Estudios de Economía Aplicada

VOL. 38-1 2020 PP. 1-14

THE INTEGRATED FUZZY AND RELATIVE INDEX FOR POVERTY ANALYSIS: A REVIEW OF APPLICATIONS IN THE SOCIAL SCIENCES

GIANNI BETTI

Department of Economics and Statistics, UNIVERSITY OF SIENA, ITALY
E-mail: gianni.betti@unisi.it

ANTONELLA D'AGOSTINO

Department of Management and Quantitative Studies, UNIVERSITY OF NAPLES PARTHENOPE, ITALY
E-mail: antonella.dagostino@uniparthenope.it

FRANCESCA GAGLIARDI

Department of Economics and Statistics, UNIVERSITY OF SIENA, ITALY
E-mail: gagliardi10@unisi.it

CATERINA GIUSTI

Department of Economics and Management, UNIVERSITY OF PISA, ITALY
E-mail: caterina.giusti@unipi.it

Recibido: 27 de Diciembre de 2019
Aceptado: 21 de Enero de 2020

ABSTRACT

We review the Integrated Fuzzy and Relative (IFR) approach with the aim of showing how its universal and interdisciplinary features can be used to define composite indicators in different settings. This methodology, introduced for the purpose of measuring poverty by means of a multidimensional perspective and fuzzy logic, can be applied in different research frameworks. The article provides and discusses two practical examples of applications of this methodology in two different settings, namely, children's wellbeing and agro-food sustainability. The paper concludes with warnings that should be heeded by analysts, policymakers, and audiences when computing, examining or reading the results of this methodology.

Keywords*:* Multidimensional and fuzzy approach, poverty, composite indicators.

RESUMEN

Revisamos el enfoque Fuzzy Integrado y Relativo (IFR) con el objetivo de mostrar cómo se pueden utilizar sus características universales e interdisciplinarias para definir indicadores compuestos en diferentes entornos. Esta metodología, introducida con el propósito de medir la pobreza mediante una perspectiva multidimensional y una lógica fuzzy, puede aplicarse en diferentes marcos de investigación. El artículo proporciona y discute dos ejemplos prácticos de aplicaciones de esta metodología en dos entornos diferentes, a saber, el bienestar de los niños y la sostenibilidad agroalimentaria. El artículo concluye con advertencias que deben ser atendidas por analistas, responsables de políticas y el público al calcular, examinar o leer los resultados de esta metodología.

Palabras clave: *Enfoque fuzzy y multidimensional, pobreza, indicadores compuestos.*

JEL Classification Codes: I32, C18

1. INTRODUCTION

Composite Indicators (CIs) combine information from a number of different dimensions into a single index on the basis of an underlying model of the specific multidimensional concept that is being measured, with the goal of simplifying the concept's interpretation (Greco et al., 2019, Saltelli, 2007; Grupp and Mogee, 2004). For this reason, CIs have received substantial attention in many areas of economic, social and environmental statistics in recent years, as they represent a useful way to summarize and present information. Consequently, various methodologies have been developed to handle different aspects of issues related to their empirical implementation (Bandura, 2011; Liang et al., 2017; OECD, 2011, Kaklauskas et al., 2018; Giambona and Vasallo, 2014; Sanchez and Ruiz-Martos, 2018). The abstract concept of poverty and its multidimensional nature, which can be only partially captured by a single indicator (usually based on income or consumption), has offered an interesting setting for the development of different CIs in socioeconomic literature (Bourguignon and Chakravarty,1999; Anand and Sen, 1997; De Muro et al., 2011). Indeed, one should enlarge the range of indicators to encompass all necessary information on a matter that is generally multidimensional in nature (Atkinson and Bourguignon, 1982; Atkinson, 2003; Tsui, 2002; Alkire et al., 2015). However, monitoring one phenomenon – such as poverty – using several indicators can be a complicated task for the public, especially when a common trend for the indicators cannot be identified. Therefore, it would be easier for the public to understand the phenomenon using a single number that summarizes the necessary information.

The UNPD's Human Development Index (UNDP, 1990, 1997, 2010) is an example of such a summary number. It is computed using the simple arithmetical average of three dimensions (i.e., long and healthy life, knowledge and a decent standard of living). Furthermore, the definition of composite indices in multidimensional poverty analysis is sometimes complemented by the assumption that poverty is not only a multidimensional phenomenon but also a vague predicate that manifests itself in different shades and degrees (fuzzy concept) rather than an attribute that is simply present or absent for households in the population, as the traditional poverty approach assumes (Cerioli and Zani, 1990; Chiappero Martinetti, 1994, 2000). Over the last few years, both of these crucial aspects have stimulated the definition of CIs based on multidimensional and fuzzy approaches to poverty analysis.

The added value of this article is to review the literature on a specific multidimensional and fuzzy approach to poverty measurement (named the Integrated Fuzzy and Relative- IFR approach) introduced for the first time by Betti et al. (2006) on the basis of the seminal work of Cheli and Lemmi (1995). The aim is to demonstrate the universal and interdisciplinary nature of this approach.

In particular, this article examines previous writings on the IFR approach and attempts to develop an understanding of the role this methodology could play in defining CIs in several empirical settings. More specifically, this paper aims to achieve two goals. First, it aims to provide – from an analytic point of view – a summary view of the process used to build this CI. Second, it provides two practical examples of applications of this methodology in two different settings (i.e., children's wellbeing and agro-food sustainability). For each example, we highlight the warnings that should be clear to analysts, policymakers, and audiences when computing, examining or reading the results of these CIs. Indeed, the process of aggregating heterogeneous information is itself very challenging and subject to numerous threats.

The paper is divided into the following sections. The methodological section, which follows the present section, introduces a literature review and the steps required to build the IFR indicator within the framework of multidimensional poverty measurement; the next two sections provide examples of putting the theory into practice in two different settings; that paragraph is followed by a brief discussion and some final remarks.

2. THE IFR APPROACH

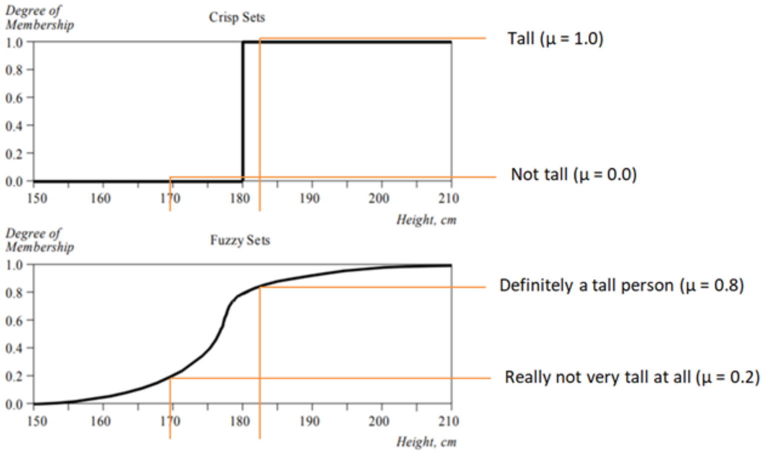
2.1 The fuzzy set concept

The fuzzy set theory, introduced by Zadeh in 1965, emerged in response to evidence that real situations are often characterized by imprecision, uncertainty and vagueness and cannot be properly described by the classical set theory, which represents reality in a simple true-false binary logic. Indeed, in the classical crisp approach, the sets are characterized by sharp and clearly defined boundaries, and thus, an item may fully belong or not belong at all to a set according to a bivalent condition (Dubois and Prade, 1980). In contrast, in fuzzy set theory, an item may belong to a set with partial degrees of membership between 0 and 1 and not only with extreme membership values of 0 and 1. A fuzzy set is hence an extension of a classical set. It is a collection of elements with a continuum of grades of membership, and it is characterized by a membership function that defines to what extent an element belongs to the set, that is, the grade of membership for the elements of a given set.

According to Zimmermann (1996), "if X is a collection of objects denoted generically by x, then a fuzzy set A in X is a set of ordered pairs $A = \{(x, \mu_A(x)|x \in X\}$ where $\mu_A(x)$ is called the membership function or grade of membership/degree of truth of x in A. It maps each element of X to a membership value between 0 and 1".

As shown in the commonly used example of tall people (Figure 1), the crisp approach identifies whether a person is tall or not in binary terms over the interval {0, 1}. In this case, tall men are those above 180 cm, and not-tall men are those below 180 cm. In contrast, the fuzzy approach describes how tall a person is through a membership function that defines how each height value is mapped to a membership value over the interval [0, 1]. All people belong to the fuzzy set "tall people", but their degrees of membership depend on their height. Indeed, the concept of "tall person" cannot often be sharply defined, as it may be ambiguous and may depend on each individual's perception.

Figure 1. Crisp vs fuzzy sets



Source: own elaboration from Negnevitsky, 2005

Therefore, fuzzy logic allows considering truth as a matter of degree in the whole interval [0, 1] rather than a simple {0, 1} dichotomy.

2.2 Literature review on the IFR approach

Fuzzy set theory has been shown to be a powerful tool to describe the multidimensionality and complexity of social phenomena; it contrasts with the classical crisp approach, which generally tends to overestimate or underestimate social dynamics (among others, for instance, Cerioli and Zani,1990; Vero and Werquin, 1997; Deutsch and Silber, 2005; Costa and De Angelis, 2008). Among these works, we are interested in those based on fuzzy logic according to the seminal works of Cheli et al. (1994) and Cheli and Lemmi (1995). In these seminal works, the authors have called their new methodology Totally Fuzzy and Relative Approach (TFR), thus modifying the approach named Totally Fuzzy Approach (TFA) used by Cerioli and Zani (1990). According to the TFR approach, each individual's propensity to poverty and deprivation is represented not only by monetary indicators, defined as the share of individuals better-off than the individual considered (1-F) or Fuzzy Monetary, but also by other supplementary nonmonetary variables (e.g., variables representing the observed items whose aggregation defines different latent dimensions of poverty), called Fuzzy Supplementary, thus overcoming the simple dichotomization of the population between poor and nonpoor in relation to a given poverty line. Betti and Verma (1999) proposed a new membership function starting from these seminal works and defined the propensity to poverty as the share of income received by individuals better-off than the individual considered (1-L).

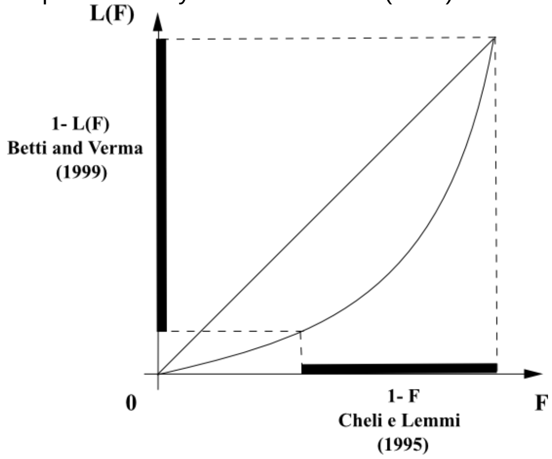
The two membership functions proposed by Cheli and Lemmi (1995) and by Betti and Verma (1999) have a graphical interpretation connected with Lorenz's curve (see Figure 2).

Over the years, several other works have been published based on this theoretical framework. They included further developments of the methodology and/or empirical studies. Cheli and Betti (1999) used the TFR approach to study poverty dynamics in Italy; the paper of Filippone et al. (2001) discussed the interpretability of TFR measures and their weighting system. Chiappero Martinetti (2000), Clark and Quizilbash (2002) and Lelli (2001) use the TFR method to analyze poverty or well-being according to Sen's capability approach (Sen, 1993).

In 2006, Betti et al. further developed the seminal work of Cheli and Lemmi (1995), introducing the Integrated Fuzzy and Relative approach (IFR). This approach combines the two membership functions proposed by Cheli and Lemmi (1995) and Betti and Verma (1999) into a unique one (see next section for further details).

Further contributions on the philosophy, mathematics and economics of the fuzzy set approach to poverty measurement can be found in the book by Lemmi and Betti (2006); additional contributions on the application of this methodology to poverty are from Belhadj (2011, 2012), Betti and Verma (2008), Betti et al. (2009), Verma and Betti (2011), Alkire and Foster (2011), Belhadj and Limam (2012) and Betti et al. (2013).

Figure 2. Membership functions by Cheli and Lemmi (1995) vs Betti and Verma (1999)



Finally, Betti et al. (2015) illustrate in detail that the IFR approach can be used to define CIs that can in turn be used to complement the traditional analysis of poverty, which is based on only a monetary variable, such as income or consumption. In particular, the authors draw on the IFR approach developed for the construction of a multidimensional index of poverty and deprivation. Recently, Verma et al. (2017) extended the fuzzy conceptualization to longitudinal poverty measures, and Betti et al. (2018) presented a methodology to estimate the standard errors of fuzzy measures.

2.3 A methodological note on the IFR approach

As we stressed in the previous section, Betti et al. (2006) introduced the so-called Integrated Fuzzy Relative (IFR) approach. The idea is to take into account a whole series of single items that are each intended to measure a particular aspect of poverty. When defining the membership function, three cases should be distinguished: dichotomous variables, polytomous variables and continuous variables.

Dichotomous variables are typically used for items that indicate whether an individual/household owns a given durable good or not; polytomous variables are qualitative items that may take more than two values, where higher values denote a higher risk of deprivation. Finally, income or consumption expenditures are good examples of deprivation indicators that are continuous.

In particular, the IFR approach works on a set of different nonmonetary indicators (e.g., dichotomous and polytomous variables), assumed to be the manifest representation of a restricted number of underlying dimensions of deprivation, in addition to a monetary indicator (e.g., a continuous variable) based on the equivalent disposable income.

Starting from this set of observed items, a membership function is defined. This function is some quantitative specification of individual propensity to poverty and deprivation depending on the other individuals included in the analysis. Accordingly, a membership function's value of 0 is always associated with the lowest risk of poverty and deprivation, whereas a value of 1 is associated with the highest risk.

Accordingly, the propensity to poverty and deprivation for any individual of rank j, that is, the degree of monetary and nonmonetary deprivation, is quantitatively specified through the generalized form of the membership function as follows:

$$\mu_{j,k} = \left(\frac{\sum_{\gamma=j+1}^{n} w_\gamma \middle| X_\gamma > X_j}{\sum_{\gamma=2}^{n} w_\gamma \middle| X_\gamma > X_1}\right)^{\alpha_k - 1} \left(\frac{\sum_{\gamma=j+1}^{n} w_\gamma X_\gamma \middle| X_\gamma > X_j}{\sum_{\gamma=2}^{n} w_\gamma X_\gamma \middle| X_\gamma > X_1}\right) \quad (1) = \left(1 - F_{j,k}\right)^{\alpha_k - 1}\left(1 - L_{j,k}\right)$$

$$j = 1, \ldots, n-1; \;\; \mu_{n,k} = 0$$

where X is the equivalized household income in the monetary deprivation or the overall score *s* in the nonmonetary deprivation (see below for details on the definition of *s*), w_γ is the sample weight of individual of rank γ and α_k (k = 1,2) are two parameters corresponding, respectively, to monetary and nonmonetary dimensions of deprivation. Each parameter α_k is estimated so that the mean of the corresponding membership function is equal to the at-risk-of-poverty rate computed on the basis of the official poverty line[1]. $\left(1 - F_{j,k}\right)$ is one minus the

[1] In other words, the α parameter re-scales the equation 1 and its estimation is based on a iterative procedure that stops when the estimated α parameter makes possible that the expected value of the membership function is equal to the share of people with disposable income below a threshold which is set at 60% of the national median equivalised disposable income (namely, the at-risk-of-poverty rate).

normalized income distribution function and indicates the proportion of individuals less poor than the person concerned (as in Cheli and Lemmi, 1995), while $\left(1 - L_{j,k}\right)$ represents one minus the value of the Lorenz curve for any individual of rank j and thus the share of the total equivalised income received by all individuals less poor than the person concerned (as in Betti and Verma, 1999).

It is worth noting that the computation of overall score s (namely, X for nonmonetary dimensions of poverty in Eq. 1) is the result of a number of steps developed sequentially. They include, first, the selection of meaningful and useful nonmonetary indicators for the analysis, which is a non-trivial task and is strictly dependent on the available data (see, among others, Guio 2009). Second, these indicators are transformed into the [0, 1] interval. Let c_l $(l = 1 \dots C_l)$ be the categories of each indicator l (l=1…L), ordered from the lowest value of deprivation to the highest. To convert each indicator l into the [0,1] interval, Betti et al. (2015) proposed the following transformation:

$$s_{l,j} = \frac{F\left(c_{l,j}\right) - F(1)}{F(C_l) - F(1)}, l = 1 \dots L, j = 1 \dots n \qquad (2)$$

where $c_{l,j}$ is the category of the l-th indicator, corresponding to the j-th (j=1...n) individual, and $F\left(c_{l,j}\right)$ is its corresponding cumulative function. Third, the underlying dimensions are identified through exploratory and confirmatory factor analysis. This means that the different latent dimensions H (h=1…H) of poverty and deprivation are computed directly from the data and they are not attributed *a priori* following any arbitrary rule. Then, within each dimension h, the procedure provides a method to compute the right weight to attribute to each single item. These weights are computed taking into account both the dispersion of a single score and its correlation with the other scores in a given dimension h.

Then, within each dimension h, the score $s_{\mathrm{h},j}$ of any individual j of the sample is calculated by a weighted mean of $s_{l,j}$ using the methodology of the Second European report on Poverty, Income and Social Exclusion (Eurostat, 2002). In other words, each score $s_{\mathrm{h},j}$ can be considered a CI specific to dimension h. Finally, the parameters α are estimated, and the overall score s is computed as the arithmetic mean of the scores for each dimension (see Betti et al. 2015, for further details). Accordingly, the score s represents the final CI provided by the IFR methodology.

3. THE IFR APPROACH IN A CHILDREN'S WELLBEING SETTING

In recent decades, the measurement of children's well-being has received growing attention, with a significant shift from the mere application of already existing indicators to the definition of measures specific to children. One core moment of this process was the release of the United Nations Convention on the Rights of the Children (1989), which shifted policy interest to childhood and contributed to a new conceptualization of children's well-being. The Convention raised concerns about children's quality of life, the spectrum of their well-being and their behavior and attitudes within their living environment (homes, schools, communities). From that moment, a new holistic view of children's development and well-being began to be widely accepted, giving equal weight to children's civic, political, social, economic, and cultural rights and stressing that these rights are interrelated, universal, and indivisible. Therefore, the idea that concepts of children's well-being must be multidimensional began to be shared in the international community (Ben-Arieh, 2008).

The recognition that multiple factors contribute to children's well-being highlighted the inadequacy of measuring child well-being through an income-consumption lens only. The criticism of using income as a proxy for human welfare in the research literature goes back to at least the 1960s, but Amartya Sen's capability approach (Sen, 1999), expanded upon by Martha Nussbaum, provided the foundation for the multidimensional approach (Gabel and Zhang, 2017). According to the capabilities approach, the well-being of individuals is the freedom of individuals to act in order to develop their capabilities in interconnected domains. According to Dean (2009, p. 262), "capabilities represent the essential fulcrum between material resources (commodities) and human achievements".

Several authors (Addabbo et al., 2014; Addabbo and Di Tommaso, 2008; Di Tommaso, 2007; Klasen, 2001; Biggeri, 2006, 2007) have proposed that children are subjects of capabilities and that the capability approach can be very useful as a framework of thought and as a normative tool in analyzing children's well-being from a multidimensional perspective. In these approaches, children's capabilities can be assumed to be vague predicates that manifest themselves in different shades and degrees. For these reasons, the use of fuzzy methodologies under the capability approach for the measurement of children's well-being has been explored by several authors from a theoretical and applied perspective (Chiappero Martinetti, 2006; Potsi et al., 2016). As stated by Chiappero Martinetti (2006), fuzzy set theory can be used to depict deprivation and well-being indicators in a gradual rather than a dichotomous manner.

Potsi et al. (2016) proposed the use of the IFR approach to define a multidimensional measure of children's well-being under the normative framework of the capability approach. In the study by Potsi et al. (2016), each capability is thus assumed to be a latent variable that is measured by multiple indicators. Such indicators are manifestations of the latent factor; thus, a variation in the capability determines a variation in all functioning measures (Figure 3). The indicators selected by Potsi et al. (2016) come from the Italian EU-SILC survey (European Union – Statistics on Income and Living Conditions), which in 2009 included a special section on children. That section included information relevant to defining their capabilities, such as their playing activities and their social interaction opportunities.

The EU-SILC 2009 indicators – although only potential proxies for capabilities – were selected by Potsi et al. (2016) as adequate to reveal aspects of the multidimensional deprivation of children aged 0-14, specifically for the construction of Fuzzy Monetary (FM) and Fuzzy Supplementary indicators (FS). Following the steps already presented in Section 2 – including exploratory and confirmatory factor analysis – the items selected for the FS indicators were classified by Potsi et al. (2016) into seven components that represent a respective latent capability (see Figure 3): the ability to play (PLAY), to be well nourished and clothed (NUTRITION & CLOTHING), to have an adequate financial budget at the household level (FINANCIAL), to have a social life (AFFILIATION & SOCIAL LIFE), to live in adequate housing (SHELTER) and in a good environment (SAFETY) and to be physically healthy (BODILY HEALTH). The FM indicator defined from EU-SILC is based on the equivalized disposable household income, which provides a reliable indication of the monetary well-being of the household.

The framework introduced by Potsi et al. (2016) – combining the use of the IFR methodology and the capability approach on EU-SILC data – was proven to be relevant to the easy measurement of children's well-being from a multidimensional perspective.

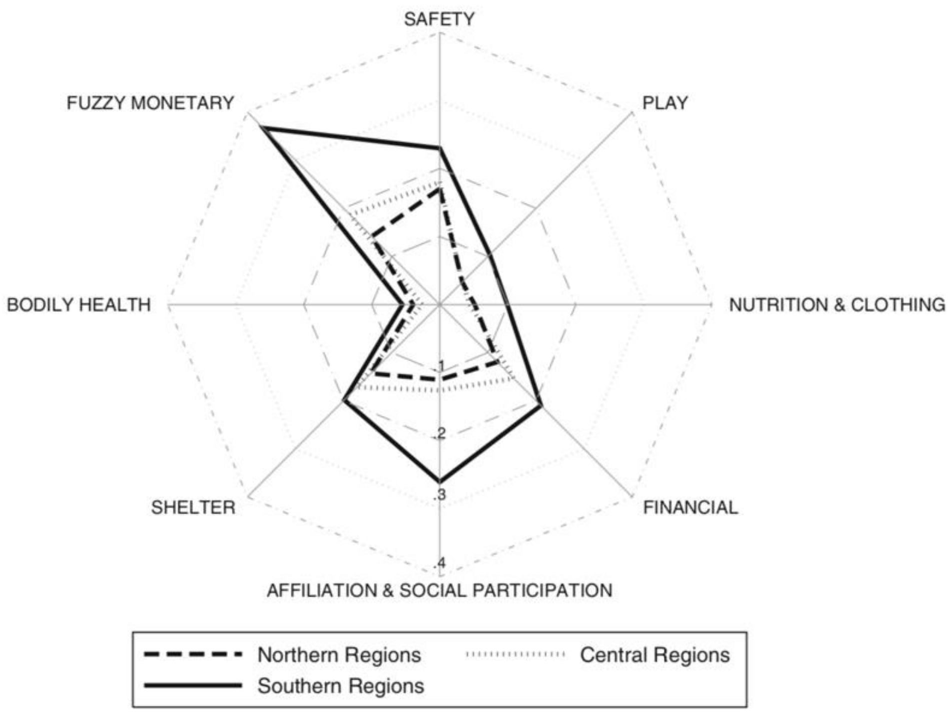


Figure 4 IFR multidimensional poverty measures by Italian macro-regions**.** Source: Potsi et al. (2016).

The authors presented important disaggregated levels of the fuzzy analysis, comparing children's well-being in Italy using three socioeconomic factors: single-parent household, household educational level, and macro-regions.

We recap here some of the main results obtained, disaggregating the analysis by the three main geographical areas characterizing the Italian territory: Northern, Central and Southern Italy. These results show the added value of using the IFR approach to measure children's well-being in a multidimensional framework: the degree of deprivation is expressed for each capability by a value in the range 0-1.

The scores observed for the monetary and nonmonetary domains are represented in Figure 4. First, the FM indicator allowed Potsi et al. (2016) to overcome the strict dichotomy between poor and nonpoor, preserving the richness of data information. Under the fuzzy approach, the degree of monetary poverty was higher for children living in southern regions (0.367) than in northern regions (0.141), whereas an average value (0.186) was observed in the center. Thus, a North/South dualism in Italy is primarily based on the financial and economic status for households with children. In northern regions, deprivation in the categories of shelter and safety seem to be more relevant than FM. Overall, the lowest values are observed in the bodily health domain. The value of the capability of play is more than double in the South in comparison with the other two macro-regions: 0.104 versus 0.047 in the North and 0.046 in the Center. Overall, the results suggest better performance for ‘‘inside’’ dimensions and worse performance for environmental quality and community life. Based on these findings, Potsi et al. (2016) suggested the existence of a sort of ‘‘dual duality’’ in Italian children’s quality of life: near the traditional North/South divide, a new internal/external life divide was highlighted by using the multidimensional IFR approach.

The results presented here can be expanded in many directions. First, since the EU-SILC survey is available for 32 European countries, the framework introduced by Potsi et al. (2016) can be used to compare children’s well-being among different EU countries. This issue was investigated by Potsi et al. (2017) and D’Agostino et al. (2018). In these works, the authors compared the FS and FM measured as presented in Figure 3 across different European countries – Portugal, Italy, Ireland, Greece, and Spain – to provide a description of children’s well-being at the beginning of the economic crisis (Potsi et al., 2017) and to investigate the gender differences in children’s well-being (D’Agostino et al., 2018).

A final important impact of the framework introduced by Potsi et al. (2016) is that it allows us to study the evolution of children’s well-being over time, as the children’s ad hoc module of the EU-SILC 2009 survey was repeated in 2014 and will also be repeated in future waves of the survey. Using this temporal perspective, D’Agostino et al. (2019) investigated the impact of the economic crisis on children's multidimensional wellbeing using the IFR approach in four European countries – Italy, Greece, France and the UK – considering 2009 and 2014 EU-SILC data.

4. THE IFR APPROACH IN AN AGRO-FOOD SUSTAINABILITY SETTING

The importance of the concept of sustainable development is widely recognized, particularly in the current era, when the environmental problems caused by human activities and the growth of social and economic inequalities are demanding serious solutions. Sustainable development is indeed a simple word but is – unfortunately – a very complex concept to be measure and summarize. However, there is definitely consensus on its multidimensional nature, which is based on three main pillars, namely, the economic, social and environmental dimensions of development (Teodorescu, 2015). The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides empirical evidence of the multiple goals (named SDGs) that are collectively an urgent call for action by all countries - developed and developing – through a global partnership. For these reasons, sustainable development represents an interesting setting for the implementation of the IFR approach.

In particular, in this paper, we refer to a specific application of this framework proposed by Casini et al. (2019). They used the IFR methodology for the construction of a composite multidimensional index for assessing agro-food sustainability in countries of the Mediterranean area (i.e. Croatia, Cyprus, France, Greece, Italy, Malta, Portugal, Slovenia, and Spain, Algeria, Egypt, Israel, Jordan, Lebanon, Morocco, Tunisia, and Turkey). In Table 1, the selected indicators (which refer to SDGs 2, 6, 12 and 15[2]) used in the analysis are reported. The choice of these indicators comes from the Partnership for Research and Innovation in the Mediterranean Area (PRIMA) programme, which proposed a shortlist of possible indicators that may be suitable for monitoring progress towards the sustainable management of water and agro-food systems in the Mediterranean.

[2] Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture; Goal 6. Ensure availability and sustainable management of water and sanitation for all; Goal 12. Ensure sustainable consumption and production patterns; Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

Figure 3 Indicators affecting Capabilities. Source: D'Agostino et al. (2018).

Table 1. Selected Indicators for the Fuzzy Multidimensional Index of agro-food sustainability

#	Indicator	Unit	Year
1	Population overweight	%	2016
2	Land use	%	2015
3	GHG emissions (total) per sq. km	t CO_{2e} /sq.km	2014
4	Cereal yield	kg/ha	2014
5	Agriculture value added	US$/worker	2016
6	Fertilizer consumption	$kg/ha_{arable\ land}$	2014
7	Crop water productivity	kg/m^3	2010
8	Annual freshwater withdrawal for agriculture	(% of total freshwater withdrawal)	2014
9	Population using safely managed water services (rural)	%	2015
10	Population using safely managed sanitation services (rural)	%	2015
11	Research and Development expenditure	% of GDP	2015

Source: Casini et al. (2019): Name of the indicator, unit of measure of the indicator and reference years of the indicator.

To weight and aggregate these indicators into a composite Fuzzy Multidimensional Index the authors develop a new method based on the IFR approach using an innovative conceptualization. The need for this methodological innovation derives from the idea that the indicators for the SDG framework may cover more than only one specific goal at the same time.

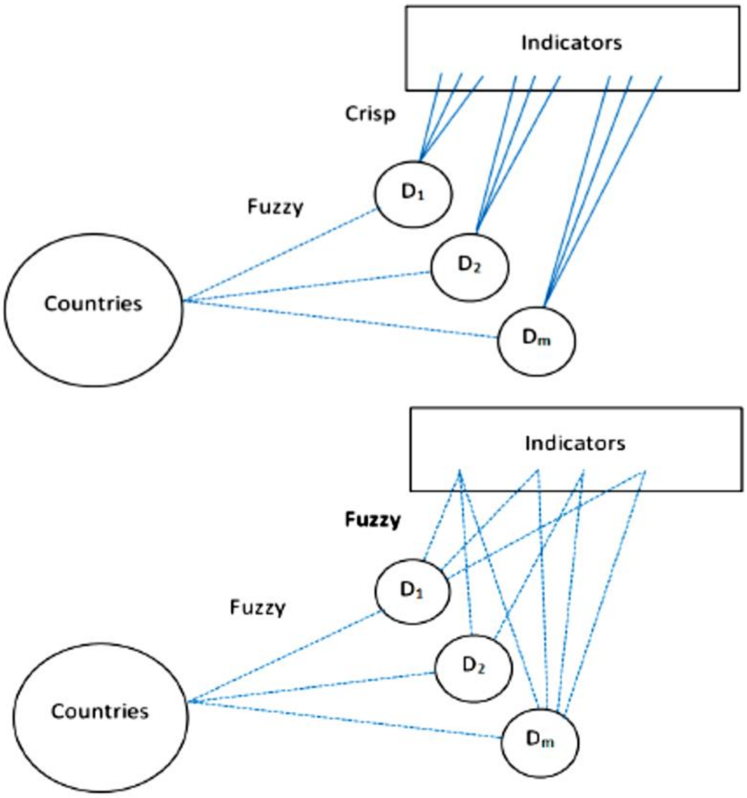
Figure 5 summarizes the difference between the IFR approach and the innovative IFR approach (henceforth I-IFR) used by Casini et al. (2019). In both approaches, the statistical units belong to all the dimensions identified according to a certain membership function, but in the innovative fuzzy approach, the indicators belong to all or almost all the dimensions with different degrees and no longer exclusively to a single dimension, as in crisp logic.

The agro-food CI is computed by adapting to this particular setting the step-by-step procedure of the IFR methodology presented in Section 2. Indeed, a different normalization was used in order to convert the indicators presented in Table l into the [0,1] interval, the procedure does not involve the computation of the α parameter that is poverty-specific, and the computation of the weights to be attributed to the single item is based on the factor analysis in order to allow that SDGs may belong to more than one dimension with a correlation represented by the estimated factor loadings (see also Belhadj, 2013 for a similar approach and for further details see Casini et al., 2019).

The CI based on the I-IFR approach allowed the author to present a rank of the 17 Mediterranean countries analyzed, where 0 indicates the best performance, that is, the best performance in terms of agro-food sustainability, and 1 the worst performance, i.e., the lowest agro-food sustainability (Figure 6).

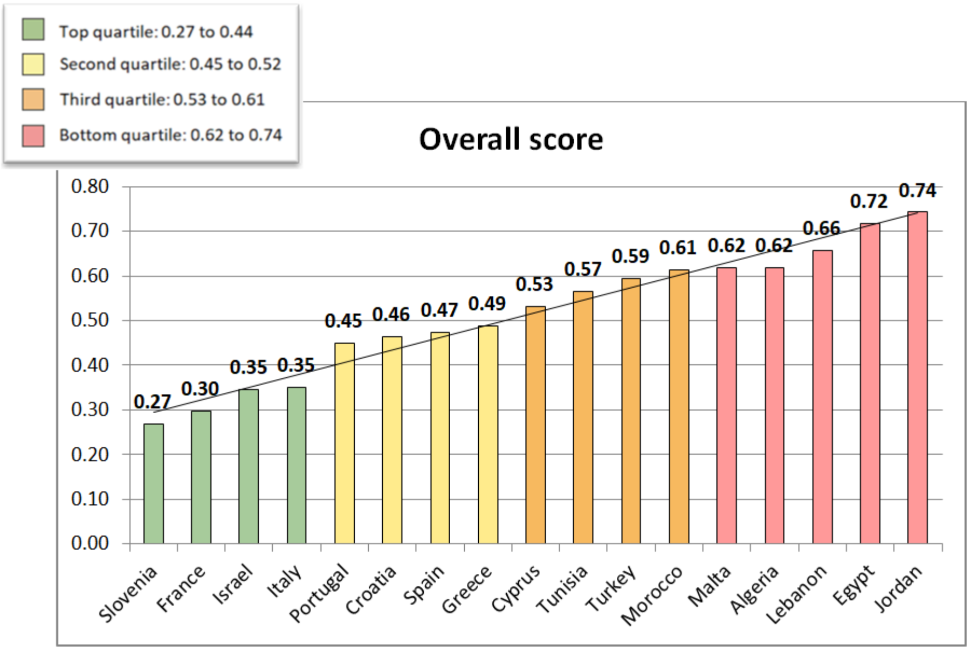
The authors then conclude that the agro-food system is generally more sustainable in northern than in southern and eastern Mediterranean countries, since the former countries perform better than the latter (except Israel) in the overall Innovative Fuzzy Multidimensional Index.

Figure 5. IFR vs I-IFR approach (bottom)



Source: Casini et al. (2019)

Figure 6. Histogram of the countries' agro-food CI.



Source: Casini et al. (2019)

5. DISCUSSION AND SOME FINAL REMARKS

The two applications summarized in the previous sections address critical issues of modern society and stressed that the IFR approach can be used to compute a fuzzy measure that preserves the richness of the latent concept under study. Obviously, the definition of composite indicators in both settings presented (children's wellbeing and agro-food sustainability) is not new. For instance, there are at least two relevant studies that produce an agro-food composite index in Mediterranean countries, namely, the SDG Index (Sachs et al., 2016, 2017) and the Food Sustainability Index that has been developed by the Barilla Center for Food and Nutrition Foundation (BCFN) in collaboration with the Economist Intelligence Unit (EIU). Nevertheless, the value of the IFR methodology can be summarized taking into account at least three very interesting features.

First, the latent dimensions of the phenomena under study are not predefined *a priori*; instead, they are identified by factor analysis and then validated by confirmatory analysis (as in the step-by-step procedure described in Section 2). Second, the aggregation of single indicators into a dimension is performed by a statistical-based weighting system that takes into account measurement errors, redundancies and other characteristics of such indicators, following a "prevalence-correlation" (i.e., taking into account both the dispersion of a deprivation indicator (prevalence weights) and its correlation with the other deprivation indicators in a given dimension (correlation weights)) method well established in the literature on composite indicators, which is not based, for example, on the subjectivity of a certain pool of experts. The variant suggested for the computation of the item weights in this particular sustainability setting also sounds very interesting and very similar to the approach used by Belhadj (2013). Actually, in this framework, as the authors explained, "*the dispersion of an indicator is not meaningful in this case; nor is the correlation of one indicator with the others of a given dimension, since we already consider a sort of "correlation weights", that is the factor loadings. Moreover, the indicators may not only be correlated with the others in a specific dimension, but also with those of other dimensions, according to the proposed membership function*".

Third, the CIs computed by IFR have the advantage of allowing the ranking of countries (specific segment of the population or periods) in one number while simultaneously maintaining the multidimensionality of the phenomenon under study using the CIs computed in each dimension. Therefore, this method should dampen the well-known critique of building composite indices, which implies losing a certain amount of information and producing results that are less transparent and in some way reintroduce unidimensionality (De Muro et al., 2011).

Fourth, other empirical applications of the IFR approach in other settings confirm the flexibility of this methodology for summarizing complex issues. For instance, Betti et al. (2011) applied this methodological approach when studying educational mismatch, namely, the lack of coherence between the required and possessed level of education for a given job. The concept of educational mismatch is indeed a very complex issue in which many causes converge and a definition based on a simple univariate measure can be too heavy a simplification of the phenomenon. Moreover, the dichotomous definition into two groups of workers can at the same time present a very misleading picture of the reality, as different degrees of membership of overeducation may exist that this simple indicator cannot take into account.

However, it is important to stress that the construction of composite indicators always involves stages where judgment must be made (i.e., the selection of sub-indicators, choice of model, weighting systems and treatment of missing values, etc.). Therefore, the composite indicator based on the IFR approach also suffers from some drawbacks, just like any other composite indicator (among others, Mitchell, May, and McDonald, 1995 emphasized that composite indicator measures without a sound theoretical background are flawed).

For instance, the major drawback of the study presented in Section 4 is related to the selection of sub-indicators. Indeed, the construction of a composite index to assess agro-food sustainability in the Mediterranean area is quite complicated since not all necessary data are readily available or updated in all countries, especially those around the southeastern seashores.

Furthermore, another limitation of this study consists of the simple membership function adopted (i.e., choice of the model); this is mainly due to the limited number of item indicators and often to the limited number of characters in each item. On the other hand, the major drawback of the study presented in Section 3 is related to the adult perspective of the single items used to measure children's well-being. Indeed, the perspectives of children can differ from those of adults.

Thus, we can assume that the composite indicator based on the IFR approach is a useful measurement tool, but only if each empirical analysis is constructed according to a transparent process.

REFERENCES

ADDABBO, T.; DI TOMMASO, M.L.; MACCAGNAN, A. (2014). "Gender differences in Italian children capabilities" Feminist Economics, 20, pp. 90-121.

ADDABBO, T.; DI TOMMASO, M.L. (2008). "Children capabilities and family characteristics in Italy" Paper Prepared for the 30th General Conference of the International Association for Research in Income and Wealth, Portoroz, 24–30 August

ALKIRE, S; FOSTER, J. (2011). "Counting and multidimensional poverty measurement" Journal of Public Economics, 95(7–8), pp. 476–487

ALKIRE, S.; FOSTER, J.; SETH, S.; SANTOS, M.E.; ROCHE, J. M., AND BALLON, P. (2015). "Multidimensional Poverty Measurement and Analysis" Oxford: Oxford University Press. Retrieved on 2 October 2015 from Oxford Scholarship Online: August 2015

ANAND, S.; SEN, A.K. (1997). "Concepts of human development and poverty: a multidimensional perspective" Human Development Papers, United Nations Development Programme (UNDP), New York

ATKINSON, A.B. (2003). "Multidimensional Deprivation: Contrasting Social Welfare and Counting Approaches" The Journal of Economic Inequality, 1, pp. 51-65.

ATKINSON, A.B.; BOURGUIGNON, F. (1982). "The comparison of multidimensional distributions of economic status" The Review of Economic Studies, 49, pp. 183–201

BANDURA, R. (2011). "Composite indicators and rankings: Inventory 2011. Technical report" Office of Development Studies, United Nations Development Programme (UNDP), New York.

BELHADJ, B. (2011). "A new fuzzy unidimensional poverty index from an information theory perspective" Empirical Economics, 40(3), pp. 687-704

BELHADJ, B. (2012). "New weighting scheme for the dimensions multidimensional poverty indices" Economics Letters, 116(3), pp. 304–307

BELHADJ, B.; LIMAM, M. (2012). "Unidimensional and multidimensional fuzzy poverty measures: new approach" Economic Modelling, 29(4), pp. 995–1002

BELHADJ, B. (2013). "New fuzzy indices for multidimensional poverty" Journal of Intelligent and Fuzzy Systems, 24, pp. 587–591

BEN-ARIEH, A. (2008). "The Child Indicators Movement: Past, Present, and Future" Child Indicators Research, 1, pp. 3-16.

BETTI, G.; CHELI, B.; LEMMI, A; VERMA, V. (2006). "Multidimensional and longitudinal poverty: an integrated fuzzy approach" in Fuzzy set approach to multidimensional poverty measurement, Lemmi, A. and Betti, G. (Eds.). Springer, New York, pp. 111–137.

BETTI, G.; D'AGOSTINO, A.; NERI, L. (2011). "Educational mismatch of graduates: a multidimensional and fuzzy indicator" Social Indicators Research, 103(3), pp. 465–480.

BETTI, G.; D'AGOSTINO, A.; LEMMI, A.; QUINTANO, C. (2009). "A parametric model for estimating fuzzy poverty measures and relative standard errors" Politica Economica, 25, pp. 279–299.

BETTI, G.; ÇALIK, G.; KARAKAS, M. (2013). "Multidimensional and fuzzy measures of poverty and inequality in Turkey at National and Regional Level" in Poverty and social exclusion around the Mediterranean Sea, economic studies in inequality, social exclusion and well-being, Bérenger, V.; Bresson, F. (Eds.), vol 9. Springer, New York, pp. 89–108

BETTI, G.; GAGLIARDI, F.; LEMMI, A.; VERMA, V. (2015). "Comparative Measures of Multidimensional Deprivation in the European Union" Empirical Economics, 49(3), pp. 1071-1100.

BETTI, G.; GAGLIARDI, F.; VERMA, V. (2018). "Simplified Jackknife variance estimates for fuzzy measures of multidimensional poverty" International Statistical Review, 86 (1), pp. 68–86

BETTI, G.; VERMA, V. (1999). "Measuring the degree of poverty in a dynamic and comparative context: a multidimensional approach using fuzzy set theory" in Proceedings ICCS-VI, vol 11, Lahore, Pakistan, August 27–31, pp. 289–301

BETTI, G.; VERMA, V. (2008). "Fuzzy measures of the incidence of relative poverty and deprivation: a multidimensional perspective" Statistical Methods and Applications, 17(2), pp. 225–250

BIGGERI, M.; LIBANORA, R.; MARIANI, S.; MENCHINI, L. (2006). "Children conceptualizing their capabilities: results of a survey conducted during the first children's world congress on child labour" Journal of Human Development, 7 (1), pp. 59–83.

BIGGERI, M. (2007). "Children's valued capabilities" in Amartya Sen's Capability Approach and Social Justice in Education, Walker, M.; Unterhalter, E. (Eds.). Palgrave McMillan, New York

BOURGUIGNON, F.; CHAKRAVARTY, S.R. (1999). "A Family of Multidimensional Poverty Measures" in Advances in Econometrics, Income Distribution and Scientific Methodology, Slottje, D.J. (ed.)

CASINI, M.; BASTIANONI, S.; GAGLIARDI, F.; GIGLIOTTI, M.; RICCABONI, A.; BETTI, G. (2019). "Sustainable Development Goals Indicators: A Methodological Proposal for a Multidimensional Fuzzy Index in the Mediterranean Area" Sustainability, 11(4), 1198.

CERIOLI, A.; ZANI, S. (1990). "A fuzzy approach to the measurement of poverty" in Income and wealth distribution, inequality and poverty, Dagum, C. and Zenga, M. (Eds.), Springer, Berlin, pp. 272–284

CHELI, B.; BETTI, G. (1999). "Fuzzy analysis of poverty dynamics on an Italian pseudo panel, 1985–1994" Metron, 57, pp. 83–104

CHELI, B.; GHELLINI, G.; LEMMI, A.; PANNUZI, N. (1994). "Measuring Poverty in the Countries in Transition via TFR Method: The Case of Poland in 1990–1991" Statistics in Transition, 1(5), pp. 585–636

CHELI, B.; LEMMI, A. (1995). "A totally fuzzy and relative approach to the multidimensional analysis of poverty" Economics Notes, 24 pp. 115-134

CHIAPPERO MARTINETTI, E. (1994). "A new approach to evaluation of well-being and poverty by fuzzy set theory" Giornale Degli Economisti e Annali di Economia 53, pp. 367–388

CHIAPPERO MARTINETTI, E. (2000). "A multi-dimensional assessment of well-being based on Sen's functioning theory" Rivista Internazionale di Scienze Sociali 8(2), pp. 207–239

CHIAPPERO MARTINETTI, E. (2006). "Capability approach and fuzzy set theory: description, aggregation and inference" in Fuzzy Set Approach to Multidimensional Poverty Measurement, Lemmi, A. and Betti, G. (Eds.). Springer, New York

CLARK, D.A.; QIZILBASH, M. (2002). "Core poverty and extreme vulnerability in South Africa" Economics Research Centre Discussion Paper 2002-3, University of East Anglia, Norwich.
COSTA, M.; DE ANGELIS L. (2008). "The multidimensional measurement of poverty: a fuzzy set approach", Statistica, 68, 3-4, pp. 303-319
D'AGOSTINO, A.; GIUSTI, C.; GAGLIARDI, F.; POTSI, A. (2019). "Investigating the impact of the economic crisis on children's wellbeing in four European countries" Social Science Research, 84
D'AGOSTINO, A.; GIUSTI, C.; POTSI, A. (2018). "Gender and Children's Wellbeing: Four Mediterranean Countries in Perspective" Child Indicators Research, 11(5), pp. 1649-1676.
DE MURO, P.; MAZZIOTTA, M.; PARETO, A. (2011). "Composite Indices of Development and Poverty: An Application to MDGs" Social Indicators Research, 104 (1), pp. 1–18
DEAN, H. (2009). "Critiquing capabilities: the distractions of a beguiling concept" Critical social policy, 29(2), pp. 261-278.
DEUTSCH, J.; SILBER, J. (2005). "Measuring multidimensional poverty: an empirical comparison of various approaches" Review of Income and Wealth, 51, pp. 145-174.
DI TOMMASO, M.L. (2007). "Children capabilities: a structural equation model for India" The Journal of Socio-Economics, 36(3), pp. 36-450.
DUBOIS, D.; PRADE, H. (1980). Fuzzy sets and systems: theory and applications, Vol. 144, Academic press.
EUROSTAT (2002), European social statistics – Income, poverty and social exclusion, 2nd Report, Luxembourg
FILIPPONE, A.; CHELI, B.; D'AGOSTINO, A. (2001). "Addressing the interpretation and the aggregation problems in totally fuzzy and relative poverty measures" ISER Working Papers Number 2001-22.
GABEL, S.G.; ZHANG, Y. (2017). "Benefits of Multidimensional Measures of Child Well Being in China" International Journal of Environmental Research and Public Health, 14, 1349
GIAMBONA, F.; VASALLO, E. (2014). "Composite indicator of social inclusion for European countries" Social Indicators Research, 116, pp. 269-293
GRECO, S.; ISHIZAKA, A.; TASIOU, M.; TORRISI G. (2019). "On the Methodological Framework of Composite Indices: A Review of the Issues of Weighting, Aggregation, and Robustness" Social Indicators Research, 141, pp. 61–94
GRUPP, J.; MOGEE, M.E. (2004). "Indicators for national science and technology policy: How robust are composite indicators?" Research Policy, 33, pp. 1373-1384
GUIO, A.C. (2009). "What can be learned from deprivation indicators in Europe?" Eurostat methodologies and working paper, Eurostat, Luxembourg
KAKLAUSKAS, A.; HERRERA-VIEDMA, E.; ECHENIQUE, V.; ZAVADSKAS, E.K.; UBARTE, I.; MOSTERT, A.; PODVEZKO, V.; BINKYTE, A.; PODVIEZKO, A. (2018). "Multiple Criteria Analysis of Environmental Sustainability and Quality of Life in Post-Soviet States" Ecological Indicators, 89, pp. 781–807.
KLASEN, S. (2001). "Social exclusion, children and education: implications of a rights-based approach" European Societies, 3(4), pp. 413-445.
LELLI, S. (2001). "Factor analysis vs. fuzzy sets: assessing the influence of different techniques on Sen's functioning approach", Paper Presented at the conference on 'Justice and Poverty: Examining Sen's Capability Approach', Von Hügel Institute, St. Edmund's College, Cambridge
LEMMI, A.; BETTI, G. (Eds.) (2006). Fuzzy set approach to multidimensional poverty measurement, Springer, New York
LIANG, H.; ZHANG, S.; SU, Y. (2017). "Evaluating the Efficiency of Industrialization Process in Prefabricated Residential Buildings Using a Fuzzy Multicriteria Decision-Making Method" Mathematical Problems in Engineering, Special Issue "Building Mathematical Models for Multicriteria and Multiobjective Applications 2017"
MITCHELL, G.; MAY, A.; MCDONALD, A. (1995). "PICABUE: a methodological framework for the development of indicators of sustainable development" International Journal of Sustainable Development & World Ecology, 2, pp. 104-123
NEGNEVITSKY, M. (2005). Artificial Intelligence, A Guide to Intelligent Systems. Addison-Wesley - Pearson Education Limited, Harlow, England
OECD (2011), How's Life?: Measuring Well-being. OECD Publishing, Paris.
POTSI, A.; D'AGOSTINO, A.; GIUSTI, C.; PORCIANI, L. (2016). "Childhood and capability deprivation in Italy: a multidimensional and fuzzy set approach" Quality & Quantity 50, pp. 2571-2590.
POTSI, A.; D'AGOSTINO, A.; GIUSTI, C. (2017). "Children's well-being in times of crisis in PIIGS countries" in Human Development in Times of Crisis Renegotiating Social Justice, Otto, H.U.; Pantazis, S.; Ziegler, H.; Potsi, A. (Eds.), Palgrave Macmillan.
SACHS, J.; SCHMIDT-TRAUB, G.; KROLL, C.; DURAND-DELACRE, D.; TEKSOZ, K. (2016). "SDG Index and Dashboards - Global Report" New York: Bertelsmann Stiftung and Sustainable Development Solutions Network (SDSN).
SACHS, J.; SCHMIDT-TRAUB, G.; KROLL, C.; DURAND-DELACRE, D.; TEKSOZ, K. (2017). "SDG Index and Dashboards Report 2017" New York: Bertelsmann Stiftung and Sustainable Development Solutions Network (SDSN).
SALTELLI, A. (2007). "Composite indicators between analysis and advocacy" Social Indicators Research, 81(1), pp. 65-77.
SÁNCHEZ, A.; RUIZ-MARTOS, M. J. (2018). "Europe 2020 Strategy and Citizens' Life Satisfaction" Journal of Happiness Studies, 19(8), pp. 2315-2338.
SEN, A. (1993). "Capability and well-being" in The Quality of Life, Nussbaum and A. Sen (Eds.), Clarendon Press. Oxford, pp. 30-52.
SEN A. (1999). Development as freedom. Oxford University Press, Oxford

TEODORESCU, A.M. (2015). "Sustainable Development, A Multidimensional Concept", Annals - Economy Series, Constantin Brancusi University, Faculty of Economics, vol. 0, pages 82-86.
TSUI, K.Y. (2002). "Multidimensional Poverty Indices", Social Choice and Welfare, 19(1), pp. 69–93.
UNITED NATIONS DEVELOPMENT PROGRAMME (UNDP) (1990). Human development report (Human development index). New York: Oxford University Press.
UNITED NATIONS DEVELOPMENT PROGRAMME (UNDP) (1997). Human Development Report 1997 (Human poverty index). Oxford University Press, New York. Oxford Poverty and Human Development Initiative (OPHI).
UNITED NATIONS DEVELOPMENT PROGRAMME (UNDP) (2010) Human Development Report 2010 (Multidimensional poverty index). New York.
VERMA, V.; BETTI, G. (2011). "Taylor linearization sampling errors and design effects for poverty measures and other complex statistics" Journal of Applied Statistics, 38, pp. 1549–1576.
VERMA, V.; BETTI, G.; GAGLIARDI, F. (2017). "Fuzzy measures of longitudinal poverty in a comparative perspective", Social Indicators Research, Vol. 130 (2), pp. 435-454.
VERO, J.; WERQUIN, P. (1997). "Reexamining the Measurement of Poverty: How Do Young People in the Stage of Being Integrated in the Labor Force Manage" (in French), Economie et Statistique, (8–10), pp.143–156.
ZADEH, L.A. (1965). "Fuzzy sets" Information and Control, 8, pp. 338–353
ZIMMERMAN, H.J. (1996). Fuzzy Set Theory and Its Applications. Kluwer Academic Publishers, Boston.