quantitative indicators can exclude significant factors, which could represent some relevant issues (e.g., social cohesion, happiness or sense of place).

The social sciences are generating qualitative indicators, such as through surveys that can be answered on scales ranging from ‘not happy-non-compliant-disagree’ to ‘totally happy-compliant-agree’ (Hak et al., 2007).

Integrating these data with quantitative data remains a critical methodological issue, even if what is very important is the scientific quality standard for the measurement of the indicators, regardless of the quantitative or qualitative nature of them.

In this paper, we want to focus the attention on the main types of indicators, dividing the discussion about the title, the type and the source of the indicator (or set of indicators), their description and finally reporting the main comments discussed by the authorities about their reliability and their concrete application.

To establish a sort of list of the main sustainability indicators examined by the Scientific Committee on Problems of the Environment (SCOPE), based on the specific features of indicators both in general terms and in terms of some of the more widely known or innovative indicator sets, frameworks, and individual indicators or indices, the present state in indicator development is the following (Hak et al., 2007):

- Millennium Development Goals (MDGs) indicators
- UNEP Global Environment Outlook indicators
- structural indicators (European Commission)
- human development index (HDI)
- the UK headline indicators
- material flow analysis-based indicators
- energy flow analysis-based indicators
- ecological footprint (EF)
- living planet index
- environmental sustainability index (ESI)
- environmental vulnerability index (EVI)
- well-being of nations
- biodiversity indicators
- driving force-pressure-state-impact-response framework
- three-pillar versus four-pillar frameworks
- corruption perception index, freedom index

- well-being index
- emergy analysis
- exergy analysis
- environmental certification.

In the next part, we will explain the main characteristicsm and how to calculate three of the most important and most widely known sustainability indicators.

3.1 Ecological footprint

The EF is a measure of the total amount of ecologically productive land (forests, arable land, pasture sea, built-up area, etc.) required to support the consumption of a given population, at different scales ranging from individual and urban to the global scale, using current technology.

It is used by the scientific community and the media; it is strongly communicative on public and policy levels (raises public awareness efficiently); it shows low global and supranational policy relevance but stronger at local level.

Moreover, it uses ranking and communicates the urgency of environmental sustainability, emphasising effects of exported impacts.

This environmental accounting methodology was proposed by William Rees (ecologist at the British Columbia University of Vancouver, Canada) with Mathis Wackernagel (director of the Indicators Program of Redefining Progress, San Francisco, and coordinator of the Center for Sustainability Studies at Anahuac University of Xalapa, Mexico) in the early 1990 (Wackernagel and Rees, 1996; Wackernagel et al., 1997, 1999).

Since the EF measures the ecological services of a population, we can define it as the portion of carrying capacity necessary to that population.

Carrying capacity is the quantity of population or activity that an ecosystem can support without losing its intrinsic integrity.

The method is based on the following concepts (Tiezzi and Marchettini, 1999):

1 Space in the productive sense is necessary for energy and matter flows from the environment which is necessary for human life and activities.

2 Space in the ecological sense is necessary for the assimilation of waste: every productive process transforms a low entropy energy and matter flow into a high entropy one, generating pollution and waste that need to be absorbed.

3 Space in the physical sense is necessary for human settlements, roads, etc. which reduce the amount of ecologically productive land.

The methodology is based on the idea that to have a unit of energy or matter we need a given area of ecosystem to produce the resources for consumption and to assimilate wastes.

To determinate the total land necessary for a certain consumption model, every flow has to be expressed in terms of ecologically productive land.

Due to the complexity of the systems, we have to use some approximations, considering only major categories of goods (Tiezzi and Marchettini, 1999):

1 Average annual consumption pro-capita (*C*, kg/per) of a good (*B*) is the sum of production and import minus export.

2 Land pro-capita (*L*, ha/per) for each good *B*, is given by the average consumption (*C*) divided by the productivity (*P*, kg/ha) [formula (1)]

$$L_B = \frac{C_B}{P_B} \tag{1}$$

3 To calculate the *EF* of a single person, all footprint components in that category of bio-productive areas are added up [formula (2)].

$$EF = \sum_{B=1}^{n} L_B \tag{2}$$

4 To calculate the *EF* of a population (EF_P) the footprint is multiplied by total population (*T*) [formula (3)]:

$$EF_P = T * (EF) \tag{3}$$

The results are a rough estimate (underestimate) of actual productive land due to the number of approximations.

The EF is useful as a comparative tool: for example, comparing it with the real supply of bio-capacity of a region or with hypothetical EF derived from changing in life style of the same population.

Since the beginning of the last century, the area of ecologically productive land per person has decreased from 5–6 ha to only 1.5 ha.

At the same time, the EF per person of industrialised nations has exceeded 4 ha. These opposite trends show the difficulty of achieving sustainability: the EF of a man living in a rich country is 2 or 3 times greater than the available productive land.

Because the EF expresses the concept of sustainability in simple terms, it provides an intuitive scenario of the fundamental requirements for ecological sustainability.

3.2 Emergy analysis

Emergy analysis, in respect of other classical energy and economic analyses that only consider items that can be quantified in terms of energy or money (omitting most free inputs from the environment), is a thermodynamic methodology [introduced by Odum (Faculty of Environmental Engineering, University of Florida, USA) in the 1980s (Brown and Herenden, 1996; Marchettini and Panzieri, 1999; Odum, 1988, 1996; Ulgiati et al., 1994)] which considers both the economic and environmental aspects of a system by converting all inputs, flows and outputs to the common denominator of solar energy, the basic energy behind all the processes of the biosphere (Tiezzi and Marchettini, 1999).

To convert all environmental products and services to a common energy unit, they are evaluated in terms of equivalent solar energy, called ‘solar emergy’, defined as the solar energy directly or indirectly necessary to obtain a good or service (Tiezzi and Marchettini, 1999).

Energy exists in forms of different quality (for example, to obtain a few units of a high quality energy, such as electricity, many units of low quality energy as oil are required).

A conversion factor called 'solar transformity', defined as the equivalent solar energy necessary to obtain an energy unit (Joule) of a certain product, is used.

Emergy is an extensive quantity (it depends on system dimensions), and is measured in 'solar emergy joules' (sej); transformity is an intensive quantity measured in 'solar emergy joules/Joule' (sej/J) (Brebbia et al., 2007).

For products and flows more readily quantified in mass units, transformity can be expressed in sej/g.

Emergy analysis is useful to check applications of the first rule of sustainable development (Daly, 1996), the so called sustainable yield principle, that states that resources should be exploited at a rate compatible with their replacement by nature.

Emergy can be regarded as 'energy memory', the memory of all the solar energy necessary to sustain a system; the greater the total emergy flow necessary for a process, the greater the consumption of solar energy and thus the greater the past and the present environmental cost to maintain it.

Transformity is an indicator of quality because for processes with different products, the higher its value, the more complex is the process and the higher the quality of its product.

It is also an indicator of efficiency because for equivalent processes, giving the same product, the lower the transformity, the higher the efficiency of production.

It is then possible to calculate a set of sustainability indicators that can be used with emergy and transformity to evaluate the efficiency and environmental impact of the system and to give indications for its sustainable development.

Some of the most commonly used indicators are (Tiezzi and Marchettini, 1999):

1 The emergy yield ratio (EYR), given by the emergy of the output divided by the emergy of the inputs from the economic system.

   A value of this ratio close to one means that the system only returns the emergy that it received from the economy.

   This index is thus a measure of competitivity of a system to provide a certain product, or a measure of the ability of the system to exploit environmental resources, for a given economic input.

   The greater the EYR, the more efficient the system at exploiting natural resources for a given economic investment (expressed in emergy terms).

2 The empower density is emergy per unit area.

   Generally, we can find a high value of the empower density in concentrated emergy areas, such as the industrial sites; on the other side, this index is lower in undeveloped and rural areas.

   This index can also be seen as a measure of the carrying capacity of the system, beyond which the system is not sustainable.

3 The environmental loading ratio (ELR), given by the emergy of inputs form the economic system and from local non-renewable resources divided by the emergy from local renewable resources.

   A high value of this index reflects high environmental stress and/or a high level of technology.

This ratio increases when high technology is used or when less renewable inputs are used.

Many other sustainability indicators can be calculated and new indicators can be introduced to suit the characteristics of urban systems like cities or regions, it was useful to calculate the emergy/person ratio, namely the emergy used in a certain area divided by the population (Tiezzi and Marchettini, 1999).

This ratio is a measure of the standard of living, where for standard of living we mean the availability of goods and resources.

A high emergy pro-capita is usually an index of a high level of technological development, and if renewable resources are not used, of high environmental stress.

The wide set of possible indicators also increases the field of application of emergy analysis, so that systems of very different nature and different dimension can be studied, from the agricultural, to the urban ones, from the tourist, to the industrial and biological ones, from micro-systems to large dimension systems as cities, provinces, or even countries.

In Italy, some researchers have already carried out many studies to evaluate the sustainability and environmental impact of different types of systems using emergy analysis and its indicators.

Among these (Bastianoni and Marchettini, 1996; Bastianoni et al., 1997, 1998; Panzieri and Marchettini, 2001):

- studies of agricultural production systems
- studies of industrial production systems
- territorial analyses on provincial, regional and national scales
- studies on waste management systems
- analysis of tourism.

An advantage of emergy analysis is that the same methodology can be used to study very different systems and that emergy indicators are easy to interpret, presenting at the same time a valid scientific basis, when most of the currently methods used in environment and sustainability field usually lack in this characteristic.

In conclusion, emergy analysis is one of the most powerful modern methods to evaluate the sustainability and environmental impact of systems of different types, and can be used in the planning phase, and for the certification, improvement or restoration of systems, always in the optic of sustainable exploitation of natural resources and of an economic development able to respect the nature and to find an integration with the environment.

As explained before, for definition, emergy is the available solar energy previously used up, directly and indirectly, to make a service or product (Odum, 1971, 1983, 1996).

In fact, by means of the emergy evaluation, we can assign a value to some products and/or services; this conversion is made up by the use of an equivalent form of energy, namely the solar energy; finally, this equivalent energy represents the common denominator through which we can compare other different forms of resources, such as energy or matter (Brebbia et al., 2007).

The dimensional unit used for emergy is the sej.

The emergy of different products is assessed by multiplying mass quantities (kg) or energy quantities (Joule) by a transformation coefficient, namely transformity or specific emergy (Brebbia et al., 2007).

Transformity is defined as the solar emergy required, directly or indirectly, to provide one Joule or kilogram of a product or service.

Every time a process is evaluated, previously calculated transformities are used as a practical way of determining the emergy (sej) of commonly used products or services (Brebbia et al., 2007).

By definition, the solar emergy B_k of the flow k coming from a given process, for example housing, including the processes of building manufacturing, maintenance and use, is [formula (4)]:

$$B_k = \sum_i T_{r_i} \cdot E_i \qquad i = 1, \ldots, n \tag{4}$$

where E_i is the actual energy content of the i^{th} independent input flow to the process (e.g., materials, human work, solar irradiation, etc.) and T_{r_i} is the solar transformity of the i^{th} input flow (Brebbia et al., 2007).

There are two interesting examples of application of emergy analysis in two previous papers (Pulselli et al., 2004, 2006), where an emergy analysis of the urban system of Ravenna (north-eastern Italy) as a whole, and of buildings of the municipality of Ravenna are presented with a special focus on housing and on the trend of growth of the building industry.

3.3 Exergy analysis

Today, in an industrial world, the use of energy and other resources is organised in a network that is becoming more and more complex.

Technological improvements in matter and energy transformations are bringing more advanced solutions, however these solutions are more efficient.

For instance, we are able to use electricity derived from a nuclear power station for cooking, heating water or powering air conditioning systems.

The indicator ‘exergy’ represents a more effective way to verify how much a system is efficient and this control can be made in a single productive process or on a territorial level.

Exergy originates from classical thermodynamics, with applications in engineering, and more recently, in ecology and sustainability.

Regarding engineering and the exergetic analysis in chemistry, a fundamental work is that of Szargut et al. (1988), while exergy applications at a level of energetic planning in a territory were introduced by Wall (1990).

Jørgensen’s (1992, 1992b) group has developed, in recent years, the exergy application to ecological systems and in particular to aquatic ecosystems.

Recently, this approach was used to study agricultural systems as well.

Exergy is the maximum work that can obtained from a system when the system is brought from its present state to the so called ‘dead state’; the dead state represents a state of thermal, mechanical and chemical equilibrium with the surrounding environment.

The exergy formula is [formula (5)] (Tiezzi and Marchettini, 1999):

$$Ex = S(T - T_0) - V(p - p_0) + \sum_i N_i(\mu_i - \mu_{0i}) = T(S - S_{eq}) \quad (5)$$

where T, p, μ_i, T_0, p_0 and μ_{0i}, are respectively temperature, pressure and chemical potential of the system and of the surrounding environment, V is volume, N number of molecules and S is the entropy of the system, while S_{eq} is the entropy of the system at equilibrium.

Exergy is measured in Joule.

Natural resources are traditionally divided in energy and other resources.

Such a division is often arbitrary: for instance, wood can be considered whether a building material or a fuel; the same thing is true for oil.

All these aspects need to be considered on a common basis which cannot simply be reduced to economic value.

Exergy is the appropriate foundation to value the utility of a resource from a fruitor's point of view.

In general, the exergetic amount of an object can be calculated by multiplying its energetic amount by a conversion factor, always smaller than 1 because the work we can obtain employing a certain amount of energy is always smaller than its amount of heat.

Man uses a very small portion of exergy from Sun, for instance by farming (Tiezzi and Marchettini, 1999).

Only less than 20% of the total flow of resources, that converge towards productive systems of the industrial society, arrives at its final use.

Some of the enormous energy loss can be avoided by designing productive process in a different way.

For such a process, the measure of exergy is principally based on the sum of the individual parts of the system, that is, raw materials, energy use, final product.

This approach is based on the hypothesis that many properties and functions of a substance or a chemical can be considered, at least in a first stage, as the combination of the contribution of molecular atoms and bonds.

An exergetic analysis at a territorial level gives information on the level of organisation of a system related to balanced resources management (Tiezzi and Marchettini, 1999).

This information can be useful to identify the areas where technical improvements or conservation measures can be designed.

This kind of analysis is more effective if it is used as a mean of comparison between similar systems.

Recently, Jørgensen (1992a, 1992b) extended this approach to systems at a bio-ecological level.

His results considered the relations between entropy and information, using the genetic information of each species to account for the level of organisation of the ecosystem.

For example, the exergy of an aquatic ecosystem whose components are phytoplankton (P), zooplankton (Z), fish (F) and detritus (D), is given by formula (6) (Jørgensen, 1992a, 1992b):

$$\begin{aligned} Ex = RT\big[&P(1.79*10^6) + Z(3.15*10^7) + F(2.52*10^8) \\ &+(D + P + Z + F)\cdot 7.34*10^5\big] \end{aligned} \quad (6)$$

This formula is useful only to compare some ecosystems and evaluate the level of the system organisation.

In recent years, the ratio exergy/emergy was proposed as an indicator (Bastianoni and Marchettini, 1997).

This ratio measures the efficiency with which an ecosystem transforms its inputs (in emergy terms) in organisation.

Jørgensen (1992a, 1992b) showed that emergy and exergy had a very strong correlation in the development of natural selection.

This ratio can be useful to determinate the level of evolution of an analysed ecosystem and compare different natural and artificial ecosystems.

In Italy, the exergy analysis has been proposed as a validated approach in order to (Wall et al., 1994):

- Check the state of aquatic ecosystems such as lakes, rivers, wetlands, etc. using information from similar ecosystem studies realised by arca (Association for Environmental Research and Preservation).
- Measure the efficiency of a system, in particular farming, pisciculture and breeding of livestock.

3.4 Environmental certification

Environmental protection has recently become important in international policy mainly for what concern businesses because they must increasingly meet urgent requests for 'environmental quality' of products and services from governments and environmental associations and movements.

Environmental certification is also increasingly required by public administrations.

Until a few years ago, the responsibility for environmental conservation was delegated totally to public institutions, which had to reconcile environmental requests with production needs.

They often had inadequate operative and legislative instruments.

A new mentality is now growing in advanced countries.

Environment and development are no longer seen as competitors, but cooperation between all parties to find a solution to environmental problems is sought.

In this context was born the 'environmental certification', that is a voluntary participation in an environmental management program, the targets of which are observation of laws, rules and existing agreements, and continuous improvement of environmental performance.

To demonstrate the improving of the environmental efficiency is a fundamental requirement of every type of certification, the European regulations suggest that indicators of the status of the environmental management system be used.

The sustainability indicators introduced in this chapter, especially of those derived from emergy analysis of Odum (1996), are suitable for this purpose because they monitor environmental performance of a system and enable comparison with similar systems.

Unlike many other commonly used indicators, they are not only easy to interpret, but also have a strong theoretical basis and are both practical and scientifically rigorous.

Organisations wishing to undertake certification must consult experts in environmental problems, to identify the environmental impact factors that must be considered, to organise a correct environmental policy with well defined objectives, and to establish an appropriate environmental management system for the proposed objectives.

These experts must be up to date with the most advanced world research and modern methodologies.

This certification is thus particularly important for agriculture and food products.

Environmental certification has a wide range of applications, because not only industry can be certified, but also public structures such as towns or sectors as tourism.

Accommodation with particular characteristics of ecocompatibility is in increasing demand and some tour-operators indicate the environmental qualifications together with the category (Panzieri and Marchettini, 2001).

Environmental certification is therefore the concrete application of the scientific-theoretical methods summarised before.

It is the first step that organisations must make to show that they are operating with respect for the environment.

Environmental certification is not the final goal, but the definition of starting conditions that must be improved in the long way of environmental restoration and sustainable development.

In particular, lately environmental certification is becoming widespread for cities, especially of tourist, historical and cultural interest, that intend to demonstrate their effort in environmental field, to improve their environmental performances and promote, thus, their images.

4 The role of policy in the application of the sustainability indicators

As depicted before, the sustainable development represents one of the most important tools in the hands of the governments, to achieve a better future for our planet, due to its vision and practice; furthermore, it represents in a certain sense the need of humankind to achieve the perfect sharing of the benefits offered by our planet.

Democratic processes help to ensure access to all the dimensions of development, by moderating the relationship between the level of economic development as well as the institutional quality, even if globalisation could exert a negative impact on sustainable development (Langnel and Pathranarakul, 2021; Uzar, 2020).

It is clear that, if we want to live in a well-being society, with a dignified life, the new service economy must be based on a set of new access rights, which include, among the others (Hak et al., 2007):

- *Biophysical environment:* It includes access to the most part of land and natural resources, safe drinking water, housing and energy; this access must be guaranteed both from the environment and through adequate infrastructure, such as the technologies of a modern information society (computer, telephone, internet).
- *Economic dimension:* This dimension should include the possibility, for everyone, to contribute to the general wealth growth, both in the market economy, by means of employments, and in the non-market economy, by means of unpaid and voluntary work.

This approach will guarantee free access to markets for all potential producers, with non-discriminatory credit conditions.

Extending this economic dimension on an international level, it involves all the obstacles to the participation in the global economy, such as the trade barriers erected by the affluent societies.

- *Social dimension:* This dimension can be considered as a non-discriminatory education, in so far as it includes wide access to knowledge, information and experience; furthermore, it involves the opportunity to work and participate in social processes and free access to information technology.
- *Institutional dimension:* This dimension includes free access to information, by means newspapers, the internet and expertise, information exchange and decision making.

Thus, it is clear that democratic processes are particularly important in defining ends, means, and indicators of sustainable development, because they can ensure access to and inclusion of the diverse perspectives in a society.

Democratic representation helps these institutions to be transparent, accessible and accountable (Hak et al., 2007).

To obtain the democratic participation, it is important to improve the capacity of policymakers to understand and use sustainability indicators in a right way; than, we need to increase the public participation in the setting of targets for the sustainability.

This requires that the public administration understands the role and use of indicators.

The enlargement and review of the European Union sustainable development strategy provide a unique opportunity to reinforce sustainable development (Hak et al., 2007).

Generally, the main field of application of the sustainability indicators is related to the monitoring of the environmental systems and the actions regarding the development policies.

The monitoring of an environmental system can be extended from a local level (city or region) to a national or international level.

As for example, in more recent years, many efforts have been made in the perspective to realise the so-called *smart cities*, which could be considered as realities in which a collaboration between citizens and local governments to advance sustainable development is feasible (Tomor et al., 2019).

These projects are based on the development of a smart governance, which tries to include the citizen participation in connection with the governmental organisation, by means of a strong application of modern technologies (Tomor et al., 2019).

The attention can be focused to such parameters as those related to the atmosphere, the water, the soil, but also to other sectors such as economical sectors or the variations in the number of the global population; the main goal is that of reducing the energetic consumption and the environmental decay, by means of the replacement of the no-renewable sources with renewable sources and with defence of the biodiversity (Sun et al., 2019).

Thanks to these data, it is now possible to improve many factors, such as the livability, the buildability and the economical pattern of a system.

Together with these actions, we must consider also the political actions for the development, which are actions of local or national policies aimed to maintain a good level of sustainable development for the environment.

A good political action could be followed considering the different sustainability indicators and could concern many settings, such as:

- A better organisation of the public transport, aimed to reduce the CO_2 emissions and the acoustic pollution.
- The enlargement of cycle lanes, to improve the quality of the environment and that of human life.
- The protection of the green spaces still present in the urban centres, with the aim of increasing the green spaces for the improving of the environmental and urban biodiversity.
- The allocation of industries and farms outside of the urban borders, to guarantee the citizens' healthy, to reduce the polluting emissions and the damages for the ecosystem.
- A campaign of awareness to improve the waste differentiation for the citizens.
- A campaign of awareness to obtain a better commitment of the public institutions for the waste disposal, also by means of the production of energy coming from biomass combustion.
- A consistent reduction of electro-magnetic pollution, by means of the removing of phone repeaters from the roofs of urban buildings, and their outplacement in places far from urban areas.
- A commercial regulation regarding the reduction of trade of chemical products or of electrical appliances which produce high amounts of CFC, HFC and other types of greenhouse gasses.
- A commercial regulation regarding the reduction of the use of goods packaging, which are often excessive, very pollutant and very difficult to dispose.
- The promotion of the environment, the ecosystem and the cultural heritage, which could improve a great amount of economical and touristic advantages.

Other indicators are used in impact assessments or outlooks, when new policy proposals are being developed, and still others contribute to the mid-term to long-term monitoring of policy implementation (Hak et al., 2007).

Nowadays, the contemporary society discusses problems and their possible solutions in a very different way in respect of the past, when environmental problems were less urgent and could often be addressed by autonomous policies.

Blühdorn (2002) illustrates this when he writes that specific problems may have lost some of their identity in the traditional sense by merging into the larger pool of conflicting social interests, values, and preferences.

Recently, Ingold et al. (2019) have proposed a model of smart governance based on the development of six different governance modes capable of producing policies and solutions to deal with challenges arising from three key environmental problem characteristics (uncertainties, cause-effect mismatches and norm plurality).

Often, it can happen to overstate the role of sustainable development indicators and indicators as a whole.

In fact, they are tools for informing decision making, but it can be easily understood that even the best indicators may not be able to influence decision making processes if the area addressed is outside the political priority issues.

Public concern is a key driver in advancing policy issues, and the media are instrumental in raising public awareness (Hak et al., 2007).

5 Conclusions

In the framework of the management of the sustainable development, during the last years, there has been a useful progress, especially since the Rio Earth Summit in 1992, when an international indicator process was launched.

Since there, a number of indicator sets have been assembled by researchers in all the world; individual countries have organised their own indicator programs at the national level; and many aspects of sustainability have been studied with a more precise definition or measure through indicators.

Gradually, the methodologies developed in the field of the sustainable development became standardised, and policy decisions provide clear directions and unique targets to achieve.

However, major conceptual challenges remain, methods need further development, and more must be learned about the most effective ways to influence policy.

In fact, we have not still achieved a fully integrated sets of indicators or indices to support a self-regulating sustainability.

The author thinks that the main limit existing at the present in the development and application of the indicators of sustainability is represented by the fact that there is not an indicator better than the others.

As we have underlined in the previous sections, there is a number of different indicators, whose applicability is often limited to a single country, or to a single region, so that it is impossible to export its efficient in a different field of application.

The author thinks that one of the main objectives of the next years in the sustainable development is that of developing a list of the main characteristics of the different indicators, in such a way to allow the different governments to identify which is the best for them.

We must underline also the lack of a common international strategy to indicate a future direction for indicators of sustainability, including their environmental, economic and social dimensions.

We can consider two lines of strategy for the future development of the sustainability indicators.

The first is to let the status quo unchanged, but this behaviour will lead to the survival of the strongest countries in contrast with the weakest countries.

The second option concerns the implementation of a more strategic process of interventation and guidance.

Maybe, the best approach to be applied for the sustainability indicators is not a fixed approach to be applied in every context, but an auto adaptive implementation process, which allows the indicators to improve automatically along with the science of integrated indicators, frameworks and models advances.

We need to learn by doing. Each country or institution should select indicators and approaches suited to its needs, priorities, and means, having in mind the focus to develop an adequate policy able to lead the country toward an effective sustainable development.

However, major conceptual challenges remain, methods warrant further development, and more must be learned about the most effective ways to influence policy.

Anyway, we think that the present progress is now sufficient to allow the different countries applying the sustainability indicators at a national level; and to guarantee a comparison at international level among the different countries and institutions for the achievement of the sustainable development on a global scale.

A next paper could be written considering the most recent developments in the effective application of the indicators of sustainability at different levels, in different countries.

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