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Margherita Casini
Francesca Gagliardi
Gianni Betti

Sustainable Development Goals indicators: a methodological proposal for a fuzzy Super Index in the Mediterranean area

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Abstract

This paper provides a methodological proposal for the construction of a multidimensional index for sustainability assessment in the context of the Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development. In particular, the paper proposes a new methodology to properly estimate the multidimensional nature of sustainable development and the SDGs introducing an innovative fuzzy approach. Specifically, we present a multidimensional methodology to build a Super Index to measure the performance of the Mediterranean countries towards the SDGs with a focus on the agro-food sustainability in line with the Partnership for Research and Innovation in the Mediterranean Area (PRIMA).

For this purpose, drawing on the fuzzy approach developed by Betti *et al.* (2015), a step by step procedure is provided in the paper: first the underlying dimensions of a set of selected indicators for the SDGs are identified through an exploratory factor analysis and then an innovative weighting methodology is applied for the aggregation of the indicators to calculate the countries' scores for each dimension and finally the overall index.

Jel Codes: C43, Q01, Q53, C82

1. Introduction

In order to assess sustainability, the development of methods able to capture its multidimensional nature is today fundamental to guide policy makers in implementing appropriate strategies to achieve the SDGs of the 2030 Agenda for Sustainable Development (hereinafter Agenda 2030) as well as to monitor the progress towards such goals.

Sustainable development plays indeed nowadays a key role for humanity and the future of our planet. It is a complex phenomenon which involves not only economic growth, but also the integration of other important dimensions for long term global development: social equity and environmental protection. The relationship between these multiple dimensions is at the core of the SDGs in the Agenda 2030 and it was first advocated in the 1987 Brundtland Report which paved the way for the modern concept of sustainable development. In the recent years, in fact, growing concerns have been raised about the unsustainability of the current patterns of economic growth associated to inequality, social issues, environmental degradation and natural resources depletion. Such concerns have sparked public and literature debate to rethink development worldwide. In 2015, the UN established 17 SDGs, also called the Global Goals, to set the world towards a sustainable form of development. Hundreds of official indicators have been adopted to monitor and quantify the progress on these goals, which are integrated, indivisible and balance the multiple dimensions of sustainable development.

It is hence necessary to consider these multiple and interrelated dimensions simultaneously to correctly assess sustainability and the progress on the SDGs. To this end, we have introduced a methodological proposal for the construction of a multidimensional index for sustainability assessment through an innovative fuzzy approach. This enables to weight and aggregate the SDG indicators to better capture the multidimensionality of sustainable development. The basic idea of the new approach is that the indicators for the SDGs may belong to more than one goal at the same time and not only to one specific goal exclusively due to their multidimensional and integrated nature. According to the proposed methodology, the dimensions identified using a set of indicators for the SDGs are seen in the form of fuzzy sets to which the indicators may simultaneously belong to varying degrees. The membership of an indicator to more than one dimensions thus becomes a matter of degree rather than a simple true-false binary attribute as in the classical crisp approach.

This new methodology draws on the fuzzy approach developed by Betti *et al.* (2015) to build a multidimensional index of poverty and deprivation. Indeed, the fuzzy set theory, initiated by Zadeh in 1965, has proved to be an effective tool to describe the multidimensional nature, complexity and vagueness of social phenomena such as poverty, the quality of life and sustainable development.

In particular, the methodology is applied to the 17 Mediterranean countries involved in the PRIMA programme to construct a Super Index to measure the agro-food sustainability in such countries. Today, in fact, environmental, economic and social issues are severely challenging the sustainability of the agro-food system in the region with harmful impacts on the well-being and prosperity in the Mediterranean basin.

Building a Super Index to assess the sustainability in a multi-country comparative context, such as the Mediterranean area, is a complex task for the difficulty in finding available and internationally comparable data for all countries, the choice of suitable and statistically sound indicators and the adoption of appropriate weighting and aggregation methods able to capture the multidimensional nature of sustainable development and the SDGs.

This paper is organized as follows. In section **2**, after the description of the concept of sustainable development, the Agenda 2030 and the PRIMA programme, we analyse the statistical quality of the main datasets available for the SDGs indicators according to specific criteria examining both the primary and secondary sources. Then, in section **3**, we identify and evaluate the indicators covering mainly the SDGs related to the agro-food sustainability (namely 2, 6, 12 and 15) in conformity to statistical selection criteria. Next, in section **4**, after an overview of the fuzzy set theory and the main works developed in the literature for the construction of multidimensional indices, the new methodological proposal for a fuzzy Super Index is described in detail providing a particular step by step procedure to weight and aggregate different indicators of sustainability through an innovative fuzzy approach. This constitutes the original theoretical contribution of the paper since the new fuzzy approach allows to consider sustainable development and the SDGs in their multiple and interrelated dimensions simultaneously. Finally, section **5** presents the empirical contribution of the paper. The results of the proposed methodology, applied to the 17 Mediterranean countries involved in the PRIMA programme using a set of selected indicators for the SDGs, are provided to assess the agro-food sustainability in the Mediterranean area. Section **6** concludes the paper providing some recommendations for further research.

2. State of the art and data sources analysis

2.1. State of the art

The modern concept of sustainable development finds its roots in the famous definition introduced in 1987 by the UN World Commission on Environment and Development (WCED) in the report Our Common Future, also known as the Brundtland Report. It is defined as follows: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

- The concept of 'needs', in particular, the essential needs of the world's poor, to which overriding priority should be given; and
- The idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs" (UN, 1987).

This concept of sustainable development requires hence an integrated approach combining economic growth with social equity and environmental protection to ensure the well-being of the current and future generations. The relevance of both *inter*-generational (*within* each generation) and *intra*-generational (*between* generations) equity[1], i.e. equal access to resources and opportunities, is thus highlighted in the report. According to the report itself, "what is needed now is a new era of economic growth - growth that is forceful and at the same time socially and environmentally sustainable" (*ibid*).

[1] In the context of *inter*-generational equity, see for example, among others, Solow (1974) and Hartwick (1977) (*weak* sustainability), Noël & O'Connor (1998) and Ekins *et al.* (2003) (*strong* sustainability), while for *intra*-generational equity Arrow *et al.* (2004).

Indeed, on the one hand, the considerable economic growth experienced after the industrial revolution in the late 18th century and its recovery after the end of the World Wars along with the advent of globalization have generated significant improvements in income and living standards, reducing extreme poverty and facilitating the access to basic needs, health and education worldwide. Furthermore, the spread of information and communications technology (ICT) and the development of scientific and technological innovations has led to increased opportunities, faster cross-border communication as well as easier human and capital flows among countries. However, on the other hand, the benefits of economic growth have sometimes been achieved without taking into account the long-term consequences of these changes on the natural environment and human society. Our generation is indeed the first to suffer the negative effects of an overexploitation of non-renewable resources such as climate change, pollution and environmental degradation. Moreover, a large part of the population is still living in poverty and there are rising inequalities and social tensions within and between countries causing conflicts, terrorism and migrations.

Since the late 1960s, a number of important events as the first view of our planet from the moon and several publications have contributed to raising awareness about the negative effects of an unsustainable economic growth (Carson, 1962; Hardin, 1968; Ehrlich, 1968 and Meadows *et al*., 1972). In 1972, the UN held the first global conference on environmental issues (known as the Stockholm conference) to promote international cooperation around this topic. The oil crisis in 1973 and the Chernobyl disaster in 1986 further called for a rethinking of the current production and consumption patterns.

As mentioned before, the concept of sustainable development intended as composed of multiple dimensions – economic, social and environmental - ("broad sustainability") was first advocated in the Brundtland Report in 1987 overcoming the concept of "narrow sustainability" which considered only the relationship between the economic and environmental dimensions of sustainability. This broader concept of sustainable development obtained formal recognition in the international arena at the Rio Earth Summit in 1992. It was a milestone event bringing together Heads of State from all over the world, after the Cold War, to define shared strategies to pursue sustainable development in its multiple dimensions. An important result of the summit was the Convention on Climate Change, which then led to the Kyoto Protocol in 1997 and the Paris Agreement in 2016.

Sustainable development is hence today conceived as a multidimensional concept where all economic, social and environmental dimensions are interrelated. This conceptualization breaks the previous rigid boundaries existing between these different areas in favour of a cross-sectoral view of development. The importance to consider the multidimensional nature of the quality of life along with the need to adopt new measures of well-being in addition to GDP and economic variables emerged during the 1970s and the 1980s. Indeed, since the 1940s, GDP had been the most widely used measure of economic growth and development. However, the limitations of GDP as a measure of human welfare have been generally recognized by a number of economists such as Kuznets (1934), Sen (1993), Layard (2006) and Stiglitz *et al.* (2009) shifting the focus of development thinking from per capita economic growth only to a more comprehensive view of well-being. Also Kennedy in his famous speech in 1968 noted that GDP "measures everything in short, except that which makes life worthwhile" since it is mainly a measure of market production and does not account, inter alia, for non-market activities, wealth distribution

as well as social and environmental externalities, i.e. inequality and pollution. The Sen's capability approach (1989) defines human well-being as "a combination of functionings - the various things a person may value doing or being that are feasible for them to achieve". It is thus conceived not merely in terms of resources or utility, but rather as the various *functions* a person may wish to perform and its *capabilities* to achieve these, which may include a wide array of factors, i.e. social, besides the economic ones. This approach has encouraged throughout the years the development of a multidimensional view of well-being in contrast to the one-dimensional focus on monetary measures. Indeed, Sen's ideas have paved the way for the concept of human development introduced in 1990 by UNDP and the Human Development Index (HDI), which comprises other indicators of well-being (life expectancy and education) besides per capita income. Moreover, Sen's work had largely influenced the process that led to the adoption of the UN Millennium Development Goals (MDGs) at the dawn of the century in 2000. The MDGs were eight global goals committing the international community to face the serious issues related to poverty, education, health, gender and the environment thus going beyond the narrow idea of development represented by economic growth only. The goals on poverty reduction were reached five years ahead of the deadline. The MDGs laid the foundations for the Sustainable Development Goals (SDGs) adopted by the UN in 2015.
In 2002, the World Summit in Johannesburg resulted in a plan of implementation including concrete actions for sustainable development emphasizing the "collective responsibility to advance and strengthen the interdependent and mutually reinforcing pillars of sustainable development - economic development, social development and environmental protection - at the local, national, regional and global levels" (UN, 2002).
At the Rio +20 Summit in 2012, the UN member states agreed to initiate an intergovernmental process for the definition of a new set of global goals, called SDGs, to be effective after the expiration of the MDGs, contributing to the "full implementation of the outcomes of all major summits in the economic, social and environmental fields" (UN, 2012). This process culminated in the adoption, in September 2015, of the 2030 Agenda for Sustainable Development including 17 SDGs to guide the world on a path towards sustainable development by 2030. The SDGs are universal, integrated and indivisible and balance the multiple dimensions of sustainability. They provide a roadmap to help the world to end poverty, hunger and promote sustainable agriculture, ensure healthy lives, quality education, gender equality, sustainable consumption and production patterns, protect the environment, tackle climate change and promote peaceful societies. Associated to these global goals there are 169 targets and more than 200 official indicators have been identified by the UN to monitor the progress towards such goals. The Agenda 2030 highlighted the importance to implement the goals at global, regional and national levels and to develop a follow-up and review framework at all levels "to ensure that no one is left behind" (UN, 2015).
Indeed, in order to support the implementation of the SDGs and their localization, several *Sustainable Development Solutions Networks (SDSNs)* have been created to promote cooperation between universities, civil society and the private sector to advance practical solutions and the elaboration of indicators for the SDGs at regional and national level.
SDSN Mediterranean is the regional network of SDSN in the Mediterranean area and its activities are coordinated by the University of Siena. It plays a key role since the challenges to sustainable development are particularly critical in the Mediterranean region, which is an area

of the world with unique characteristics, such as the Mediterranean climate and diet, the exceptional ecosystems and biological diversity as well as a long-lasting history and cultural heritage. Notwithstanding these common features, significant socio-economic differences exist nowadays between the Northern Mediterranean Countries (NMCs) and the Southern and Eastern Mediterranean Countries (SEMC). Most of the NMCs are EU member states with an average income per capita much higher than the SEMCs (with the exception of Israel). Population growth is stagnant in the North while it is increasing fast in the South East. Moreover, weak national institutions and lack of effective governance especially in the SEMCs are generating political instability and migration. Today, the sustainability of the agro-food system in the Mediterranean area is seriously threatened by environmental, economic and social challenges: climate change, population growth, urbanization, unsustainable agricultural practices, environmental degradation, water scarcity, food insecurity, loss of biodiversity, low profitability of smallholders and lack of adequate infrastructures and innovation along the agro-food value chain.

In this context, important is the *Partnership for Research and Innovation in the Mediterranean area (PRIMA),* a joint research and innovation programme among the Euro-Mediterranean countries, managed by the University of Siena, aimed at promoting the sustainable management of the agro-food systems and water resources in the region contributing to the implementation of the SDGs.

The partnership is a ten-year initiative (2018 – 2028) to face the evolving challenges affecting the agro-food sustainability in the region. It is set in the context of the several policies adopted to strengthen the Euro-Mediterranean cooperation in order to promote prosperity and stability in the region, i.e. the Euro-Mediterranean partnership, also known as the Barcelona process, started in 1995, the European Neighbourhood policy in 2003 and the Union for the Mediterranean in 2011.

In line with the PRIMA initiative, we have indeed proposed a methodology for the construction of a Super Index to assess the agro-food sustainability in the *17 countries* bordering the Mediterranean Sea participating in this programme, namely, among the NMCs, Portugal, Spain, France, Italy, Malta, Slovenia, Croatia, Greece, Cyprus, and among the SEMCs, Turkey, Lebanon, Israel, Jordan, Egypt, Tunisia, Algeria, Morocco.

2.2. Datasets for SDG indicators

In order to select suitable and statistically sound indicators for inclusion in the Super Index, we have first analysed the statistical quality of the main datasets available for the SDGs indicators examining both the primary and secondary sources.

For this purpose, we have used *six criteria* identified on the basis of internationally recognized criteria for data quality selection. These are the following:

1. **Completeness (in terms of indicators):** The indicators provided by a compiling agency have to cover most of the SDGs.
2. **Availability for all or most MED Countries (Coverage):** Data are available for most of the 17 Mediterranean countries considered in this analysis.
3. **Clarity:** Data are available in a clear and understandable way.
4. **Timeliness:** Data have to be disseminated by a compiling agency in a prompt manner and be available for the most recent years.

5. **Comparability over time (ability to monitor):** Data of the same phenomenon are available and comparable at different points in time.
6. **Comparability among indicators (internal):** Data have to be compiled in a statistically reliable and valid manner using common standards, definitions, classifications and units in the different sources and countries.

According to this criteria, among the *primary sources,* we have evaluated the databases of the main agencies responsible for compiling the UN official SDG indicators, namely *UN organizations*, and *Eurostat*, which is the principal institution providing indicators for the SDGs in an EU context. Concerning the *secondary sources*, we have investigated the compliance with the aforementioned criteria of the datasets used by *SDSN* (the UN Sustainable Development Solutions Network) in the SDG Index (Sachs *et al.*, 2017) as well as those of *CIHEAM* (international Centre for Advanced Mediterranean Agronomic Studies) and *BCFN Foundation* (Barilla Centre for Food and Nutrition Foundation) which are focused on the Mediterranean agro-food system.

2.2.1. Primary sources

In order to monitor the progress towards the SDGs, in 2017 the UN adopted a *global indicator framework* including 232 official indicators for the 17 SDGs. For each indicator, specific international institutions have been identified as "custodian" agencies responsible to collect data from national sources and to compile internationally comparable estimates. These are then provided to the United Nations Statistics Division (UNSD), the UN Statistical Office, to be included in the *Global SDG Indicators Database*.

The main UN organizations committed to this task are: FAO, WB, WHO, UNESCO, ILO, UNICEF, UNEP, WTO and IMF. In addition, OECD is responsible for a number of UN official SDG indicators.

The *Food and Agriculture Organization (FAO)* plays a leading role in providing food and agriculture statistics at global level through a series of databases of which *FAOSTAT* is the world's most comprehensive on these topics. It is custodian agency for *21* SDG global indicators (around 10% of the total) covering overall *6* SDGs. Most of these indicators (9) cover SDG #2, dedicated to food security and sustainable agriculture, since this goal is at the hearth of FAO's efforts.

The *World Bank (WB)*, whose aim is to reduce poverty worldwide, provides data on global development in its *World Development Indicators (WDI)* database. It is responsible for *22* UN official indicators related to *10* SDGs.

The *World Health Organization (WHO)* is the custodian agency for the highest number of SDG indicators *(31)* covering *7* SDGs with a focus on SDG #3 concerning health promotion which is central to its mission. The *Global Health Observatory (GHO)* is the main WHO database of health related statistics.

The *International Labour Organization (ILO)* committed to promote decent work and employment opportunities around the world is custodian agency for *5* SDGs with *15* indicators, of which 9 for SDG #8 as such goal is precisely related to its aim. *ILOSTAT* is the world's largest database on labour market statistics.

The *UN Educational, Scientific and Cultural Organization (UNESCO)* is the global leader of data for education which are disseminated through the *UNESCO Institute for Statistics (UIS)*

databases. It is responsible for *22* indicators across *10* SDGs and significant is indeed its contribution for SDG #4, aimed to ensure quality education, providing 9 of the total 11 indicators for this goal.
The *United Nations Children's Fund (UNICEF)* aims to protect the rights of children through humanitarian and development assistance and is the leading global provider of data for children with *17* indicators across *7* SDGs.
The *United Nations Environment Programme (UNEP)* is the UN authority dedicated to the environmental issues and it is custodian agency for a significant number of indicators *(29)* across *6* SDGs. Among these indicators, 11 out of the total 13 cover SDG #12 promoting sustainable consumption and production patterns. The *UNEP Environmental Data Explorer* contains datasets on a wide range of environmental statistics.
The *World Trade Organization (WTO)* and the *International Monetary Fund (IMF)* are responsible for a lower number of indicators, respectively *8* for *5* SDGs and *4* across *3* SDGs. The *WTO Statistics Database* provides data on international trade and, among the IMF databases, the *World Economic Outlook (WEO)* contains global macroeconomics data.
Also the *Organization for Economic Cooperation and Development (OECD*) is responsible for *20* SDG global indicators covering overall *13* SDGs. It provides a large number of databases related to its field of action concerning mainly its 35 member countries, of which only 7 are Mediterranean countries (Greece, Italy, Israel, Portugal, Slovenia, Spain and Turkey).
All these primary sources provide generally statistically sound data for the SDG global indicators, which are timely, available in a clear way, for different time periods and compiled through internationally comparable standards. They cover all or most of the Mediterranean countries in our analysis except for OECD.
Besides the UN, also the EU adopted in 2017 a set of indicators to monitor the implementation of the SDGs in an EU context, including 100 indicators equally distributed across all the 17 SDGs. *Eurostat*, the EU statistical office, provides most of these indicators (69) for almost all the SDGs. However, its databases cover EU member countries only, thus 9 of the 17 Mediterranean countries considered in our analysis, namely Croatia, Cyprus, France, Greece, Italy, Malta, Portugal, Slovenia and Spain. The data for the SDGs indicators are clear and internally comparable, even if not all are updated annually or are available for a long period of time.
The overall evaluation of the primary data sources for the SDG indicators according to the six criteria identified is shown in the table below through a traffic light rating system indicating the level of suitability of the datasets (green: high; green/yellow: high/medium; yellow: medium; red/yellow: low; red: low).

Table 2.1: overall primary sources evaluation

	Primary sources										
	FAO	**WB**	**WHO**	**ILO**	**UNESCO**	**UNICEF**	**UNEP**	**WTO**	**IMF**	**OECD**	**Eurostat**
1. Completeness	yellow	green/yellow	yellow	yellow	green/yellow	yellow	yellow	yellow	yellow	green/yellow	green
2. Geographical coverage	green	green	green	green	green	green	green	green	green	red	red
3. Clarity	green	green	green	green	green	green	green	green	green	green	green
4. Timeliness	green	green	green	green	green	green	green	green	green	green	green/yellow
5. Comparability over time	green	green	green	green	green	green	green	green	green	green	green/yellow
6. Internal comparability	green	green	green	green	green	green	green	green	green	green	green

Source: own elaboration

In conclusion, the primary data sources for the SDG indicators that satisfy all or most of the six criteria are FAO, WB, WHO, ILO, UNESCO, UNICEF, UNEP, WTO and IMF, while OECD and Eurostat datasets do not cover most of the 17 Mediterranean countries.

2.2.2. Secondary sources

The UN Sustainable Development Solutions Network (SDSN) in 2016 issued the *SDG Index and Dashboards* which was then revised in 2017 (Sachs *et al.*, 2016, 2017). It is a composite index that aggregates available data on the SDGs to measure the countries' performance on the Agenda 2030. It builds on 99 unofficial indicators to monitor all the 17 SDGs using data available for all the Mediterranean countries. The data used in the index derive mainly from official sources but also from other unofficial reputable sources. These are clear, but not all data are updated annually at the same time across countries and only the most recent available data are included in the index.

The *Barilla Center for Food and Nutrition Foundation (BCFN)* is a private non-profit institution devoted to foster more sustainable agro-food systems in order to face the global challenges related to food and nutrition. It has developed, in collaboration with the Economist Intelligence Unit (EIU), the *Food Sustainability Index (FSI)* to assess the sustainability of the countries' agro-food systems. Its activities are hence consistent with the implementation of mainly *6* SDGs related to this topic (SDGs # 2, 3, 10, 12, 13 and 15). In the 2017 edition of the FSI, 34 countries are included in the study, of which 12 are Mediterranean countries (France, Greece, Italy, Portugal, Spain, Egypt, Israel, Jordan, Lebanon, Morocco, Tunisia and Turkey). The data used for the construction of the FSI derive mainly from the UN institutions (primarily FAO) and EIU databases which are available in a clear manner and are compiled in a reliable way. However, not all the indicators selected to build the index are available in the most recent years and most of these are provided only for a single year.

The *International Centre for Advanced Mediterranean Agronomic Studies (CIHEAM)* is a Mediterranean intergovernmental organization aimed to promote the sustainability of the agro-food system in the Mediterranean countries. Its *2015 version of the Statistical Review* includes several indicators on agriculture, food and development in the Euro-Mediterranean area deriving from different sources such as the UN organizations and Eurostat. These statistics concern the 13 CIHEAM member states (Albania, Algeria, Egypt, France, Greece, Italy, Lebanon, Malta, Morocco, Portugal, Spain, Tunisia and Turkey) and 6 other Mediterranean countries (Bosnia and Herzegovina, Croatia, Jordan, Libya, Montenegro and Syria). Therefore, CIHEAM provides indicators for most of the Mediterranean countries in our analysis (14) covering mainly *5* SDGs regarding the agro-food sustainability (SDGs # 2, 6, 12, 14 and 15). The data are collected over several decades, from the 1960's to the most recent years, even if these are not always available for all countries. Moreover, the estimates are not updated annually, i.e. the previous edition of the 2015 version of the Statistical Review was published in 2012, and more information on the criteria used for data selection could be provided.

Table 2.2 reports the evaluation of the secondary data sources for the SDG indicators in conformity to the criteria identified for the analysis of the statistical quality of the datasets.

Table 2.2: overall secondary sources evaluation

	Secondary sources		
	SDSN	BCFN	CIHEAM
1. Completeness			
2. Geographical coverage			
3. Clarity			
4. Timeliness			
5. Comparability over time			
6. Internal comparability			

Source: own elaboration

In summary, all the secondary data sources analyzed may be considered suitable for our study even if they do not fully meet all the six criteria and SDSN as well as BCFN Foundation databases do not generally provide time series data.

3. Indicators selection

After the datasets analysis, we have then identified and evaluated the indicators that may be appropriate to gauge the sustainability of the agro-food systems in the Mediterranean region according to specific statistical criteria. Among the 17 SDGs, we have thus focused on four specific goals related to the agro-food sustainability, namely SDGs #2 ("End hunger, achieve food security and improved nutrition and promote sustainable agriculture"), #6 ("Ensure availability and sustainable management of water and sanitation for all"), #12 ("Ensure sustainable consumption and production patterns") and #15 ("Sustainable land use, forest and other terrestrial ecosystems").

The criteria adopted for the selection of suitable indicators to be included in the Super Index are *internationally recognized criteria proposed by the University of Siena*. These criteria are arranged in a hierarchical order and are the following:

1. **Policy relevance**
   - *Ability to measure the direct impact of PRIMA Programme*
     Indicators have to be relevant and clearly linked to the PRIMA programme.

2. **Admissibility Requirements**
   - *Availability for all or most MED Countries (Coverage)*
     They cover most of the 17 Mediterranean countries considered in this analysis.
   - *Statistical process adequacy*
     Indicators have to be produced in a statistically reliable and robust way according to internationally established methodologies and standards.
   - *Compliance: Type of sources (Official, internal, censuses, surveys, etc.)*
     They comply with international common standards in the different type of sources (official, internal, censuses, surveys, etc.).

3. **Data Quality**
   - *Timeliness*
     Data are disseminated promptly and are available for the most recent years.
   - *Comparability over time (ability to monitor)*
     Data are available and comparable at different time periods.

- *Comparability among indicators (internal)*
  Indicators are processed using common standards, definitions and classifications in different countries.

Following these criteria, for each of the four goals considered, we have analysed first the indicators provided on the *UNSD Global SDG Indicators Database* (primary source), which contains data on the countries' performance in terms of the official indicators provided by the custodian agencies mentioned before, and then those used by SDSN in the *SDG index* (secondary source). Indeed, since not for all the UN indicators internationally established methodologies or standards yet exist nor data are widely available, SDSN has selected alternative unofficial indicators from other reputable sources to complement the official indicators when gaps remained. The official indicators are in fact classified into three tiers in descending order of methodological development and data availability (tier I, II and III). Table 3.1 reports the number of indicators for SDGs 2, 6, 12 and 15 along with their tier classification. All these goals include tier III indicators with SDG 12 showing a particularly high number of these. For this type of indicators, methodology and standards are not yet developed and thus are normally not available on the UN official database. SDG 15 presents the largest number of indicators classified as tier II while SDGs 2 and 6 the highest number of tier I indicators, for which agreed methodologies exist and data are easily available.
Finally, the most suitable indicators identified by the PRIMA programme to measure the agro-food sustainability in the Mediterranean region in relation to the aforementioned goals are described in detail in section 3.5. We have hence used these indicators to build the Super Index.

Table 3.1: Official indicators for SDG 2, 6, 12 and 15 and tier classification

	Tier I	**Tier II**	**Tier III**	**Tier I/III**	**Tot**
SDG 2	6	4	3	-	**13**
SDG 6	4	4	3	-	**11**
SDG 12	1	1	11	-	**13**
SDG 15	2	7	3	2	**14**
Tot	**13**	**16**	**20**	**2**	**51**

Source: own elaboration

3.1. SDG 2: Food security and sustainable agriculture

All the 13 official *UN* indicators for SDG 2 are relevant and clearly linked to the PRIMA programme. However, some of these indicators are not available on the UNSD Global SDG Indicators Database and only 4 cover most of the 17 Mediterranean countries. We have thus analyzed these 4 indicators, namely *2.1.1* "Prevalence of undernourishment" (FAO, 2017a), *2.5.1* "Conservation of genetic resources for food and agriculture" (FAO, 2017b), *2.5.2* "Risk status of livestock breeds" (FAO, 2017c), and *2.a.1* "Public Investment in agriculture" (FAO, 2017d). All these indicators derive hence from the same official source.
The 6 indicators used by *SDSN* for SDG 2 in the SDG Index are policy relevant and available for all the Mediterranean countries in our study. Among these, we do not consider the indicator "Prevalence of undernourishment (%)" since it is similar to the one in the official database. The indicators analysed are thus the following: "Prevalence of stunting, under-5s (%)" (UNICEF *et al.*, 2017), "Prevalence of wasting, under-5s (%)" (UNICEF *et al.*, 2017), "Prevalence of adult

obesity" (WHO, 2017a), "Cereal yield (t/ha)" (FAO, 2017e) and "Sustainable Nitrogen Management Index" (Zhang & Davidson, 2016). These indicators are provided by official sources excluding the last one which is described in a research paper.

Table 3.2 shows the overall evaluation of the UN official indicators and those used by SDSN according to the criteria for indicators selection described before. The level of suitability is indicated through a traffic light rating system (green: high; green/yellow: high/medium; yellow: medium; red/yellow: low; red: low).

Among the *UN* indicators, the 2.1.1 covers almost all the selection criteria. It is indeed classified as tier I and it is an estimate of the proportion of population undernourished which is today below 5% in all the 17 countries in this study. The other UN indicators are classified as tier II and include different components/sub-indicators. Even if they rely on established methodologies and standards, data for these indicators are not regularly produced by all the 17 countries at the same time for all the components/sub-indicators and the most recent data are not widely available on the official database. The internal comparability depends on the quality of the country data compiled by the official source.

Concerning the *SDSN* indicators, "Prevalence of stunting, under-5s (%)" and "Prevalence of wasting, under-5s (%)" are perfectly matched to the official indicators 2.2.1 and 2.2.2 which are not available for most of the 17 Mediterranean countries on the UN global SDG indicators database. For these, an established methodology exists but data are not provided for the most recent years in all countries at the same points in time. Also the indicator "Prevalence of adult obesity" is closely aligned to the official indicator 2.2.2 while "Cereal yield" and "Sustainable Nitrogen Management Index" are not in the UN official database. The first two indicators satisfy almost all the criteria excluding timeliness but the last one shows some limits since its methodology is provided in a research paper and it is available only for a few not recent years.

Table 3.2: SDG 2 UN and SDSN indicators evaluation

SDG 2	UN indicators				SDSN indicators				
	2.1.1	2.5.1	2.5.2	2.a.1	Prev. of stunting, under-5s	Prev. of wasting, under-5s	Prev. of adult obesity	Cereal yield	Sust. Nitrogen Management Index
1. Policy Relevance									
2. Admissibility Requirements									
Geographical coverage									
Statistical process adequacy									
Compliance									
3. Data Quality									
Timeliness									
Comparability over time									
Internal comparability									

Source: own elaboration

In conclusion, the potential indicators that may be suitable to monitor SDG 2 in the Mediterranean region are indicators 2.1.1, 2.5.2, "Prevalence of adult obesity" and "Cereal yield" since they meet most of the selection criteria.

3.2. SDG 6: Clean water and sanitation

The 11 *UN* official indicators for SDG 6 are all policy relevant, but only 6 of these are available on the UNSD database. Among the remaining indicators, 3 cover most of the Mediterranean countries in the study, namely indicators *6.1.1* "Proportion of population using safely managed drinking water services" (WHO & UNICEF, 2017), *6.2.1* "Proportion of population using safely managed sanitation services" (WHO & UNICEF, 2017) and *6.4.2* "Level of water stress: freshwater withdrawal as a proportion of available freshwater resources" FAO (2017f). All these indicators derive thus from official sources. In this case, among the 4 indicators used by *SDSN* for this goal we do not consider the one measuring a spillover effect, that is the effect occurring when one country's action generates externality on another country, since it is not relevant to the PRIMA programme. We also do not evaluate the other indicators "Access to improved water", "Access to improved sanitation" and "Freshwater withdrawal" because these are perfectly matched to the official indicators 6.1.1, 6.2.1 and 6.4.2.
As shown in table 3.3, the indicators 6.1.1 and 6.2.1, which are classified as tier I, almost completely satisfy all the selection criteria, while for the tier II indicator 6.4.2 there is an agreed methodology but the most recent data are not easily available in all countries as well as time series data. In summary, all these indicators may be considered appropriate to monitor the progress towards SDG 6 in the 17 Mediterranean countries.

Table 3.3: SDG 6 UN indicators evaluation

SDG 6	UN indicators		
	6.1.1	6.2.1	6.4.2
1. Policy Relevance			
2. Admissibility Requirements			
Geographical coverage			
Statistical process adequacy			
Compliance			
3. Data Quality			
Timeliness			
Comparability over time			
Internal comparability			

Source: own elaboration

3.3. SDG 12: Sustainable consumption and production patterns

Of the 13 UN indicators for SDG 12, only 3 are available on the official database. Indeed, almost all the indicators for this goal are classified as tier III and do not have yet established methodologies. Among these 3 indicators, the tier I indicator 12.4.1 is not policy relevant while the remaining indicators 12.2.1 "Material footprint, material footprint per capita, and material footprint per GDP" (UNEP, 2017a) and 12.2.2 "Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP" (UNEP, 2017a) are relevant to the PRIMA programme and are available for all the 17 Mediterranean countries. Both derive from the same official source.
Among the 8 indicators selected by SDSN for this goal, we do not analyze the two indicators measuring spillover effects neither the one covering OECD countries only. All the other 5 indicators are policy relevant and cover most of the 17 countries. These derive from research papers and are the following: "E-waste (Kg/capita)" (UNU-IAS, 2015); "Wastewater treated

(%)" (Hsu *et al.*, 2016); "Production-based SO2 emissions (Kg/capita)" (Zhang *et al.*, 2017); "Nitrogen production footprint (Kg/capita)" Oita *et al.* (2016) and "Municipal solid waste" (WB, 2012). "Wastewater treated" and "Municipal solid waste" are similar to the official indicators, respectively 12.4.2 and 12.5.1, which are not available on the UN official database. The other indicators **"**E-waste", "Production-based SO2 emissions" and "Nitrogen production footprint" are not related to any of the official SDG indicators. As reported in table 3.4, among the UN indicators, the 12.2.1 (tier III) and 12.2.2 (tier II) do not meet most of the criteria since they are produced compiling data from different international or national sources which are not easily available in all countries, for the most recent years and are not comparable over time.
The SDSN indicators are provided in research papers only at a point in time and generally not for the most recent years. They are indeed produced through methodologies which are not easily applied in all countries according to common definitions.
Therefore, the UN and SDSN indicators for SDG 12 do not seem the most appropriate indicators for this study.

Table 3.4: SDG 12 UN and SDSN indicators evaluation

SDG 12	UN indicators		SDSN indicators				
	12.2.1	12.2.2	E-waste generated	Wastewater treated	Production-based SO2 emissions	Nitrogen production footprint	Municipal solid waste
1. Policy Relevance							
2. Admissibility Requirements							
Geographical coverage							
Statistical process adequacy							
Compliance							
3. Data Quality							
Timeliness							
Comparability over time							
Internal comparability							

Source: own elaboration

3.4. SDG 15: Sustainable management of terrestrial ecosystems

Among the 14 UN official indicators for SDG 15, all are policy relevant with the exception of indicators 15.6.1, 15.a.1 and 15.b.1 and 5 are not available on the UNSD database (15.3.1, 15.7.1, 15.8.1, 15.9.1 and 15.c.1). The remaining 6 indicators cover most of the Mediterranean countries in our analysis. These are the following: *15.1.1* "Forest area as a proportion of total land area" (FAO, 2017g), *15.1.2* "Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type" (BirdLife International *et al*., 2017), *15.2.1* "Progress towards sustainable forest management" (FAO, 2017h), *15.4.1* "Coverage by protected areas of important sites for mountain biodiversity" (BirdLife International *et al*., 2017), *15.4.2* "Mountain Green Cover Index" (FAO, 2017i) and *15.5.1* "Red List Index" (Birdlife international & IUCN , 2017). We do not consider the 5 SDSN indicators for this goal because one of these measures a spillover effects and the other 4 are the same or are closely aligned to the official indicators 15.1.1, 15.1.2 and 15.5.1.
Table 3.5 shows that the UN indicators for SDG 15 satisfy a high number of selection criteria. For all the indicators, there is indeed an internationally agreed methodology. The 15.1.1 and 15.1.2, classified as tier I, may be suitable for our study, even if the first one is not provided

every year, but at intervals of years. Concerning the other indicators (tier II), although there is uncertainty around the quality of the data for some countries, the indicators 15.4.1 and 15.5.1 meet almost all the criteria, while the 15.2.1, which comprises a number of sub-indicators, as well as the 15.4.2 are not easily available in the most recent years and at different points in time. Therefore, overall, the most appropriate indicators seem to be 15.1.1, 15.1.2, 15.4.1 and 15.5.1.

Table 3.5: SDG 15 UN indicators evaluation

SDG 15	UN indicators					
	15.1.1	15.1.2	15.2.1	15.4.1	15.4.2	15.5.1
1. Policy Relevance						
2. Admissibility Requirements						
Geographical coverage						
Statistical process adequacy						
Compliance						
3. Data Quality						
Timeliness						
Comparability over time						
Internal comparability						

Source: own elaboration

3.5. PRIMA indicators

The PRIMA programme in order to measure the performance of the Mediterranean countries in terms of agro-food sustainability has identified a set of Key Performance Indicators (KPIs) (Saladini *et al.*, 2018) contributing to the implementation of the SDGs, namely SDGs 2, 6, 12 and 15, in the region. We have hence used these indicators for the construction of the Super Index adjusting some of these to provide a more accurate measure of the phenomena concerned (table 3.6). The selected indicators are described in detail below.

Table 3.6: PRIMA selected indicators

#	Indicator	Unit	Year	Source
1	Population overweight	%	2016	WHO (2017b)
2	Land use	%	2015	FAO (2017l)
3	GHG emissions (total) per sq. Km	t CO_{2e} /sq.Km	2014	UNFCCC (2017), FAO (2017m)
4	Cereal yield	kg/ha	2014	FAO (2017e)
5	Agriculture value added	US$/worker	2016	WB (2017)
6	Fertilizer consumption	$kg/ha_{arable\ land}$	2014	FAO (2017n)
7	Crop water productivity	kg/m^3	2010	Zwart (2010)
8	Annual freshwater withdrawal for agriculture	(% of total freshwater withdrawal)	2014	FAO (2017o)
9	Population using safely managed water services (rural)	%	2015	WHO, UNICEF (2017a)
10	Population using safely managed sanitation services (rural)	%	2015	WHO, UNICEF (2017a)
11	Research and Development expenditure	% of GDP	2015	UNESCO (2017a)

Source: own elaboration from Saladini *et al.* (2018)

1. Population overweight (%)

The indicator is defined as the percentage of adult population with a body mass index (BMI) of 25 kg/m^2 or higher. It is similar to the indicator used by SDSN for SDG 2 in the SDG Index "Prevalence of adult obesity (%)". The proportion of adult population overweight may indeed be a useful indicator to describe the nutritional situation in the Mediterranean area characterized by growing overweight and obesity rates in the population along with the demise of the traditional Mediterranean diet.

2. Land use (%)

This indicator provides an estimate of the proportion of land for Agriculture, Forestry, and Other Land Use (AFOLU). We have calculated such indicator as the sum of "Forest area (% of land area)" and "Agricultural land (% of land area)". The difference between the total land area (%) and this sum represents the proportion of land devoted to other use. "Forest area" and "agricultural land" are precisely defined by FAO (2017l). It allows to compare the proportion of forest and agricultural land to that for other use, i.e. the land covered by urban areas, and thus to assess the status of the conservation of land for forestry and agriculture.

3. GHG emissions (total) per sq. Km

This indicator measures the total net greenhouse gas (GHG) emissions expressed in tons of CO_2 equivalent (tCO2e) in line with the United Nations Framework Convention on Climate Change (UNFCCC). For a more accurate estimate, we have divided the total GHG emissions (tCO2e) by the surface area of a country (sq. Km) to measure the total net greenhouse gas emissions (tCO2e) per square kilometer limiting the possible distortions caused by different surface area sizes in the countries considered in our analysis. Emissions of CO2e derive mainly from fossil fuel combustion, such as oil, coal and natural gas as well as from industrial processes causing air pollution which may seriously damage human health, the environment and increase earth's surface temperature.

4. Cereal yield (kg/ha)

It is an indicator of agriculture productivity and it is the same as the indicator used by SDSN in the SDG Index for SDG 2. It is measured as kilograms per hectare of harvested land. Increases in crop yields contribute to agriculture efficiency, however, new crop production systems may cause negative environmental impacts, such as pollution from fertilizers consumption, soil degradation and biodiversity loss. Therefore, this indicator should be better used in combination with indicators #6 (fertilizer consumption), #7 and #8 in terms of water availability and efficiency as well as indicator # 2 concerning the changes in AFOLU.

5. Agriculture value added (US$/worker)

The value added in agriculture is an important indicator of agricultural productivity. "Value added in agriculture measures the output of the agricultural sector (ISIC divisions 1-5) less the value of intermediate inputs. Agriculture comprises value added from forestry, hunting and fishing, as well as cultivation of crops and livestock production" (WB, 2017). It is calculated in constant 2010 U.S. dollars.

6. Fertilizer consumption (kg/ha $_{\text{arable}}$)

Fertilizer consumption measures the quantity of fertilizers used (Kg) per unit of arable land (ha). It is a relevant indicator because the use of fertilizers is unsustainable and harmful for health and the environment. "Fertilizer products cover nitrogenous, potash, and phosphate fertilizers (including ground rock phosphate). Arable land includes land defined by the FAO as land under temporary crops (double-cropped areas are counted once), temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow" (FAO, 2017n).

7. Crop water productivity (kg/m^3)

Crop water productivity is defined by Zwart (2010) as the marketable crop yield (kg ha^{-1}) over the seasonal crop water consumption by actual evapotranspiration (m^3 ha^{-1}). This indicator provides a measure of water productivity in agriculture and may be better interpreted in conjunction with the indicator #8 (freshwater withdrawal for agriculture) as its meaning changes according to the availability of water resources, i.e a higher water productivity may be caused by the use of less water resources and the same production level or an increase in production with the same resources. It is a useful indicator since the increasing pressure on water resources negatively affects the agricultural sector, which is the major water-consuming sector in most of the Mediterranean countries and has to face the competition for a higher water demand from the other sectors. Along with indicators #4 (Cereal yield) and #5 (Agriculture value added), it provides a picture of the agriculture productivity in the Mediterranean region.

8. Annual freshwater withdrawal for agriculture (% of total freshwater withdrawal)

This indicator measures the pressure exerted by the agriculture sector on the renewable water resources of a country and it is similar to the official indicator 6.4.2. The spread of irrigated agriculture, along with population growth and industrialization, are nowadays the main causes for higher water demand. It is an important measure since water scarcity is one of the major issues in the Mediterranean area characterized by the presence of arid and semi-arid ecosystems, drought and infrequent rainfalls and the agriculture sector is the main water-consuming sector in the region.

9. Population using safely managed water services (rural, %) and **10. Population using safely managed sanitation services (rural, %)**

These indicators are similar respectively to the official indicators 6.1.1 and 6.2.1. However, the indicators identified by the PRIMA programme measure only the percentage of rural population using safely managed water and sanitation services and not the urban one. Indeed, the rural population has normally less access to water and sanitation facilities in the Mediterranean area. "Safely managed drinking water" is defined as "the use of an improved drinking water source which is located on premises, available when needed, and free of faecal and priority chemical contamination" while "safety managed sanitation" as "the use of an improved sanitation facility which is not shared with other households and where excreta is safely disposed in situ or excreta is transported and treated off-site" (WHO, UNICEF, 2017a).

11. Research and development expenditure (% of GDP)

R&D expenditure is a fundamental indicator of countries efforts for innovation in science and technology. Total R&D expenditures include current and capital expenditures carried out by both public and private sector and are expressed as a percentage of a country GDP. This indicator is essential for the development of innovative solutions along the Mediterranean agro-food value chain.

The proposed methodology for the construction of the Super Index is applied to the 17 Mediterranean countries involved in the PRIMA programme using these 11 indicators.

4. Construction of a multidimensional Super Index

In the previous section, after the datasets analysis, we have selected the most suitable indicators to measure the performance of the Mediterranean countries towards the four SDGs related to the agro-food sustainability in line with the PRIMA programme. Then, in order to weight and aggregate these indicators into a Super Index to properly estimate the multidimensional nature of sustainable development and the SDGs, we have proposed a new methodology based on an innovative fuzzy approach. This new methodological proposal is described in detail in this section after an overview of the fuzzy set theory and the main works developed in the literature for the construction of multidimensional indices.

4.1. Literature review

The multidimensional nature of sustainable development and the quality of life in general has been widely recognized, as mentioned in section 2[2]. Indeed, in literature, several methodological studies on multidimensional indices have been developed in the recent years especially in the field of sustainability (UNDP, 1990; Sachs *et al.*, 2016, 2017), the quality of life (OECD, 2011; Betti *et al.*, 2016; Betti, 2016, 2017) and poverty (Cerioli and Zani, 1990; Cheli and Lemmi, 1995; Anand and Sen, 1997; Betti and Verma, 1999, 2008; UNDP, 1997, 2010; Eurostat, 2002; Belhadj, 2011; Betti *et al.*, 2015, 2017).

Among these works, noteworthy are those based on the fuzzy logic. In fact, the fuzzy set theory has shown to be a powerful tool to describe the multidimensionality and complexity of social phenomena replacing the classical crisp approach which generally tends to overestimate or underestimate social dynamics, i.e. transient and persistent poverty.

The *fuzzy set theory*, introduced by Zadeh in 1965, emerged in response to the evidence that real situations are often characterized by imprecision, uncertainty and vagueness and cannot be properly described by the classical set theory representing 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 does not belong at all to a set according to a bivalent condition. On the contrary, in the fuzzy set theory, an item may belong to a set with partial degrees of membership between 0 and 1 and not only with the 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 defining to what extent an element belongs to the set, that is the grade of membership for the elements of a given set.

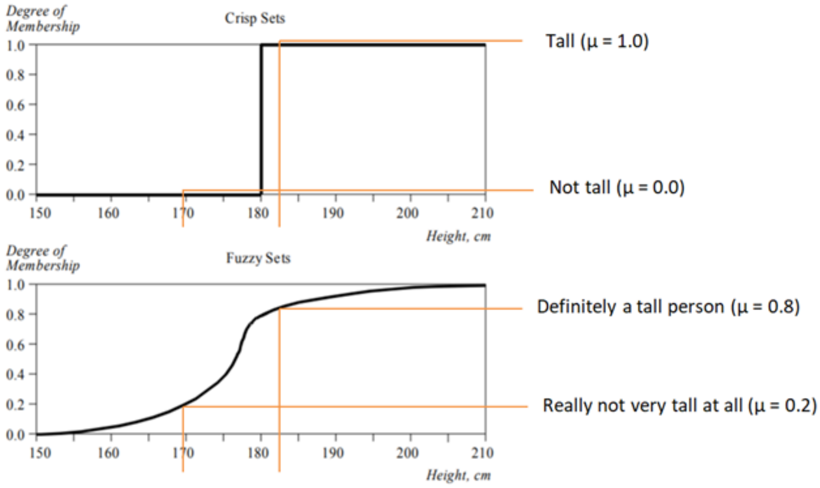
According to Zimmermann (1996), "if X is a collection of objects denoted generically by x, then a fuzzy set A in X is a set of ordered pairs $A = \{(x, \mu_A(x)|x \in X\}$ where $\mu_A(x)$ is called the membership function or grade of membership/degree of truth of x in A. It maps each element of X to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

As shown in the commonly used example of tall people (fig. 4.1), 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

[2] Concerning the multidimensional nature of the quality of life and poverty, see also, among others, Sen (1993, 1999), Atkinson and Bourguignon (1982), Tsui (1985), Maasoumi (1986), Atkinson (2003) and Bourguignon and Chakravarty (2003).

those above 180 cm, and not tall men those below 180 cm. The fuzzy approach, instead, describes how tall a person is through a membership function which 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 4.1: Crisp vs fuzzy sets



Source: own elaboration from Negnevitsky, 2005

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

The methodological proposal for the construction of a multidimensional index for sustainability assessment is hence based on the fuzzy set theory. In particular, it draws on the fuzzy approach proposed by Betti *et al.* (2015) to build a multidimensional index of poverty and deprivation. This approach relies on the contributions of Cerioli and Zani (1999), Cheli and Lemmi (1995), Cheli and Betti (1999) and it has been further elaborated in Betti *et al.* (2005, 2006) and Betti and Verma (2008). It considers poverty and deprivation as a matter of degree overcoming the simple dichotomization of the population into poor and non-poor with respect to a given poverty line. The state of deprivation is described by monetary and also non-monetary aspects of living conditions, defined respectively as Fuzzy Monetary (FM) and Fuzzy Supplementary (FS). The propensity to poverty and deprivation for any individual of rank *j*, that is the degree of monetary and non-monetary deprivation, is quantitatively specified through the following generalized form of membership function:

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

$$j : 1, \dots, n-1; \;\; \mu_{n,K} = 0$$

where X is the equivalised income in the monetary deprivation or the overall score s in the non-monetary deprivation; 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 non-monetary 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 (ARPR) computed on the basis the official poverty line. $F_{j,k}$ and $L_{j,k}$ are respectively the normalized distribution of income and the value of the Lorenz curve for any individual of rank j. Therefore, $\left(1-F_{j,k}\right)$ represents the proportion of individuals less poor than a given person (as in Cheli and Lemmi, 1995) while $\left(1-L_{j,k}\right)$ indicates the share of the total equivalised income received by all individuals less poor than a given person (as in Betti & Verma, 1999). Both the parameters α_K have thus an economic interpretation: the mean of the membership functions is expressible in terms of the generalised Gini measures $G_{\alpha K}$, a generalisation of the standard Gini coefficient: $\frac{\alpha K+G_{\alpha K}}{\alpha K(\alpha K+1)}$ = ARPR.

For non monetary deprivation, Betti *et al.* (2015) provides the following *step-by-procedure* to combine different supplementary indicators of living conditions into a composite index:

1. Selection of meaningful and useful indicators for the analysis;
2. Trasformation of the indicators into the [0, 1] interval ($s_{j,i}$ is the standardized j-th indicator for the i-th individual where $j = 1,2,\dots,k$ and $i = 1,2,\dots,n$).
3. Identification of underlying dimensions through exploratory and confirmatory factor analysis;
4. Calculation of weights within each dimension;
5. Calculation of scores for each dimension;
6. Calculation of an overall score and the parameter α of the m.f.;
7. Construction of fuzzy supplementary indicators in each dimension and overall.

After the indicators selection, their normalization and the identification of the latent dimensions, the indicators are weighted within each dimension to calculate the scores of any individual i for each dimension (step 5) using the methodology of the Second European report on Poverty, Income and Social Exclusion (Eurostat, 2002):

$$s_{hi}=\frac{\sum w_{hj}\cdot s_{hj,i}}{\sum w_{hj}}$$

where w_{hj} is the weight of the j-th indicator in the h-th dimension ($h = 1,2,\dots,m$).

The weights to be assigned to a given item within each dimension (step 4) are calculated using the "prevalence-correlation" method proposed by Betti and Verma (1999) 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).

The dispersion of a deprivation indicator $\left(w_{hj}^{a}\right)$ is the coefficient of variation of the complement to one of the deprivation scores s. Thus, the weights for the items affecting a large proportion of the population are low and on the opposite, the items with lower dispersion get higher weights since these can be respectively considered less/more critical in describing deprivation.

The correlation among indicators within a given dimension (w_{hj}^{b}) is computed in a way through which low weights are given to the indicators more highly correlated with others in the same dimension to limit the effect of redundancy and arbitrariness in assigning weights to the indicators.

The final weights for the indicators are hence calculated as:

$w_{hj} = w_{hj}^{a}\cdot w_{hj}^{b}$ where $j = 1,2,\dots,k_h$.

Then, the overall score, that is the non-monetary indicator FS for any individual *i*, is calculated (step 6) with the following arithmetic mean:

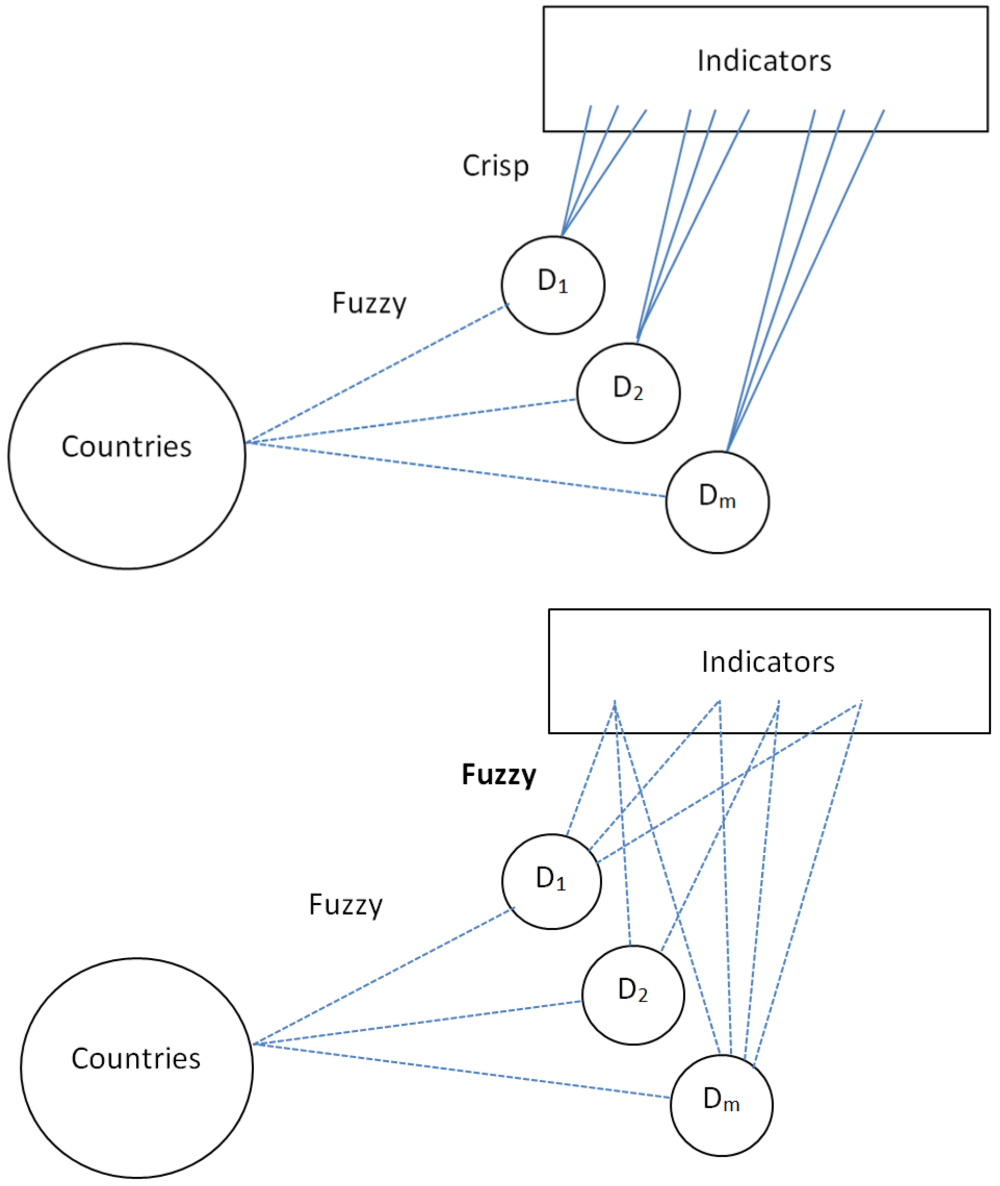
$$s_i = \frac{\sum_{h=1}^{m} s_{hi}}{m}$$

These values are then used in the m.f. to calculate the parameter α_2, so that the mean of the FS values is equal to the conventional at-risk-of-poverty rate (ARPR).
Finally, the estimated parameter α_2 is used in the m.f to calculate the FS indicators for each dimension of deprivation and overall.
This multidimensional methodology has proved to be robust and applicable also to other fields besides poverty (among others, Aassve *et al.*, 2007, 2009; Betti *et al.*, 2011; Belhadj, 2015). In this context, we have introduced a methodological proposal for a new fuzzy approach in the field of sustainability assessment.

4.2. Methodological proposal

This study proposes a new methodology to describe sustainability in its multiple dimensions. In order to properly assess the progress towards the SDGs, we have proposed an innovative fuzzy approach to weight and aggregate a set of indicators for the SDGs into a Super Index in a way that allows to capture their multidimensional and interrelated nature. Such methodological proposal starts from the idea that the indicators for the SDGs may cover not only one specific goal exclusively but more than one goal at the same time. According to the proposed multidimensional methodology, the dimensions identified through an exploratory factor analysis, performed on a set of indicators for the SDGs, are seen in the form of fuzzy sets to which the indicators may simultaneously belong with different degrees. Hence, the new approach enables to consider the membership of an indicator to more than one dimensions as a matter of degree, replacing the conventional crisp membership to only one dimension in a classical binary logic.
Figure 4.2 shows graphically the traditional fuzzy approach (Betti *et al*., 2015) in contrast to the proposed innovative fuzzy approach at the bottom. In both approaches, the statistical units, in this case the countries, belong to all the dimensions identified with a certain membership function but in the innovative fuzzy approch the indicators belong to all or almost all the dimensions with different degrees and do not belong anymore exclusively to only one dimension as in the crisp logic.
Precisely, in order to build a multidimensional Super Index to measure the agro-food sustainability in the Mediterranean region in line with the PRIMA programme we have proposed a particular step by step procedure drawing on the procedure of Betti et al. (2015) described before. First, the most suitable indicators to measure the Mediterranean agro-food sustainability are selected. Then, after their normalization, the latent dimensions are identified through an exploratory factor analysis (EFA) and finally the indicators are weighted and aggregated to calculate the score of each country over each dimension and the overall index.

Figure 4.2: Fuzzy approach – traditional vs innovative methodological proposal



Source: own elaboration

Each step is described in detail below.

1. *Selection of indicators to measure the agro-food sustainability in the Mediterranean area.* For this purpose, we have used the 11 indicators identified by the PRIMA programme described in paragraph 3.5. Since the values of some indicators were not available for some countries, in order to preserve all cases (countries), we have imputed the missing values, that is we have replaced these with a substituted value estimated using other available information in the dataset. Indeed, missing data in our analysis may create problems to examine the agro-food sustainability in the Mediterranean region introducing bias and affecting the statistical quality of the results. Therefore, we have replaced the missing values for the countries in the north and south Mediterranean areas respectively with the mean of the values of the northern and southern Mediterranean countries. In this way, we could

proceed with the analysis using standard techniques for complete data. Annex 1 reports the values of these selected indicators for each country considered in the study along with the imputed missing values (highlighted in red).

2. *Transformation of the indicators into the [0, 1] interval.*

   In order to ensure data comparability across the selected indicators, these are normalized to a 0 to 1 scale, where 0 indicates the best performance, alias the highest sustainability, and 1 the worst performance or lowest sustainability.

   The indicators for which a higher value denotes a better performance ("Land use", "Cereal yield", "Agriculture VA", "Crop water productivity", "Rural population using safely managed water and sanitation services" and "R&D expenditures") have been normalized into the [0; 1] interval using the following formula:

$$s_{ji} = 1 - \frac{x_{ji} - \min(x_j)}{\max(x_j) - \min(x_j)}$$

   where x_{ji} is the value of the *j*-th indicator ($j = 1,2,\ldots,11$) for the *i*-th country ($i = 1,2,\ldots,17$) and max/min(x_j) are the maximum and minimum values of each indicator in the 17 Mediterranean countries.

   On the contrary, the indicators for which a higher value represents a worse performance ("Population overweight", "Fertilizer consumption" and "Freshwater withdrawal") have been transformed using this formula:

$$s_{ji} = \frac{x_{ji} - \min(x_j)}{\max(x_j) - \min(x_j)}$$

   As an exception, the indicator "GHG emissions per sq. Km", has been normalized using the first formula and not the second one due to its strong negative correlation on the first dimension resulted from the factor analysis (factor loading: -0.5).

   The normalized values of all the indicators are reported in annex 2.

3. *Exploratory factor analysis to identify underlying dimensions of the Mediterranean agro-food sustainability.*

   The latent dimensions explaining the interrelationship among the selected indicators are identified through an EFA using the SAS software.

4. *Calculation of weights for the indicators (factor loadings).*

   The innovative character of the new fuzzy approach can be found in this step. Indeed, in line with the aforementioned idea, we have proposed a particular weighting system according to which the indicators for the SDGs may belong to more than one dimension with a certain correlation represented by the *factor loadings*. Hence, the weights to be assigned to the selected indicators are the factor loadings. In this paper, we have proposed a membership function considering a threshold of zero. This is the following:

$$w_{jh} = \mu(\gamma_{jh}) = \begin{cases} 0 & \gamma_{jh} \leq 0 \\ \gamma_{jh} & \gamma_{jh} > 0 \end{cases}$$

   where γ_{jh} is the factor loading of the *j*-th indicator on the *h*-th dimension ($h = 1,2,\ldots,m$).

   In this way, the indicators may belong to more than one dimension with different degrees, represented by the factor loadings higher than zero, and not exclusively to the dimension with the highest factor loading as in the traditional crisp approach.

Concerning the 'prevalence-correlation' method used for the calculation of weights in the context of poverty evaluation, we do not use this weighting system since the dispersion of an indicator is not meaningful in this case nor the correlation of an indicator with the others of a given dimension since we already consider a sort of "correlation weights", that is the factor loadings and furthermore the indicators may be correlated not only to the others within a specific dimension, but also to those of other dimensions according to the proposed membership function.

5. *Calculation of scores for each dimension.*
   The indicators for the i-th country are aggregated over each dimension to calculate the countries' scores for each dimension through the following weighted mean:
   $$s_{hi} = \frac{\sum_{j=1}^{11} s_{ji} \cdot w_{jh}}{\sum w_{jh}}$$
   where s_{ji} is the standardized *j*-th indicator for the *i*-th country and w_{jh} is the weight of the *j*-th indicator in the *h*-th dimension.
6. *Calculation of the overall score.*
   The overall Super Index measuring the agro-food sustainability in each country i is calculated as the following arithmetic mean:
   $$s_i = \frac{\sum_{h=1}^{m} s_{hi}}{m}$$
   where m is the number of identified dimensions.

We have therefore followed this step-by-step procedure to build the Super Index applying the new methodology to the 17 Mediterranean countries using the indicators identified by the PRIMA programme in order to assess the agro-food sustainability in the Mediterranean region.

5. Empirical analysis

As an empirical contribution of the paper, we present the results of the new methodology to measure the sustainability of the agro-food systems in the Mediterranean countries considered in this study. Since this methodology relies on the outcomes of the factor analysis, in this section we first analyse the latent dimensions identified through the EFA as well as the factor loadings selected according to the membership function proposed in step 4. Then, we describe in detail the results of the new methodology examining the countries' scores for each dimension and the overall Super Index.

After the indicators selection and their normalization, we have thus performed an EFA to identify the underlying dimensions. Starting from the correlation matrix of the selected indicators, four dimensions have been identified as appropriate dimensions to explain the interrelationships among the indicators and thus to describe the Mediterranean agro-food sustainability.

The correlation matrix in annex 3 reports the correlations among the 11 indicators selected. The indicators *"Rural population using safely managed water services"* and *"Rural population using safely managed sanitation services"* show the highest correlation (.80) Indeed, both measure the percentage of rural population using types of services (water and sanitation) which are interrelated. *"GHG emissions per sq. km"* and *"Research and development expenditures"*

are also strongly correlated (0.70). In fact, when R&D expenditures are high also GHG emissions are usually high. This is normally the case in industrialized countries and vice versa in developing countries. Moreover, the correlation is significant (0.70) for the indicators "*Cereal yield"* and *"Crop water productivity"* as well as for *"Agriculture value added"* and *"Annual freshwater withdrawal for agriculture"* since all these indicators are a measure of agriculture productivity.
In order to determine the number of factors to be retained, we have used the following three statistical / heuristic criteria:

- Eigenvalue greater than one rule (Kaiser-Guttman rule; Guttman, 1954 and Kaiser, 1960): only those factors whose associated eigenvalues are higher than one should be extracted (it is indeed meaningful to retain only the components that explain at least the same amount of variance accounted by the observed variables which are standardized and hence their variance is equal to one).
- Cumulative proportion of variance higher than 70-75%: only the factors that explain at least this share of the original variability should be retained since a 30-25% loss of variability can be generally accepted in favor of a reduction of the number of dimensions.
- Scree plot (reporting the eigenvalues on the y axis and the number of factor on the x axis) "elbow rule": the number of factors to be selected is that number prior to the point where the slope of the curve starts to flatten out (the elbow).

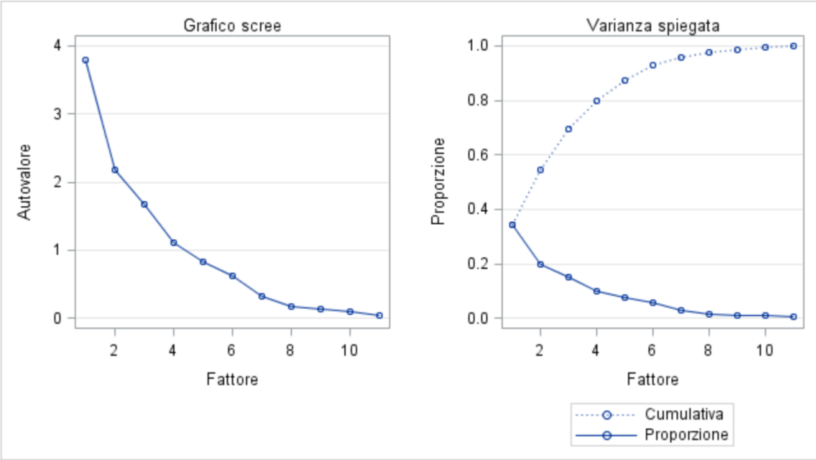
Table 5.1 shows the eigenvalues associated to each factor in descending order, along with their difference, the proportion and the cumulative proportion of the original variability explained by each factor, while Figure 5.1 reports the scree and variance plots, respectively, with the eigenvalues and the proportion of variance on the y axis and the number of factors on the x axis.

Table 5.1: Eigenvalues

Eigenvalues of the Correlation Matrix: Total=11 Average=1				
	Eigenvalue	**Difference**	**Proportion**	**Cumulative**
1	3.7845	1.5958	0.3440	0.3440
2	2.1886	0.5107	0.1990	0.5430
3	1.6780	0.5609	0.1525	0.6956
4	1.1171	0.2928	0.1016	0.7971
5	0.8243	0.2055	0.0749	0.8720
6	0.6189	0.2861	0.0563	0.9283
7	0.3328	0.1614	0.0303	0.9586
8	0.1714	0.0417	0.0156	0.9741
9	0.1297	0.0214	0.0118	0.9859
10	0.1084	0.0621	0.0099	0.9958
11	0.0463		0.0042	1.0000

Source: own elaboration (SAS)

Figure 5.1: Scree and variance plots



Source: own elaboration (SAS)

According to the rule of eigenvalues greater than one, the first four factors may be retained since their associated eigenvalues are respectively 3.7845, 2.1887, 1.680 and 1.1171, while the eigenvalue of the fifth factor is below 1 (0.8243). Indeed, the four factors explain together a large proportion of the original variance (80%). Moreover, the scree and variance plots show that the curve becomes more flat after factor 4. Therefore, for these reasons, four factors may be considered appropriate to explain the Mediterranean agro-food sustainability.

We have however examined, for the sake of completeness, also the results of the factor analysis with three factors since three factors may potentially be sufficient to explain the interrelationship among the indicators due to the cumulative proportion of variance explained by these number of factors (70%).

In Table 5.2 are reported the communality estimates with four and three factors. The proportion of the original variability accounted for by four factors is very high for all the indicators, ranging from 59.4% ("Forest and agricultural area") to 93.8% ("R&D"). The communality explained by three factors is still high, even if of course lower, from 53.3% ("Agriculture value added") to 93.5% ("R&D").

Table 5.2: Final Communality Estimates

Final communality estimates												
	Pop_ overweight	Forest_agr _area	GHG_ sqKm	Cereal_ yield	Agr_VA	Fertilizer	Crop_ water	Freshwater_ withdrawal	Rur_pop_ water	Rur_pop_ sanitation	R_D	Total
F4	0.8444	0.5936	0.9278	0.7241	0.8483	0.8583	0.7943	0.7506	0.7052	0.7842	0.9376	**8.7682**
F3	0.7811	0.5914	0.7828	0.7059	0.5329	0.6860	0.6727	0.5778	0.6808	0.7047	0.9348	**7.6511**

Source: own elaboration (SAS)

Then, in order to calculate the weights for the indicators through the new methodology, that is the factor loadings, we have first investigated the possible different factor loading matrixes from the factor analysis to identify the most suitable solution for the proposed innovative fuzzy approach. We have thus analysed the factor loading matrix with four and three factors considering both the non-rotated and rotated solutions (Annexes 4 and 5). The *non-rotated factor loading matrix with four factors* has been identified as the most appropriate for the proposed multidimensional methodology. Indeed, we have decided to extract the number of factors resulted from the factor analysis, run with a default eigenvalue of 1, instead of arbitrarily limiting the number of factors to be retained. Moreover, we have chosen the non-rotated solution since rotation (orthogonal rotation through the varimax method), which is normally applied in factor analysis to enhance factor interpretability, would tend to convert the proposed fuzzy approach back to a crisp logic. Indeed, the varimax rotation, the most common rotation method, maximizes the variance of the squared loadings of each factor increasing high loadings and decreasing low loadings so that the new factors are strongly associated with few original variables and weakly to the remaining variables facilitating factor interpretability. However, in such a way, rotation tends to polarize the factor loadings to the extremes of their range (zero or one) missing the intermediate factor loadings which are instead meaningful for the innovative fuzzy approach. In conclusion, considering the results of the factor analysis with four and three factors, with and without rotation, we have decided to adopt the non-rotated solution with four factors. We have thus calculated the weights for the indicators through the innovative methodological proposal selecting all the factor loadings consistent with a given threshold according to the proposed membership function (in this case a zero threshold) in all the identified dimensions. As shown in Table 5.3, almost all the indicators belong to more than one dimension simultaneously and not only to the dimension with the maximum factor loading as in the classical crisp approach commonly used in factor analysis (Table 5.4).

Table 5.3: F4 factor loading matrix: selected factor loadings according to the innovative fuzzy approach (threshold: 0)

	Factor1	Factor2	Factor3	Factor4
Pop_overweight	0.5213	0.6948	0	0.2515
Forest_agr_area	0.2998	0.7034	0.0828	0
GHG_sqKm	0.4602	0	0.6900	0.3808
Cereal_yield	0.8228	0	0	0
Agriculture_VA	0.6769	0.2457	0.1197	0
Fertilizer	0	0.7670	0.2739	0.4150
Crop_water	0.7550	0.1235	0	0.3487
Freshwater_withdrawal	0.7194	0.1892	0.1567	0
Rural_pop_water	0.6603	0	0	0.1560
Rural_pop_sanitation	0.7146	0	0	0.2819
R_D	0.1379	0	0.9492	0

Source: own elaboration (SAS)

Indeed, as shown in Table 5.3, the indicator *"Population overweight"* has a membership function of .52 on the first dimension, .69 on the second one and .25 on the forth one. Instead, it does not belong to the third dimension since the factor loading is in this case below zero. It thus has the highest degree of membership in dimension 2 (.7), followed by a degree of .5 in dimension 1 and then the lowest one in dimension 4. The indicator *"Forest area and agriculture"* is strongly associated to the second dimension (.7), while it belongs to the first and third dimensions with a low degree of membership, respectively .3 and .1, and it does not belong to the forth one. *"GHG emissions"* is mainly related to D3 (.7), followed by D1 (.5) and D4 (.3). *"Cereal yield"* is the only indicator belonging to only one dimension showing a particularly high correlation with the first dimension (.8). *"Agriculture value added"* and *"Freshwater withdrawal"* belong with a high membership degree to D1 (.7) and a lower degree to D2 and D3. *"Fertilizer consumption"* and *"crop water productivity"* are highly correlated respectively to D2 and D1 and with lower degrees, the first indicator to D3 and D4, and the latter to D1 and D2. *"Rural population using safely managed water services"* and *Rural population using safely managed sanitation services"* are both significantly associated to D1 (.7) and lower to D4. Finally, *"R&D"* has the highest membership function of .9 to D3 and belongs also to D1 with a low degree of .1.

Therefore, the EFA has identified four dimensions including the following indicators:

- Dimension 1: all the indicators except indicator 6 (Fertilizer consumption).
- Dimension 2: indicators 1 (Population overweight), 2 (Forest and agricultural area), 5 (Agriculture value added), 6 (Fertilizer consumption), 7 (Crop water productivity) and 8 (Freshwater withdrawal).
- Dimension 3: 2 (Forest and agricultural area), 3 (GHG emissions), 5 (Agriculture value added), 6 (Fertilizer consumption), 8 (Freshwater withdrawal) and 11 (R&D).
- Dimension 4: 1 (Population overweight), 3 (GHG emissions), 6 (Fertilizer consumption), 7 (Crop water productivity), 9 (Rural population using safely managed water services) and 10 (Rural population using safely managed sanitation services).

In conclusion, the indicators belong to all or almost all the dimensions to varying degrees given by the factor loadings higher than zero. Thus, the innovative fuzzy approach allows to consider the dimensions identified through the factor analysis in the form of fuzzy sets and the indicators may belong to more dimensions simultaneously. On the contrary, in Table 5.4, are reported the factor loadings that would be selected following the traditional crisp approach.

Table 5.4: F4 factor loading matrix: selected factor loadings according to the classical crisp approach (threshold: 0.55)

	Factor1	Factor2	Factor3	Factor4
Pop_overweight	0	0.6948	0	0
Forest_agr_area	0	0.7034	0	0
GHG_sqKm	0	0	0.6900	0
Cereal_yield	0.8228	0	0	0
Agriculture_VA	0.6769	0	0	0
Fertilizer	0	0.7670	0	0
Crop_water	0.7550	0	0	0
Freshwater_withdrawal	0.7194	0	0	0
Rural_pop_water	0.6603	0	0	0
Rural_pop_sanitation	0.7146	0	0	0
R_D	0	0	0.9492	0

Source: own elaboration (SAS)

According to the classical crisp approach, considering a threshold of 0.55, the first factor is strongly related to the indicators "*Cereal Yield", "Agriculture value added", "Crop water productivity", "Freshwater withdrawal" "Rural population using safely managed water services"* and *"Rural population using safely managed sanitation services"*, while the second factor is positively associated to *"Population overweight", "Forest and agricultural area"* and

"Fertilizer consumption", and finally the third factor has large positive loadings with *"GHG emissions"* and *"R&D"*, showing a particularly high correlation with the latter (0.9600). None of the indicators belong to the fourth dimension due to the low factor loadings on such dimension.

Therefore, following the traditional crisp approach, the dimensions are described only by the indicators with the highest factor loadings. Thus, in such a way, an indicator belongs to a specific dimension only without describing the multidimensional nature of sustainable development. The new proposed methodology enables indeed to better capture the multiple and interrelated dimensions which are at the core of sustainable development and the SDGs.

After the calculation of weights, we have then weighted and aggregated the indicators as described in step 5 and 6 calculating the countries' scores for each dimension and the overall Super Index.

The results of the new methodology to assess the performance of the 17 Mediterranean countries in terms of agro-food sustainability are shown in Table 5.5. In this table, the 17 Mediterranean countries in our analysis are ranked according to their scores on the overall index and over each dimension where 0 indicates the best performance, that is the highest sustainability, and 1 the worst performance, thus the lowest sustainability.

The results show that generally the NMCs tend to perform better in the overall index and across the four dimensions in contrast to the SEMCs, which are in the lowest positions excluding Israel whose results are similar to the countries of the North.

Table 5.5: countries' overall score and scores for each dimension

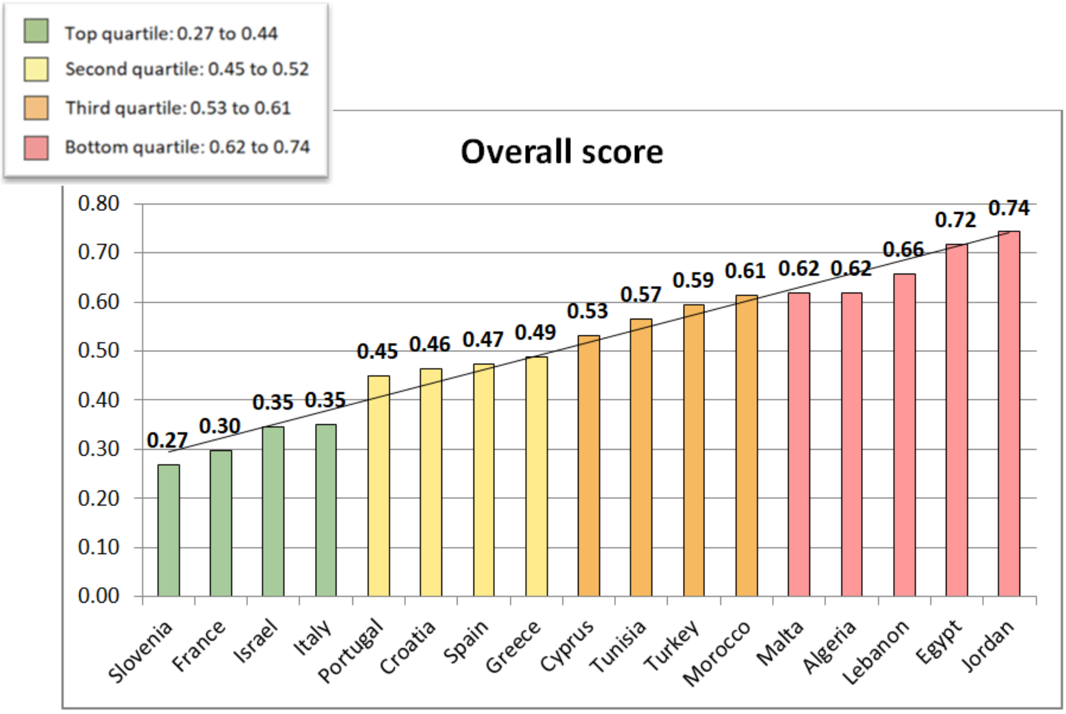
Ranking	Overall		S1		S2		S3		S4	
1	Slovenia	0.27	Slovenia	0.15	Slovenia	0.12	Israel	0.16	Italy	0.23
2	France	0.30	France	0.20	France	0.22	Slovenia	0.49	Israel	0.24
3	Israel	0.35	Italy	0.31	Italy	0.26	France	0.53	France	0.24
4	Italy	0.35	Croatia	0.35	Portugal	0.32	Italy	0.60	Slovenia	0.31
5	Portugal	0.45	Israel	0.41	Morocco	0.33	Turkey	0.67	Portugal	0.31
6	Croatia	0.46	Portugal	0.44	Spain	0.33	Lebanon	0.68	Cyprus	0.31
7	Spain	0.47	Malta	0.47	Tunisia	0.34	Morocco	0.69	Greece	0.36
8	Greece	0.49	Spain	0.48	Greece	0.35	Algeria	0.70	Spain	0.38
9	Cyprus	0.53	Greece	0.49	Croatia	0.36	Spain	0.71	Croatia	0.41
10	Tunisia	0.57	Egypt	0.50	Cyprus	0.46	Portugal	0.72	Tunisia	0.46
11	Turkey	0.59	Cyprus	0.54	Algeria	0.51	Croatia	0.74	Malta	0.49
12	Morocco	0.61	Lebanon	0.62	Turkey	0.51	Jordan	0.75	Turkey	0.54
13	Malta	0.62	Tunisia	0.65	Israel	0.58	Greece	0.75	Algeria	0.54
14	Algeria	0.62	Turkey	0.66	Lebanon	0.62	Tunisia	0.81	Egypt	0.57
15	Lebanon	0.66	Jordan	0.72	Malta	0.70	Cyprus	0.82	Morocco	0.62
16	Egypt	0.72	Algeria	0.73	Jordan	0.83	Malta	0.82	Jordan	0.67
17	Jordan	0.74	Morocco	0.82	Egypt	0.85	Egypt	0.95	Lebanon	0.70

Source: own elaboration

Figures 5.2 and 5.3 show the countries' performance in relation to overall index, that is the Super Index, represented graphically through a histogram and a map.

Slovenia, France, Israel and Italy are the top performers and seem to be today the most sustainable countries in terms of agro-food sustainability. They are followed by Portugal, Croatia, Spain and Greece in the second quartile. Cyprus, Tunisia, Turkey and Morocco are in lower positions in the third quartile. Lastly, Malta, Algeria, Lebanon, Egypt and Jordan in the bottom quartile appear to have the least sustainable agro-food system. In summary, most of the NMCs are in the best positions except for Cyprus and Malta which are in lower rankings. All the SEMCs perform worse with the exception of Israel with similar patterns to the NMCs.

Figure 5.2: Histogram of the countries' overall score



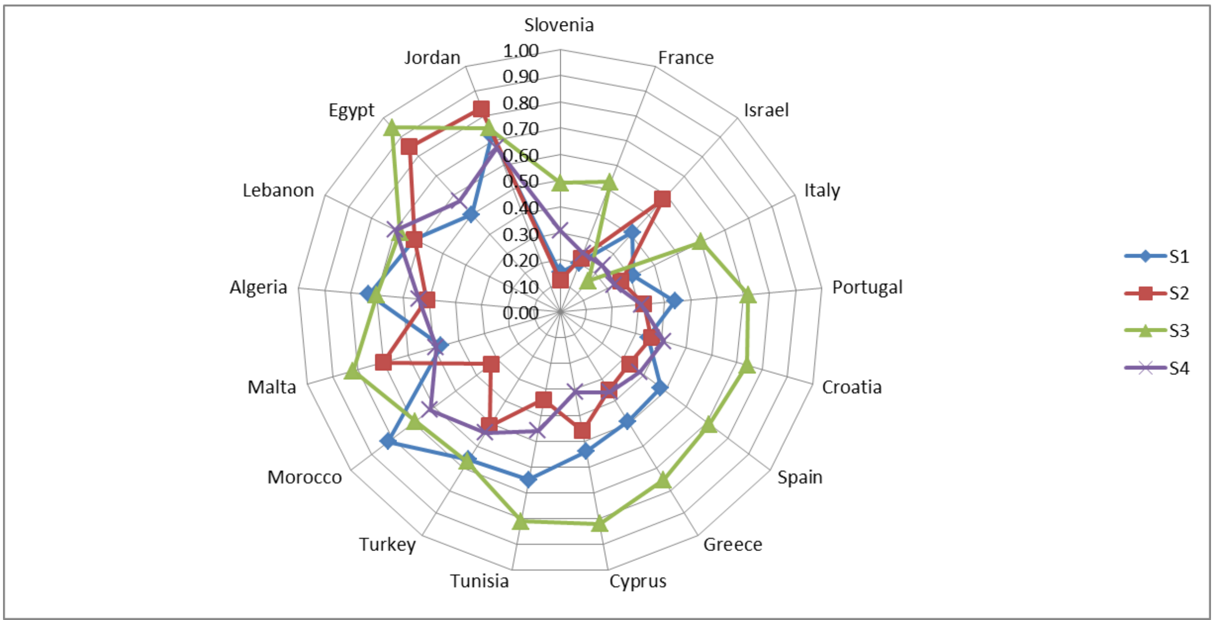
Source: own elaboration

Figure 5.3: Map of the countries' overall score

Source: own elaboration (MapPoint)

The scores of the countries, classified on the basis of the overall ranking, over the four dimensions are shown graphically in the radar chart below (Figure 5.4).

Figure 5.4: Radar chart of the countries' scores over each dimension



Source: own elaboration

The performance of most of the countries appear to be particularly negative on the *third dimension*, which is mainly described by investments in R&D and GHG emissions. Only Israel perform well on this dimension due to its high expenditures in R&D. Slovenia, France and Italy are in the top positions even if with a much higher value than Israel while Egypt is the least sustainable country on this dimension. Concerning the other dimensions, the scores of the NMCs, with the exception of Israel, which are on the right side of the radar chart, are generally closer to zero than the SEMCs, on the opposite side, whose scores are further from zero. In terms of the *first dimension*, which chiefly refers to agriculture productivity and water management, Slovenia, France and Italy are respectively the best performers while Jordan, Algeria and Morocco the worst. On the *second dimension*, covering mostly aspects related to nutrition ("population overweight") and the sustainable management of land ("forest and agricultural area" and "fertilizer consumption"), Slovenia, France and Italy show again the highest performance followed by other NMCs and in this case also by some SMCs such as Morocco and Tunisia due to their positive performance on "fertilizer consumption", whereas Malta, Jordan and Egypt are in the lowest rankings. Finally, regarding the *fourth dimension*, which may be considered as intensive production since it is characterized primarily by the indicators "fertilizer consumption", "GHG emissions" and "crop water productivity", Italy is the top performer, followed by Israel, France and Slovenia, while Morocco, Jordan and Lebanon are in the bottom rankings.

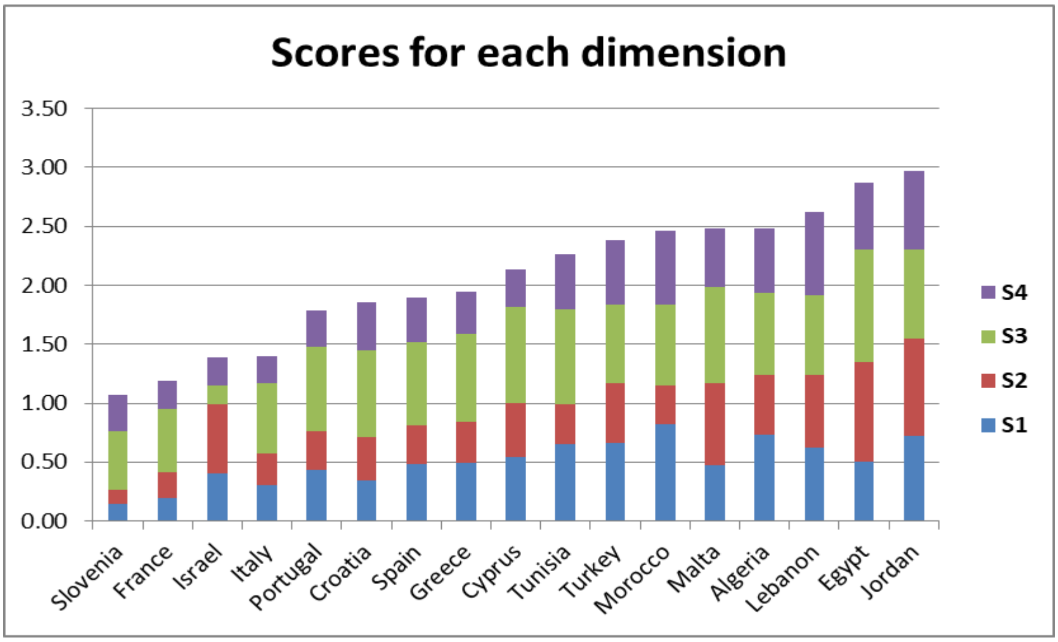
Table 5.6 reports the scores of the countries for each dimensions along with the sum of their scores over the four dimensions, their minimum and maximum scores on such dimensions as well as some measures of variability. The sum of the countries' scores on each dimension is also shown graphically in the histogram in Figure 5.5.

Table 5.6: countries' scores over each dimension

Overall ranking		S1	S2	S3	S4	∑	∩ = Min	∪ = Max
1	Slovenia	0.15	0.12	0.49	0.31	1.07	0.12	0.49
2	France	0.20	0.22	0.53	0.24	1.19	0.20	0.53
3	Israel	0.41	0.58	0.16	0.24	1.38	0.16	0.58
4	Italy	0.31	0.26	0.60	0.23	1.40	0.23	0.60
5	Portugal	0.44	0.32	0.72	0.31	1.80	0.31	0.72
6	Croatia	0.35	0.36	0.74	0.41	1.86	0.35	0.74
7	Spain	0.48	0.33	0.71	0.38	1.89	0.33	0.71
8	Greece	0.49	0.35	0.75	0.36	1.96	0.35	0.75
9	Cyprus	0.54	0.46	0.82	0.31	2.12	0.31	0.82
10	Tunisia	0.65	0.34	0.81	0.46	2.26	0.34	0.81
11	Turkey	0.66	0.51	0.67	0.54	2.38	0.51	0.67
12	Morocco	0.82	0.33	0.69	0.62	2.45	0.33	0.82
13	Malta	0.47	0.70	0.82	0.49	2.47	0.47	0.82
14	Algeria	0.73	0.51	0.70	0.54	2.48	0.51	0.73
15	Lebanon	0.62	0.62	0.68	0.70	2.63	0.62	0.70
16	Egypt	0.50	0.85	0.95	0.57	2.87	0.50	0.95
17	Jordan	0.72	0.83	0.75	0.67	2.97	0.67	0.83
Min		0.15	0.12	0.16	0.23			
Max		0.82	0.85	0.95	0.70			
Range		0.67	0.72	0.79	0.47			
Mean		0.50	0.45	0.68	0.44			
Var		0.03	0.04	0.03	0.02			
Stdev		0.18	0.21	0.17	0.15			
Cv		0.37	0.46	0.25	0.35			

Source: own elaboration

Figure 5.5: Histogram of the countries' scores over each dimension (sum)



Source: own elaboration

Most of the countries, especially those in the first three quartiles, present the maximum score on the third dimension due to their negative performance on such dimension, as mentioned before, with exception for Israel with the minimum score. The mean is in fact the highest among the dimensions as well as the range (0.79) due to the significant gap existing between Israel with the minimum score and the other countries, specifically Egypt with a considerable high score (0.95), as evident also in the histogram. The variability of the countries' scores around the mean is instead the lowest one (25%). On the other dimensions, among which the mean values are more similar, the coefficient of variation is higher on the second dimension, thus the level of dispersion of the countries' scores around the mean seem to be greater. Slovenia, France and Italy show the minimum score respectively on the second, first and third dimension. Italy is indeed the most sustainable country on the fourth dimension. Compared to the other countries in the top rankings, Israel has instead the highest score on the second dimension. The countries in the lowest rankings report high scores across all the dimensions with the minimum and maximum values varying depending on the country. The maximum score of Lebanon, Egypt and Jordan, overall the least sustainable countries, is respectively on the fourth, third and second dimension.

Therefore, the overall Super Index and the countries' scores for each dimension show that there are significant divergences between the NMCs and the SEMCs since in general the countries of the North are today more sustainable than those in the South East, excluding Israel, in terms of agro-food sustainability. It may hence be interesting to further investigate the reasons for such differences existing between the North and South East countries of the Mediterranean basin.

6. Conclusions and further research

The contribution of this paper is the proposal for a new methodology to properly describe the multidimensional nature of sustainable development and the SDGs in the context of the Agenda 2030. In particular, the paper introduces an innovative fuzzy approach to weight and aggregate a set of indicators for the SDGs into a multidimensional index for sustainability assessment. Indeed, the definition of methods able to capture the multidimensionality of the SDGs and to detect their interrelations providing proper estimates of sustainability is key to their success and thus to steer the world on a sustainable development path. Since today the sustainability of the agro-food system in the Mediterranean countries is seriously compromised by environmental, economic and social challenges, we have proposed a multidimensional methodology for the construction of a Super Index to measure the performance of the Mediterranean countries in terms of agro-food sustainability in line with the PRIMA programme. In order to construct the Super Index, we have analysed the statistical quality of the main datasets available for the SDGs indicators and selected suitable and statistically sound indicators. Then, we have weighted and aggragated these indicators using a new fuzzy approach. The proposed methodology is based on the fuzzy set theory since it is well suited to describe the complexity and multidimesionality of social dynamics allowing truth to be a matter of degrees rather than a simple true or false attribute.

The multidimensional nature of sustainable development has been indeed widely recognized.

In particular, the new methodology draws on the fuzzy approach and the step by step procedure developed by Betti et al. (2015) for the construction of a multidimensional index of poverty and deprivation. In this context, we have provided a step by step procecedure to build a Super Index for sustainability assessment. A set of indicators for the SDGs are thus weighted and aggregated within and across the different dimensions identified through an exploratory factor analysis to calculate the countries’ scores over each dimension and the overall index using an innovative fuzzy approach.

The study shows that the multiple and interrelated dimensions of sustainable development and the SDGs may be better captured by a methodology that allows to consider the dimensions identified using a set of indicators for the SDGs in the form of fuzzy sets to which the indicators may simultaneously belong with different degrees. Indeed, in this way, the indicators belong to more than one dimension at the same time and do not belong anymore exclusively to only one dimension as in the classical crisp approach. The new fuzzy approach thus enables to properly weight and aggregate a set of indicators for the SDGs embracing the multidimensional nature of sustainable development.

The empirical results of the new methodology applied to the 17 Mediterranean countries involved in the PRIMA programme using a set of indicators for the SDGs related to the agro-food sustainability show that generally the agro-food system is more sustainable in the Northern Mediterranean countries than in the Southern and Eastern countries since the countries of the North of the region perform better on the overall Super Index and on the four dimensions than those in the South (with exception for Israel). In conclusion, the NMCs seem to be characterized today by more sustainable patterns than the SEMCs in terms of agro-food sustainability.

The construction of an index to assess the agro-food sustainability in the Mediterranean region is today quite complicated since not all data are easily available or updated in all the Mediterranean countries, especially in the South East. Therefore, strengthening data collection and statistical capacity in the region may be of primary importance. Moreover, further research may be needed to identify additional meaningful indicators providing a more comprehensive picture of sustainability in the Mediterranean area. Finally, further developments may help to improve our methodological proposal, i.e. concerning the membership functions, in order to capture the multidimensional nature of sustainable development and the SDGs. Indeed, the construction of a multidimensional Super Index to measure the sustainability of the Mediterranean countries is a complex and ambitious task and we know that this study is only a start in this direction.

Annexes

Annex 1: indicators values and imputed missing values

	Pop_ overweight	Forest_ agr_ area	GHG_sqKm	Cereal_yield	Agriculture _VA	Fertilizer	Crop_water	Freshwater_ withdrawal	Rural_pop_ water	Rural_pop_ sanitation	R_D
Algeria	62.00	18.22	74.09	1369.20	6221.59	51.32	0.72	59.23	81.80	82.20	1.87
Croatia	59.60	61.31	537.57	6036.70	35659.22	250.99	0.98	1.29	99.70	95.80	0.85
Cyprus	59.10	30.39	803.37	291.00	20087.79	175.86	1.11	65.65	100.00	100.00	0.46
Egypt	63.50	3.84	295.07	7230.80	5453.83	662.53	1.22	85.90	99.00	93.10	0.72
France	59.50	83.56	909.05	7634.30	88578.25	151.46	1.42	10.40	100.00	98.90	2.23
Greece	62.30	94.87	762.13	4134.00	16847.68	157.23	1.05	87.83	100.00	98.10	0.96
Israel	64.30	32.47	3808.08	4355.80	18431.95	239.27	1.01	57.78	100.00	100.00	4.27
Italy	58.50	76.35	1601.63	5709.00	59978.17	130.95	1.21	44.07	100.00	99.60	1.33
Jordan	69.60	13.08	304.51	1455.50	8414.43	388.04	0.51	64.96	92.30	98.90	1.87
Lebanon	67.90	77.74	781.73	2619.90	74760.60	473.90	0.62	59.54	99.00	80.70	1.87
Malta	66.40	33.06	891.02	4763.20	65670.82	468.00	1.11	64.02	100.00	100.00	0.77
Morocco	60.40	81.16	180.13	1454.30	5017.63	66.71	0.82	87.79	65.30	65.50	1.87
Portugal	57.50	75.14	786.38	4415.90	10069.69	184.76	1.07	78.70	100.00	99.80	1.28
Slovenia	56.10	92.50	1039.70	6481.30	248524.77	260.02	1.11	0.31	99.40	99.10	2.21
Spain	61.60	89.95	688.34	3246.10	45620.96	151.36	0.91	68.19	100.00	100.00	1.22
Tunisia	61.60	71.54	242.78	1756.40	18431.95	31.82	0.95	80.00	93.20	79.80	0.63
Turkey	66.80	65.32	567.44	2831.50	10723.61	105.27	0.64	80.93	100.00	85.50	1.87

Source: own elaboration from Saladini et al. (2017)

Annex 2: normalized indicators values

	Pop_ overweight	Forest_ agr_ area	GHG_sqKm	Cereal_yield	Agriculture _VA	Fertilizer	Crop_water	Freshwater_ withdrawal	Rural_pop_ water	Rural_pop_ sanitation	R_D
Algeria	0.44	0.84	1.00	0.85	1.00	0.03	0.77	0.67	0.52	0.52	0.63
Croatia	0.26	0.37	0.88	0.22	0.87	0.35	0.48	0.01	0.01	0.12	0.90
Cyprus	0.22	0.71	0.80	1.00	0.94	0.23	0.34	0.75	0.00	0.00	1.00
Egypt	0.55	1.00	0.94	0.05	1.00	1.00	0.22	0.98	0.03	0.20	0.93
France	0.25	0.12	0.78	0.00	0.66	0.19	0.00	0.12	0.00	0.03	0.53
Greece	0.46	0.00	0.82	0.48	0.95	0.20	0.41	1.00	0.00	0.06	0.87
Israel	0.61	0.69	0.00	0.45	0.94	0.33	0.45	0.66	0.00	0.00	0.00
Italy	0.18	0.20	0.59	0.26	0.77	0.16	0.23	0.50	0.00	0.01	0.77
Jordan	1.00	0.90	0.94	0.84	0.99	0.56	1.00	0.74	0.22	0.03	0.63
Lebanon	0.87	0.19	0.81	0.68	0.71	0.70	0.88	0.68	0.03	0.56	0.63
Malta	0.76	0.68	0.78	0.39	0.75	0.69	0.34	0.73	0.00	0.00	0.92
Morocco	0.32	0.15	0.97	0.84	1.00	0.06	0.66	1.00	1.00	1.00	0.63
Portugal	0.10	0.22	0.81	0.44	0.98	0.24	0.38	0.90	0.00	0.01	0.78
Slovenia	0.00	0.03	0.74	0.16	0.00	0.36	0.34	0.00	0.02	0.03	0.54
Spain	0.41	0.05	0.84	0.60	0.83	0.19	0.56	0.78	0.00	0.00	0.80
Tunisia	0.41	0.26	0.95	0.80	0.94	0.00	0.52	0.91	0.20	0.59	0.95
Turkey	0.79	0.32	0.87	0.65	0.98	0.12	0.86	0.92	0.00	0.42	0.63

Source: own elaboration

Annex 3: Correlation matrix 11 indicators

	Pop_ overweight	Forest_ agr_ area	GHG_sqKm	Cereal_yield	Agriculture _VA	Fertilizer	Crop_water	Freshwater_ withdrawal	Rural_pop_ water	Rural_pop_ sanitation	R_D
Pop_overweight	1.00	0.45	0.02	0.32	0.37	0.45	0.64	0.41	-0.01	0.16	-0.15
Forest_agr_area	0.45	1.00	-0.01	0.18	0.42	0.47	0.17	0.21	0.06	-0.10	0.00
GHG_sqKm	0.02	-0.01	1.00	0.26	0.13	-0.02	0.27	0.19	0.36	0.42	0.70
Cereal_yield	0.32	0.18	0.26	1.00	0.46	-0.36	0.70	0.54	0.48	0.47	0.09
Agriculture_VA	0.37	0.42	0.13	0.46	1.00	-0.11	0.30	0.70	0.27	0.26	0.18
Fertilizer	0.45	0.47	-0.02	-0.36	-0.11	1.00	-0.04	0.01	-0.34	-0.25	0.10
Crop_water	0.64	0.17	0.27	0.70	0.30	-0.04	1.00	0.33	0.37	0.48	-0.16
Freshwater_withdrawal	0.41	0.21	0.19	0.54	0.70	0.01	0.33	1.00	0.28	0.36	0.22
Rural_pop_water	-0.01	0.06	0.36	0.48	0.27	-0.34	0.37	0.28	1.00	0.79	-0.10
Rural_pop_sanitation	0.16	-0.10	0.42	0.47	0.26	-0.25	0.48	0.36	0.79	1.00	-0.01
R_D	-0.15	0.00	0.70	0.09	0.18	0.10	-0.16	0.22	-0.10	-0.01	1.00

Source: own elaboration

Annex 4: F4 factor loading matrixes

F4 Non-rotated factor loading matrix				
	Factor1	**Factor2**	**Factor3**	**Factor4**
Pop_overweight	0.5213	0.6948	-0.1634	0.2515
Forest_agr_area	0.2998	0.7034	0.0828	-0.0460
GHG_sqKm	0.4602	-0.3079	0.6900	0.3808
Cereal_yield	0.8228	-0.1079	-0.1314	-0.1351
Agriculture_VA	0.6769	0.2457	0.1197	-0.5616
Fertilizer	-0.1508	0.7670	0.2739	0.4150
Crop_water	0.7550	0.1235	-0.2957	0.3487
Freshwater_withdrawal	0.7194	0.1892	0.1567	-0.4156
Rural_pop_water	0.6603	-0.4600	-0.1824	0.1560
Rural_pop_sanitation	0.7146	-0.4227	-0.1243	0.2819
R_D	0.1379	-0.1216	0.9492	-0.0531
F4 Rotated factor loading matrix				
	Factor1	**Factor2**	**Factor3**	**Factor4**
Pop_overweight	0.2929	0.2578	0.8173	-0.1554
Forest_agr_area	-0.0840	0.3816	0.6636	-0.0244
GHG_sqKm	0.4126	-0.0118	0.0322	0.8697
Cereal_yield	0.6454	0.5543	0.0137	0.0110
Agriculture_VA	0.1383	0.9002	0.1223	0.0624
Fertilizer	-0.3087	-0.2036	0.8341	0.1605
Crop_water	0.7684	0.1792	0.4014	-0.1032
Freshwater_withdrawal	0.2433	0.8053	0.1470	0.1461
Rural_pop_water	0.7973	0.1503	-0.2058	0.0673
Rural_pop_sanitation	0.8607	0.1012	-0.1040	0.1495
R_D	-0.1707	0.1977	-0.0456	0.9313

Source: own elaboration (SAS)

Annex 5: F3 factor loading matrixes

Non-rotated factor loading matrix			
	Factor1	**Factor2**	**Factor3**
Pop_overweight	0.5213	0.6948	-0.1634
Forest_agr_area	0.2998	0.7034	0.0828
GHG_sqKm	0.4602	-0.3079	0.6900
Cereal_yield	0.8228	-0.1079	-0.1314
Agriculture_VA	0.6769	0.2457	0.1197
Fertilizer	-0.1508	0.7670	0.2739
Crop_water	0.7550	0.1235	-0.2957
Freshwater_withdrawal	0.7194	0.1892	0.1567
Rural_pop_water	0.6603	-0.4600	-0.1824
Rural_pop_sanitation	0.7146	-0.4227	-0.1243
R_D	0.1379	-0.1216	0.9492
Rotated factor loading matrix			
	Factor1	**Factor2**	**Factor3**
Pop_overweight	0.2078	0.8423	-0.1689
Forest_agr_area	-0.0592	0.7667	0.0119
GHG_sqKm	0.3187	-0.0162	0.8252
Cereal_yield	0.7912	0.2683	0.0890
Agriculture_VA	0.4443	0.5339	0.2248
Fertilizer	-0.5298	0.6321	0.0758
Crop_water	0.6855	0.4316	-0.1286
Freshwater_withdrawal	0.4933	0.5055	0.2810
Rural_pop_water	0.8130	-0.1218	0.0710
Rural_pop_sanitation	0.8269	-0.0600	0.1318
R_D	-0.1128	0.0212	0.9600

Source: own elaboration (SAS)

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