Unveiling the path towards sustainability: scientific interest at HEIs from a scientometric approach in the period 2008–2017

by

Núria Bautista-Puig

A dissertation submitted by in partial fulfillment of the requirements for the degree of Doctor of Documentation in

Library Science: Archives and Libraries in the Digital Environment

Universidad Carlos III de Madrid

Advisor(s):
Dr. Elías Sanz Casado
Dr. Luís Enrique Moreno Lorente

Getafe, 2020

Dedication

To Ivan.
To my parents: Rosa Puig and Joaquim Bautista.

Acknowledgments

"Science means constantly walking a tightrope between blind faith and curiosity; between expertise and creativity; between bias and openness; between experience and epiphany; between ambition and passion; and between arrogance and conviction — in short, between an old today and a new tomorrow"

Heinrich Rohrer, Swiss physicist who received the Nobel Prize in Physics in 1986.

Extracted from a lecture given in Stockholm (April 2012).

The present doctoral thesis presents the research that I have been working on during the past four-year journey. This has been possible thanks to an FPI grant from the Ministry of Economy and Competitiveness, as well as other grants which have allowed me to enjoy different research stays and participate in different congresses (1st Yerun Mobility Award to Antwerp University in Belgium; Erasmus+ Training to University of Aveiro in Portugal and the Early-Career Grant for attending the 14th RDA Plenary in Helsinki, Finland). Moreover, it would not have been possible without the support and encouragement from a number of people, both at the professional and personal level. Therefore, I would like to express my gratitude explicitly to the following persons:

- First of all, I would like to thank Professor Elías Sanz Casado and Professor Luís Enrique Moreno, my supervisors, who have guided and supported me on this journey, for their expert guidance, encouragement, and patience. Without their guidance and persistent help, this thesis would not have been possible. I thank them for their support at all stages of the process and their trust in my capabilities. Elías' knowledge and experience have been crucial for this thesis. Our trips to the heart of citizen science and science shops have been an inspiration and motivation on this journey. Luis' models and "cooking" methodologies, and his many insights and suggestions from an "engineering" perspective, have really opened my mind.
- Thanks to my colleagues in the Laboratory Metric of Information Studies (LEMI), for their warm welcome from the beginning and for introducing me to the interconnected bibliometric world. I thank the ones who are remaining, the ones who left and the ones who are still in contact: Andrés Pandiella, Antonio Eleazar Serrano, Carlos García-Zorita, Daniela de Filippo, Jorge Mañana, Maria Luisa Lascuráin and Sergio Marugán. I thank them for their enthusiasm, support, fresh ideas and suggestions for improving my work, and for including me as a member of all the parties and events since the very beginning. (There's always time for a sweet and a celebration!) My thanks to Elba (and our little "ERC" son) and Raquel, for how we laughed and our debates about what is a science shop (and our fight with the ethics world). Thanks all for making me passionate about this new world.
- To the INAECU members for connecting and always giving feedback in the meetings on a wide variety of fields.

- To the University of Carlos III and especially to the Library and Information Sciences Department. Thanks for giving me the opportunity to belong to it. Of the Department, I would like to thank Professor Virginia Ortiz-Repiso (for her constant care and encouragement), Tony Hernández, Eva Méndez and the rest of the professors for their support during this journey and for allowing me to represent the doctoral students in the doctoral programme.

- To the CWTS research group, thank you very much for giving me the opportunity to be able to work and learn at the centre: I thank the group for their inspiration and for all the people I had the chance to meet. I especially thank Rodrigo Costas for the warm welcome to the north, for so many ideas for improving my methodology, for his inspiration and motivation, and for his catchy altmetric enthusiasm and support.

- To my conference colleagues, thank you for inspiration, motivation and suggestions for improving my work.

- To my parents, I thank them for their endless love and support. Father, I wonder if you are proud of me.

- To Ivan, for her unwavering love, support, and patience that goes beyond the stars. For always being by my side, no matter how, when and where. And to my little Duque, who has witnessed this long journey very curious by my side.

- And finally, to the Ministry of Economy and Competitiveness (MINECO) for financial support in the form of the FPI grant.

PUBLISHED AND SUBMITTED CONTENT

1. Bautista-Puig N., Carlos García-Zorita C., Mauleón E. (2019). European Research Council: excellence and leadership over time from a gender perspective, *Research Evaluation*, Volume 28, Issue 4, October 2019, Pages 370–382, https://doi.org/10.1093/reseval/rvz023
   Partially included. The material from this source included in the thesis is not indicated by typographic means or references.

2. Bautista-Puig, N.; Dudek J. (2019). *Can Twitter hashtags be used for field delineation? The case of Sustainable Development Goals (SDGs)*. In the 17th International Conference on Scientometrics & Informetrics (ISSI 2019), Rome (Italy), Volume II, ISBN 978-88-3381-118-5, p.2774-2775.
   Totally included in Chapter IV (Results). All material from this source included in the thesis is indicated by typographic means and an explicit reference

3. Bautista-Puig, N.; Mauleón E. (2019). *Unveiling the path towards sustainability: is there a research interest on sustainable goals?* In the 17th International Conference on Scientometrics & Informetrics (ISSI 2019), Rome (Italy), Volume II, ISBN 978-88-3381-118-5, p.2770-2771.
   Totally included in Chapter IV (Results). All material from this source included in the thesis is indicated by typographic means and an explicit reference

4. Bautista-Puig, N., Mauleón, E., & Sanz-Casado, E. (2019). The role of universities in sustainable development (SD): the Spanish Framework. In *Higher Education and Sustainability* (pp. 91–116). Taylor & Francis Group, 2020.: CRC Press. https://doi.org/10.1201/b22452-5
   Totally included in the Chapter 1. All material from this source included in the thesis is indicated by typographic means and an explicit reference.

5. Bautista-Puig, N.; Mauleón E.; Sanz-Casado E. (2019). Analysis of Social, Environmental and Economic Sustainability Core: A Bibliometric Overview. *International Journal of Innovation and Sustainable Development*, ISSN: 1740-8830, In press.
   Partially included. The material from this source included in the thesis is not indicated by typographic means or references.

6. Bautista-Puig N., Pandiella A., Lascurain M.L. 2016. Dynamics and predictions with AR and ARMA models of patent applications on renewable energies in Spain from 1985 to 2014. National Congress of the Environment (Conama). December. Available at: http://www.conama11.vsf.es/conama10/download/files/conama2016/CT%202016/1998973589.pdf
   Partially included in the Chapter 1. All material from this source included in the thesis is indicated by typographic means and an explicit reference.

Spanish Abstract:

La humanidad ha experimentado el impacto de un modelo económico insostenible a todos los niveles. Este tema se ha cristalizado en diferentes cumbres y conferencias durante el siglo XX. Como resultado de esta preocupación, surgió el concepto de Desarrollo Sostenible (DS). Sin embargo, este concepto ha recibido muchas críticas por ser altamente antropocéntrico y compartimentado, carente de coherencia conceptual o interconexión entre todos los aspectos involucrados. Más tarde, la aparición de los Objetivos de Desarrollo del Milenio (ODM) en 2000 y los recientes Objetivos de Desarrollo Sostenible (ODS) en 2015 constituyen una nueva era. Este es el plan para lograr un futuro mejor y más sostenible para todos, en el que todos los agentes involucrados deben participar. En este punto, las instituciones de educación superior (IES) tienen un papel central y la sostenibilidad se ha convertido en una prioridad política para la ciencia.

El objetivo de este estudio es conocer los patrones de la investigación llevada a cabo en investigación de sostenibilidad, incluido el flujo de actividad científica, así como la colaboración o el impacto que genera dicha investigación. Este estudio de doctorado explora cómo se puede delinear este concepto desde un enfoque bibliométrico, lo cual conduce a la 'ciencia de la sostenibilidad'. La producción científica de artículos fue identificada y analizada en el período 2008-2017 en la Web of Science (WoS). Además, este estudio explora las instituciones de educación superior (IES) y su papel en el fomento de la sostenibilidad, mediante la evaluación de su investigación y la implementación de prácticas de sostenibilidad en las IES españolas. Además, presenta una delineación de los Objetivos de Desarrollo Sostenible (ODS) y propone una metodología para clasificar la producción científica en cada uno e los objetivos. El análisis de esta producción se realiza a través de indicadores bibliométricos unidimensionales y multidimensionales. Estos indicadores se han dividido y analizado en diferentes niveles de agregación, desde el más general hasta el más específico, comenzando con las características generales de investigación y descendiendo al nivel de país, instituciones o temática, entre otros.

Los resultados muestran un interés creciente en la investigación de sostenibilidad y se observa una fuerte influencia del pilar medioambiental. Además, hay países con una alta producción científica pero no tan especializados en el tema como otros con una menor producción. En cuanto a las instituciones, los resultados obtenidos muestran que las IES realizaron un importante esfuerzo de investigación para el desarrollo sostenible y son las que producen un mayor número de documentos. Además, se observa que las instituciones tienden a colaborar con centros geográficamente próximos. Al analizar las Prácticas de sostenibilidad en las IES españolas, se encuentran asociaciones altas entre variables como la presencia de un Plan de Sostenibilidad y de una Oficina Verde. Sin embargo, este estudio demuestra claramente que, aunque se reconoce que el desarrollo sostenible es muy importante para las IES y la sociedad, todavía no está integrado en las estrategias, actividades y políticas de todo el sistema.

Como conclusión, se afirma que es esencial identificar estrategias de sostenibilidad e introducir desarrollo sostenible en todas las actividades en el entorno de las IES. Finalmente, esta tesis contribuye a la literatura sobre instituciones de educación superior sostenibles, así como al análisis y la mejora de educación superior para el desarrollo sostenible, especialmente en el sistema de educación superior español. Además, este estudio contribuye al análisis bibliométrico al ofrecer dos propuestas de delineación científica para la ciencia de la sostenibilidad y los objetivos de desarrollo sostenible, así como metodologías para clasificar la producción científica. Este análisis denota la importancia de los estudios bibliométricos para el estudio y la caracterización de la producción científica en un campo transdisciplinario que, además, se puede extrapolar a otros campos de estudio.

Palabras clave: *Cienciometría; Bibliometría; Sostenibilidad; Desarrollo sostenible; Ciencia de la sostenibilidad; Educación superior para el desarrollo sostenible; Instituciones españolas de educación superior; Sistema Universitario Español; Implementación del desarrollo sostenible; Objetivos de Desarrollo Sostenible (ODS), Objetivos de Desarrollo del Milenio (ODM).*

English Abstract

Humanity has experienced the impact of an unsustainable economic model at all levels. This topic has crystallized in different summits and conferences during the 20th century. As a result of this concern, the concept of sustainable development (SD) emerged. However, it has received much criticism for being highly anthropocentric and compartmentalized, and lacking conceptual coherence or interconnectedness among all the aspects involved. The introduction of the Millennium Development Goals (MDGs) in 2000 and the recent Sustainable Development Goals (SDGs) in 2015 heralded a new era. They represent a blueprint to achieve a better and more sustainable future for all, in which all stakeholders need to be involved. At this point, higher education institutions (HEIs) have a central role to play and sustainability has emerged as a policy priority for science.

The objective of this study is to investigate the patterns of sustainability research, including the flow of scientific activity, as well as the collaboration or impact that such research generates. This doctoral study explores how can sustainability can be delineated from a bibliometric approach, leading to a new approach of "sustainability science". The scientific production of articles was identified and analysed for the period 2008–2017 using the Web of Science (WoS). Moreover, this research study explores HEIs and their role in fostering sustainability, by assessing their research and the implementation of sustainability practices in Spanish HEIs. As well, it presents a delineation of the Sustainable Development Goals (SDGs) and proposes a methodology for classifying the output on each SDG. This analysis is done through unidimensional and multidimensional bibliometric indicators. These indicators have been divided and analysed in different levels of aggregation, from the most general to the most specific, starting with general research features and progressing to country, institutional, and thematic levels, among others.

The results indicate a growing interest in sustainability research and a strong influence on the environmental pillar. Moreover, some countries with the highest scientific output are not as specialized in terms of topics as others with a lower output. Regarding institutions, the results obtained indicate that HEIs made an important research contribution to SD and are the ones that produce a higher number of documents. It was found that institutions tend to collaborate with other institutions that are close. By analysing sustainability practices in Spanish HEIs, it was found that there are more associations between variables such as having a sustainability plan and having a green office. However, this study clearly demonstrates that although SD is recognized as being very important to HEIs and society, it is not yet embedded in the whole system's strategies, activities, and policies.

In conclusion, this research study reveals that it is essential to identify sustainability strategies and introduce SD in all activities in the HEI environment. Finally, this thesis contributes to the literature on sustainable HEIs, as well as to how higher education for SD is understood and can be improved, especially in the Spanish higher education system. Moreover, this contributes to bibliometric study by offering two delineation approach to sustainability science and sustainable development goals as well as methodologies for classifying scientific output. This denotes the importante of bibliometric studies for the study and characterization of scientific output in a transdisciplinary field that can be extrapolated to other fields of study.

Keywords: *Scienometrics; Bibliometrics; Sustainability; Sustainable development; Sustainability science; Higher education for sustainable development; Spanish higher education institutions; Spanish university system; Implementation of sustainable development; Sustainable Development Goals (SDGs); Millennium Development Goals (MDGs).*

TABLE OF CONTENTS

List of tables

List of figures

List of abbreviations and acronyms

General

A&HCI	Arts and Humanities Citation Index
AI	Activity index
BKCI-S	Book Citation Index-Science
BKCI-SSH	Book Citation Index-Social Sciences and Humanities
BOKU	University of Natural Resources and Life Sciences
CAGR	Cumulative average growth rate
CCR Expanded	Current Chemical Reactions
CPCI-S Conference	Proceedings Citation Index: Science
CPCI-SSH	Conference Proceedings Citation Index: Social Sciences and Humanities
CORDIS	Community Research and Development Information Service
CRUE	Conference of Spanish University Rectors
CSAF	Campus Sustainability Assessment Framework.
CSR	Corporate social responsibility
CWTS	Centre for Science and Technology Studies
DESD	Decade of Education for Sustainable Development
EPO	European Patent Office
ERA	European Research Area
ESD	Education for Sustainable Development
FA	Funding acknowledgments
FECYT	Spanish Foundation for Science and Technology
FP1	First Framework Programme
FP7	Seventh Framework Programme
FP8	Eighth Framework Programme
GASU	Graphical Assessment of Sustainability in Universities
GHESP	Global Higher Education for Sustainability Partnership
GPI	Global Patent Index
HE	Higher Education
HEIs	Higher Education Institutions
HESD	Higher Education for Sustainable Development
HESI	Higher Education Sustainability Initiative
IC	Index Chemicus
ICI	Institutional collaboration index
IF	Impact Factor
IIASA	International Institute for Applied Systems Analysis
INRA	Institut National de la Recherche Agronomique
IPC	International Patent Classification
ISCN	International Sustainable Campus Network
ISI	Institute for Scientific Information
ISO	International Organization for Standardization
IWRM	Integrated water resources management
JCR	Journal Citation Reports
KCI	Korean Journal Database
LEMI	Laboratorio de Estudios Métricos de Información
M&SDG	Millennium and Sustainable Development Goal
PER	Renewable Energy Action Plan
PFL	Productivity in foreign languages
RC	Research Centre
REDS	Sustainable Solutions Development Network
RMSE	Root mean square error
SCI	Science Citation Index
SCI-EXPANDED	Science Citation Index Expanded
SD	Sustainable development
SDG	Sustainable Development Goal

SDSN	Spanish Sustainable Development Solutions Network
SHE	Sustainability in higher education
SHEI	Sustainable Higher Education Institution
SIC	Subject index classification
SQL	Structured Query Language
SS	State space
SSCI	Social Sciences Citation Index
STARS	Sustainability Tracking, Assessment & Rating System
STAUNCH	Sustainability Tool for Assessing Universities Curiculla Holistically
SUE	Spanish University System
TPP	Total publication productivity
T-SQL	Transact SQL
ULSF	University Leaders for a Sustainable Future
UNESCO	United Nations Educational, Scientific and Cultural Organization
USPTO	United States Patent and Trademark Office (USPTO)
WIPO	World Intellectual Property Organization
WoS	Web of Science

Universities

CEU	Universidad San Pablo CEU
COMILLAS	Universidad Pontificia Comillas
DEUSTO	Universidad de Deusto
EHU	Universidad del País Vasco
IE	IE University (including SEK)
MUNI	Universidad de Mondragón
NEBRIJA	Universidad Antonio de Nebrija
SANDAMASO	Universidad Eclesiástica Sandamaso
UA	Universidad de Alicante
UAB	Universidad Autònoma de Barcelona
UAH	Universidad Alcalá de Henares
UAL	Universidad de Almería
UAM	Universidad Autónoma de Madrid
UAO	Universidad Abat Oliba CEU
UAX	Universidad Alfonso X El Sabio
UB	Universidad de Barcelona
UBU	Universidad de Burgos
UC3M	Universidad Carlos III de Madrid
UCA	Universidad de Cádiz
UCAM	Universidad Católica San Antonio
UCAVILA	Universidad Católica Santa Teresa de Jesús de Avila
UCHCEU	Universidad Cardenal Herrera
UCJC	Universidad Camilo José Cela
UCLM	Universidad de Castilla-La Mancha
UCM	Universidad Complutense de Madrid
UCO	Universidad de Córdoba
UCV	Universidad Católica de Valencia San Vicente Mártir
UDC	Universidad de A Coruña
UDG	Universidad de Girona
UDIMA	Universidad a Distancia de Madrid
UDL	Universidad de Lleida
UEB	Universidad Europea de Barcelona
UEC	Universidad Europea de Canarias
UEM	Universidad Europea de Madrid
UEMC	Universidad Europea Miguel de Cervantes
UEV	Universidad Europea de Valencia

UFV	Universidad Francisco de Vitoria
UGR	Universidad de Granada
UHU	Universidad de Huelva
UI	Universitas Indonesia
UI1	Universidad Isabel I de Castilla
UIA	Universidad Internacional de Andalucía
UIB	Universidad de las Illes Balears
UIC	Universidad Internacional de Catalunya
UIMP	Universidad Internacional Menéndez Pelayo
UJAEN	Universidad de Jaén
UJI	Universidad Jaume I de Castellón
ULL	Universidad de La Laguna
ULOYOLA	Universidad Loyola Andalucía
ULPGC	Universidad de Las Palmas de Gran Canaria
UM	Universidad de Murcia
UMA	Universidad de Málaga
UMH	Universidad Miguel Hernández de Elche
UNAV	Universidad de Navarra (Privada)
UNAVARRA	Universidad Pública de Navarra
UNEATLANTICO	Universidad Europea del Atlántico
UNED	Universidad Nacional de Educación a Distancia
UNEX	Universidad de Extremadura
UNICAN	Universidad de Cantabria
UNILEON	Universidad de León
UNIOVI	Universidad de Oviedo
UNIR	Universidad Internacional de La Rioja
UNIRIOJA	Universidad de la Rioja
UNIZAR	Universidad de Zaragoza
UOC	Universidad Oberta de Catalunya
UPC	Universidad Politécnica de Catalunya
UPCT	Universidad Politécnica de Cartagena
UPF	Universidad Pompeu Fabra
UPM	Universidad Politécnica de Madrid
UPO	Universidad Pablo de Olavide
UPSA	Universidad Pontificia de Salamanca
UPV	Universidad Politécnica de Valencia
URJC	Universidad Rey Juan Carlos
URL	Universidad Ramon Llul
URV	Universidad Rovira i Virgili
US	Universidad de Sevilla
USAL	Universidad de Salamanca
USC	Universidad de Santiago de Compostela
USJ	Universidad San Jorge
UV	Universidad de Valencia
UVA	Universidad de Valladolid
UVIC	Universidad de Vic
UVIGO	Universidad de Vigo
VIU	Universidad Internacional Valenciana

Chapter I: Introduction

1.1. The concept of sustainability: Evolution of an ambiguous term

Humanity has experienced the impact of an unsustainable economic model in all spheres. As a result, global concern and debate emerged in the 1970s. The "United Nations Conference on the Human Environment" (1972), held in Stockholm, was the first conference related to sustainability and has been recognized as the starting point for bringing political attention to environmental problems (Nilsson, 2004). This conference had the participation of 113 countries, the production model was questioned, and it produced 26 principles related to the environment and development, as well as an action plan with 109 recommendations grouped in three types of action (environmental assessment – Earthwatch; environmental management; supporting measures) (United Nations, 1973). These recommendations were further elaborated in the "World Conservation Strategy" (1980) of the "International Union for the Conservation of Nature", which advanced sustainable development (SD) by "identifying and prioritizing conservation and proposing policies" (Amador & Padrel Oliveira, 2013). Another breakthrough was the integration of concerns for the relationship between environment and development into the concept of "conservation" (Mebratu, 1998). Around the same time that the Stockholm Declaration was made, a group of scholars, the Club of Rome, published the report "*Limits to Growth*", which highlighted the vulnerability of the natural resources in contrast to industrial development and economic growth (Saadatian et al., 2012). This report provides an early definition of SD. Moreover, according to Quental, Lourenço and Da Silva (2011 and, based on the United Nations Environment Programme, 2002), the predictive model that the authors considered indicated sustainability was achievable if the population and economic growth ceased. In 1983, due to the interest arising around this topic, the World Commission on Environment and Development (WCED) was created, and it prepared the document "*Our Common Future*" (also known as the Brundtland Report). In this document, SD was defined as a "kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 1987). Du Pisani (2006) points out that the concept of SD is one of the "driving forces" of history in the period of the 20th century and became the core element of environmental discourse. As Ciegis, Ramanauskiene and Martinkus (2009) point out, this concept has become a universal moral principle (although more imagined than practically applied) and a turning point from "growth or environment" discourse to "economic growth and environment", joining both concepts in complementary interaction.

However, some studies have determined that this concept can in fact be traced to ancient times. Mebratu (1998) argues, for example, that religious beliefs and laws have a "socialized nature" (in human terms), denoting that nature has been linked with humanity since ancient times. As Du Pisani (2006) has shown, the "demand for raw materials and its impact on the environment" has been a problem through human history. For instance, Egyptians, Mesopotamians, Greeks, and Romans have been concerned about problems such as deforestation or salinization, problems similar to our current sustainability problems. Another example comes from the 18th century, when wood consumption led to "a new way of thinking, in favour of the responsible use of natural resources"—this 18th-century conception of sustainability is similar to that of SD as defined in the Brundtland report (Du Pisani, 2006). Other examples that implicitly raise the concept of SD include the following: Carls von Carlowitz in a book about sustainable forestry, where he formulates ideas for the "sustainable use" of wood; Malthus, in his book on limits to population growth (Malthus, 1872), which states "the increase in population threatened to outstrip food production and had to be restricted"; the publication "*Limits to Growth*" (Meadows et al., 1972) by the Club of Rome in 1972, which "emphasized that industrial society was going to exceed its ecological limits if it continued to promote this growth" (Disterheft et al., 2013); and the Sustainable Society's work in 1974 (Lozano, 2008). Moreover, the severity of environmental problems led to a series of reactions such as the creation of the "International Union for Conservation of Nature" in 1948, an international organization dedicated to the conservation of natural resources.

This term has been globally accepted; however, it has received many critiques for being very broad and have multiple interpretations (Robinson, 2004), being highly anthropocentric (Waas, Verbruggen & Wright, 2010) and compartmentalized, lacking conceptual coherence or interconnectedness among its various aspects (Lozano, 2008). Goldin and Winters (1995) point out that this concept is "elusive" (Marshall & Toffel, 2005) or even has been tagged as a cliché (Fuller, 2010). Other authors have considered this concept an oxymoron because there are two opposite concepts inherent in its definition (sustainable and development) (Rees, 1997; Mulder, 2017). For Quental et al. (2011), it has even been considered to require a "utopia of a society where human development and nature conservation go in hand and no obvious concessions are necessary".

Despite the lack of consensus, there are several definitions identified in the literature. Steer and Wade-Gery (1993) have estimated 70 different definitions of SD, with different modifications to the development process; Johnston et al. (2007) mentioned that around 300 definitions of "sustainability" and SD in the domain of environmental management and its disciplines. Despite the different definitions of the concept, the essence is very simple: "making sure that our economic growth makes us maintain a model that produces fair outcomes and to better people's livelihood". However, its meaning and focus depends on the collective. For instance, Mebratu (1998) summarizes the definitions of SD from ideological, institutional, and academic perspectives. In this study, the author shows that the interpretations of different institutions (e.g. World Commission on Environment and Development [WCED]), the International Institute of Environment and Development [IIED], and the World Business Council for Sustainable Development [WBCSD]) are similar in terms of "need identification" but differ among definitions of the identification of the epicentre of the solution, the platform, and the leadership for the solution, relative to the objectives of the institution. Another issue is that SD does not have a "valid" theoretical model linked with one particular set of actions to develop, so their divergences' in the conceptualization are an inherent problem for finding a set of potential solutions.

In addition, SD is used as a synonym for sustainability and is commonly interchanged with it (Lozano, 2008). Defining "sustainability" is complicated, however, due to the ambivalence of the term (Mitcham, 1995; Holland, 2000). Compared to the concept of sustainability itself, SD relates more closely to economic growth as a development strategy that aims to achieve "better" growth, whereas sustainability is environmentally related, and its main objective is related to humankind and its ability "to live within the environmental limits of the planet" (Disterheft et al., 2013). Other studies have stated that the main difference lies in the fact that SD is a journey or a path by which to achieve sustainability (Lozano-Ros, 2003). For Lozano-Ros (2003), both concepts entail a "change process in which the societies improve their quality of life, reaching dynamic equilibrium between the economic and social aspects, while protecting, caring for and improving the natural environment: the SD change process must have sustainability as its dynamic goal". At its origins, sustainability has been more closely related to the environment than social and economic pillars (Leal Filho, 2000; Sibbel, 2009). Nevertheless, the social and economic dimensions were incorporated as the main pillars and are usually incorporated in a triangular concept. The combination of these three pillars has been defined as a "triple bottom line" (TBL) (Elkington, 1998), "three-pillar model" (Kastenhofer & Rammel, 2005) or the three "Ps: people, planet, and profits" (Zimmerman 2005; Sosik and Jung, 2018). Sustainability lies at the intersection between these three pillars. According to the core model of the triple bottom line, decision-makers seek strategies to optimize "not only environmental conditions but also social and economic ones" (Wright, 2002). According to Ciegis et al. (2009), apart from the three basic components of SD (social, economic and environmental) are the three dimensions of wellbeing (economic, ecological and social) and their interrelations. Other studies incorporate other dimensions to the model, such as institutional (Leal Filho, Manolas & Pace, 2015b), cultural (Axelsson et al. 2013; Leal Filho, Manolas & Pace, 2015b), spatial (Alshuwaikhat and Abubakar, 2008), temporal (Martens, 2006; Zimmerman, 2005) or global governance (European Commission, 2005).

Sustainability has become a revolutionary movement, to the point of being labelled in some studies as a "sustainability revolution", and it happens at different levels (Burns, 2012). Many governments and conferences have highlighted the necessity of adopting SD principles and educating people towards a sustainable future. Countries that want to achieve SD must undertake transformations at different levels: education, health, energy systems, land-use, urban development, and many other dimensions. These transformations require "long-term changes involving a large number of stakeholders (government, HEIs, businesses, civil society)" (Stiftung and SDSN, 2018). All these societal stakeholders face this challenge and need to be involved (Brown, 2006).

1.2. Towards a new sustainability paradigm: Sustainable Development Goals

Sustainability and SD have been the core discussion at different summits and conferences. Table 1 indicates the number of countries that have participated in the most important conferences and summits on this topic. These summits and conferences can be interpreted as a sign of growing awareness of this issue and increasing compromise by countries to work together on this issue, leading not only to the discussion of these concepts but also to the emergence of new terms the proposal of solutions. For instance, after the United Nations Conference on the Human Environment in Stockholm in 1972, the terminology about the environment included new concepts such as “environment and development”, “development without destruction” and “eco-development”, which was introduced in 1978 (Mebratu, 1998), before the “official” definition of SD in 1987.

In 1992, the United Nations Conference on Environment and Development (UNCED), known as the Earth Summit, was held in Rio de Janeiro, Brazil, with the participation of 172 countries. At this conference, world leaders agreed to 27 principles on the environment and development, and an action plan on SD. One fact that needs to be mentioned is the participatory character of this conference: it involved and encouraged the participation of major stakeholders at all levels (Mebratu, 1998).

Rio+5, a conference held in New York in 1997, comprised the first comprehensive status review of work to implement the UNCED’s agreements. The Assembly concluded that little progress had been made, which was unsatisfactory, because issues such as inequality in “income and the deterioration of the global environment needed to be addressed more properly” (Saadatian et al., 2002). In 2000, the celebration of the Millennium Summit led to the Millennium Declaration and the creation of eight Millennium Development Goals (MDGs). The goals were the following: “1) eradicate extreme poverty and hunger; 2) achieve universal primary education; 3) promote gender equality and empower women; 4) reduce child mortality; 5) improve maternal health; 6) combat HIV/AIDS, malaria and other diseases; 7) ensure environmental sustainability; 8) global partnership for development.”

These goals have been criticized for not being adequately aligned “with human rights standards and principles” (International Human Rights Instruments, 2008), and because they are relevant and focussed only on developing countries (Fukuda-Parr, 2016). Another criticism that has been levelled against the MDGs is that their ambitious character, or even their configuration, have had the unfortunate effect in some regions, such as Africa, that the successes achieved look like failures (Easterly, 2009). However, this consensus was a huge milestone, because it represented a common commitment by countries to establish a series of measures on the path toward sustainability and work together in order to find potential solutions. As drawbacks, the difficulty of measuring their objectives, uneven compliance, and too many “generalists” have been mentioned. The goals were established to be accomplished by 2015; not all goals have been accomplished but some progress has been made. For instance, “the number of people living in extreme poverty has declined by more than half since 1990 and the literacy rate among youth aged 15 to 24 has increased globally, from 83% in 1990 to 91% in 2015", among other things.[1]

In 2002, the World Summit on Sustainable Development (WSSD), a 10-year review after Rio, adopted the Johannesburg Declaration on SD. Whereas Rio was mostly environmentally oriented, the WSSD incorporated a social and economic perspective as well (Edwards, 2005), which indicates the growing interest of the governments of various countries in sustainability. This conference recognized "the strong link between SD and poverty eradication, as well as the urgent need for the modification of the unsustainable modes of production and consumption". In 2009, the United Nations Climate Change Conference (Copenhagen Summit) was held in Denmark and focussed on new issues in the field (e.g. climate change and global risks). It also adopted a "meaningful agreement between the United States, China, India, South Africa, and Brazil and terms such as sustainability mobility and sustainable citizenship were highlighted" (Saadatian et al., 2012).

The Rio+20 conference in 2012 adopted a 15-year plan called Agenda 2030 (2015–2030), with the aim of achieving sustained "economic growth, social development, and environmental protection" (United Nations, 2016). As a result, the conference established 17 Sustainable Development Goals (SDGs), indicators in the development agenda on the sustainable path, to be achieved by 2030. The agenda has 169 targets, proposed by the Open Working Group, and various indicators for monitoring progress (Minas et al., 2015). "A preliminary set of 330 indicators was introduced in March 2015" (Hák, Janousková, & Moldan, 2016), but 232 indicators were eventually adopted. Different from the MDGs, in which the indicators were decided on an internal basis, the SDG indicators are based on public consultation that was led by the Open Working Group established in 2013. Moreover, the indicators "come from a mix of official and non-official data sources", subjected to an extensive and rigorous data validation process (e.g. the World Bank, the Organisation for Economic Co-operation and Development [OECD], the World Health Organization [WHO], the FAO, the ILO and UNICEF) (Stiftung & SDSN, 2019).

Since 2016, the SDG Index is being elaborated with the aim of evaluating the achievement of each goal and obtaining information from countries. This allows for the identification of priorities for action, supporting discussions/debates and identifying gaps in the data, among other things. In this regard, the number of participating countries has increased from 149 in 2016 (first edition) to 162 in 2019 (the last edition). The criteria for being a country eligible to participate is that at least 80% of the required data must be available and that the national population must be more than 1 million. There is also a remarkable difference regarding monitoring compared to the MDGs. The High-level Political Forum on

[1] Ki-Moon, B. (2013). The millennium development goals report 2013. *United Nations Publications*.

Sustainable Development meets annually and has the central role of following up and reviewing the 2030 Agenda at a global level. The topics of the goals cover five critical areas (the five p's): "people, planet, prosperity, peace, and partnership" (Sam, 2016) and the indicators allow for analysing the achievements of each country in terms of the SDGs.

Table 1. Summary of the Conferences Related to SD or Sustainability and Number of Countries Participating[2]

Conference/Summit	***Participation***
United Nations Conference on the Human Environment (1972)	113 countries
United Nations Conference on Environment and Development (UNCED), Earth Summit (1992)	172 countries
Millennium Summit (2000)	147 countries
World Summit on Sustainable Development (WSSD) (2002)	123 countries
United Nations Conference on Sustainable Development, Rio+20 (2012)	192 countries
United Nations Sustainable Development Summit (2015)	193 countries

Source: Own elaboration from the data provided by the summit/conference summaries.

The MDGs and SDGs appeared as a result of the interest and commitment of various countries around the world in sustainable growth. The main difference between the MDGs and the SDGs is the focus (MDGs focussed on poor countries, whereas the SDGs focus on all countries, no matter their level of development) and the structure of the indicators (e.g. the SDGs include new indicators such as SDG11 for cities and communities) (Table 2). One fact that has been observed is that achieving sustainability can be a challenge, and all societal stakeholders need to be involved (Brown, 2006). As Caiado et al. (2018) have stated, "The SDG agenda calls for a global partnership – al all levels – between all countries and stakeholders who need to work together to achieve the goals and targets, including a broad spectrum of actions such as multinational businesses, local governments, regional and international bodies, and civil societal organizations." This revitalized global partnership has the purpose to ensure the

[2] Only world leaders and participant countries were considered. Organizations and other stakeholders were not considered.

implementation of Agenda 2030 and includes a "wide range of actors, from governments to civil society to the private sector, among others" (United Nations, 2015a).

Table 2. Summary of the MDGs and SDGs

MDGs		***SDGs***	
No.	**Goal**	**No.**	**Goal**
1	"Eradicate extreme poverty and hunger"	1	"No poverty"
2	"Achieve universal primary education"	2	"Zero hunger"
3	"Promote gender equality and empower women"	3	"Good health and well-being"
4	"Reduce child mortality"	4	"Quality education"
5	"Improve maternal health"	5	"Gender equality"
6	"Combat HIV/AIDS, malaria, and other diseases"	6	"Clean water and sanitation"
7	"Ensure environmental sustainability"	7	"Affordable and clean energy"
8	"Develop a global partnership for development"	8	"Decent work and economic growth"
		9	"Industry, innovation and infrastructure"
		10	"Reduced inequalities"
		11	"Sustainable cities and communities"
		12	"Responsible consumption and production"
		13	"Climate action"
		14	"Life below water"
		15	"Life on land"
		16	"Peace, justice and strong institutions"
		17	"Partnerships for the goals"

Source: Prepared by the author based on the United Nations website (2015a).

1.3. Sustainability as a policy priority

Global concern about the type of development carried out in most countries, especially in developed countries, started in the early 1970s and has crystallized in various international events, where countries began to question established economic models that do not solve existing environmental problems. To achieve SD, countries must undertake transformations at various levels: "education, health, energy systems, land-use, urban development, and many other dimensions" (Stifstung & SDSN, 2018).

One of the main features of sustainability is that it has gained interest over time, not only from the scientific community by becoming a multidisciplinary, interdisciplinary and transdisciplinary (Kajikawa, 2008) topic, but also from the perspective of policymakers, with countries worldwide adopting sustainability-oriented policy approaches. This fact is linked with the idea that a sustainable society has become a central task of science and technology and that sustainability is a contract between science and society (Kajikawa, 2008). Proof of this was the creation of the World Commission on Environment and Development (WCED) by the United Nations in 1983, "with the aim of looking for new models of SD that ensure the availability of existing resources for future generations". The Brundtland Report (United Nations, 1987), commissioned by the WCED, was the product of these debates and an important milestone, not only for the definition of SD but also to increase awareness of the importance of this topic.

With the outbreak of the economic crisis of 2007–2008, the international community had to face changed economic and social beliefs. The traditional way of thinking and acting was determined not to be sustainable, as it wreaked havoc "on the environment, society and the economy". In this regard, sustainability, more than a theory, became a call to action, a work in progress for the agendas of all countries. This fact means that environmental issues do not have borders, but are a global challenge and the international cooperation between countries is crucial to address them. This cooperation must be horizontal (between governments) and vertical (within states).

Not only the various conferences and summits are important milestones, but also the international agreements, of which the following are some examples: the Vienna Convention for the Protection of the Ozone Layer (1985),[3] the Convention for the Protection of the Natural Resources and Environment of the South Pacific Region in Nouméa (1986), the Montreal Protocol on Substances that Deplete the Ozone Layer (1987), the Protocol on Environmental Protection to the Antarctic Treaty in Madrid (1991), the Convention for the Protection of the Marine Environment of the North-east Atlantic (OSPAR Convention) in Paris (1992), the Convention on the Protection of the Marine Environment of the Baltic Sea Area in Helsinki (1992), the Convention on Biological Diversity (CBD) in Nairobi (1992), the United Nations Framework Convention on Climate Change (1994), the Convention on Nuclear Safety in Vienna (1994), the Kyoto Protocol (1997), and the Paris Agreement on Climate Change at COP21 (2015).

The sustainability boom introduced concepts such as "corporate social responsibility" (CSR) (meaning that "a company should be interested in and willing to help society and the environment as well as be

[3] Treaty available at the following link: https://treaties.un.org/doc/Treaties/1988/09/19880922%2003-14%20AM/Ch_XXVII_02p.pdf and https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-2&chapter=27&lang=en#1 accessed 8 August 2019.

concerned about the products and profits it makes") and social responsibility (defined as "the practice of producing goods and services in a way that is not harmful to society or the environment"[4]). Another idea is that of the "smart citizen", who "produces and uses information through systems in an efficient and sustainable way in order to form smart cities". These citizens participate in their cities' daily governance and are concerned, among other issues, about protecting the environment. Smart cities provide a sustainable environment to implement efficient systems that process information for the use of smart citizens (Bayar, 2017). The idea is to raise public awareness about SD with each individual and to create collective behaviour in order to solve the societal challenges of the current century from a holistic viewpoint. It also necessary to change the approach from a top-down one to a bottom-up one.

1.3.1. Sustainability in the European framework

At the European level, there is a long tradition of protecting the environment. In this regard, the European Commission (EC) has demonstrated a strong commitment to sustainability since the 1970s. "SD is one of the objectives of the European Union (EU) and has been included in EU policies and regulations". There have been significant events related to SD, such as the creation of the Environment Committee at the European Parliament in 1973 and the launching of the first action programme on the environment (1973–1976). At the beginning of the 1990s, with the signing of the Maastricht Treaty, community actions linked to the environment gained prominence. These included the incorporation of environmental protection in all EU policies and activities. The EU committed for the first time to SD in June 2001, when the Gothenburg European Council adopted the European Union Strategy for Sustainable Development (ESD) on the basis of an EC Communication (European Commission, 2005). The aim was to:

> "identify and develop actions to enable the EU to achieve a continuous long-term improvement of quality of life through the creation of sustainable communities able to manage and use resources efficiently, able to tap the ecological and social innovation potential of the economy and in the end able to ensure prosperity, environmental protection and social cohesion."[5]

Other important EU milestones are the creation of the European Environment Agency in 1994; the Amsterdam Treaty on Balanced and Sustainable Development in 1997; the Lisbon Strategy in 2000; and the EU Strategy for Sustainable Development (EU-SDS) in 2001. In 2002, the Kyoto Protocol, an international agreement concerning climate change, was ratified. The Communication from the European Commission (2005) about the Review of the EU Sustainable Development Strategy represented important progress towards a strong integration of proposals in areas of SD. It highlighted

[4] Definition extracted from: https://dictionary.cambridge.org/dictionary/english/social-responsibility accessed 5 June 2019.
[5] Information extracted from https://ec.europa.eu/environment/sustainable-development/strategy/review/index_en.htm accessed 5 June 2019.

the need for innovation, research, and education which contribute to poverty reduction. Moreover, it remarked that the EU and the member states should invest in research and technology, among other things, to find new forms of profitable production and consumption and to use resources efficiently. This European framework "includes seven priority areas: climate change and clean energies; sustainable transport; sustainable production and consumption; public health challenges; management of natural resources; social inclusion; and demography[6]". In 2010, the Europe 2020 Strategy for Smart, Sustainable and Inclusive Growth was launched with the aim of putting the EU in a position to lead global SD (European Commission, 2010).

At present, there are numerous policies and regulations aimed at achieving a positive impact on SD, both socially, economically and environmentally. It is possible to identify successful experiences in the field of Research and Development and innovation (R&D+i) in this sector and in the transfer of knowledge and technologies applied to SD. Regarding research activities, the Seventh Framework Programme (FP7) (2007–2013) included two thematic fields within its Cooperation programme: one on energy and the other on the environment (including climate change). In one of the three main pillars of the H2020 program (the Eighth Framework Programme [FP8]) (2014–2020), Societal Challenge, there are specific calls related to climate, the environment, energy, and transport. As a result, "it is expected that at least 60% of the budget for this programme should be related to SD and that climate-related expenditure should exceed 35% of the budget, with measures improving resource efficiency" (European Commission, 2018). In addition, the European Commission provides funding to projects and initiatives with programmes such as LIFE, pilot projects and preparatory actions. Even the next European Framework Programme, Horizon Europe (2021–2027), is expected, apart from strengthening science and technology, to implement the SDGs in the EU.

The European Commission's 7th Environment Action Programme to 2020, a new environment programme which constitutes a common strategy to guide future actions, has defined three key objectives: "1) to protect, conserve and enhance the Union's natural capital; 2) to turn the Union into a resource-efficient, green, and competitive low-carbon economy; and 3) to safeguard the Union's citizens from environment-related pressures and risks to health and wellbeing"[7]. Furthermore, the European Commission has realized that poor implementation of laws and policies could have many negative effects, from the loss of credibility of national/EU authorities to environmental costs. As a palliative measure, the EC established an Environmental Implementation Review (EIR) in 2016, with the aim of delivering the benefits of EU environmental laws and policies to the citizens and business. Also, its purpose is to find gaps and estimate solutions.

[6] Information extracted from: https://ec.europa.eu/environment/eussd/ accessed 5 June 2019.
[7] Information extracted from: https://ec.europa.eu/environment/action-programme/ accessed 5 June 2019.

At the European level, inhabitants have demonstrated concern about sustainability. In this regard, statistics of the Eurobarometer state that 95% of those surveyed stated that the protection of the environment is important for them and more should be done. Responsibility among citizens is increasing: for example, 75% of citizens are willing to buy environmentally friendly products. Regarding legislation, 77% of citizens believe that environmental legislation is necessary for protecting the environment.[8] In the last Eurobarometer report (European Union, 2018), Europeans said in order to protect the environment they would give priority to preserving natural resources (41%), further developing renewable energies (39%) and increasing recycling and waste sorting in Europe (38%).

1.3.2.- Sustainability in the Spanish framework

Sustainability has also become a priority for the Spanish government. Following the strategic vision of the EU, in 2007 the Spanish Sustainable Development Strategy (SSDS)[9] was launched by "the Interministerial Group for the Review of the Sustainable Development Strategy of the European Union" and the SSDS was prepared with the cooperation of the "Economic Office" of the President of the Spanish Government.[10] Its main aim is to follow the sustainability perspective of the EU in order to achieve sustainability and it will be developed in collaboration with the Autonomous Communities (AACC) and municipalities, with budget stability defined by the government for this purpose.

Spain has approved different laws that regulate environmental aspects, for example Law 21/2013, of December 9, on environmental assessment;[11] Law 42/2007 on Natural Heritage and Biodiversity;[12] Law 26/2007, of October 23, on Environmental Responsibility;[13] Law 34/2007, of November 15, on air quality and protection of the atmosphere;[14] and Law 26/2007, of October 23, on Environmental Responsibility.[15] Another important milestone is the Sustainable Economy Law (Law 2/2011 of March 4[16]), which aims to make the economy more competitive by promoting environmental sustainability in some fields, such as energy, transport, sustainable mobility and housing. Actually, the government is moving toward Agenda 2030. In this regard, an Implementation Plan for Agenda 2030 has been approved (Spanish Government, 2019).

Regarding its accomplishment of the SDGs, as measured by the SDG Index, Spain has moved from the 30th position in the 2016 Ranking to the 25th in 2017 and 2018 and, more recently, the 21st position in

[8] Information extracted from https://europa.eu/rapid/press-release_IP-14-976_es.htm accessed 5 June 2019.
[9] Document available at https://www.miteco.gob.es/en/ministerio/planes-estrategias/estrategia-espanola-desarrollo-sostenible/09047122800cfd5b_tcm38-88639.p accessed 10 August 2019.
[10] Information of the authors available at: https://www.miteco.gob.es/en/ministerio/planes-estrategias/estrategia-espanola-desarrollo-sostenible/ accessed 5 June 2019.
[11] Law available at https://www.boe.es/buscar/act.php?id=BOE-A-2013-12913 accessed 15 July 2019.
[12] Law available at https://www.boe.es/buscar/act.php?id=BOE-A-2007-21490 accessed 15 July 2019.
[13] Law available at https://www.boe.es/buscar/act.php?id=BOE-A-2007-18475 accessed 15 July 2019.
[14] Law available at https://www.boe.es/buscar/act.php?id=BOE-A-2007-19744 accessed 20 July 2019.
[15] Law available at https://www.boe.es/buscar/act.php?id=BOE-A-2007-18475 accessed 20 July 2019.
[16] Law available at https://www.boe.es/buscar/act.php?id=BOE-A-2011-4117 accessed 20 July 2019.

the 2019 SDG Index. However, none of the goals are green yet (except SDG5, gender equality, in SDG Index 2016), by analogy with a traffic light, associated with the best degree of achievement. Moreover, the last report (Stifstung & SDSN, 2019) indicated that major challenges remain with regard to the following goals: "SDG2, zero hunger; SDG9, industry, innovation and infrastructure; and SDG13, climate action. Significant challenges also remain with regard to the following goals: SDG5, gender equality; SDG8, decent work and economic growth; SDG1, reduced inequalities; SDG11, sustainable cities and communities; SDG12, responsible consumption and production; and SDG14, life below water".

In the scientific field, the current "Spanish Strategy for Science, Technology and Innovation 2013–2020" and the "State Plan for Scientific and Technical Research and Innovation",[17] following the H2020 challenges (e.g. safe, efficient and clean energy; action on climate change; the economy and digital society; changes and social innovations), are explicitly included in the global challenges for Spanish society, and are the focus of the next R&D+i actions to finance under the current announcement.

1.3.3. Sustainability in the technological framework: green patents

The OECD, anticipating that the current production model could lead to the depletion of natural resources, the loss of biodiversity and levels of pollution with irreversible consequences, has proposed the Green Growth Strategy, considering that no government has the technological, scientific or financial resources necessary to implement green growth on its own (OECD, 2011). In this way, green growth is presented as a way to encourage and promote the growth of economic development accompanied by environmental protection, ensuring a stable balance between the productive system and the environment.

In 2009, ministers from 34 countries signed the "Declaration on Green Growth", which proposed as objectives the following: "reform environmentally damaging policies, encourage green investment and more sustainable management of natural resources, and strengthen international collaboration as a response to the crisis, among other things" (OECD, 2009a). The implementation of this new growth strategy has been structured around two action lines: 1) the creation of a context of conditions aimed at strengthening economic growth and the conservation of natural capital, within which special importance is given to the role of green innovation; and 2) policies aimed at encouraging the efficient use of natural resources and penalizing pollution (OECD, 2011). Regarding policies, each country has developed its own, adjusting its reality to the lines of the Green Growth Strategy.

[17] Plan available at
http://www.ciencia.gob.es/stfls/MICINN/Investigacion/FICHEROS/Plan_Estatal_Inves_cientifica_tecnica_innovacion.pdf
accessed 20 July 2019.

Green innovation has acquired a very important role within the first line of action of the Green Growth Strategy, as one of the main axes on which to support sustainable growth. Green technologies will allow progress towards the achievement of objectives related to natural resources, especially those related to alternative energies, and therefore represent one of the most important approaches for responding to the thorny problems of development and the environment (Maskus, 2005; Samad & Manzoor, 2015). In fact, many governments have noted the importance of patents, which are a way to measure a country's technological innovation, to stimulate green technologies in their countries and the impossibility of green growth without innovation (Dutz & Sharma, 2012; Fay et al., 2013; Hall & Helmers, 2013).

Consequently, patent data are an essential source of information for the knowledge of science and technology activities and, related to other types of data, offer a fundamental support for the study of other areas of innovation of great relevance for the elaboration of science and technology policies, such as the determination of the role of intellectual property in economic growth, entrepreneurship, etc. (OECD 2009b). Patents are a privilege granted by the state that allows for the exclusive exploitation of an invention or its improvements, preventing third parties from making use of them. This right constitutes a way of protecting inventions developed by innovative agents. Therefore, although patents protect inventive activity and are indicators of innovative activity, they can be considered as a proxy for innovative activity to the extent that invention is the basis of much technological innovation.

Specifically, in relation to the main area of green technologies and renewable energies, investment flows to renewable energies in developed countries have gradually been increasing until 2011. From 2011 to 2013 there was a great period of recession in investment (REN 21, 2015). This change can be explained by the economic crisis, with its resultant reduction in public funds. In addition, another factor that may affect the evolution of these flows, and consequently the application for green patents, is the country's legislative framework. In the case of Spain, legislation on renewable energies were introduced in the 1980s, but it was not until the 1990s that the first National Energy Plan 1991–2000 was established, which began to encourage the production of this type of energy. In 1999, the new Plan for the Promotion of Renewable Energies established as an objective that production of this type of energy should cover 12% of primary energy by 2010 (MCYT, 1999). However, this plan was insufficient and, consequently, the subsequent Renewable Energy Plan (2005–2010) continued with this commitment (MITYC, 2005). Despite this favourable legislative framework for the promotion of renewables, in the midst of the crisis and budget cuts, Royal Decree 14/2010 (BOE, 2010) changed this trend, limiting the number of hours dedicated to renewables entitled to a premium for companies. Subsequently, Royal Decree 1/2012 and Law 15/2012 were approved in 2012, establishing a tax rate of 7% for this type of energy and the "suspension of economic incentives for the creation of renewable energy plans, events that had a further influence on the decline of this type of energy". Another unfavourable reform was the Energy Reform of 2013, which changed the regulations supporting renewables and further accelerated their decline.

During this period, a new Renewable Energy Action Plan (PER) was also approved for the period 2011 to 2020, which had as a goal that by 2020, 20.8% of the gross final consumption of energy in Spain should be generated by this type of energy. Despite this unfavourable framework and the decreasing trend in recent years, it seems that there is general consensus that this is a crucial sector for the improvement of the future and that it is necessary to invest in and promote the consumption of renewable energy throughout society.

1.4.- Sustainability in higher education institution

Achieving SD can be a challenge, and all actors need to participate. In this regard, "higher education institutions (HEIs) should play an active and fundamental role in promoting sustainability practices. In the past, universities played a role in transforming societies and serving the greater public good, so there is a societal need for universities to assume responsibility for contributing to SD" (Waas et al., 2010), especially as "agents responsible for knowledge creation and dissemination" (Madeira et al., 2011). In addition, universities make "an important contribution to the development of our society, and they have societal responsibility, not only in training young and future leaders but also in stimulating public awareness of sustainability". In this regard, "they should be leaders in the search for solutions and alternatives to current environmental problems and agents of change" (Hesselbarth and Schaltegger, 2014). Apart from their traditional functions of research and teaching, including this third mission for universities, the transfer of knowledge to societies fits with this commitment.

The "sustainability movement in higher education has been be rooted in the recognition of the greening university in the environmental education movement of the 1960s and 1970s" (Corcoran, Walker & Walls, 2004). This movement implies that all dimensions (academic, administrative policies, or facilities management) defined by Koester, Eflin, and Vann (2006) comprise a "whole system approach". According to Filho-Leal et al. (2015a), "Greening the campus" is one of the crucial elements of implementing sustainability in higher education (SHE) and is one of the most advanced areas for demonstrating engagement. However, according to the authors, the entire community must participate in the process. It is even considered a laboratory.

These institutions have made great efforts to integrate sustainability into their actions. This progress is undoubtedly linked to the different conferences held and the declarations and agreements that emerged from them. During the 1990s, universities signed declarations to show their commitments to sustainability, and their number has increased over time. Ever since the Stockholm Conference in 1972, where it was stated that "education played an important role in environmental protection and conservation, many declarations, charters, and partnerships have been developed in HEIs": for instance, the Stockholm Declaration (1972), the Talloires Declaration (1990), the Halifax Declaration (1991), the Copernicus University Charter (1993), the Lüneburg Declaration on Higher Education for Sustainable

Development (2001), the Kyoto Declaration of the International Association of Universities and Colleges of Art, Design and Media (2008), and the Torino Declaration on Education and Research for Sustainable and Responsible Development (2009) (Corcoran, Walker and Wals, 2004; Lozano et al., 2013a). In addition, initiatives such as partnerships or networks like the University Leaders for a Sustainable Future (ULSF) in 1992, the Global Higher Education for Sustainability Partnership (GHESP) in 2000, the International Sustainable Campus Network (ISCN) in 2007 or the Higher Education Sustainability Initiative (HESI) in 2012 are other examples (Corcoran, Walker and Wals, 2004). However, it has been highly debated that this signing commitment does not ensure the implementation of SD into their systems (Grindsted, 2011).

In recent years, many universities have engaged in SD activities, and SD is considered a significant challenge. This challenge is complex and multifaceted, and all parties in the university (professors, students, researchers, research results transfer offices [OTRI], management teams, clerks, and services staff, green offices and environment offices, or services) are required to contribute in substantial ways by working in a third space (Chambers and Walker, 2016). In addition, the concept of SD is subject to debate over whether it is a philosophical or an economic concept and how it can be translated into a policy prescription (Meadowcroft, 2007). Several definitions of sustainability in HEIs and how to apply it have arisen. According to Chambers and Walker (2016), “sustainability must be incorporated into the dimensions of the university: research, teaching and community engagement, and campus operations”. Cortese (2003) writes “that it is a system that includes education, research, campus operation, and community outreach”. Cole (2003) explains that a sustainable campus “acts upon its local and global responsibilities to protect and enhance the health and well-being of humans and ecosystems. It actively engages the knowledge of the university community to address the ecological and social challenges that we face now and in the future”. For Velazquet et al. (2006), “a sustainable university is defined as a higher educational institution, as a whole or as a part, that addresses, involves and promotes, on a regional or a global level, the minimization of negative environmental, economic, societal, and health effects generated in the use of their resources in order to fulfil its functions of teaching, research, outreach and partnership, and stewardship in ways to help society make the transition to sustainable lifestyles.” As stated by Alshuwaikhat and Abubakar (2008), a “sustainable university campus should be a healthy campus environment which combines a prosperous economy (energy and resource conservation, waste reduction, etc.) and one that promotes equity and social justice and exports those values to the community”. Wals (2014) considers that HEIs are “making systemic changes towards sustainability by reorienting their education, research, operations, and community outreach activities, and some of them have converted this sustainability paradigm into a new way of organizing and profiling themselves”. According to Ryan et al. (2010), sustainability at HEIs reaches “beyond individual curriculum changes and isolated environmental practices and policies; it also requires actions in academic priorities, organizational structures, and financial systems”. This sort of action “leads to the emergence of the concept of sustainable higher education institutions (SHEIs)" (Almarshad 2017; Aleixo, Azeiteiro and Leal, 2017).

Regarding the implementation of these practices in higher education, no set of single criteria is provided, only recommendations. While in some universities being considered a "sustainable university is based on having an environmental plan, environmental guidelines, or a statement, others consider declarations, institutional policies, or the implementation of the ISO 140001 standard, among others" (Alshuwaikhat and Abubakar, 2008). As Clugston and Calder (1999) have stated, "every institution committed to sustainability will find the way of defining sustainability for itself". For instance, different items have been mentioned in the literature: environmental plans and environmental guidelines; declarations, statements, and institutional policies; "greening the curriculum" with education for sustainability; implementation of standards (ISO 14001) or tools for evaluating sustainability at campuses, including on campus and in other forms of education (STARS, CSAF, STAUNCH). Additionally, in the literature can be found tools at national level (e.g. Larrán et al., 2016b). As Clugston and Calder (1999) describe from the ULSF project, the "implementation of sustainability" (or "greening the higher education") can be summarized as follows: "It 1) includes the commitment to sustainability in their mission and purpose of the institutions; 2) incorporates the concept of SD into all academic disciplines, professional education requirements, faculty and student research; 3) creates conscious reflection of the role of an institution in its social and ecological systems or, in other words, creates critical-thinking; 4) incorporates knowledge of sustainability in the hiring, tenure, and promotion systems (e.g. reward faculty members' its contributions to sustainability); 5) aligns the institution with sustainability and considers its ecological footprint; 6) fosters institutional support and campus student life services that emphasize certain sustainability awareness for students; 7) develops local and global partnerships in order to improve sustainability". As Caeiro et al. (2013) have stated, "the emergent fields of sustainability science and Education for Sustainable Development [ESD] have advanced the efforts toward sustainability from the HEIs but despite some progress, only a few institutions follow a holistic implementation". Moreover, for Lozano (2006a), referring to Rogers study (1962), there are five stages of implementing SD, corresponding to different groups of participants: "(i) innovators who are willing to try new ideas and to risk their capital and time; (ii) early adopters who serve as reference individuals; (iii) the early majority who adopt new ideas before the average member; (iv) the late majority, who adopt new ideas after the average member; and (v) laggards, who are the last to adopt and innovation." In this framework, "most HEIs are in the first stages or early stages of SD implementation". Moreover, another challenge has been stated by Corcoran, Walker and Wals (2004): the field of sustainability is complex because "there are no two institutions alike and within institutions, no two schools alike". For instance, there are factors such as the cultural and national border that could affect the involvement in sustainability. In this regard, higher education strategies need to be developed considering the environment of HEIs. According to Lozano (2013b, 2015), he defines the following five dimensions in which sustainability can be approached at HEIs: “a) education (courses and curricula); b) research; c) campus operations; d) community outreach; e) assessment and reporting”.

According to Lozano (2013c, 2018[18]), assessment and reporting is voluntary in the HEIs has to main purposes: “1) to assess the current state of an organisation’s three pillar dimensions and 2) to communicate a company’s efforts and sustainability progress to the different stakeholders”. According to this author, their results “can be used to assess sustainability performance over time, benchmark against other companies, or demonstrate how the organization influences and is influenced by stakeholders”. However, it should be considered that this information may be selectively reported (Gray, 2006) or it may not provide a framework to address synergies “between and among sustainability issues” (Lozano & Huisingh, 2011). As well, these tools are important to support continuous improvement or as a driver for change, but their applicability is not generalized. A large number of tools have been used to assess and rank sustainability actions for HEIs; these tools allow these institutions to compare their own actions towards sustainability against each other. Some are adaptations of tools, like the ecological footprint or standards from the “International Organization for Standardization” (ISO), while others evaluate campuses (e.g., CSAF) or curricula (STAUNCH, CSAF). Moreover, the Graphical Assessment of Sustainability in Universities (GASU) (Lozano, 2006b), the National Wildlife Federation’s State of the Campus Environment, or the Higher Education 21’s Sustainability Indicators (Shriberg, 2002) are other tools. The GreenMetric World University Ranking is a global sustainability ranking for universities developed by Universitas Indonesia (UI) since 2010. It assesses the following six categories: “setting and infrastructure, energy and climate change, waste, water, transportation, and education”. In comparison with the first edition of GreenMetric, the most recent version features more indicators, and “verification methods were included to check data validity, among other things” (Suwartha & Sari, 2013). Some studies have criticized this ranking, arguing its simplicity in terms of “categories and indicators in comparison with other systems and that the demands of the data types required are generally low for participants and less empirical than those used in other systems” (Lauder et al., 2015).

However, involvement in SD is voluntary for universities, and many studies have described their resistance, which constitutes a limiting factor. These two issues—the fact that participation is voluntary and the rigid structure of the universities—limit the expansion of these projects and a greater commitment to SD at the HEIs. Velazquez, Munguia and Sánchez. (2005) have underlined “the importance of certain problems, such as the lack of awareness, interest, and involvement; the organizational structure; the lack of funding or support from university administrators; the lack of time or training; the lack of data access; the lack of more strict regulations; and the lack of policies to promote

[18] Information extracted from the presentation “Assessing sustainability in higher education institutions holistically” of Rodrigo Lozano (2018) in the I Conference “Advances towards the sustainability of universities” organized by INAECU: http://www.inaecu.com/wp-content/uploads/2018/10/Rodrigo-Lozano.pdf accessed 20 July 2019.

sustainability on campus". Another factor that has been identified is university conservativism or resistance to change (Lozano et al., 2006a). Fien (2002) highlights that HEI strategies for advancing sustainability need to be developed by individual systems and institutions because no two institutions are the same. For Leal Filho et al. (2017), the "areas of administration and management are where the greatest obstacles to SD in HEIs can be found and the lack of interest in sustainability". According to these authors, these obstacles have caused a lack of administrative structure for SD (e.g. environment committees). Leal Filho et al. (2018a) have analysed case studies from different countries (South Africa, Nigeria, United States, Brazil and Germany) and determined that lack of planning or financial support is one of the drawbacks identified, but also the integration of three main components of SD that need to be holistic and comprehensive. Another argument focusses on environmental programmes, specifically as regards two issues: "first, reducing energy consumption, waste, and integration into mainstream university operations and, second, greening the curriculum" (Roy, Potter and Yarrow, 2008; Larrán et al., 2015b). For other authors, the problem "engagement of all participants in the major driver" (Godemann et al., 2014) and cooperation is emphasized as one strategy towards sustainability. Precisely the reason universities cannot fully implement SD is that SD is more than a theory: It is a call for action, a work in progress.

HEIs have a fundamental and unequalled role in responding to "social, cultural, economic and environmental challenges faced by humanity". In fact, the sustainable development agenda for SD worldwide adheres to "economic growth, social inclusion and environmental protection" (Caiado et al., 2018). For Bizerril et al. (2018), knowledge of SHE should be encouraged worldwide, especially in those regions with serious social and environmental challenges. In this sense, researchers must discuss how cooperate and to share knowledge for a sustainability society, and a network can respond to HEIs sustainability through cooperation. Consequently, HEIs within the framework of the 2030 Agenda can collaborate through education, research, knowledge transfer and innovation to promote sustainable policies and commitment not only in terms of environment but also as regards the rest of the goals.

In the case of teaching, one of the ways to approach the study of the SDGs would be through an analysis of programs, including the subjects of undergraduate and postgraduate courses that are directly and indirectly related to these goals. Different studies have analysed the inclusion of the SDGs in the curriculum. Albareda-Tiana et al. (2018) have analysed the content strategies for sustainability education at the International University of Catalonia and determine that implementing the SDGs in this type of institution can represent a good opportunity to create synergies (between university and society, between departments, etc.). Gough and Longhurst (2018) analyse the inclusion of the development objectives at UWE Bristol University and determines that there has been an alignment of SDGs with the focus of each of its faculties, and they have begun to analyse the inclusion in the curricula. On the other hand, Aleixo, Azeiteiro and Leal (2018) point out that one of the barriers to the inclusion of sustainability in HEIs in Portugal is the lack of financial resources. In this framework, it is also important to mention the "United Nations Decade of Education for Sustainable Development" (DESD)[19] (2005–2014) in which "the principles, values and practices of SD are integrated in all aspects of education and learning".

However, certain challenges do not centrally regard the HEIs strategy. A number of statements reinforce the importance of ESD and SDGs in educational institutions and higher education appointments. The United Nations Educational, Scientific and Cultural Organization (UNESCO, 2017) document outlines a strategy for including the teaching of SDGs. However, the implementation of SD in HEIs must first be established so that it can feel a greater responsibility for SDGs. There are several barriers to this goal, among which are "lack of environmental commitment, governmental barriers, lack of research and development, lack of incentive for innovation, lack of entrepreneurial and public private partnerships, lack of integration in teaching, and lack of extensive research" (Leal Filho et al., 2017).

For Albareda-Tiana et al. (2018), several visions, difficulties and challenges are related to SDGs and pedagogic strategies in HEIs, with the aim to produce critical and active citizens. As reported by these authors, five relate premises to achieve this purpose are "(i) HEIs' promotion of a culture of sustainability through incorporation of ESD and SDGs into the curriculum; (ii) the integration of curriculum modifications and a new ministerial approval of the degree reports; (iii) deficient human values and reductionist conceptual approaches; (iv) the development holistic methodological strategies; and (v) ESD and SDGs as an opportunity for synergies inside and outside HEIs".

In the contribution of HEIs to the achievement of SDGs, research is one of the most important dimensions and needs to be highlighted. For Leal Filho et al. (2018), these goals are an opportunity to encourage sustainability research through interdisciplinary and transdisciplinary study. Several authors reaffirm the importance of research to achieve SDGs (e.g., Wuelser & Pohl, 2016), namely as a way to solve concrete social problems, and the science of sustainability could support the transition to sustainability. As reported by Leal Filho et al. (2017), certain "aspects are essential for sustainability research concerned with SDG implementation, namely interdisciplinary and transdisciplinary of sustainability research, the development of local-level research, sustainability closer to societal communication of scientific results to the stakeholders, and the linking of science to policymaking". In this sense, HEIs have a fundamental role in responding to SD implementation, as a way of responding to their own missions, namely research. Hence, an increasing push has been made to firm this objective. The aim is to increasingly qualify HEIs at the level of excellence and quality and to finance the research that is done in this type of institution. There are different examples of data sources for research into SDGs: research strategies, flagship initiatives, projects and grants, publications, and research excellence

[19] Information about the UN decade of ESD: https://en.unesco.org/themes/education-sustainable-development/what-is-esd/un-decade-of-esd accessed 5 June 2019.

ranking. For instance, regarding projects, the European Commission (European Commission, 2019) has developed several calls to respond to the societal challenges of today. In this regard, as reported by Aleixo, Azeiteiro and Leal (2018), Horizon 2020 is "an essential financial instrument for the sustainability of HEIs and could address the constraints identified in relation to conducting research, improving infrastructure and the development of new skills in their employees and students".

1.4.1. Sustainability in HEIs in the Spanish framework

Interest in sustainability in Spain has been mounting: "Many institutional statements have emphasized the need to implement SD at HEIs" (Larrán et al., 2014). The 2015 University Strategy (*Ministerio de Educación*, 2010) gave great importance to the "social responsibility of the university system" and highlighted the relationship with the environment. The main aim was to adapt the "guidelines proposed by the European Higher Education Area and [establish] a special commission responsible for the elaboration of a document titled University Social Responsibility and Sustainability" (Andrades Peña et al., 2018).

At the legislative level, the Spanish government also introduced "Organic Law 4/2007 on universities, which aims to incorporate sustainability in areas such as management and accountability, and Law 2/2011 on Sustainable Economy" (Larrán et al., 2015b). These constitute the basis for "the implementation of sustainability at HEIs". At the research level, VI National Scientific Research, Development and Technological Innovation Plan (2008–2011) incorporates "strategic action about energy and climate change". The State Plan (2013–2016) included a programme called Societal Challenges on issues such as sustainable transport, action for climate change and energy, secure and efficient energy and clean energy, among others; these issues are also present in the current Innovation Plan (2017–2020).

In Spain, interest in sustainability issues is a recent topic (Larrán et al., 2016a). The group on Evaluation of University Sustainability at the Sectoral Commission for Environmental Quality, Sustainable Development and Risk Prevention (CADEP, as per its Spanish acronym) (Conference of Spanish University Rectors, CRUE) was created in 2004 "with the aim of increasing the incorporation of environmental and sustainability concerns in HEIs" (Alba, 2007). The group established a "set of indicators to assess the progress of Spanish universities on their path to sustainability". These indicators are grouped into three areas: (1) management, (2) teaching and research, and (3) environmental management. In 2009, they created a sectoral group on sustainability, in response to several universities that aimed to "collect the experience of universities in environmental management, the advances in the environmentalisation of the university community and work on risk prevention while promoting cooperation in these areas for the exchange of experiences and the promotion of good practices" (CRUE, 2018). The sectoral group was made up of nine working groups: "1) University Sustainability

Assessment; 2) Environmental Improvements in University Buildings; 3) Participation and Volunteering; 4) Prevention of Occupational Hazards; 5) Curricular Sustainability; 6) University and Sustainable Mobility; 7) Healthy Universities; 8) University Planning and Sustainability; and 9) Gender Policies".[20] This has also led to an autodiagnosis tool, with the participation of 33 universities. Its last report stated that HEIs have improved in these areas and great efforts have been made in environmental aspects; however, curricular sustainability has not been implemented (CRUE, 2018).

Various studies have analysed sustainability in Spanish HEIs. According to León Fernández (2015), "Spanish HEIs are making a great effort to incorporate environmental management and sustainability into their activities and the creation of sustainable campuses". Larrán et al. (2016a) have analysed the strategic plans of universities, and their "findings suggest that there is a low presence of sustainability strategies at Spanish universities". Alba (2007) has stated that all universities have some activity related to sustainability. Other studies have focussed on the learning context or the teachers' competences (Leal Filho et al., 2018b; Albareda-Tiana et al., 2018), or on environmental habits (Chuvieco et al., 2018).

Although sustainability in HEIs has been studied for over 20 years, relatively little is known about the status of its implementation in Spanish HEIs. However, HEIs are not only a key sector for the analysis of sustainability, but also a "crucial agent in the generation of knowledge". Between 2012 and 2016, the Spanish university sector (public and private) was responsible for 61% of the Spanish scientific production in the Web of Science (WoS) database. Universities constitute the first sector in terms of scientific output, followed by the health sector (28%), mainly hospitals, and the Superior Council of Scientific Research (CSIC), responsible for 16% of the Spanish scientific production in the WoS database in that period (Bordons et al., 2017). The Spanish University System (SUE, as per its Spanish acronym), in the term 2017–2018, constituted 83 universities, 50 of them public and 33 private (Sanz-Casado et al., 2018). In this study, all universities have been considered, despite the private ones having a greater dedication to teaching, to the detriment of research (Manzano et al., 2016). Teaching and research staff in the SUE in 2016 amounted to 64,296 staff members.

1.5. The evaluation of science and technology

Scientific knowledge is of vital importance for societies, because it influences the life quality of humans at many levels: from the routine workings of everyday life to societal needs and global issues. Moreover, science informs public policy on different topics (e.g., energy, agriculture, and health), which demonstrates that this knowledge has an important impact on society at all levels, from citizens to policymakers. Consequently, Moravcsik (1989) has affirmed that it is necessary to evaluate scientific performance due to the high impact it has on society. The measurement of research is crucial, because

[20] Information of the working groups available at: http://www.crue.org/SitePages/Crue-Sostenibilidad.aspx accessed 5 June 2019.

it provides insights into the relational and contextual elements of science and can be used to complement other scientific studies and "provide additional understanding of how knowledge is produced" (Sugimoto and Larivière, 2018). This section presents a summary of the concepts and principles characteristic of the evaluation of scientific activity and technology.

1.5.1. Methodologies for evaluating science and technology

Today countries and governments are more aware of the need for optimizing resources intended for research and development purposes and the analysis of scientific output. In this regard, it is possible to understand the interest of the most developed countries in the analysis and evaluation of research output and the elaboration of indicators adequate for analysing the process of creating new scientific knowledge and technology and its transfer to society.

1.5.1.1. Peer review

Taking into consideration that the research is fundamental for the progress of countries, with the aim of optimizing the use of these resources and promoting scientific quality, different evaluation procedures have been established (Van Raan, 1996). There are mainly two methods for analysing scientific output: qualitative methods and quantitative methods. Qualitative methods refer to peer-review processes, the most usual method to determine the quality of scientific contributions and one of the systems with a higher tradition. According to Brown (2004), qualitative review "is the evaluation of scientific research findings or proposals for competence, significant and originality, by qualified experts (peers) who research and submit work for publication in the same field". The procedure consists of two or more reviewers reading and analysing the papers with the aim of determining the "validity of the ideas, their results and the potential impact in the scientific world" (Campanario, 2002). This process is seen as one of the "duties of the scientific community, in order to improve the rigor and validity of the knowledge that is generated". As Ziman (1986) stated: "The referee is the lynchpin about [which] the whole business of science is pivoted." Peer-review evaluation systems can be used for evaluating research projects or papers for publication. It is based on the assumption that the researchers from a specific area are the most capable to evaluate the scientific results that are produced in this area (Gómez-Caridad and Bordons, 2009). In addition, it is considered the most appropriate method in order to evaluate the development of a specific field and the quality of the contributions to the area.

However, this process is a construct and it is constructed from the public's need for accountability and transparency, the autonomy of the researchers and a political need that the outcomes are achieved in a fair process (Dahler-Larsen, 2011; Derrick G., 2018). As a consequence, some criticisms and drawbacks have been pointed out in the literature: the biases or subjectivity of the reviewers that could affect the impartiality of their judgments (Kassirer and Campion, 1994; Buela-Casal G., 2003); the slowness of the process (Campanario, 2002); the tendency to encourage the more conservative side of the academic community and the appearance of scientific lobbies (that is, some fields are controlled by a community of researchers from certain companies or universities) (Rojo, 1999); and the input resources such as time or administrative costs of reviewers are ignored (King, 1987). Some authors have also pointed out the “old boy network”, suggesting that some areas receive greater recognition than new, emerging research areas, leading to an ineffective restructuring of scientific activity (King, 1987). Bordons and Zulueta (2013) have also emphasized its high cost and that its application is limited to small units. Moreover, these authors have highlighted the needs of scientific policy to go beyond the opinions of the experts, which constitutes another limitation.

Another type of research evaluation is the so-called “expert panel review”, which is a standard for evaluating research groups. This “refers to a group of experts working together in their evaluation of a research group, institution or research grant application” (Boyack, Chen and Chacko, 2014). The “panel arrives at conclusions and recommendations by consensus and provides guidelines for the improvement of the research quality based on its assessments”. The main difference with peer-review processes is that this research presupposes constant contact and communication between the evaluators (Jakaria-Rahman, 2017), even including site visits (Lawrenz et al., 2012).

Several bibliometric studies have compared the judgment of scholars on the quality of research (Cole & Cole, 1978; Nederhof & van Raan, 1989). Van Raan (1996) found a “correspondence between the results of bibliometric analysis and judgments of scientific quality by peers, denoting the positive effects of this procedure”. However, other studies have determined that a sample of experts coincides in accepting a paper but for different reasons and contradictory motives (Cicchetti, 1991; Marsh et al., 2008), denoting that it can be a very subjective process. Furthermore, differences in fields are encountered: across the humanities, scholars state “there is a lack of consensus on quality criteria and that comparing or assessing research quality is impossible” (Hug et al., 2013). In the light of these results, various authors have suggested recommendations in order to improve the peer-review process. Campanario (2002) has suggested the following recommendations:

a) An open peer review (OPR): it is based on the idea that authors and reviewers are aware of each other’s identities. Other variants of this method is transparent peer review (signed but not published). The main aim is to achieve greater responsibility and seriousness in the evaluation task. With the open science movement, whose origin can be traced back to 2002, this new approach of reviews has become one of its important pillars. Despite the fact that there is an absence of consensus about its definition and what it implies (Ross-Hellauer, 2017), the aim is clear: make peer review more transparent and accountable. As a result, more journals have adopted this methodology, becoming more popular in the scientific community.[21]

b) Payment of incentives to reviewers. The main purpose is to increase the seriousness of the evaluation process, although it has also generated controversy about who is in charge of the payment (e.g. authors, journals) and several studies have supported the idea that such incentives cannot have a positive response (Kohn, 1993).

c) Elimination of reviewers. This proposal argues that peer reviews should be abolished and left to the scientific community itself to act as a giant jury. With this system, readers of the papers would add any comments to the paper directly. Computer systems would, for instance, allow readers' comments to be added to the file.

d) Use other sources. In some fields, such as physics, the main communication channel is the internet and not all scientists are waiting for the publication of their research in journals.

Other studies have made other suggestions for improving the peer-review process: clear guidelines on the criteria employed or external peers from other countries (King, 1987). Allen et al. (2019) have made various recommendations regarding the "principles of peer review" ("content integrity; content ethics; fairness; usefulness and timeliness"). For instance, it is recommended that, on content quality decisions, reviewers "should focus on the quality of the methodology, the completeness of the data and the interpretation of the results rather than positive or negative results".

By comparison, for evaluating scientific activity quantitative indicators can be used. The use of objective scientific indicators offer crucial information about research performance and can complement the review process (Van Raan, 1996; Lewison et al., 1999). In this regard, research and education policies require a group of "indicators to inform governments' decisions about research funding". In this context, indicators can be defined as the parameters which are used in the evaluation process of any activity. These evaluation indicators can be grouped into the following classification:

1) Input indicators, which are the resources available in order to develop the research, for instance, indicators related to the staff (number of persons, dedication, category).

2) Output indicators, which are related to the results obtained in the research. These indicators could be classified into direct (e.g. the number of publications) or indirect (e.g. Ph.D., developed by a research group or awards) indicators.

One example of output indicators is bibliometric indicators, which are discussed in the next section.

[21] Examples are MDPI Editorial (https://www.mdpi.com/about/announcements/1405) or journals from Elsevier (Find information here: https://www.elsevier.com/reviewers-update/story/innovation-in-publishing/is-open-peer-review-the-way-forward) accessed 20 July 2019.

1.5.1.2. Bibliometrics, scientometrics, and informetrics

The etymology of "bibliometrics" has Latin and Greek roots and is composed of "book" (*biblos*) and "measure" (*metron*). This field has expanded beyond books and includes other sources (e.g. scholarly publications, citations, acknowledgments, and patents). The creation of this field can be considered recent, as it has a history of less than 100 years. As precursors to the creation of this field, Lotka (1926), Bradford (1934) and Zipf (1936) employed mathematical formulations (referred to as laws) to express the relation between sources and the items in three areas (authors, journals and frequency), and prepared the ground for many mathematical treatments of informetric phenomena (De Bellis, 2014). However, the emergence of this field was triggered by the development of the Institute for Scientific Information's (ISI) Science Citation Index (SCI) by Eugene Garfield in the 1960s, a database of references of articles published, with the aim to support scientific literature searching. Another important milestone is the first issue of the *Frascati Manual* by the OECD in 1963, a "handbook with the aim to establish a standard practice for the measurement of scientific and technical activities". Definitions included in this document are widely accepted and it has become a relevant document and international standard for the compilation and presentation of comparable statistics on economic and human resources based on research and experimental development.

There are a number of standard definitions of bibliometrics. The first is the definition by Pritchard (1969), who defined this field as follows: "the application of mathematics and statistical methods to books and other media of communication". This definition has been considered vague, wide-ranging and imprecise (Broadus, 1987). Other authors suggest this concept has French precedent from Paul Otlet book in 1934 (Wilson, 1995). Different definitions have been proposed; however, the essence of the concept remains the same. As defined by the *ALA Glossary of Library and Information Science* (Young et al., 1983), bibliometrics is the "use of statistical methods in the analysis of a body of literature to reveal the historical development of subject fields and patterns of authorship, publication, and use". Sanz-Casado and Martín-Moreno (1997) have defined it as "numerical data extracted from the documents published or used by scientists, and that allow the analysis of the different characteristics of their scientific activity, linked to both their production and their consumption of information". In this sense, "scientific outputs, references, and citations represent the raw facts on which bibliometric indicators are constructed" (Todeschini and Baccini, 2016).

Bibliometrics involves the measurement of "properties of documents, and of document-related processes and includes analysis techniques such as word frequency analysis, citation analysis, co-word analysis and simple document counting" (Thelwall, 2008). The research community has focussed its attention especially on the use of these indicators for evaluation purposes. The discipline even includes various journals that publish bibliometric studies. The journal *Scientometrics* was launched in 1979, which created a scientific community engaged with the development of the field. Other journals related to these studies are the *Annual Review of Information Science and Technology*, the *Journal of the American Society for Information Science* and *Scientometrics*.

Costas (2008) has summarized the advantages of bibliometric indicators versus peer review, as follows:

- They provide greater objectivity than peer-review judgment.
- Their development and application require low economic and time consumption (e.g. researchers do not need to move).
- It is possible to detect new emerging areas and outstanding scientists.
- These indicators allow detecting non-visible aspects of research activity (e.g. a network of researchers).
- They allow understanding the strengths and weaknesses of regions and countries and can be used for evaluating a group of researchers, information that could complement and support peer review.

There are three approaches to the field of bibliometrics (Todeschini and Baccini, 2016):

1) Positive bibliometrics: The main aim is to describe and explain the phenomena in science and scientific communication. For instance, the diffusion of a new idea may be proxied by the number of citations received; that is the impact of the article.
2) Evaluative bibliometrics: The main aim is to define quantitative instruments in order to evaluate articles, scientists, journals or institutions. For instance, indicators such as impact factor are included in this group.
3) Normative bibliometrics: This refers to the establishment of a set of indicators and rules for use in research evaluation and research policy.

In 1969, Nalimov and Mulchenko coined the term "scientometrics", which "includes all quantitative aspects of the science of science, communication in science and science policy" (Hood and Wilson, 2001; Wilson, 2001). In this regard, "scientometrics is restricted to the measurement of science communication, whereas bibliometrics is more focussed on general information processes" (Glänzel, 2003). Later on, the term "informetrics was proposed in 1979 by Nacke and refers to the measurement of information phenomena and the application of mathematical methods to the discipline's problems" (Hood and Wilson, 2001). "Informetrics also deals with electronic media and includes analysis such as the analysis of scientific text and hypertext system, models for information production processes", among things (Glänzel, 2003). This constitutes the emergence of the three metric fields.

1.5.1.2.1. Features of bibliometric indicators

The main aspects associated with bibliometric indicators are the following (Martin and Irivin, 1983; Martin 1996; Archambault et al., 2009):

- Bias: These indicators quantify a concrete aspect of scientific activity. In this regard, its use must be selective and careful.
- Convergence: Partial indicators are able to measure complex issues of scientific activity, and combined use of them can provide more information.
- Relativity: Indicators refer only to a specific discipline and cannot be extrapolated to other collectives or discipline.
- Reproducibility: Indicators "can be more reproducible than peer review"; however it is difficult to reproduce a selection in other databases.
- Robustness: "These indicators are a robust tool for measuring science".

Another feature to be considered is level of application, of which Vinkler (1988) specifies three: macro level (e.g. discipline or a group of countries), meso level (e.g. subdiscipline or institution), and micro level (e.g. researcher group or an individual). Regarding classification, different authors have proposed classification of indicators. López-Piñero and Terrada (1992) classify bibliometric indicators, based on their activity, into the following types: production, circulation, dispersion and consumption. Glänzel (2003) divides them into five types: 1) publication activity; 2) citation impact; 3) scientific collaboration; 4) indicators and advanced data-analytical methods (e.g. techniques such as co-word or bibliographic coupling, among others); 5) bibliometric technology (e.g. user of the database or database producer).

However, other authors (Vinkler, 2001; Lewison et al., 2008) have proposed another classification based on bibliometric techniques, diving them into two groups: 1) unidimensional indicators based on univariable statistic techniques and 2) multidimensional indicators that work with multivariate statistical techniques. The latter is more closely linked to the development of multivariate statistical analysis and the increase of technological capacity in the 90s. In addition to this proposal, Sanz-Casado (2000) proposes the inclusion of another classification: "connexionist" indicators (the ones that work with social network analysis).

Traditionally, bibliometric indicators have been built on the basis of two measures: publications and citations. However, four general dimensions can be structured as follows:

- Research output: This dimension values the results of the research, by indicating its volume. The types of output can differ and encompass scientific publications or patents. By considering scientific publications, the most well-known indicators are the number of publications for an author, institution or country, journal or thematic area. However, this metric does not give information about the quality of the publication (Sancho, 2011). This group can also include a productivity indicator, which is the ratio of research output to research input, an average measure of the efficiency of production of research output. It can be analysed at an institutional level (e.g. total publication productivity [TPP]) or productivity in foreign languages (PFL) and productivity in SCI papers (Todeschini & Baccini, 2016). Productivity can be assigned "normal" (one unit is assigned to the publication) and "fractional counting" (dividing the unit between the number of signers of the paper). Aleixandre-Benavent et al. (2017) propose a classification of three levels of productivity: 1) small producers (with only one published work and a productivity index equal to 0); 2) medium producers (between 2 and 9 published works and a productivity index greater than 0 and less than 1); and 3) large producers (with 10 or more published works and a productivity index equal to or greater than 1).

- Impact: This dimension captures the influence of publication on research activities conducted by scholars, as reflected in the number of citations received (Todeschini & Baccini, 2016). This metric is highly controversial and has been widely-discussed in the bibliometric community. Impact factor was created as a tool for selecting the top journals by the SCI of Garfield. However, many criticisms have been raised. Less than 20% of the papers encompasses 50% of the citations, and a higher percentage receives fewer or none citations, leading to the conclusion that IF are grouped by a minority of journals. In this regard, alternatives for measuring journals' prestige haven been proposed. For instance, the SCImago journal rank indicator (González-Pereira, Guerrero-Bote & Moya-Anegón, 2010), source-normalized impact per paper indicator (Moed, 2010) or the eigenfactor (Bergstrom, West and Wiseman, 2008) are some of them.
- Collaboration: This is obviously a process in which two or more researchers work together, sharing their resources (knowledge and materials) with the aim to produce new scientific knowledge. Collaboration differs by level (e.g., authorial, institutional or national). The factors that affect the collaboration also diverge depending on discipline (e.g., basic or applied science), funding, language or country.
- Visibility: This dimension gives insight into the quality of the papers by considering the journal in which the paper has been published, based on international bibliometric indicators (WoS, Scopus).

The above dimensions just presented can be operationalized through the use of different indicators. These indicators are some mostly used in the bibliography of the field (Aleixandre-Benavent et al., 2017). Table 3 summarizes the dimensions described with some indicators proposed on each one.

Table 3. Summary of the Dimensions Considered with their Corresponding Indicators

Dimension	***Indicators***
Scientific production	• Production index or fractionized production index • Activity index (AI) • Productivity index (or Lotka) or fractionized productivity index

	• Transience index
Impact	Based on citations: • Number of citations • Average number of citations per publication • Highly cited papers • H-index (Hirsch) • Crown indicator Based on references: • Obsolescence and semi-period • Price index • Isolation index Based on impact factor: • Impact factor • 5-year impact factor • Immediacy index • Eigenfactor[22] • SCImago journal rank • Source-normalized impact per paper
Scientific Collaboration	First[23] generation scientific collaboration indicators • Number and rate of documents in co-authorship • Co-authorship index • Institutional collaboration Second generation collaboration indicators. Collaboration networks *Collaboration between authors* • Number of documents in co-authorship • Collaboration between institutions *Inter-institutional collaboration* • National or international inter-institutional collaboration *Collaboration between countries* • International collaboration

[22] Based on Aleixandre-Benavent, R., González de Dios, J., Castelló Cogollos, L., Navarro Molina, C., Alonso-Arroyo, A., Vidal-Infer, A., & Lucas-Domínguez, R. (2017). Bibliometría e indicadores de actividad científica (III). Indicadores de impacto basados en las citas (1). *Acta pediátrica española*, *75*(5-6), e75-e84.

[23] Aleixandre-Benavent, R., de Dios, J. G., Cogollos, L. C., Molina, C. N., Alonso-Arroyo, A., Vidal-Infer, A., ... & Sixto-Costoya, A. (2017). Bibliometría e indicadores de actividad científica (V). Indicadores de colaboración (1). Acta Pediatrica Espanola, 75(9/10), 108-113.

	• International collaboration[24] by groupings of countries[25]
Visibility	- First quartile documents (1Q)

Source: Own elaboration based on Aleixandre-Benavent et al. (2017)

Another type of analysis that has gained popularity in recent years in bibliometrics is acknowledgments information. Since 2008, this information has been included in WoS and constitutes one of the edges from the reward triangle (based on citations, authorship and acknowledgments) proposed by Costas and van Leeuwen (2012). This authors determines that there are two types of acknowledgments: financial support or peer-review communication.

1.5.1.2.2. Limitations of bibliometric indicators

Several studies have highlighted the limitations, misuses, and abuses of bibliometric indicators, affirming that their use could be problematic. This attention has led to concern about their capacity as suitable means for assessing research activity. For instance, one of the main criticisms is that evaluation considering only bibliometric indicators cannot provide complete information. García-Zorita (2001) highlights the danger of massive use of bibliometric indicators, which could lead to manipulation, with the aim of obtaining certain advantages or affecting an evaluation. In this regard, classic indicators such as publication counts, citation scores or impact factor could have different impacts over time, and these indicators may not reflected these contributions. Therefore, García-Zorita have suggested that this methodology should be combined with others (e.g. peer review) in order to be complementary. Gómez-Caridad and Bordons (1996) highlight three biases of bibliometric indicators: 1) not all countries are well-represented, and English journals are prioritized; 2) basic science is better represented than is applied science; and 3) global topics are better represented than are local topics. Notwithstanding, some of these limitations have been improved over time. For instance, in Spain, the subscription to Web of Knowledge (WoK) (later known as WoS) by Spanish Foundation for Science and Technology (FECYT) was held in 2004, denoting a delay in the community's access to the database. Another important fact worth mentioning is the growth of national journals indexed in WoS in journal citation reports (JCRs) that has passed from 31 journals in 2000 (Bordons et al., 2002) to 171 journals in 2013 (Abadal et al., 2015), denoting an increase of non-English speaking journals.

Another criticism of bibliometric indicators, as Okubo (1997) has stated, is that these indicators consider only scholarly publications, whereas other communication forms remained unconsidered. This argument

[24] Aleixandre-Benavent, R., de Dios, J. G., Cogollos, L. C., Molina, C. N., Alonso-Arroyo, A., Vidal-Infer, A., ... & Sixto-Costoya, A. (2017). Bibliometría e indicadores de actividad científica (V). Indicadores de colaboración (1). *Acta Pediatrica Espanola*, *75*(9/10), 108-113.

is aligned with that of Sancho (1990), who affirmed that bibliometric indicators are based only on scientific publications, not other typologies (e.g. patents).

Not all problems with bibliometric indicators are related to the document itself. Another important fact is that scholars face social and political pressure to publish in order to gain prevalence in the curriculum and be successful in a minimum amount of time. This publication pressure has led to habits among the researchers, such as focussing on the "least publishable unit", leading to the division of the research into small pieces in order to publish more.

Considering the limitations and misuses of bibliometric indicators, several authors have emphasized the responsible use of metrics. For instance, different initiatives, such as the "San Francisco Declaration of Research Assessment" (American Society for Cell Biology, 2012), have emerged with the aim to support the adoption of good practices in research assessments, Leiden Manifesto (Hicks et al., 2015), a policy-oriented document with a list of 10 principles with the aim to achieve best practices in metric-based assessment, or the MetricTide, a report of the "role of metrics in research assessment and management" (Wilsdon et al., 2015). As defined by Rosseau (2018), different forms of scientific misconduct can be classed as follows: fraud, plagiarism, and retraction that could affect the integrity of a researcher's publication record. In this context, demand has been increasing demand for new indicators "related to societal impact, open science or responsible research and innovation to respond to new policy demands to address societal challenges" (Rafols, 2018). As Rafols (2018) has written, it is based on a transformation towards contextualizing indicators (e.g. complement the statistical analysis with qualitative methods), and these are "not new indicators but are about indicators' playing different roles in political appraisal". More accurate analysis is expected to lead to a "the democratization of science" with new approaches to these indicators, which will be more open than the datasets. Moreover, this movement has been helped by the open science movement, which should be emphasized as well. As Rosseau (2018) has pointed out, this movement "is a reaction to the fact that universities, research institutes, and other scientific institutions are confronted with huge increases in the price of journal subscro`topms, leading to cancellations and hence nonavailability of scientific information". The origin of the term open science can be traced to 2002 and marks "a cultural change in the way researchers, educators and other stakeholders create, store, share and deliver the results of their activity" (Ayris et al., 2018).

1.5.1.3. The new metric study: Cybermetrics, webometrics and altmetrics

Change in the "tools and platforms that support scholarly exchange are giving rise to a new wave of metrics". In this sense, bibliometrics can be seen as an anachronistic concept in comparison with new lexical terms such as webometrics and scientometrics. However, "bibliometrics" is a broader term than these other terms.

Björneborn (2004) define cybermetrics as "the study of the quantitative aspects of the construction and use of information resources, structures and technologies on the whole Internet, drawing on bibliometric and informetric approaches". In addition, with the developments of the technology and internet, a new sub-discipline has been created called "webometrics", first formulated by Almind and Ingwersen (1997), who stated that webometrics "covers research of all network-based communication using informetric or other quantitative measures". According to Rousseau et al. (2018) the difference between bibliometrics and webometrics is not clear, but they concluded "web sources is not webometrics, but studying their use is". Later, Björneborn (2004) defined webometrics as "the study of the quantitative aspects of the construction and use of information resources, structures and technologies on the Web drawing on bibliometric and informetric approaches". Webometrics groups studies with a common object, the web, and it is based on the idea that web is an enormous repository; webometric research covers quantitative aspects of that repository, such as the construction and usage side. For instance, it includes analysis such as "link analysis, web citation analysis, search engine evaluation, descriptive analysis (e.g. average web page size, meta-tags used or technologies used) or web 2.0" (Thelwall, 2008). In comparison with webometrics, cybermetrics is a broader concept, which includes not only web but also chats, discussion groups or e-mail lists. In this regard, Bollen (2008) mentioned usage indicators: the data on user access to scientific literature through journal platforms.

In face of the limitations of bibliometric indicators in reflecting the value of research beyond the impact and its contributions to the society (third mission), they have nevertheless led to the development and popularization of alternative metrics. Internet access has led to a change in the paradigm for consuming and publishing scientific content. In this sense, the availability of indicators about social media has emerged as a new set of metrics with the aim to track and measure interactions on social media relating to scholarly communication, called altmetrics or social media metrics (Haustein, Bowman & Costas, 2015a). In this regard, social media platforms (e.g. Facebook, Twitter, Wikipedia, blogs, social bookmarking tools like Mendeley, and Zotero) and academic social networking (ResearchGate, Academia.edu) can be considered. As Moed (2015) has stated, altmetrics can be defined as "traces of computerization of the research process, and as a tool for the practical realization of the ethos of science and scholarship in a computerized or digital age". A theoretical framework for the use of altmetrics has also been introduced: Haustein, Bowman, and Costas (2016) define "altmetrics as events on social and mainstream media platforms related to scholarly content or scholars, which can be easily harvested (i.e., through APIs), and are not the same as the more 'traditional' concept of citations as social media metrics". This definition consider events as "research objects", and it considers "scholarly agents". The analysis of these indicators will include not only interactions with the "objects" but also interaction between "scholars", as well as different forms of interaction (Fig 1). This rise has changed the way and scholars use these platforms for professional purposes through communication, collaboration and dissemination of research among various audiences (Gruzd, Staves, & Wilk, 2012).

Which indicators and aspects can be analysed with altmetrics? Apart from the metrics related to usage and activity counts (number of mentions of on this platforms, profiles of the users, etc.), one can analyse platform characteristics (e.g. Twitter for more public general; LinkedIn more professional) and uses for different profiles (e.g. presentation of self and reputation management of different profiles such as researcher, communicator, and public) or forms of action and participation (Figure 1). For instance, network structure on the social channels are analysed as in bibliometric patterns. "Communities of attention" (Haustein, Bowman & Costas, 2015b), "follower–followee" relations (Robinson-Garcia, van Leeuwen & Rafols, 2015) and readership coupling links (Haunschild & Bornmann, 2015) are examples of network interactions.

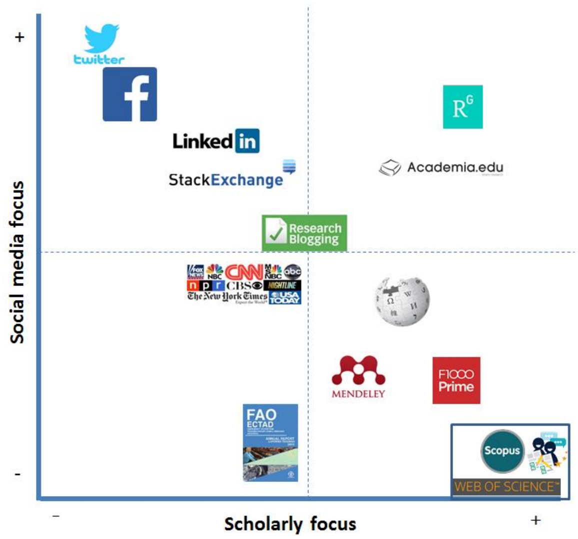


Figure 1. Social media studies of science lecture. Source: Extracted from Wouters, Zahedi and Costas (2019).

Moreover, the Altmetric manifesto (Priem et al., 2010) has incentivised "the use of altmetrics for impact assessment and is seen as able to complement traditional scholarly impact analyses" (Priem, Piwowar, & Hemminger, 2012). In addition, the open science movement has contributed to the development of altmetrics (Moed, 2017). However, not yet enough evidence has yet amassed in the literature to show how altmetrics can actually reveal the societal impact of research (Bornmann, 2014, Priem et al., 2012). However, in recent years altmetrics have received much attention from research funders and science policy makers with respect to understanding how scientific research has contributed to society (Wilsdon, et al., 2015).

Moreover, developments in the field of network techniques should be mentioned here. According to Rosseau et al. (2018), in a "more globalized, networking world, studies of collaboration, networking or diffusion of ideas have gained significance". For instance, their visualization (Van Eck and Waltman, 2009; Chen 2006) and the "increase of software and the commonly known as maps of science" (Borner, 2010; Leyesdorff, Carley and Rafols, 2013) have gained interest.

1.5.1.3.1. New metrics, new data sources

Considering that researchers feel under pressure in order to improve the metrics by which their success is judged, global demand has been placed on the scientific community to clarify which metrics are used to evaluate scholars. Data sources have become a fundamental point in demand project. The "success and development of bibliometric and scientometric indicators has been favoured by the launches of bibliographic databases and the development of computer technologies" (Katz and Hicks, 1997). Nowadays, there now exist specialized data sources in all scientific fields. However, the disparities in structure and organization complicate its use. In this regard, the great majority of bibliometric studies use multidisciplinary sources.

One of the most well-known databases is WoS, and it is among the most used in bibliometric studies (Clarivate Analytics, 2019). WoS, previously known as WoK, is a platform formed by a set of bibliographic databases of a multidisciplinary nature, "which allows an in-depth exploration of the fields and sub-fields of an academic or scientific discipline". Originally produced by the ISI and created by Eugene Garfield, was later bought by Thomson Reuters (2008) and, more recently, in 2016, by Clarivate Analytics (2016). It is composed by the following databases:[26]

- The Science Citation Index Expanded (SCI-EXPANDED) is a multidisciplinary databased with content starting in 1990 and coverage of 8,300 journals from 150 scientific disciplines.
- The Social Sciences Citation Index (SSCI) is a multidisciplinary index of literature from social science journals since 1990. It has indexed 2,900 journals from 50 disciplines related to social sciences. In addition, it indexes relevant elements selected from 3,500 more important scientific and technical journals.
- The Arts and Humanities Citation Index (A&HCI) is a multidisciplinary index of arts and humanities journals. It has a coverage of 1,600 journals of arts and humanities all over the world since 1975.
- The Conference Proceedings Citation Index is divided into the Conference Proceedings Citation Index: Science (CPCI-S) and Conference Proceedings Citation Index: Social Sciences and Humanities (CPCI-SSH); the first covers conference proceedings in all scientific and technical fields, and the second covers conference

[26] Information on the databases extracted from https://images.webofknowledge.com/WOKRS519B3/help/es_LA/WOS/hp_database.html accessed 5 January 2019.

proceedings from social sciences, arts and humanities. Information is available from 1990 on.

- The Book Citation Index-Science (BKCI-S) and Social Sciences and Humanities (BKCI-SSH) comprise a multidisciplinary index that includes literature related to science, humanities and social sciences since 2005. It includes 14 disciplines.
- The Emerging Sources Citation Index includes records of journal articles that are not included in the SCI-EXPANDED, SSCI or A&HCI databases.
- Current Chemical Reactions (CCR Expanded) includes synthetic methods from the most important journals and patents of 36 issuing authorities since 1985.
- Index Chemicus (IC) contains fundamental support structures and information on new organic compounds from the most prestigious journals internationally since 1993.

These databases constitute the WoS Core Collection. However, other databases are also included (subject-specialized and regional indexes such as the Korean Journal Database [KCI], Medline and the Zoological Record, among other resources such as Current Contents Connect or the Derwent Innovations Index [Patents]). Regarding the coverage, WoS coverage of 159 million records (journals, books and proceedings); however, the WoS core collection—composed of the databases Science and Social Sciences Citation Index, Arts and Humanities Citation Index, Conference Proceedings Citation Index, Book Citation Index and Emerging Sources Citation Index—has a coverage of 74 million records, more than 104,000 books and over 8 million conference papers.[27] Its features have been highlighted: its multidisciplinary character, selectiveness (journals are selected based on quantitative criteria and expert opinion), full coverage, completeness of addresses (information about authors addresses are included) and bibliographical references available, among others (Glänzel, 2003).

However, in recent years, different data sources have emerged:

- Google Scholar is a "free academic search engine that indexes scholarly literature from different disciplines, types of documents (e.g. articles, theses, books and abstracts) and sources".[28] It also provides additional services (bibliographic references adapted to various styles and format, access to the full text of academic documents, metrics like number of citations, h-index, and h-core. Differing from WoS and Scopus, Google Scholar never been monetized and has an inclusive approach, indexing any document available "on the web and replicating the simplicity of Google's basic search engine" (Martín-Martín, 2019). The coverage of Google Scholar was 197 million articles (331 million if references and patents are considered) in 2017 (López-Cózar et al., 2018). However, later studies have determined this number to rise to an estimated 389 million in 2018 (Gusenbauer, 2019).

[27] Data of the coverage obtained in the following link: https://clarivate.libguides.com/webofscienceplatform/coverage accessed 17 August 2019.
[28] Information of Google Scholar Available at: https://scholar.google.com/intl/es/scholar/about.html accessed 5 January 2019.

- Dimensions is a dynamic, linked-research data platform that allows one to search for information about grants, publications, clinical trials, patents, policy documents and metrics (altmetrics and number of citations). It is been described as "a next-generation linked research information system that makes it easier to find and access the most relevant information, analyse the academic and broader outcomes of research and gather insights to inform future strategy".[29] It is based on delivery of a cutting-edge research insights platform that could connect the needs and information of different stakeholders (research organizations, funders and publishers). As Hook (2018) argues, Dimensions has been possible because of the large amount of open data by the "publishers and as a consequence of the open access movement". It covers a total of 128 million publications, grants, policies, data, and metrics.[30]
- Microsoft Academic is a specialized semantic search engine (not keyword-based) in scholarly literature based on cards that allows the user to have the information of the publications and was created in 2011. However, it does not allow one to download the full text, and metrics by cited reference should be taken with caution (Jacsó, 2011). It also provides sheets with information about the journals.[31] It covers an estimated 220,607,278 papers.
- Lens is an open platform that includes information on global patents and scholarly knowledge "as a public resource to make science and technology-enabled problem solving more effective, efficient and inclusive".[32] The scholarly data it makes available is from "PubMed, Crossref, Microsoft Academic, Core and PubMed Central and includes information such as citations, recommended works, references, and funding and grant information".
- 1findr, as it is described on the website, is an "inclusive discovery platform with the aim to index articles in peer-reviewed journals in all fields of research, all languages and from all over the world".[33] It is estimated to cover 90 million records and around 27 million open-access articles. It is linked with the open science philosophy and exploits the open access movement, providing fee-based and freely accessible scholarly articles published in peer-reviewed journals to download for free.

1.5.1.4. Bibliometrics in sustainability

The importance and growing interest in the concept of sustainability have also been seen in the scientific field. Research can be used to tackle global, multi-faceted societal challenges such as sustainability goals. Several studies have analysed sustainability in the scientific field. Bibliometrics, which studies

[29] Information available in the following link: https://www.dimensions.ai/ accessed 5 January 2019.
[30] Coverage information obtained from https://www.dimensions.ai/2018/01/dimensions-a-next-generation-research-and-discovery-platform-linking-128-million-documents/ accessed 5 January 2019.
[31] Detailed information about Microsoft Academic functi onalities available here: https://www.lluiscodina.com/microsoft-academic/ accessed 5 January 2019.
[32] Information of Lens available at https://about.lens.org/ accessed 5 January 2019.
[33] Information of 1findr extracted from the following source: https://www.1science.com/1findr/ accessed 5 January 2019.

academic publications, has developed tools for examining scientific activity in a given subject area, institution, or country, and it offers a powerful way to generate a global picture of research in a particular area. Various bibliometric studies have investigated sustainability or SD (Hassan and Zhu, 2014; Pulgarin et al. 2005; Olawumi and Chan, 2018; Ramírez et al., 2016) or sustainability science (Kajikawa et al., 2014; Nučič, 2012; Schoolman et al., 2012)). Pulgarin et al. (2005) studied SD research output over 13,093 documents from different countries (Brazil, Spain, and Sweden), and Ramírez et al. (2016) consider sustainability discourse in the Scopus database. Other studies also analyse sustainability research output. Hassan, Haddawy and Zhu (2014) have examined the world's research activity (2000–2010) in SD at the country level and the institute level, using scientific literature in Scopus. Olawumi and Chan (2018) have reviewed 2,094 records from WoS related to sustainability and SD. Other studies focus on analysing the output of SHE (Bizerril, 2018; Veiga-Ávila et al., 2018; Alejandro Cruz et al., 2019; Hallinger and Chatpinyakoop, 2019). As Kajikawa et al. (2007) have stated, "around 12,000 papers on sustainability are published annually". Moreover, Kajikawa et al. (2014) consider that "most scientific disciplines are expected to contribute toward sustainability because issues in sustainability have complex structures, including environmental, technological, societal and economic facets".

Some other studies have focussed specifically "on the analysis of the scientific production regarding renewable energies" (Dong et al., 2012; Romo-Fernández et al., 2012; Sanz-Casado et al., 2014). Tang et al. (2018) focus on analysing 6,459 publications from a sustainability journal called *Sustainability* from a bibliometric point of view. If we consider the three main pillars of sustainability, we found papers on the literature that focusses on certain aspects. For instance, Fu and Zhang et al. (2017) have assessed the trajectory of urban sustainability concepts; Feng et al. (2017), CSR; and Ruhanen et al. (2015), sustainable tourism research. In Bautista et al., (2019e) the core of the three pillars of sustainability are examined in order to determine the concept's core features.

Moreover, "the emergence of a new scientific field in the 21st century called sustainability science" (Kates et al., 2001; Komiyama and Takeuchi 2006; Kajikawa et al; 2007; Kajikawa, 2008; Kajikawa et al., 2014; Nučič, 2012) emphasizes that interest is growing in this subject. Sustainability science was originally created at the World Congress "Challenges of a Changing Earth 2001" (Mochizuki, 2015). Sustainability science investigates "complex and dynamic interactions between natural and human systems: It aims "to bridge the gap between science and society and limit its knowledge to actions for sustainability" (Wiek et al., 2012; Disterheft et al., 2013). Although no consensus has emerged on its definition, many topics (e.g. renewables, sustainability) have been analysed from this perspective, and its characteristics have been widely described in the literature. Concepts such as transdisciplinarity or its being action-oriented have been used to characterize this new field (Kates et al., 2001; Disterheft et al., 2013). The structure of this new field has been explored qualitatively (Miller, 2013; Jerneck et al., 2011). Similarly, bibliometric approaches have been adopted to "examine the development of sustainability science through the analysis of citations" (Kajikawa et al., 2007, 2014; Buter and Van Raan, 2013), journal interdisciplinarity (Bettencourt and Kaur, 2011; Buter and Van Raan, 2013), or its dynamics such as patterns of collaboration (Yarime et al., 2010). According to Spangenberg (2011), "sustainability science is seen as research providing the necessary insights to make the normative concept of sustainability operational, and the means to plan providing the necessary insights to make the normative concept of sustainability operational, and the means to plan and implement adequate steps towards this end". Moreover, according to these authors there is the science *for* sustainability (mono/multi-disciplinary) and science *of* sustainability (inter/trans-disciplinary). On the other hand, it should be mentioned of this interest that in 2016 the scientific database WoS created a new category called "green and sustainable science and technology", denoting interest in and the emergence of a new discipline.

However, few studies have specifically analysed scientific output among SDGs. Nakamura et al. (2019) has examined 2,800 documents (with an expansion of 10,300 documents by using direct citations), as well as an SDG topic map. On the other hand, Bautista-Puig (2019b) considers the core of scientific production of the MDGs and the SDGs to be 4,532 documents and highlights the growth from 2015–2019, which coincides with the launch of the SDGs, in addition to the interrelations between different SDGs. Regarding scientific production related to universities, the Aurora project reviews the scientific production of several universities in each of the objectives through a bibliometric analysis. Salvia et al.'s (2019) study intends to identify the main SDGs addressed by experts from different geographical regions, as well as the relation between SDGs and main local issues and challenges in each region. Several studies have examined the interrelations among SDGs (Griggs et al., 2017, Le Blanc, 2015). However, to the best of our knowledge, no other study has approached the study of SDGs in relation to scientific output from a bibliometric point of view.

Several studies have explored sustainability itself from a bibliometric point of view, but despite the growing interest in this subject, we find very little analysis of sustainability at HEIs in Spain from a bibliometric point of view. Some of these studies have focussed on virtual laboratories (Salmerón-Manzano and Manzano Agugliario, 2018); others considered the theses and dissertations on sustainability education (Leetch et al., 2017).

1.6. Overview of the chapters

This doctoral thesis has been carried out in the Laboratory of Metric Information Studies (LEMI), in the Department of Library and Information Science at Carlos III University. It has been integrated with the project "Research on Energy Efficiency and Sustainable Transport in Urban Areas: Analysis of Scientific Development and the Social Perception of the Subject from the Perspective of Metric

Information Studies", a project framed by the State Plan for Scientific and Technical Research and Innovation 2013–2016 from the Economy and Competitiveness Ministry. The main aim of this project is to identify Spain's scientific, technological and social capacities in the field of sustainable urban transport and energy development and the analysis of systems that generate scientific and technical knowledge and of the role played by universities, companies and public research bodies in generating social awareness of the efficient and sustainable use of energy resources and transport in cities. It is a coordinated project, between the Autonomous University of Madrid (UAM) and University Carlos III of Madrid (UC3M). In this framework, the UC3M has developed a part of the research from metric information studies, whose main aim is to analyse research through scientific publications to obtain indicators of production, collaboration, impact and visibility and to prepare thematic maps on these topics.

This thesis is structured in six chapters. In Chapter 1, we have presented a literature review of the broader topic and context of the research presented in this thesis. The concept of sustainability and its development in a policy priority setting and the Sustainable Development Goals (SDGs) are presented. Considering that the focus is on universities, a framework for sustainability in the higher education institutions (HEIs) is presented, focussing on the situation in the Spanish framework. In addition, a section related to the measurement of the impact of science and technology, Scientometrics and its indicators is presented.

The second chapter is dedicated to the description of the hypothesis and the principal and secondary objectives of the doctoral thesis.

The third chapter describes the data and the methodological procedures for the thesis. In this regard, the sources of information, the field delineation strategy, data treatment (information and processing and software used), and indicators used are presented.

In the fourth chapter, according to the delineation of field of study, the results obtained for the research activity of HEIs in Spain between 2008 and 2017 are presented. The commitment of Spanish HEIs is presented. Moreover, in this chapter maps of the connexionist indicators (countries, institutions, topics and SDGs Classification) are presented. Moreover, multidimensional scientometric indicators related to different dimensions (countries vs years; organizations vs years; WoS categories vs years) are presented. In the final part of this chapter, an overview of HEIs and SDGs s presented by analysis of their research output and thematic analysis.

In the fifth chapter, these results are interpreted and discussed by in relation to the theoretical bases established above.

The sixth and final chapter presents a summary of the findings, policy recommendations, the limitations of the study and suggestions for further research.

Chapter II: Hypothesis and objectives

This metrics study allows the evaluation of output and scientific activity, contributing to the study of quantitative aspects of science as a discipline. The role of sustainability in HEIs is analysed from the this perspective.

2.1 Hypothesis

According to the importance of sustainability at HEIs as well as the literature review, the following hypotheses are proposed:

H1. Considering the difficulty of delineating the concept of sustainability, metric studies are good tool to help in the construction of a study object.

H2. HEIs have a central role as agents of change in the implementation of policies and strategies on sustainability.

H3. The universities with the highest production in sustainability research are those that have a greater awareness of this issue.

H4. Collaboration is a factor of great importance in the study, since the global societal challenge makes cooperation with other research centres necessary.

2.2. Objectives

2.2.1. Principal objective

In a new sustainability paradigm, there is an urgent need to understand and characterize the HEIs' approach to SD. In this regard, the principal objective of this research is to delineate the field of sustainability and SDGs and to describe the evolution of scientific and technological output through bibliometric indicators of research output, impact, collaboration and visibility about sustainability at HEIs during the period of 2008–2017 through WoS. Furthermore, this research puts special emphasis on the SUE. The purpose of this study is to analyse the university's commitment to sustainability within research and knowledge transfer missions.

- **Research:** Scientific production.
- **Knowledge transfer:** Technological activity and European projects; Sustainability Plans; GreenMetric ranking.

The other primary mission of a university, teaching, is not considered, since its characteristics and dynamics would require a different conceptual and methodological approach.

2.2.2 Secondary objectives

In order to achieve the principal objective, the following specific objectives are proposed:

- Describe the evolution of the scientific output through bibliometric indicators of production, impact and collaboration of scientific and technological activity in sustainability.
- Identify the main actors (countries and institutions) that produce scientific output on this topic globally.
- Analyse the network of scientific collaboration in this topic between institutions and countries and elaborate graphics that allow visualization and exploration of these relationships to facilitate an understanding of them.
- Identify the centres and groups with the highest production scientific and repercussion.
- Detect research fronts of this topic through thematic networks.
- Identify and analyse other tools regarding sustainability in the Spanish HEIs: Sustainability plans, strategic plans, and participation in European projects, among others.
- Delineate and analyse the scientific output of SDGs and the role of HEIs.

The information that provides the achievement of these objectives may have a high value and interest for the managers of sustainability policies at the universities, as well as for researchers, since it will provide a broad vision of the research activity on this topic.

Chapter III: Data and Methodology

The thesis has been proposed as an analysis of the evolution of the production, impact and collaboration of the global scientific and technological activity in sustainability at HEIs. To achieve this purpose, methods, techniques and tools of metric information studies have been used. On this matter, the theoretical bases of the area of knowledge are assumed, and the general restrictions of the area are accepted, as well as the specific limitations related to the specific object of study. This chapter describes the methodology followed in this dissertation: sources of information, search strategy, the process of obtaining and processing the data and the indicators used for the analysis. Furthermore, network analysis and statistical analysis techniques are used, as well as computing tools.

3.1. Sources of information used

To achieve the objectives proposed in this thesis, a combination of various sources of information has been used. Data sources can be classified as below.

3.1.1. Bibliographic and alternative databases

The Centre for Science and Technology Studies (CWTS) in-house WoS database has been used for this study. Three databases have been selected (SCI-EXPANDED, SCI and A&HCI, also known as the "Core Collection"). However, some limitations have been highlighted in the literature: unequal coverage across scientific fields, with the under-representation of the social sciences and humanities; the skewness of the articles between other methodologies; and the under-representation of non-English speaking countries (Bordons and Gómez, 1997). However, despite its long tradition in bibliometric studies, the scientific output on this database has been selected for analysis. Access to this database has been made possible by the Carlos III University of Madrid (UC3M), through the license provided since 2004 by the FECYT (Bolaños-Pizarro et al., 2011). Access has been also possible from the CWTS in-house version of the WoS database from the Leiden University during the research stay carried from January to April 2019.

- JCRs is a database with information about the journals in two annual editions (JCR Science Edition and JCR Social Sciences). It covers 11,896 journals from 236 disciplines from 81 countries.[34] Basically, it measures the impact factor of a journal based on citations received by articles published and collected on the WoS. It allows measurement of the influence and impact of the research carried out at the journal and category-level. However, the impact factor has been highly criticized for its use in the evaluation of the scientific output of individuals and institutions, and its wise use has been often remarked upon. In fact, in "San Francisco Declaration on Research Assessment" (American Society for Cell Biology,

[34] Coverage information collected from https://clarivate.com/products/journal-citation-reports/ accessed 5 January 2019.

2012) has recommended “the need to eliminate the use of journal-based metrics, such as Journal Impact Factors, in funding, appointment, and promotion considerations” and “the need on its own merits rather than on the basis of the journal in which the research is published” (American Society for Cell Biology, 2012). Another important fact is the growth of national journals indexed in WoS. The JCRs grew from 31 journals in 2000 (Bordons et al., 2002) to 171 journals in 2013 (Abadal et al., 2015) in the Spanish case.

- The Altmetrics.com data aggregator was founded in 2011 by the Digital Science Company based in London (United Kingdom). It tracks mentions of scholarly works across the social web. In fact, it contains metrics from Twitter, Facebook, policy documents, Wikipedia, news, blogs, Mendeley, Pub peer and Publons, Faculty of 1000 Prime Reddit, Stack overflow, Google Plus, YouTube, Open Syllabus Project, Scopus and WoS citation. The category of impact that it offers is Altmetric Attention Score (with the distinctive donut and Altmetric score), mentions and readers, and “more than 64 million mentions of 9 million research output were covered by this database in January 2018” (Zahedi, 2018). Mentions are “tracked for scholarly output unique identifiers (e.g. ArXiv id or PubMed id)”. In addition, it makes available an Altmetric API. Access to this database has been possible in the CWTS in-house version of WoS database.

3.1.2. Technological databases

There are different patent databases: however, this study has focussed on the following:

- The European Patent Office (EPO). The European Patent Organization is an intergovernmental organization created on 1977 under the European Patent Convention signed in Munich in 1973. This organization is composed by two entities: i) the EPO and ii) the Administrative Council that oversees the activities of the office. Moreover, decisions can be can be appealed to its Boards of Appeals. Through this database, patents published worldwide can be accessed, including the “World Intellectual Property Organization” (WIPO) database, the Japanese patent database (since 1976), the USPTO and the EPO itself. The latter contains more than 110 million patent documents (EPO 2019). The information obtained on this work is through Global Patent Index (GPI) and its decision is based on global coverage (patents from all over the world), accessibility and quality of the information.

3.1.3. Projects and rankings

- The Community Research and Development Information Service (CORDIS) database “contains information on the projects funded by the European framework programme for research and innovation”. The Framework Programmes for Research and Technological Development (also known as the Framework Programmes) are funding programs “created by the European Union and European Commission to support and foster research in the European Research Area (ERA)”. It was fostered in

1984 with the First Framework Programme (commonly called FP1). There has been eighth Framework Programmes until 2019 and the periods between the programme vary (e.g. until FP7, it was five-year period and since then, a seven-year period) and their specific objectives and their associated actions vary between funding periods. For instance, the last programme (H2020 or FP8) is based on three pillars[35] ("excellent science, industrial leadership, and societal challenges") and two specific objectives ("spreading excellence and widening participation", along with "science with and for society"). CORDIS provides information from FP1 to the Horizon 2020 programme. Its management depends on "the Publications Office of the European Union on behalf of the European Commissions research and innovation Directorates-General, Executive Agencies and Joint Undertakings", as well as the support of specialised contractors for editorial, data and technical services.[36] Its main mission is to "bring research results to professionals in the field to foster open science, create innovative products and services and stimulate growth across Europe".[37] It contains basic information (date, call, budget, a fact sheet with the objectives...) on each project such as the participants (with information on the coordinator, institution, country and budget), reports, deliverables, website, patent fillings or videos, and links to open-access publications (Figure 2).

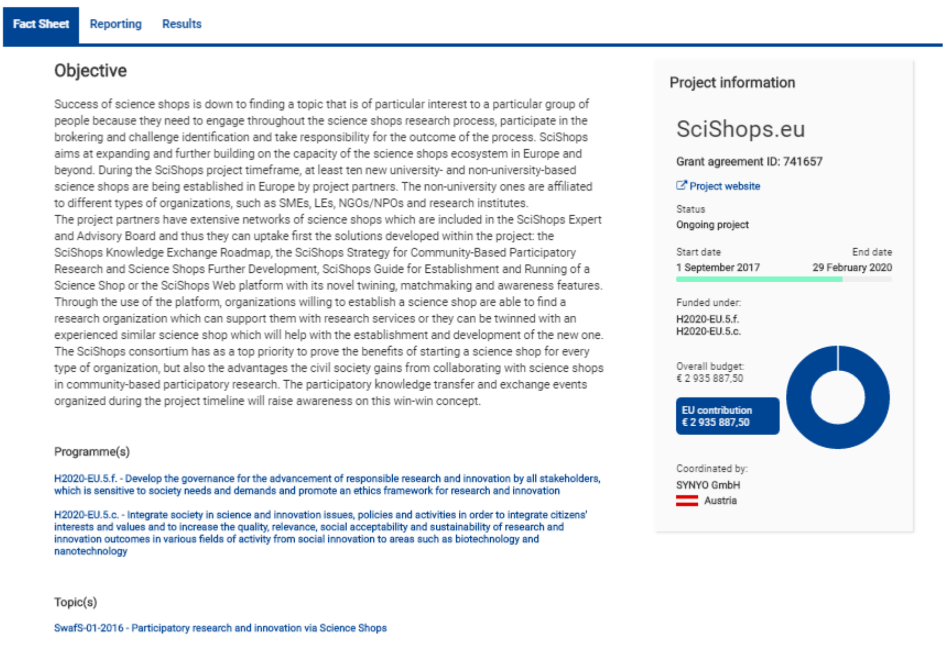


Figure 2. Example of CORDIS database project information. Source: Screenshot from CORDIS website.

[35] Information extracted from https://ec.europa.eu/research/participants/docs/h2020-funding-guide/grants/applying-for-funding/find-a-call/h2020-structure-and-budget_en.htm accessed 25 June 2019.
[36] Management information mission information obtained from https://cordis.europa.eu/about/en accessed 25 June 2019.
[37] Mission information obtained from https://cordis.europa.eu/about/en accessed 25 June 2019.

- The GreenMetric World University Ranking it is a global sustainability ranking developed by the UI in 2010. The "main purpose of the ranking is to provide the result of online survey regarding the current condition and policies related to green campus and sustainability in the universities all over the world".[38] It is expected to have an impact on university leaders and different stakeholders, with the aim of tackling sustainability challenges at HEIs. It analyses six categories with its different weights: "setting and infrastructure (15%), energy and climate change (21%), waste (18%), water (10%), transportation (18%), and education (18%)". It was not until 2012 that the education perspective was included. Other rankings have evaluated the achievement of HEIs on sustainability, such as the College Sustainability Report Card; however, it is only for United States of America HEIs. Despite its criticisms on the indicators and the number of participants (Lauder et al., 2015), it is the only ranking that offers an overview of sustainability at HEIs worldwide.

3.1.4. Other sources: SD at HEIs

Considering how sustainability can be applied at HEIs, Lozano (2006a) presents different dimensions. Moreover, the commitment of Spanish HEIs towards sustainability based on different dimensions has been analysed. The majority of these sources have been collected in the HEIs' websites. For this analysis, the following items have been checked:

1) University and governance: This includes administration-related topics about mission and planning. The following aspects have been analysed:

- *Inclusion of sustainability in the strategic plans.* The Strategic Plans of Private and Public Universities of the SUE were searched and located on their own websites. Not all universities have a strategic plan, and not all plans are publicly available (Cavanna & Medina, 2017). Subsequently, the search for the term "sustainability" (including environmental, social or economic) was analysed for each document.
- *Network participation.* Two Spanish networks were considered: a working group on sustainability at the Conference of Spanish University Rectors (CRUE) and Sustainable Solutions Development Network (REDS), the Spanish Sustainable Development Solutions Network (SDSN). For checking the participation, the list of universities on this network has been reviewed through their websites.

2) Assessment and reporting: This includes special reporting from HEIs. In this regard, the following indicator has been analysed:

Sustainability plans. For this information, a search was done on the website of each university and the sustainability section of the website was consulted. All projects were listed on the corresponding section.

3) Campus operations include sustainability on campus (e.g. setting and infrastructure, waste, etc.).

[38] Purpose of Greenmetric ranking extracted from http://greenmetric.ui.ac.id/what-is-greenmetric/ accessed 5 January 2019.

-Green campus and green offices. This information was also checked on the websites of the universities. Only HEIs explicitly indicating this information were considered.

3.2. Field delineation: Search strategy and data extraction

The delineation of a field is crucial for decision-support studies: It allows us to understand which actors are involved (institutions, countries, etc.) and analyse the dynamics of a scientific field (output; patterns of collaboration; impact and collaboration). Sustainability has gained interest over time in the scientific community, leading to it becoming a multidisciplinary topic. That is, the field of sustainability involves a wide variety of fields and approaches. Furthermore, it can be considered a transdisciplinary topic, since it crosses many disciplinary boundaries, creating a whole, a holistic approach. It is the combination of interdisciplinarity with participatory research (non-academic actors can participate in the process to reach a common goal).[39] Considering the importance of this topic, the study aimed to propose a delineation procedure to retrieve scientific datasets on sustainability, by considering the three main pillars (environmental, social and economic). The methodology consists of using a WoS category to define environmental sustainability and using research areas clustered by the CWTS WoS publication-level classification system (Waltman and Van Eck, 2012) for the identification of social and economic sustainability. Their delineation has been tested with different tests: a) content analysis and b) golden figures. On the other hand, a delineation procedure for SDGs is proposed. The main goal is to identify the documents explicitly mentioned this research and consider the role of HEIs.

3.2.1. Sustainability delineation

One of the main difficulties of bibliometric analysis is how to retrieve from a database the relevant information for an object of study. International databases such as WoS usually adopt classification by areas, subareas or scientific disciplines with criteria that have been broadly criticized (Ggruz and Schubert, 2003). A problem of research classification arises within interdisciplinary fields, due to the fact that it is critical to provide a balanced representation of growth areas, the delimitation of which is considered a challenge in bibliometrics (Zipp, 2011). This difficulty can be variously explained: The diversity of these fields that encompass sub-areas makes capturing the whole landscape of study impossible (Zitt and Bassecoulard, 2006). In the age of academic globalization, where knowledge crosses boundaries and “new research areas emerge in line with technological development and global challenges” (Degn, Mejlgaard and Schneider, 2019), is crucial our understanding to research areas. With this aim, in this section makes a methodological contribution to the delimitation on an interdisciplinary field, in this case, sustainability. By searching “sustainability” (“sustainab*”) across the databases of WoS, one can appreciate the evolution of this concept, denoting that scientific interest in it has grown exponentially over time (Figure 3).

[39] Information on transdisciplinary research extracted from the following website: https://blogs.lt.vt.edu/grad5104/multiintertrans-disciplinary-whats-the-difference/ accessed 1 November 2019.

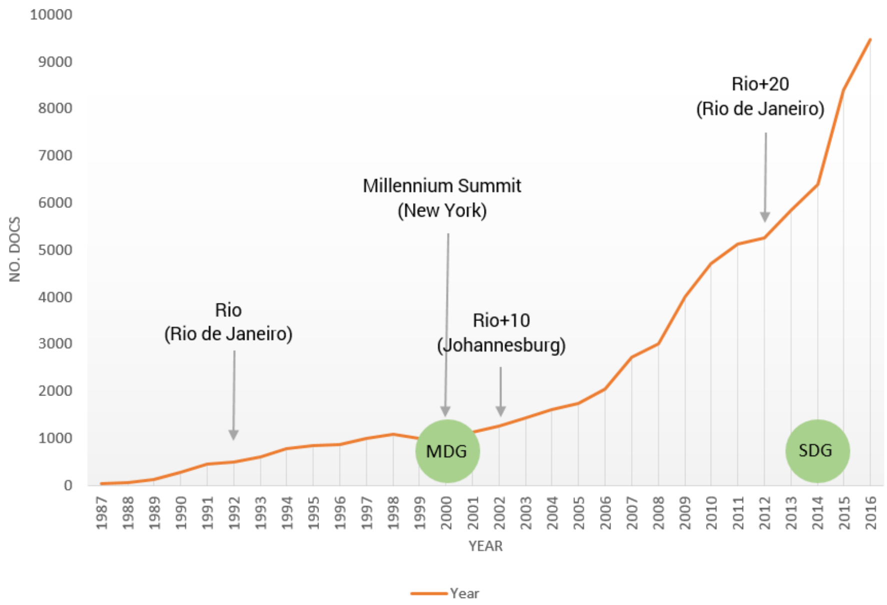


Figure 3. Evolution of the term "sustainability" in the WoS. Search in title field ("sustainab*") in the SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC databases without temporal limitation.

Source: Elaborated by the author using data from the WoS (Clarivate Analytics, 2019).

Moreover, the term "sustainability" has been checked in a publication-level classification system of scientific study (Waltman and Van Eck, 2012). This classification works at the level of individual classifications and covers around 10 million publications. Its methodology is based on an optimization algorithm inspired by Rotta and Noack (2011) which produces hierarchical classification systems. Basically, there are three levels of classification: level 1 consists of 20 research areas (linked to the five main fields) with an average number of publications per research area of about 470,000; label 2 consists of 672 research areas (related to 252 journal subject categories), with clusters that vary from 5,000 to 48,000 publications; label 3 is composed by 22,412 research areas (4,535 micro-level fields), with an average of 422 publications per cluster. On this system, when a publication belongs "to more than one main field, the publication is assigned fractionally to each of the fields". Regarding its structure, "each publication belongs to a single research area at the lowest level; this research area belongs to a single area at the second-lowest level, and so on". Moreover, labels are assigned to each research area in the system based on the extraction of suitable terms from the titles and abstracts of the publications. Figure 4 shows the location and distribution of the concept of sustainability on the map of different disciplines, according to this classification. The size and colour (i.e. yellow indicates a higher percentage) of the nodes indicates the percentage of sustainability documents in the micro-level fields cluster, the distance between two nodes, and the relatedness of two-micro-level fields (determined by citation relations). Sustainability has a presence in all areas, with more presence in areas such as the social sciences and humanities or life and earth sciences, but less in areas such as biomedical and health sciences, denoting its multidisciplinary character (Figure 4).

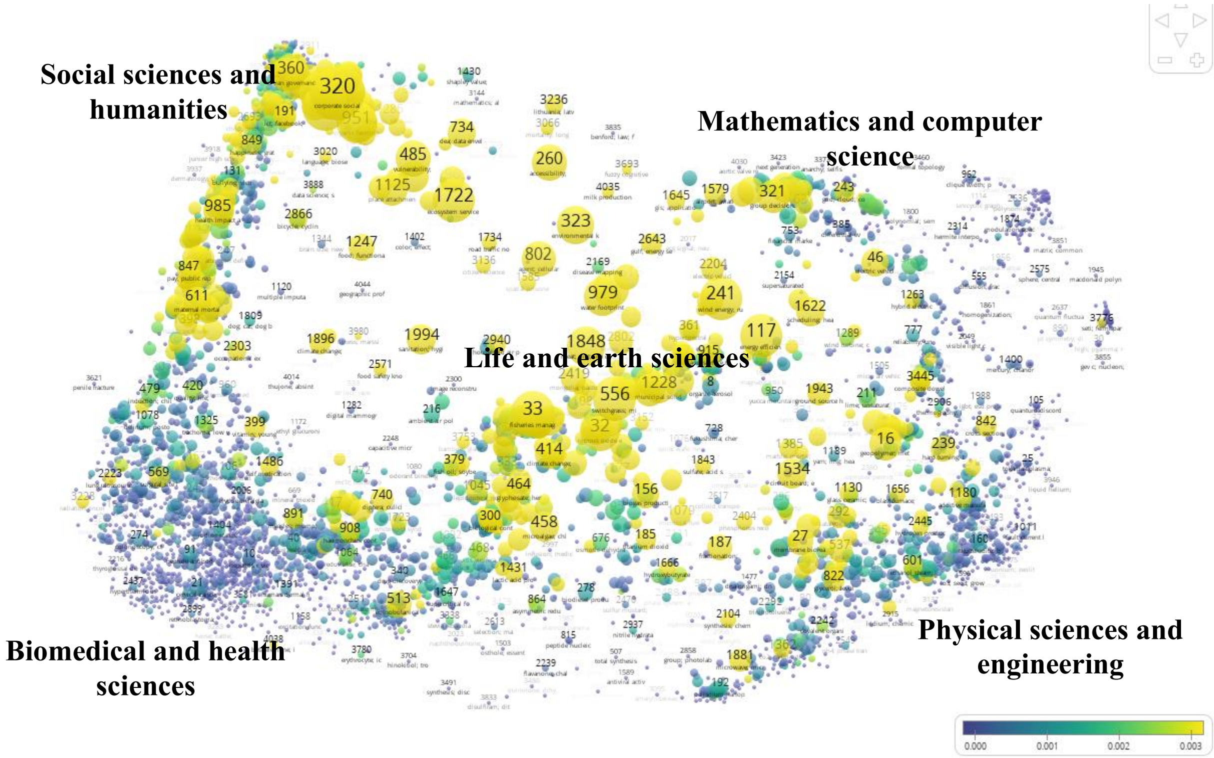


Figure 4. Sustainability publications distribution searched in title or abstract (*n* = 44,308 documents; 518 clusters) in the CWTS WoS publication-level classification system.
Source: Elaborated by the author through the in-house CWTS database.

Considering the importance of sustainability and the primary pillars (environmental, social and economic) for solving the societal challenges of the current century, a delineation procedure is proposed. The methodology is summarized in Figure 5. In this regard for environmental sustainability, a WoS category recently created, namely green and sustainable science and technology, has been used: the relation of this category to environmental sustainability has been tested by keyword content analysis in previous studies (Pandiella-Dominique et al., 2018). By matching the UT (Unique Article Identifier) retrieved previously from this WoS category using the LEMI research group techniques with the CWTS database, the final dataset includes 75,216 documents from 2008 to 2017.

Another common method of field delineation is use of journals, authors or keywords (or search strings). Search strings can be used to target different elements of publications, such as title, abstract or keywords. For instance, according to previous studies, the title of the publication is the most important for stating the intent of a publication and is constructed to attract the attention of the readers (Noyons, 1999).

However, this fact is problematic for interdisciplinary research. For social and economic sustainability pillars, another strategy has been proposed in this dissertation. The approach is based on identifying a core of documents and expanding it based on citation relations (seed+expand methodology), with the CWTS WoS publication-level classification system. For that purpose, a query with "social sustainab*" and "economic sustainab*" has been checked in the in-house WoS database on title, abstract and keywords. The main purpose of this check was to locate the micro-level field clusters in which these "core" documents are located and their relatedness to the rest of the documents in the cluster, in order to retrieve these documents and complement the environmental dataset. With that procedure, 10 clusters have been selected and checked with a validation procedure described below: These clusters constitutes the final dataset of social, environmental and economic sustainability.

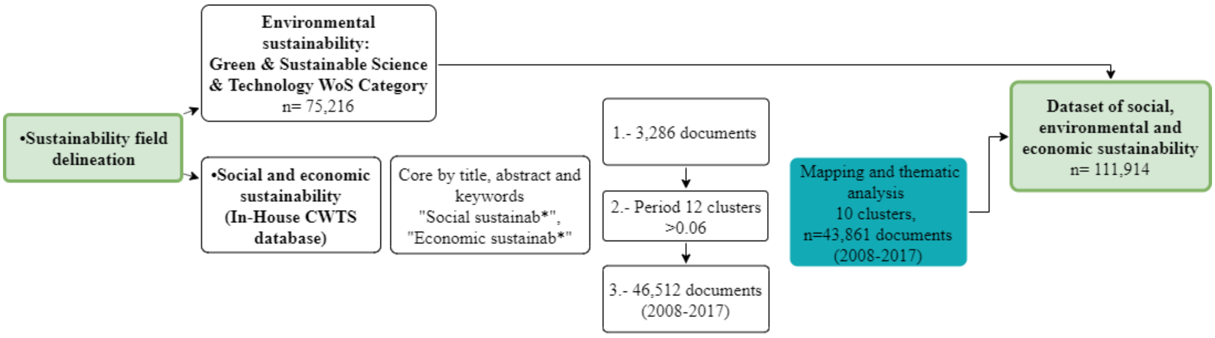


Figure 5. Search strategy followed for identifying the social, economic and environmental sustainability.
Source: Elaborated by the author.

3.2.1.1. Validation procedure

In the core, 3,286 documents were identified as related to social and economic sustainability. These documents were located in 12 clusters in the publication level-classification system (see Table 4) with at least 0.7% of documents in the clusters. The number of documents of these clusters is 59,130. The number of the cluster is assigned in the CWTS publication level classification system. Keywords on this clusters are assigned according to an algorithm that uses the most representative terms from the titles and abstracts of these papers, leading sometimes to unambiguous labels.[40] Table 4 lists the output of the cluster (P) and the documents related to the core identified.

Table 4. List of Clusters of the CWTS publication-level classification system

No. cluster	*Keywords*	*P*	*Docs related to the core*

[40] Information on the labels available at the following CWTS blog: https://leidenmadtrics.nl/articles/the-pain-of-labeling-things?fbclid=IwAR2Kxyj388FOUbNTo0MX5eFIW6Xfk5UY-yYFUHbnt-BEoFen1IbIkNGqV7I Accessed 12 November 2019.

1722	“ecosystem service; degrowth; natural capital; ecological economic; trade off”	4747	134
951	“organic farming; rurality; local food; multifunctionality; Scotland”	7743	216
3618	“sustainable development; forest management; state forest; damage; Vojvodina”	666	18
556	“switchgrass; miscanthus; biomass production; sweet sorghum; biofuel“	10516	120
2775	“fair trade; forest certification; global governance; wood; forest stewardship council“	2034	23
320	“CSR; environmental performance; environmental management system; sustainable supply chain management“	12825	136
1848	“meat; diet; life cycle impact assessment; wheat production; meat consumption“	4337	37
3798	“dairy animal; Erzurum province; buffalo; Saudi Arabia; theatre“	489	4
1124	“water governance; integrated water resources management (IWRM); adaptive management; water framework directive“	6919	54
3744	“light pollution; edible bird; nest; artificial light; night“	530	4
2163	“Bangladesh; periphyton; biofloc; life cycle assessment; artificial substrate“	3457	25
1675	“environmental education; higher education; sustainable consumption; planned behaviour; university“	4867	35

Source: Elaborated by the author through the in-house CWTS database.

The next step would be to check its relatedness to the topic. With that aim, different validation procedures were considered:

- 1) *Title and abstract relatedness.* Checking the titles and abstracts of the publications located in the abstract. The documents were ranked by the frequency of citations. However, considering the total number of documents on each cluster, only top-cited documents were checked.

- 2) *Thematic analysis.* For this point, a content analysis based on a keyword co-occurrence map and frequency of terms based on the noun phrases developed in the enhanced CWTS WoS was held. Based on its content, from 12 clusters, two were discarded (numbering 3,744 and 2,163), and 10 were finally selected (Figure 6).

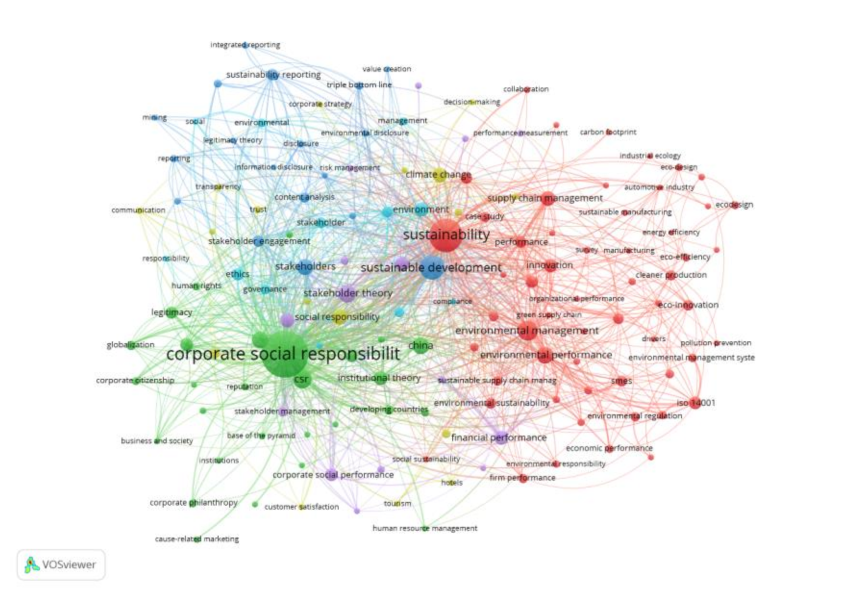
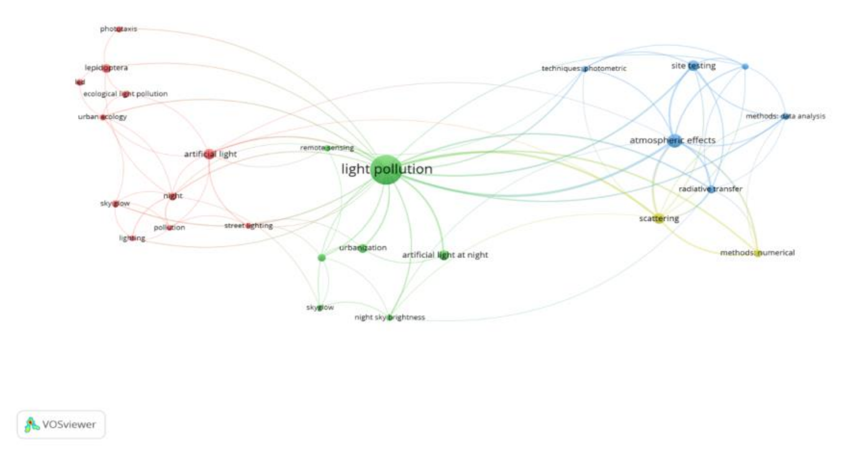
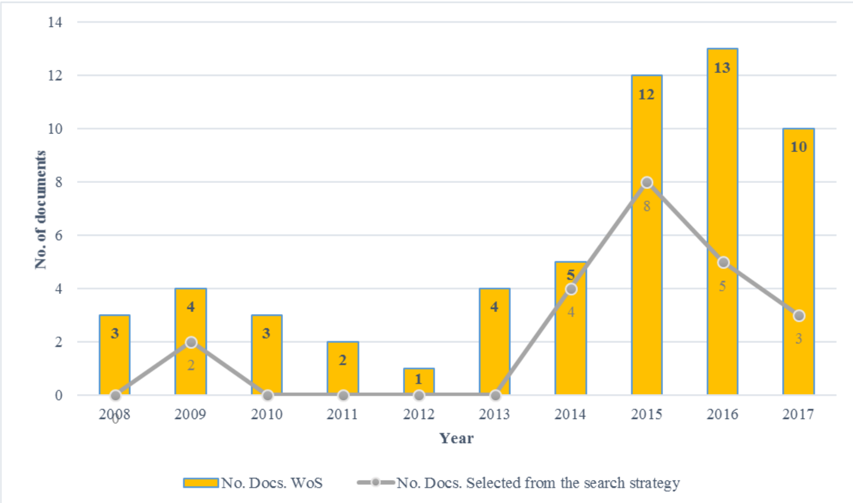
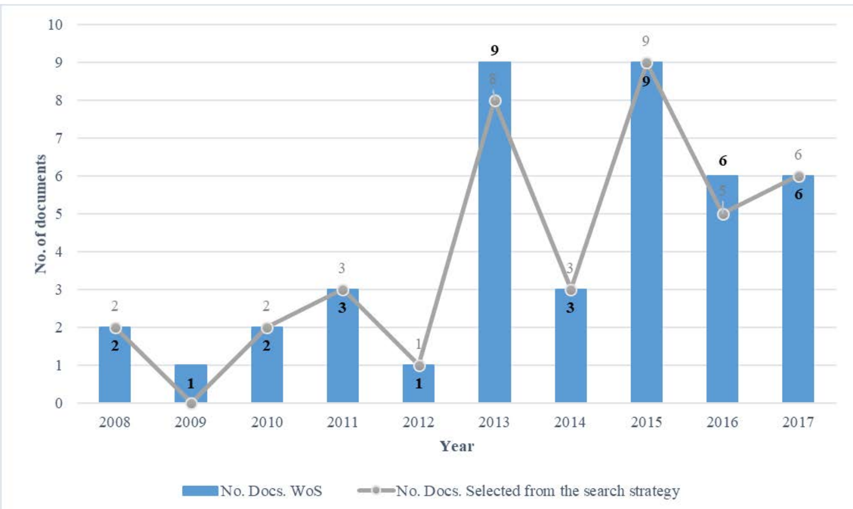
<table>
<tr><th></th><th>Keyword co-occurrence map</th><th>Frequency of non-phrases</th></tr>
<tr><td>a</td><td>
</td><td>
<table>
<tr><th>np</th><th>Frequency</th></tr>
<tr><td>corporate social responsibility</td><td>1407</td></tr>
<tr><td>role</td><td>456</td></tr>
<tr><td>sustainability</td><td>424</td></tr>
<tr><td>evidence</td><td>384</td></tr>
<tr><td>impact</td><td>380</td></tr>
<tr><td>case</td><td>343</td></tr>
<tr><td>effect</td><td>332</td></tr>
</table>
</td></tr>
<tr><td>b</td><td>
</td><td>
<table>
<tr><th>np</th><th>Frequency</th></tr>
<tr><td>light pollution</td><td>57</td></tr>
<tr><td>nest</td><td>41</td></tr>
<tr><td>artificial light</td><td>40</td></tr>
<tr><td>edible bird</td><td>40</td></tr>
<tr><td>effect</td><td>34</td></tr>
<tr><td>night</td><td>33</td></tr>
<tr><td>impact</td><td>17</td></tr>
<tr><td>light</td><td>13</td></tr>
<tr><td>influence</td><td>8</td></tr>
<tr><td>light source</td><td>8</td></tr>
</table>
</td></tr>
</table>

Figure 6. Example of keyword co-occurrence map of two clusters (320 and 3,744). The first one was accepted and the second was discarded.
Source: Elaborated by the author through the in-house CWTS database.

3) "Golden" figures. This validation point consists of checking an institution, an author or group of authors specialized on the field and the documents selected by the search strategy to determine whether their papers (or at least, a percentage of scientific output) are included. Considering that an institution was found specialized in social and economic sustainability, three well-known authors having published on these topics were considered for testing is validity. A profile of the authors is summarized below:

- Author 1: Senior professor of a university of applied sciences in United Kingdom and Germany. This researcher is specialized on SD, climate change, water or energy and has several sustainability-related projects.
- Author 2: Full Professor at the Faculty of Engineering and Sustainable Development in Sweden. This researcher does research in corporate sustainability, ESD, assessment and reporting, collaboration, and organisational change management, among other things.
- Author 3: Associate professor in a biology department, coordinator of a climate change and biodiversity unit and member of the Research Centre for Environmental and Marine Studies in Portugal. The topics of this researcher are HEIs and sustainability and education for sustainable development.

Figure 7 shows the scientific output evolution of the three authors in the period selected in this study (2008–2017). Moreover, the number of documents retrieved within the search strategy from each one of the authors is indicated. The percentage of documents collected based on the search strategy is 38.6% for the total scientific output of the first author, 92.85% for the second, and 18.75% for the third.

Author number	Scientific output evolution
Author 1	
Author 2	

Author 3

Figure 7. Scientific output of three authors.

Source: Own elaboration through WoS (Clarivate Analytics, 2019).

- 4) Thematic "variability": Content topics were analysed by a keyword co-occurrence maps in two phases, namely before and after the expansion, to observe the variability of topics. The first map is based only on the "Green and sustainable science and technology" subject category dataset. The great majority of the terms are related to the environment pillar, as is also defined in previous studies.

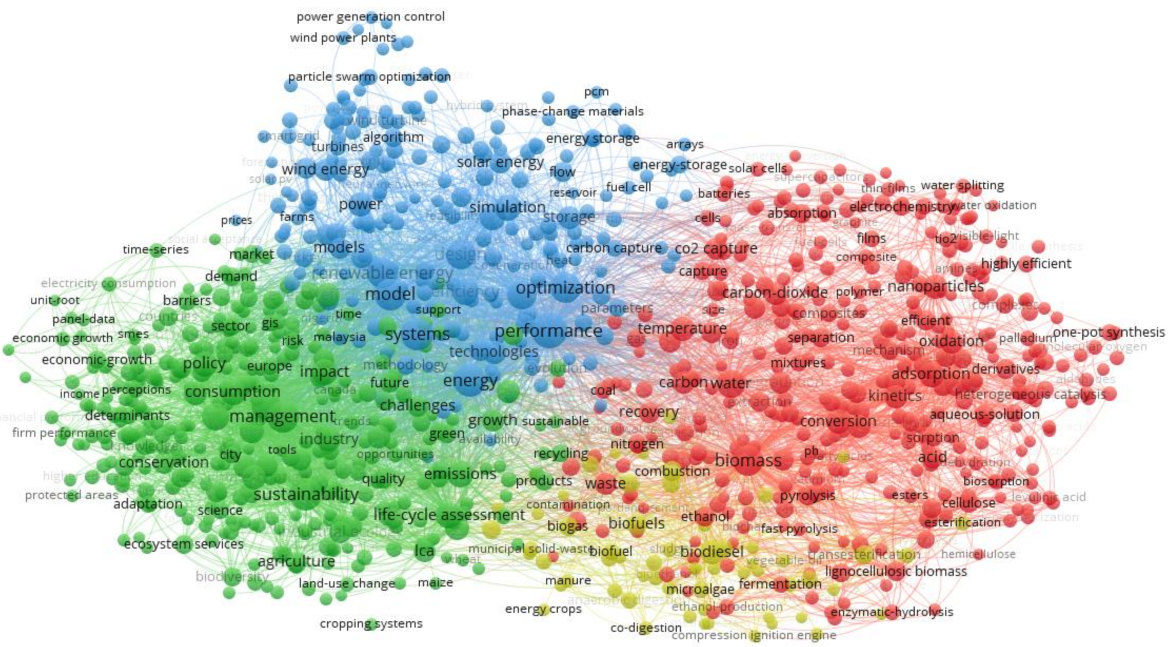


Figure 8. Co-occurrence map by keywords (>30 keywords) in the green science and technology WoS category (n = 75,216).

Source: Own elaboration through the in-house CWTS database.

However, when the new documents from the cluster publication level about social and economic sustainability are included (n = 111,914 documents), new terms related to these pillars appear on the map (red circle). For instance, governance, CSR, social learning, agriculture or urban SD appeared, among other things, denoting the inclusion of these concepts (Figure 9).

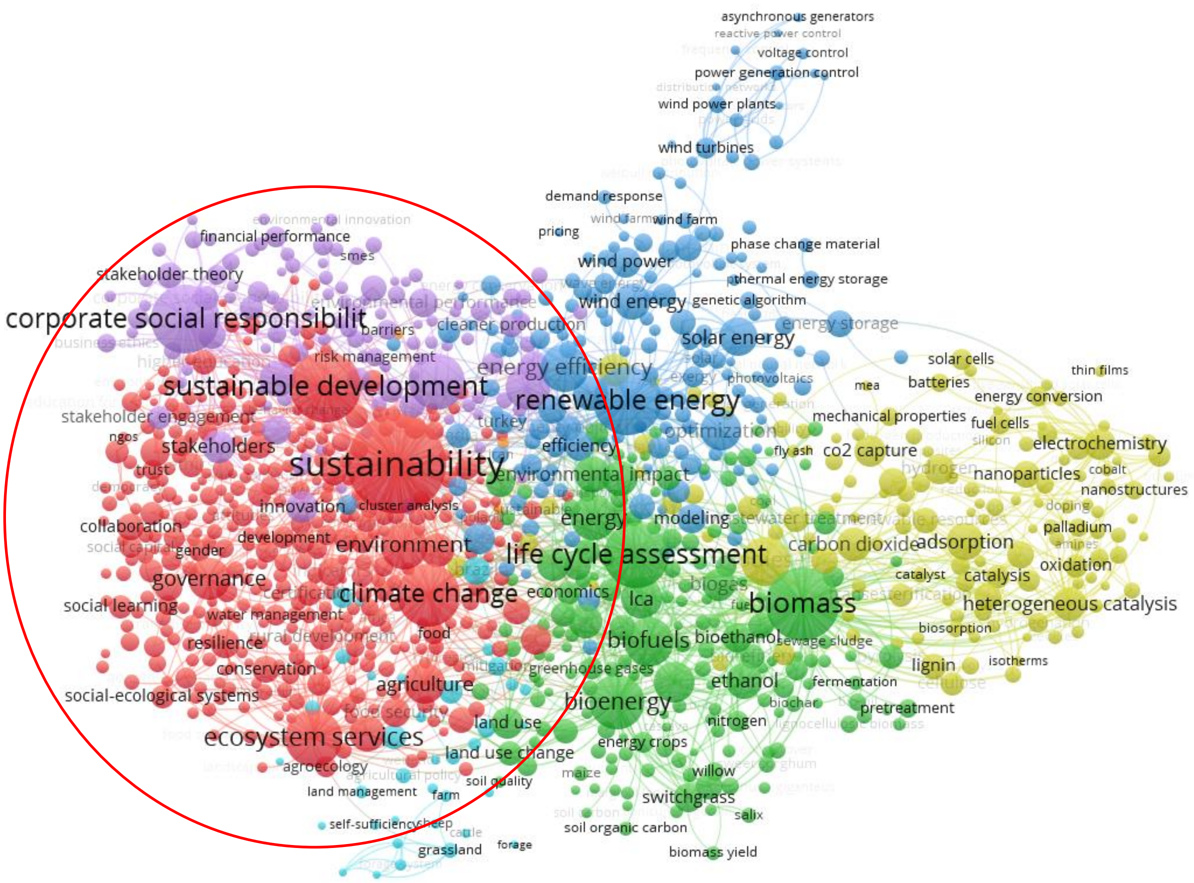


Figure 9. Co-occurrence map of the economic, social and environmental sustainability by keywords (>30 keywords) n = 111,914.

Source: Own elaboration through the in-house CWTS database.

In addition, other methodologies were tried. For instance, the following journals related to the field were considered as a "validation strategy": *Sustainability Science* (n = 565); *Journal of Cleaner Production* (n = 13,575); *International Journal of Sustainability in Higher Education* (n = 469); *Journal of Sustainable Tourism* (n = 860). In this regard, these journals were checked into the publication-level classification. However, due to its disciplinary nature, none of these journals was considered valid enough to serve as a validation tool.

3.2.2. Delineation of SDGs

A bibliometric approach was adopted as a research methodology in order to locate existing relevant peer-reviewed studies based on SDGs and MDGs research (M&SDG). This search strategy was executed independently of the previous one, to locate the documents related only to M&SDG and check the role of HEIs. Within the scope of the research methodology developed, the following steps were followed: (i) formulation of a search strategy of the core; (ii) expansion of the dataset based on direct citations (cited and citing documents); (iii) scientific output retrieval and information processing; and (iv) establishment of bibliometric indicators (Figure 10).

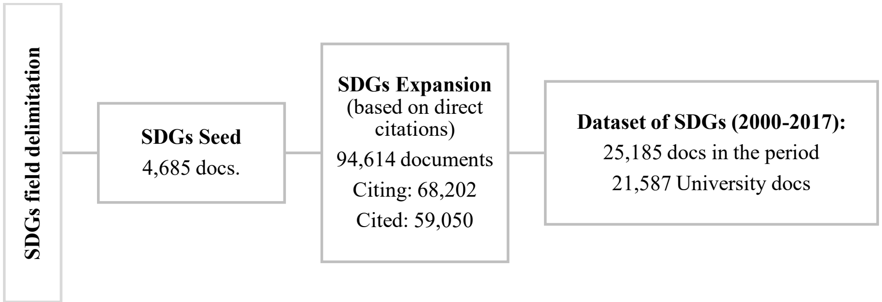


Figure 10. Methodology followed for delineating M&SDG on this study.
Source: elaborated by the author.

In the first step, we designed a search strategy composed of the following concepts in title, abstract and keywords (author and paper keywords):

“Millennium Development Goal*” OR

“Millennium Goal*” OR

“Sustainable Development Goal*”

The search strategy above was run in the WoS CWTS in-house database without any temporal restriction. A total of 4,685 documents were collected. These are considered as the *core* set of documents of this research. In a second step, the set of their direct citations (DC) with cited (n = 68,202) and citing (n = 59,050) documents were searched as an expansion (n = 119,941 unique documents). From this, only documents with at least one signature of HEIs or Research Centers (RC) were considered (n = 21,587) from 2000 to 2017. This period was considered because it corresponds with the launch of the MDGs in 2000. A second expansion based on DC was considered; however, this second approach led to results not entirely related to SDGs, creating noise in the dataset. For the establishment of this dataset, affiliations related to HEIs according to CWTS normalization were considered.

Notably, a discrepancy exists between the research on this topic (that mentions these terms explicitly) and all the research done on this topic (e.g., maybe an institution was doing research related to a topic like malaria previous to the official launch of the different goals, but was not tagged as SDG3 in the paper). However, separating these perspectives is impossible, and the dataset (on the second option) would be very limited in extent. As a result, this work focusses on the “discourse of sustainability” about how this topic has been constructed in the research by HEIs and RC.

3.2.2.1. Creation of an ontology SDGs-based

An ontology with 4,122 terms has been created (Annex 1). This ontology includes keywords related to each SDG, based on the United Nations description (e.g. "poverty" was classified into to "SDG1", "sanitation" into "SDG6") (United Nations, 2019), as well as a manual-supervision of the keywords located on the seed defined in Section 3.2.2 and its consequent extension. Moreover, certain terms have been included from Auroras' project queries.[41] The different goals have been classified into the noun phrases from the title and abstract from each paper from the in-house CWTS database, as well as the authors and paper keywords using the ontology.

3.2.3. Green patents search strategy

In order to analyse technological activity, all green patent applications were identified, as well as other documentary typologies such as utility models in Spain, in the period analysed on this study. For this purpose, they were selected using the criterion of the earliest date of application ("oldest priority"), as well as specifying that they had Spanish priority, that is, that they had been applied for through the national route. The data were obtained through a search strategy in the GPI of the database of the EPO (2019), in which the so-called green patents were delimited by searching through their type of International Patent Classification (IPC, whose codes are detailed in the WIPO inventory (2016). They are mainly classified into seven groups: "alternative energy production (1), transport (2), energy conservation (3), waste management (4), agriculture and forestry (5), administrative, regulatory or design aspects (6) and nuclear power generation (7)" (WIPO, 2016).

3.3. Data treatment

3.3.1. Information and processing

Once the documents related to the field were identified, the following procedure was the treatment and procedure of the data. Microsoft SQL Server Management was used to connect to the in-house version of WoS Core Collection database hosted at CWTS. This database includes WoS but also enhancements (e.g. noun phrases assigned to the title and abstract of each document). Moreover, the CWTS address database has been used, including the normalized affiliations' of each document. Fourteen types of organization are identified in Table 5.

Table 5. Organizations' Affiliations Normalized in the CWTS Address Database

Organisation type	***Abbreviation***
Federal university	F
University	U
University campus	UC

[41] Information of the Project available at https://aurora-network.global/project/sdg-analysis-bibliometrics-relevance/ accessed 5 January 2019.

Health science centres	HS
Teaching organisation	E
Research organisation	R
Hospital group	HG
Hospital	H
Company	C
Governmental institution	G
Funding organisation	FO
Funding channel (programme)	FC
Other	O
Ambiguous	A

Source: Information from the CWTS research group.

In order to determine the HEIs and research centres, federal university, university, university campus and research organization were considered.

The Altmetric database has also been used. This database includes the data from Altmetric.com (updated until October 2017) in the relational model developed at CWTS.

A personal database was created in the server, in order to store all the information (see Figure 11).

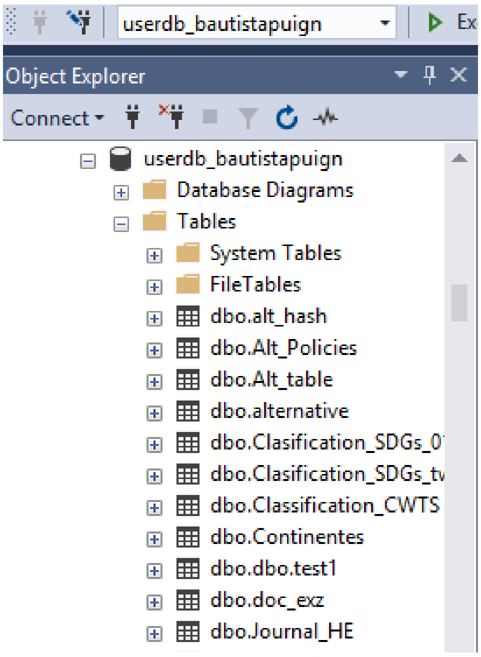


Figure 11. Screenshot of the personal database in server. Access with Microsoft SQL Server Management Studio.

Source: Screenshot from the CWTS database.

For extracting all the information, SQL queries were done to the different databases. On this framework, Transact-SQL (T-SQL) was used and is applied in "SQL Server, Azure SQL Database or Azure SQL Data Warehouse".[42] This warehouse relies on a standardized computer language, originally developed by IBM to search, alter and define relational databases using declarative sentences. The structure of this language is as follows:

> "SELECT *select_list* [INTO *new_table*]
> [FROM *table_source*] [WHERE *search_condition*]
> [GROUP BY *group_by_expression*]
> [HAVING *search_condition*]
> [ORDER BY *order_expression* [ASC | DESC]]"

It presents some differences from other SQL languages (e.g. PostgreSQL, MySQL and Oracle). For instance, this language does not support natural joins (such as "natural left join") or certain functions (e.g. timestamp, localtimestamp); however, it offers other possibilities (e.g. SQL transact offers IDENTITY as a column property for automatic key generation).

The next step of a scientometric analysis is related to quantitative processing, applying procedures for obtaining bibliometric indicators, the use of statistical methods for the analysis and visualization (co-occurrence maps, etc.).

3.3.2. Software used

The processing of the obtained information was performed with specific software for each of the tasks. For the creation of the relational database and the queries to the database, Microsoft SQL Server Management was used. On the other hand, for the statistical calculations obtained with the indicators, Excel, Xlstat, SPSS were used. The mathematical models were framed into MATLAB, and the performance of this models were calculated through R. For the social network analysis, free access software was used (VOSviewer, CiteSpace).

3.4. Bibliometric indicators

As indicated in the literature review of bibliometric or scientometric indicators, the quantitative-scientometric analysis of science is based on obtaining and assessing indicators of science and technology. These indicators are obtained from the documents under study, and the analysis of their characteristics is mainly based on the use of statistical techniques. Scientometric indicators can be classified into one-dimensional indicators and multidimensional indicators. The presentation of the results of this research is based on the type of indicator and according to this indicator classification.

[42] Information extracted from https://docs.microsoft.com/es-es/sql/t-sql/queries/select-transact-sql?view=sql-server-2017.

3.4.1. Unidimensional indicators

They have been grouped into those related to production, collaboration, and the impact of scientific production. Moreover, technological indicators and a section dedicated to mathematical indicators are presented. Within each grouping, the following sorting has been established based on the level of aggregation, from a general overview descending to the roles of HEIs. Table 6 summarizes the unidimensional and connexionist indicators catalogue that is calculated to achieve the purpose proposed for this dissertation. Unidimensional indicators are more closely related to a descriptive analysis (e.g. quantification of publications), and multidimensional indicators have made multivariable statistical techniques available to bibliometrics (e.g. content analysis, science maps) (García-Zorita, 2000).

Table 6. Table with Unidimensional Indicators Used on This Dissertation

Unidimensional indicators	
Dimension	***Indicator***
4.1.1. Scientific output	-4.1.1.1. Annual research output: Number of research output and evolution of the number of documents published in the WoS database in the period analysed on this topic. Growth rates (interannual growth rate) and cumulative average growth rate (CAGR) (percentage of increase in production in a given year with respect to base year and average period increase) is calculated (also to the different indicators). This information is presented as a general overview and by HEI. - 4.1.1.2. Documental typology by publication. This typology includes a description of the different typologies of the dataset considered. - 4.1.1.3. Scientific output by countries: research output, by absolute values and activity index (AI) calculated. - 4.1.1.4. Scientific output by institutions: research output, by absolute values and AI. A specific chapter focusses on the role of HEIs. - 4.1.1.5. Subject categories. Analysis of the WoS categories in which the research output is classified. - 4.4.1.6. Journals: List of the journals in which the documents are published. - 4.4.1.7. Identification of elite authors according to Price and Yablonsky's index.
4.1.2. Collaboration	- 4.1.2.1. Co-authorship: Number of authors by documents collected in the sustainability area. This information is calculated by country (4.1.2.1.1.). - 4.1.2.2. Patterns of collaboration, percentage and evolution of documents without collaboration (only signed by one institution), national

	collaboration (signed for more than one institution) and international collaboration (signed from institutions of two or more countries).
4.1.3. Impact and visibility	- 4.1.3.1. Citation analysis: number of citations and self-citations of the documents. - 4.1.3.2. Documents in the first-quartile (1Q) and top 3: Evolution of the absolute number and percentage of documents of 1Q documents and top 3 documents
4.1.4. Thematic analysis	- 4.1.4.1. Thematic analysis: Frequency of keywords and top keywords with the strongest citation bursts. Horizontal timeline of research specialities.
4.1.5. Acknowledgments information	- 4.1.5.1. Evolution of documents with funding acknowledgments evolution over the period. Evolution of funding acknowledgments through the period and principal funders of this research.
4.1.6. Technological	- 4.1.6.1. Evolution of green patents in HEIs. Number of patents and evolution of time. - 4.1.6.2. Evolution of green patents in Spain. Evolution of green patents in Spanish HEIs.
4.1.7. Mathematical models	Mathematical indicators applied to the following dimensions: -4.1.7.1. Scientific output. Mathematical. -4.1.7.1.1. Scientific output by countries. -4.1.7.2. Subject categories. -4.1.7.3. Collaboration. -4.1.7.4. Impact. -4.1.7.5. Performance analysis of the models.
Connexionist indicators	
4.2. Visualization mapping	Mapping is shown by considering the different items. -4.2.1. Countries -4.2.2. Institutions -4.2.3. Topics -4.2.3.1. Keywords -4.2.3.2. Subject categories -4.2.3.1. SDGs classification

Source: Prepared by the author based on the structure of the dissertation. Sections are also indicated.

Moreover, a chapter is dedicated to the commitment of HEIs towards sustainability (Table 7). The indicators used are summarized below:

Table 7. Table with Unidimensional Indicators of the Spanish HEIs

Unidimensional indicators	
Dimension	***Indicator***
4.1.8. Internationalization	- 4.1.8.1. GreenMetric ranking: participation of Spanish HEIs in GreenMetric ranking in the different editions is checked. - 4.1.8.2. Participation in projects related to sustainability: For that information, the CORDIS database for collecting FP7 and H2020 projects has been used.
4.1.9. University or governance and assessment and reporting	- 4.1.9.1. Inclusion in strategic plans and sustainability plans: it has been searched on the websites how committed are HEIs, by including "sustainability" inside their strategic plans or by having a sustainability plan/document on each university. - 4.1.9.2. Network participation: Two Spanish networks related to the topic have been considered (CRUE and REDS).
4.1.10. Campus operations	- 4.1.10.1. Green campus and green offices. This information has been checked in the website on the universities.
4.1.11. Relation analysis between variables	4.1.11. Relation calculated by the chi-square and whisker plots from the quantitative and qualitative variables.

Source: Prepared by the author based on the structure of the dissertation.

3.4.2. Multidimensional indicators

Given that sustainability is immersed in a multidimensional framework, this study could not conduct its analysis only by using simple indicators. For this purpose, multidimensional indicators that allow consideration of the different inputs or the multiple interrelations" of the scientific output on these topics are considered. The construction of these indicators is based on a group of advanced methods and statistics, known as "multivariate data analysis". Traditionally, methodologies that have been employed for representing bibliographic data include correspondence analysis, hierarchical cluster analysis, principal component analysis or multi-dimensional scaling among others). In this study, the following multidimensional analysis has been applied.

- *Correspondence analysis*. Despite that CA origins are more than 50 years in the past, the mathematician and French linguist Jean-Paul Benzécri founded modern applications of correspondence analysis in the 1960s at Rennes University (Greenacre, 2008). In this regard, correspondence analysis is a statistical technique that is used to analyse, from a graphic point of view, the dependency and independence relationships of a set of categorical variables from the data in a contingency table (also known as crosstab or cross-tabulation), which displays the multivariate frequency distribution of the variables. There are two types of correspondence analysis: simple (two dimensions) and multiple (more than two dimensions). Table 8 summarizes the indicators CA combinations conducted on this dissertation.

Table 8. Table with Unidimensional Indicators of the Spanish HEIs

Unidimensional indicators	
Dimension	***Indicator***
Multidimensional analysis	Correspondence analysis has been held into the different indicators: - 4.3.1. Countries and years. - 4.3.2. Organizations and years. - 4.3.3. WoS categories and years.

Source: Compiled by the author based on the structure of the dissertation.

3.4.3. Temporal series analysis: Application of mathematical models

The study of time series aims to analyse the evolution of a variable over time. With this analysis, the input order is very important, and its modification could suppose changing the information contained in the series. In addition, one important factor with the time series is the periodicity (e.g. annual, monthly,...) of the input series. Some components of the time series can be described as follows:

1) *Tendency.* It can be defined as a long-term change that occurs in relation to the average level, or the long-term change of the average.[43] In fact, the trend is identified with a smooth movement of the series in the long term and could be a time series with or without tendency.

2) *Variability.* A time series could be "homozygous" if its variability is constant all over the series; if it increases or decreases, it is "heteroscedastic".

3) *Seasonal effect*. Time series could have cyclic effects, meaning that the series could have a structure that repeats over and over again. When the series is non-stationary, it must be transformed by the difference between each observation with its previous observation.

However, to analyse the series, one must identify the structure that generates it, or in other words, how past observations influenced future ones (Peña, 2005). To identify this dependency, the following functions are used:

a) A simple autocorrelation function provides a linear dependence structure. For instance, for a time series z_t, the observed values are as follows:

$$z_1, z_2, \dots z_{t-2}, z_{t-1}, z_t \text{ ,}$$

where z_1 represents the first value of the time series, z_2 the second, z_t the actual value of the series, and z_{t+1} , the future value.

[43] Definition extracted from http://halweb.uc3m.es/esp/Personal/personas/jmmarin/esp/EDescrip/tema7.pdf accessed 5 March 2019.

In this regard, this function wants to obtain the correlation function, which provides a coefficient of the observations separated in a period. Their coefficients vary from −1 to 1: if the correlation is worth 0, there is no effect between the observation and its subsequent ones; if it is close to 1, there is a strong relationship, and, therefore, a positive relationship.

b) A partial autocorrelation function provides the relationship between observations separated by k delays.

In order to determine the influence of bibliometric indicators', mathematical models were used in this study. These models can be defined as follows:

- *Input-output models: Autoregressive models (AR).* These types of models are a representation of a random process that allows one to describe certain processes that vary over time, considering that there is a linear relationship with the previous values. They generalize, in this way, the idea of regression to represent linear dependency between two random variables, having a relatively long memory, since the current value is correlated with the previous ones (Peña, 2005). In the simplest case, a value at a given time depends on previous observation. The AR model is defined by the following equation:

$$y(t) = -a_1 y(t-1) \dots - a_{n_a} y(t-n_a) + e(t),$$

where a_n are the parameters of the model, n_a the polynomic order and $e(t)$ is the noise.

- *State space models*. Contrarily to input/output models, "state space models allows model systems with multiple inputs and outputs, to be more flexible for our purposes". This type of model created an origin for dynamic systems and was theorized at the end of the 19th century by H. Poincaré, considering that current behaviour is directly related to previous history or data. This "consideration is based on the idea of state variables, which are the minimum information that summarises all past information" (Domínguez et al., 2006). As well, these models make possible an understanding of not only the "input-output relationship, but the combined behaviour of all the inputs and state variables in the system, in our case the indicators inside of the system" (Ogata, 1995). As applied here, the model was defined by the following system of equations [2]:

$$\begin{cases} x_{k+1} = Gx_k + Hu_k \\ y_k = Cx_k \end{cases}, [2]$$

where x_k is the input vector (i.e. number submitted); y_k the output vector (i.e. granted); and *G, H* and *C,* matrices.

A system with "two state variables and one input the transition between states in two consecutive cycles can be expressed by the following equations" (Ogata, 1995) [3a,b]:

$$x_1(k+1) = g_{11}x_1(k) + g_{12}x_1(k+1) + h_1u(k) \text{ [3a]}$$

$$x_2(k+1) = g_{21}x_1(k) + g_{22}x_1(k+1) + h_2u(k). \text{ [3b]}$$

Or it can be expressed in a matrix notation: [4]

$$\begin{pmatrix} x_1(k+1) \\ x_2(k+1) \end{pmatrix} = \begin{pmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{pmatrix} \begin{pmatrix} x_1(k) \\ x_2(k) \end{pmatrix} + \begin{pmatrix} h_1 \\ h_2 \end{pmatrix} u(k). \quad [4]$$

With that aim, the scientific output of this institution was modelled in the different dimensions (output, subject categories, collaboration and impact), and a future trend of a three-year window was estimated. The reason for this short future range was estimated was a lack of availability of a longer time series input (10 years), making it difficult to identify a trustable future trend.

3.4.4. Data analysis and statistical tests used

With respect to the quantitative and mathematic behaviour of the scientometric analysis, statistics constitute one of the fundamentals tools for the analysis of the scientific research. In any discipline, it is necessary to establish relations between variables, presupposing a relation with the object of study. In this regard, the different analysis with tools and statistical tests in each of the chapters allows one to obtain objective information of the performance of the scientific activity of sustainability at HEIs. The different analyses carried out are described for each of the results; however, the use of the below tests can be generally highlighted.

For calculating the time series, the growth rate [1] and the cumulative average growth rate (CAGR) [5] was calculated. The equations are described below:

$$GR = \frac{(Year\ 2017 - Year\ 2000) * 100}{Year\ 2000}, \qquad [5]$$

where "Year 2017" is the value of the indicator in 2017, the most recent, and "Value 2000" is the value in 2000 (or the last year of the series to be analysed);

$$\mathrm{CAGR} = \left(\sqrt[\mathrm{n-1}]{\frac{\mathrm{X_n}}{\mathrm{X_1}}} - 1\right) \cdot 100, \qquad [6]$$

where $\mathrm{X_1}$ and $\mathrm{X_n}$ correspond respectively with the values that were obtained in the first and last period of the study. The formula is equivalent to the CAGR, which is frequently used in finance and allows one to measure average growth in time series (United Nations- ESCAP, 2015).

Moreover, an activity index (AI) is measured. The AI is defined by the following system of equations [7a, b, c, d, e]:

$$\mathbf{P} = P(\text{Sustainability dataset})_i = \textstyle\sum_{i=1}^{N} P_n, \quad [7a]$$

where P_i is the production in WoS related to SDGs identified with the search strategy of this study;

P= Production in WoS in the period (*n* = 1,926,901), [7b]
where $P_i = \sum_{i=1}^{N} P_n$, where P_i is the total production in WoS on the period. The total of P_i is 1,926,901;

$$\textbf{\% of Sust} -= \frac{P\ (\text{Sust.})}{P(WoS - \text{Sust.})}, \quad [7c]$$

where percentage of SDG is the proportion of documents related with SDGs of HEIs in the period with the total number of SDGs identified (not only HEIs and RC);

$$\textbf{\% of WoS} = \frac{P}{P(WoS)}, \quad [7d]$$

where percentage of WoS is the production of WoS on this organization with the total scientific output on WoS on the same period; and

$$\textbf{AI}\ (Sust.) = \frac{\%\ of\ \text{Sust.}}{\%\ of\ WOS}, \quad [7e]$$

where AI shows the specialization on this topic on the scientific output of sustainability.

To calculate model performance evaluation, the following tests are conducted:

- Root mean square error (RMSE) [7] is the "standard deviation of the residuals (or prediction errors) is used in forecasting or regression analysis in order to verify results". Residuals are a "measure that indicates how far from the regression line data points are; RMSE measure how spread out these residuals are from the line of best fit":[44]

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i).^2}{n}}, \ [7]$$

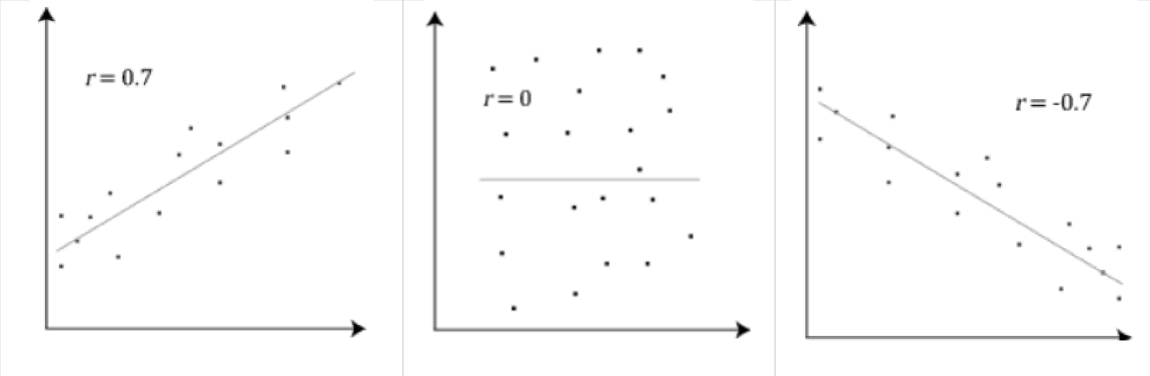
where P is the predicted value, O is the observed value, and *n* is number of times.

- The Pearson correlation coefficient (*r*) [8] is "a measure of the strength of a linear association between two variables and is denoted by a coefficient *r*: this indicates how far these points are from the line of best fit". In other words, it indicates how well the data points fit this new model:

$$r = \frac{n(\sum_{i=1}^{n} O_i \cdot P_i) - (\sum_{i=1}^{n} O_i) \cdot \sum_{i=1}^{n} P_i)}{\sqrt{(\sum_{i=1}^{n} O_i^2 - (\sum_{i=1}^{n} O_i).^2) \cdot (n \sum_{i=1}^{n} P_i^2 - (\sum_{i=1}^{n} P_i).^2)}}. \ [8]$$

The coefficients range "from +1 to −1, where 0 means there is no association between these variables, a value greater than 0 indicates a positive association and a value less than 0 a negative association" (Figure 12).

[44] Information of RMSE extracted from https://www.statisticshowto.datasciencecentral.com/rmse/ accessed 5 January 2019.



Positive correlation	No correlation	Negative correlation

Figure 12. Visual examples of positive, negative and no correlation.[45]
Source: Extracted from the source n. 45.

- Coefficient of determination (also known as R^2). This coefficient is "used to analyse how differences in one variable can be explained by a difference in a second variable". In this regard, R^2 gives the percentage variation in *y* explained by *x*-variables, and its range varies from 0 to 1. That is, 0–100% of the variation in *y* can be explained by the *x* variables:

$$R^2 = \frac{[\sum_{i=1}^{n}(O_i-\bar{O}_i)\cdot(P_i-\bar{P}_i)].^2}{\sum_{i=1}^{n}(O_i-\bar{O}_i)\cdot\sum_{i=1}^{n}(P_i-\bar{P}_i)}. \quad [5]$$

For the model performance evaluation, these predictive performances of the proposed models were calculated. Furthermore, for the time series modelled, a 95% confidence interval has been added with R software (R Core Team, 2019) by using the "loess" method on each time series. The packages used were ggplot2 (Wickham, 2016) and ggpubr (Kassambara, 2008)

[45] Extracted from https://statistics.laerd.com/statistical-guides/pearson-correlation-coefficient-statistical-guide.php accessed 5 January 2019.

Chapter IV: Results

4.1. Unidimensional indicators from sustainability dataset

4.1.1. Scientific production indicators

“Scientific activity” and “scientific production” are terms commonly used interchangeably. The scientific output of a collective is measured in terms of artefacts produced (papers, reports, etc.). The scientific activity, however also includes knowledge through non-formals channels of publication. That is, apart from scientific output, social structures for relationship between individuals that belong to institutions, or even countries, are of interest (García-Zorita, C., 2000). In this chapter, the results of the indicators of scientific activity in relation to scientific output are presented. Firstly, a general overview of the sustainability dataset is delineated in this dissertation to establish comparisons with the world production on this topic, and then, in the HEIs sphere, to analyse their contribution. This analysis is based on the strategy defined in the methodology (seed+expand) during the period 2008–2017 at different levels (years, countries, authors, institutions and topics).

4.1.1.1. Annual research output and growth rate

Figure 13 shows the research output and evolution of the number of documents published in the WoS database in the period analysed (2008–2017): sustainability dataset, environmental dataset, social and economic output, and all WoS scientific output in the period. From the total number of documents identified in the search strategy (n = 111,914) (Sustainability dataset), proceedings documents were not considered. As such, 97,876 documents were considered in the analysed period. The evolution presents an increase throughout the period, with the highest value in 2017: 18,171 documents. The growth rate arises 15.92% during this period. This rise demonstrates the evolution of this topic over time and denotes its interest in the scientific community. The coefficient of determination (R^2) is high (.95), denoting a good linear adjustment in the growth trend. Moreover, the graph the evolution of scientific output in all WoS (in red) presents a growth of 37.14% during the period.

Additionally, if we check the evolution of documents separately, by considering the Green WoS category (namely “environmental sustainability”) and the documents obtained with the clustering search strategy (namely “social and economic sustainability”), the evolution presents a different trend. Despite that environmental sustainability presents an increasing tendency over the period (20.81 of growth rate), social and economic sustainability presents a more moderate increase (8.06 of growth rate) (Figure 13).

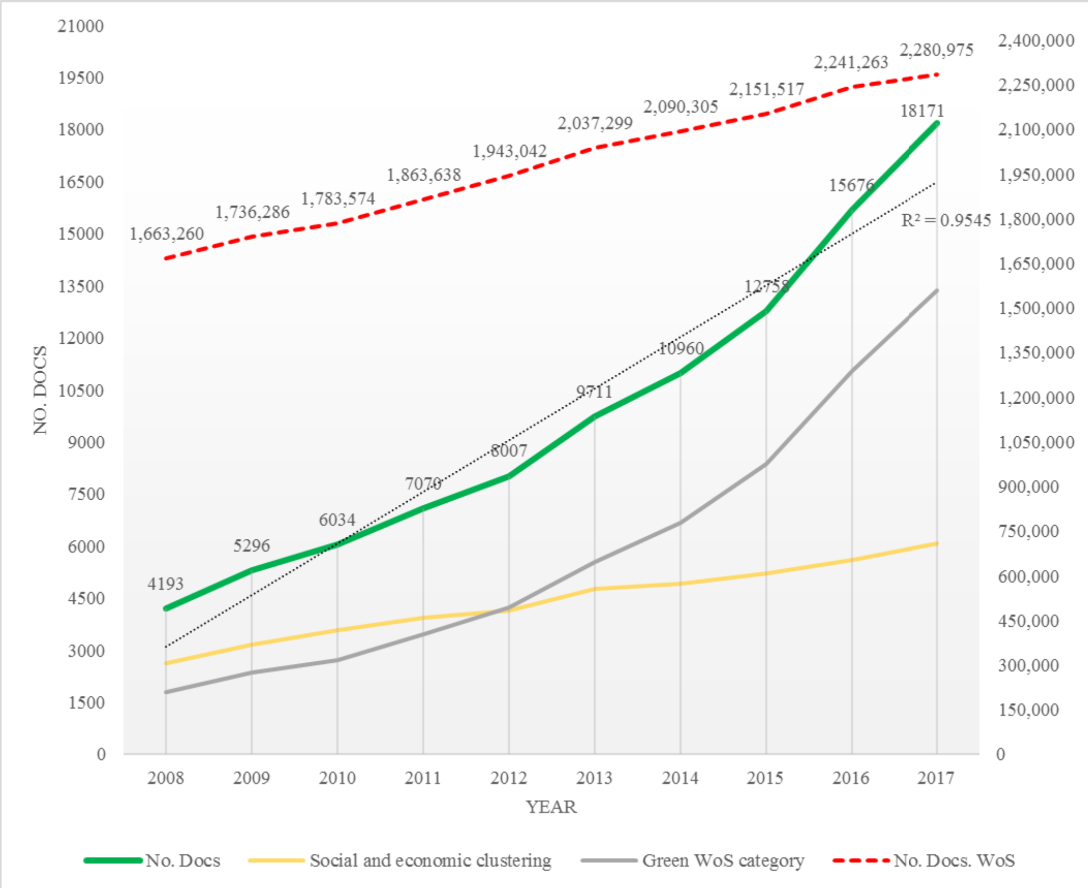


Figure 13. Evolution of the number of documents of this study (*n* = 97,876), as well as both strategies for environmental (*n* = 59,374) and social and economic sustainability (*n* = 43,861) (2008–2017). Source: Prepared by the author based on the CWTS in-house WoS database.

Once the general distribution of the data is obtained, its distribution around the countries that produce its scientific output through the analysis of the institutional addresses of the authors is analysed. The sustainability dataset with the environmental and economic and social output is henceforth considered a unified dataset. There are 183 countries involved in the scientific output for this topic. The 20 countries with the most institutions contain 76% of the world's institutions dedicated to sustainability research. The countries are ranked from more institutions to fewer, as follows: the United States, 19,663 documents (20.09%); China, 13,479 documents (13.77%); the United Kingdom, 8,833 documents (9.02%); Germany, 5,695 documents (5.82%); Australia, 5,438 documents (5.56%); Spain, 5,288 documents (5.40%); Canada, 4,966 documents (5.07%); India, 4,753 documents (4.86%); Italy, 4,385 documents (4.48%); and the Netherlands, 4,194 documents (4.29%) (Figure 14).

Table 9. Evolution of Interannual Growth Rate for the Sustainability Scientific Output and Both Strategies (Environmental; Social and Economic) in the period (2008–2017).

Year	*Total docs. (Sustainability dataset)*	*Environmental sustainability*	*Social and economic sustainability*
2008	0	0	0
2009	26.31	31.54	21.30
2010	13.94	15.70	13.21
2011	17.17	26.66	10.29
2012	13.25	22.33	5.24
2013	21.28	31.18	14.69
2014	12.86	20.70	3.03
2015	16.41	25.57	6.34
2016	22.87	32.16	7.63
2017	15.92	20.81	8.06
Growth rate	15.92	20.81	8.06
CAGR	17.78	25.06	9.85

Source: Prepared by the author based on the CWTS in-house WoS database.

4.1.1.2. Documental typology

Table 10 presents a distribution of output by documentary types. Academic articles are the predominant output type in the dataset of 84,331 documents (86.16%). Considering the documents signed by HEIs during the studied period (according to the normalization held in the CWTS in-house database), the article is even slightly higher predominant on this typology (70,672 documents, 87.14%). Proceedings papers were not considered in this study.

Table 10. Distribution of the Output by Documentary Types

	P	*% Article*	*% Review*	*% Editorial Material*	*% Letter*	*% Others*
Sustainability dataset (P)	97,876	86.16	11.29	1.16	0.46	0.93
Sustainability dataset (HEIs)	81,105	87.14	11.26	0.87	0.38	0.35

Source: Own elaboration from the CWTS in-house WoS database.

4.1.1.3. Scientific output by countries

Once the general distribution of the data is obtained, its distribution around the countries that produce its scientific output through the analysis of the institutional addresses of the authors is analysed. From now on, the sustainability dataset with the environmental and economic and social is considered as a whole dataset. There are 183 countries involved in the scientific output regarding this topic. The 20 countries with the most institutions contain 83.25% of the world's institutions dedicated to sustainability research. Countries are ranked from more institutions to fewer as follows: United States, 19,663 documents (20.09%); China, 13,479 documents (13.77%); United Kingdom, 8,833 documents (9.02%); Germany, 5,695 documents (5.82%); Australia, 5,438 documents (5.56%); Spain, 5,288 documents

(5.40%); Canada, 4,966 documents (5.07%); India, 4,753 documents (4.86%); Italy, 4,385 documents (4.48%); and the Netherlands, 4,194 documents (4.29%) (Figure 14).

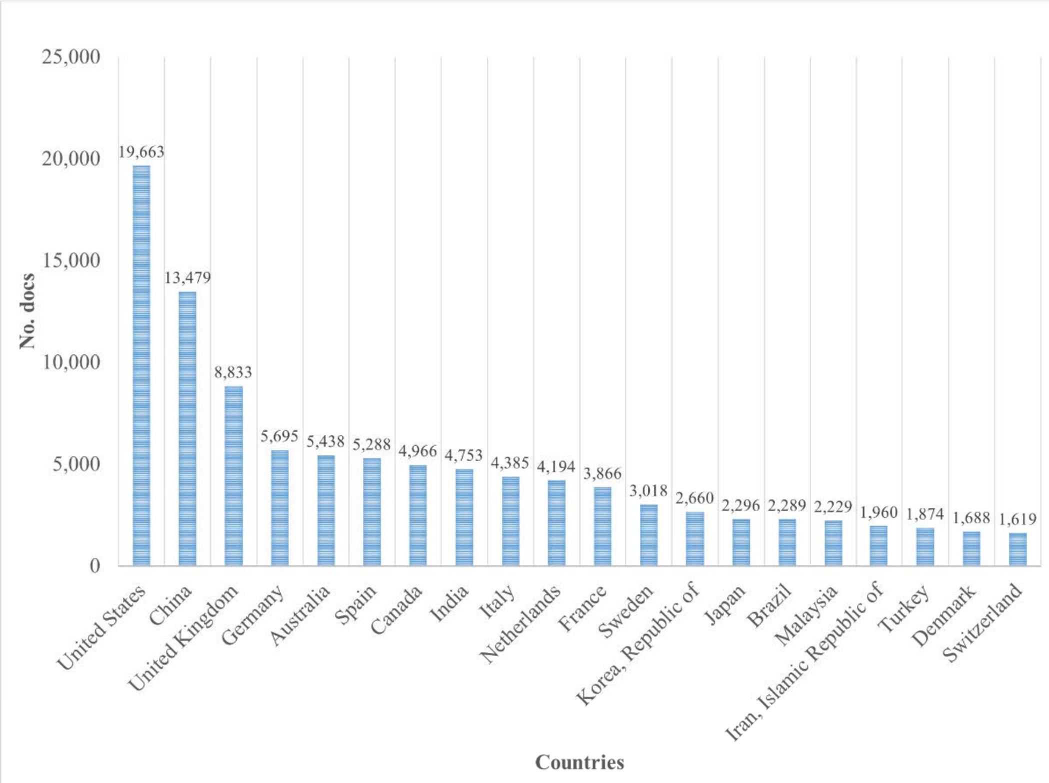


Figure 14. Top 20 countries ranked by number of documents produced in the study period (2008–2017). Source: Own elaboration from the CWTS in-house WoS database.

The results obtained from the growth rate analysis on the period (2008–2017) show that the countries which presented a major increase in the period is South Korea, at a 2075% increase; Iran, at 1911.54%; and Malaysia, at 1900%. Results from the CAGR provide a different scenario: Countries with the highest production, such as the United States or the United Kingdom, are those with the lowest growth (CAGR of 13.64% and CAGR of 13.78%, respectively). Although China is one of the main producers, it has also experienced major growth (growth rate of 1730% and CAGR of 38.13%) (Figure 15 and Table 11).

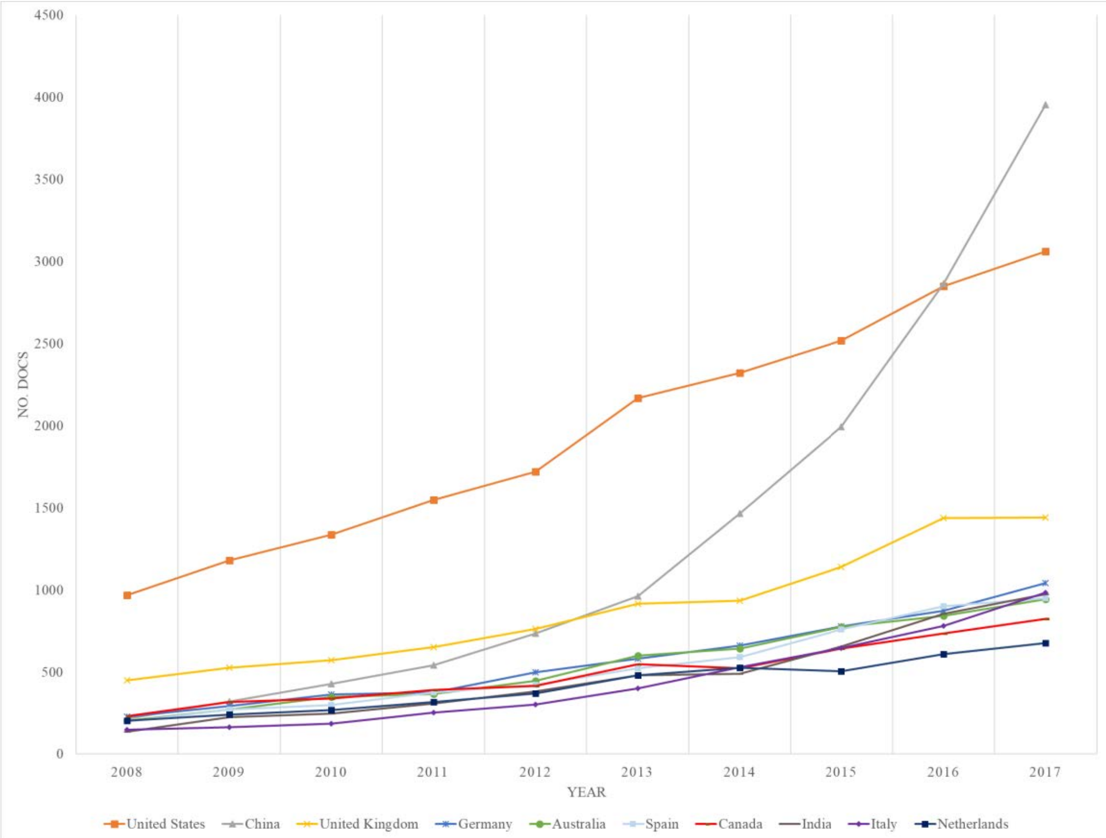


Figure 15. Evolution of scientific output from the top 10 most productive countries from 2008 to 2017.

Prepared by the author from the CWTS in-house WoS database.

Table 11. Growth Rate and Cumulative Average Growth Rate of the Top 10 First Countries (2008–2017)

Country	***Growth Rate***	***CAGR***
United States	216.12	13.64
China	1730.56	38.13
United Kingdom	220.00	13.80
Germany	356.58	18.38
Australia	360.49	18.49
Spain	382.23	19.10
Canada	257.14	15.19
India	622.22	24.57
Italy	569.39	23.52
Netherlands	229.27	14.16
France	273.60	15.77
Sweden	320.33	17.30
South Korea	2075.00	40.80
Japan	329.59	17.58
Brazil	602.74	24.19
Malaysia	1900.00	39.50
Iran	1911.54	39.58
Turkey	219.57	13.78
Denmark	469.49	21.32
Switzerland	300.00	16.65

Source: Own elaboration from the CWTS in-house WoS database.

However, this growth could be associated with the size of the country. That is, bigger countries are the main producers. To understand the specialization of each country on this topic, an AI has been developed. Figure 16 shows the distribution of documents of sustainability in all countries, as well as an AI. The AI has been calculated from countries with a scientific production at WoS higher than 500 documents. In this regard, there are countries with a high AI but with low production in sustainability. Examples of these countries include Fiji, with 41 documents in sustainability (AI of 5.96%); Mauritius, with 26 (4.75%); and Laos, with 34 (4.56%). However, other countries with a high AI have higher production. For instance, compared to the above, Malaysia has a higher number of documents (n = 2,229) and a high AI of (4.71%). Ghana has 154 documents; the Philippines, 241; the United Arab Emirates, 317; Indonesia, 334—each of these countries also present a high AI (>3.3%). At the European level, Cyprus leads with 166 documents (2.87%), followed by Finland with 1,536 (2.26%).

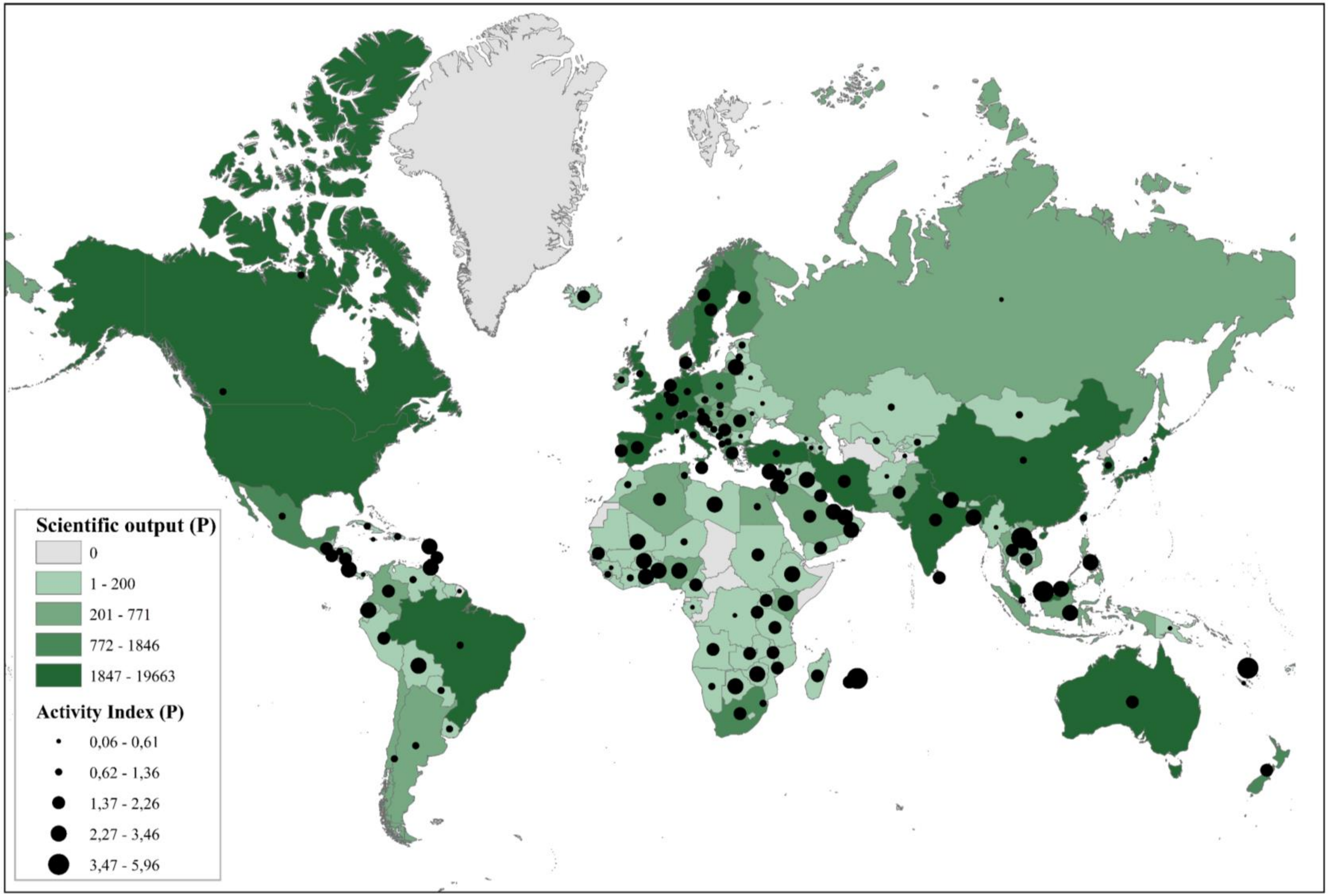


Figure 16. Distribution of scientific output and AI of sustainability by countries (2008–2017).

Source: Own elaboration from the CWTS in-house WoS database.

4.1.1.4. Scientific output by institutions

Of those considered in this study, 3,104 unique institutions have been identified during the period. Its typology has been classified considering the in-house CWTS addresses database. Affiliations are assigned to 96,454 documents (98.54%) in the database. Some organizations have two typologies (i.e. Chinese Centre for Disease Control and Prevention is classified as a research organization or governmental institution; the Dana Farber Cancer Institute, as research organization or hospital; Japan Science and Technology Agency, research organization or funding organization). As Figure 17 shows, 2,295 affiliations (73.94%) are classified as universities; 595 (19.17%) as research organizations; 124 (3.99%) as teaching organizations; and 35 (1.13%) as hospitals. Only 25 (0.81%) are classes as governmental institutions, and 18 (0.58%) are classed federal bodies universities, and less than 7 are considered affiliations, hospital groups, funding organizations, university campus, ambiguous, funding channels and companies.

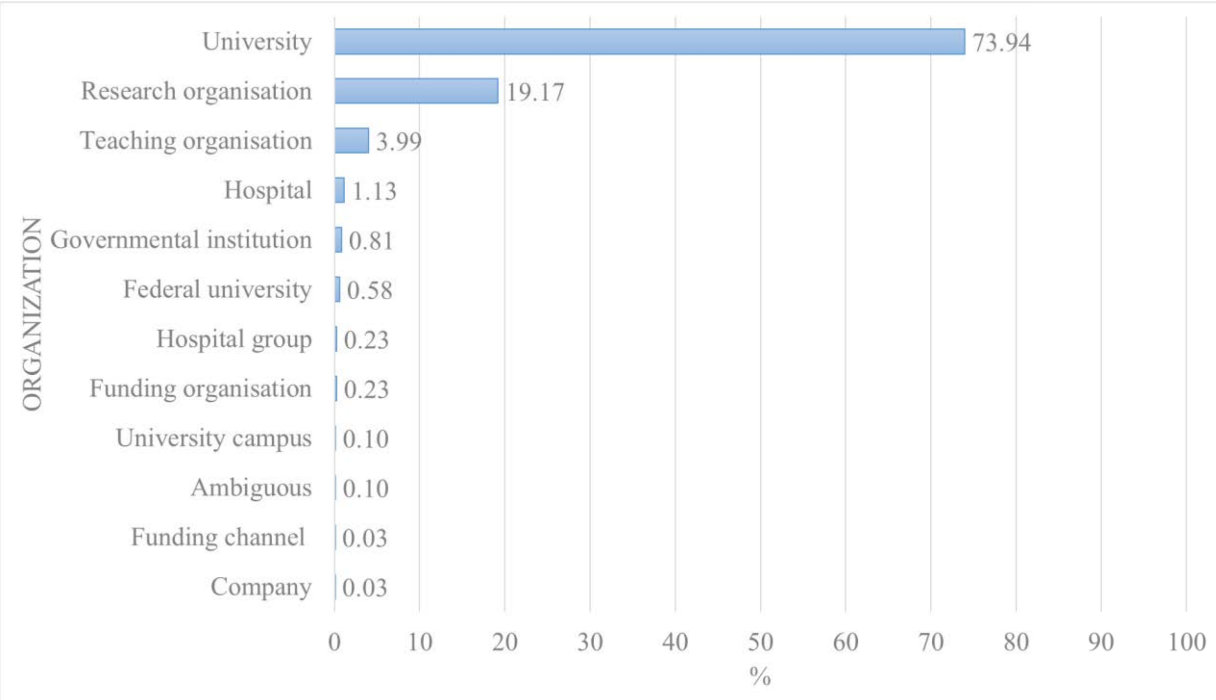


Figure 17. Profile of institutions by the organization sector according to CWTS classification. Own elaboration from the CWTS in-house WoS database.

Table 12 shows the distribution of the total number of institutions by country and organization typology. A chi-square test was applied to the contingency table of countries and institutional types. It shows a result of 1259.76 with a *p*-value of .028, denoting no relationship of dependence between the two variables. The country with the most numerous and varied organizations is the United States (467 institutions), followed by China (276 institutions) and the United Kingdom (181 institutions). From these countries, only the university sector represents a percentage higher than 70% on total number of institutions, denoting important participation in scientific output.

Table 12. Distribution of Typology of Organizations by Country on the Period (2008–2017)[46]

Country	*Teaching organization*	*Governmental organization*	*Hospital*	*Research organization*	*University*	*Total*
Albania	0	0	0	0	1	1
Algeria	1	0	0	0	27	28
Argentina	0	0	0	1	5	6
Armenia	0	0	0	0	1	1
Australia	0	0	0	1	35	36
Austria	2	0	0	15	18	35
Bangladesh	3	0	0	1	0	4
Belarus	0	0	0	0	2	2
Belgium	3	0	1	8	11	23
Bosnia and Herzegovina	0	0	0	0	1	1
Botswana	0	0	0	0	1	1
Brazil	6	2	0	13	103	126
Bulgaria	0	0	0	2	16	18
Burkina Faso	0	0	0	0	1	1
Cameroon	0	0	0	0	2	2
Canada	2	3	3	4	44	59
Chile	0	0	0	0	13	13
China	7	2	0	45	222	276
Colombia	0	0	0	0	4	4
Costa Rica	0	0	0	0	1	1
Croatia	0	0	0	1	4	5
Cuba	0	0	0	1	0	1
Cyprus	0	0	0	2	5	7
Czech Republic	2	0	1	7	19	29
Denmark	0	0	0	0	7	7
Ecuador	3	0	0	0	0	3
Egypt	0	0	0	1	14	15
Estonia	0	0	0	1	2	3
Ethiopia	0	0	0	0	1	1
Finland	0	0	0	10	15	25
France	1	0	6	28	121	171
Georgia	0	0	0	0	1	1
Germany	9	0	0	68	95	172
Ghana	0	0	0	0	3	3
Greece	2	0	0	8	26	36
Hungary	0	0	0	3	17	20
Iceland	0	0	0	0	2	2
India	0	0	1	10	81	93

[46] Not all typologies are shown on this table. Moreover, not all information of organizations is available in all countries involved in the scientific output ($n = 183$).

Indonesia	0	0	0	2	12	14
Iran, Islamic Republic of	0	0	0	0	51	52
Iraq	0	0	0	0	2	2
Ireland	0	0	0	4	15	19
Israel	1	0	0	3	13	17
Italy	0	0	1	25	74	100
Jamaica	0	0	0	0	1	1
Japan	0	2	0	23	80	109
Jordan	0	0	0	0	4	4
Kazakhstan	0	0	0	0	3	3
Kenya	1	0	0	0	2	3
Korea, Republic of	1	2	0	33	49	87
Kuwait	0	0	0	0	1	1
Lao People's Democratic Republic	0	0	0	1	0	1
Latvia	0	0	0	1	7	8
Lebanon	1	0	0	0	3	4
Liechtenstein	0	0	0	0	1	1
Lithuania	0	0	0	4	10	14
Luxembourg	0	0	0	2	1	3
Macedonia, the former Yugoslav Republic of	0	0	0	0	2	2
Malaysia	1	0	0	0	8	9
Malta	0	0	0	0	1	1
Mauritius	0	0	0	0	1	1
Mexico	0	0	0	1	14	15
Moldova, Republic of	0	0	0	1	0	1
Mongolia	0	0	0	0	1	1
Morocco	1	0	0	0	4	5
Mozambique	0	0	0	0	1	1
Namibia	0	0	0	0	1	1
Netherlands	15	0	0	21	19	55
New Zealand	0	0	0	0	7	7
Nigeria	1	0	0	0	6	7
Norway	0	0	1	25	14	40
Oman	0	0	0	0	1	1
Pakistan	0	0	2	0	11	13
Panama	0	0	0	1	0	1
Peru	0	0	0	0	2	2
Philippines	0	0	0	1	10	11
Poland	1	0	0	8	56	65
Portugal	0	0	0	7	29	36
Qatar	0	0	0	0	1	1
Romania	9	0	0	9	36	54

Russian Federation	1	0	0	5	23	29
Rwanda	0	0	0	0	1	1
Saudi Arabia	1	0	0	0	6	7
Senegal	0	0	0	0	2	2
Serbia	0	0	0	0	5	5
Singapore	0	0	0	0	4	5
Slovakia	0	0	0	1	13	14
Slovenia	0	0	0	1	5	6
South Africa	1	0	0	5	21	27
Spain	2	0	3	32	68	105
Sri Lanka	0	0	0	0	2	2
Sweden	2	0	0	13	28	43
Switzerland	3	0	0	9	12	25
Taiwan, Province of China	0	0	3	10	31	44
Tanzania, United Republic of	0	0	0	0	2	2
Thailand	0	0	0	2	15	17
Togo	1	0	0	0	0	1
Tunisia	0	0	0	0	3	3
Turkey	1	0	0	0	85	86
Uganda	1	0	0	0	1	2
Ukraine	0	0	0	1	10	11
United Arab Emirates	0	0	0	0	2	2
United Kingdom	0	1	6	40	130	181
United States	38	13	7	64	340	467
Uruguay	0	0	0	0	2	2
Viet Nam	0	0	0	1	7	9
Zimbabwe	0	0	0	0	1	1
Total	124	25	35	586	2,294	3,104

Source: Own elaboration from the CWTS in-house WoS database.

The top 50 most productive institutions are shown in Table 13. The most productive institution is the Chinese Academy of Sciences (China) with 2,385 documents (2.44%), followed by Wageningen University Research Centre (the Netherlands) with 1,197 documents (1.22%), the INRA National Institute for Agricultural Research (France) with 825 documents (0.85%), the University of Malaya (Malaysia) with 635 documents (0.65%) and Tsinghua University (China) with 614 documents. By typology, on this top 50, the great majority are universities (86%), followed by research organizations (14%) (Table 13).

Table 13. Top 50 Most Productive Institutions on Sustainability Research (2008–2017)

Ranking	***Institution***	***Country***	***P***	***Organization typology***[47]
1	Chinese Academy of Sciences	China	2,385	R
2	Wageningen University & Research Centre	Netherlands	1,197	U
3	INRA National Institute for Agricultural Research	France	825	R
4	University of Malaya	Malaysia	635	U
5	Tsinghua University	China	614	U
6	ETH Zurich	Switzerland	581	U
7	University of Queensland	Australia	554	U
8	University of California, Berkeley	United States	552	U
9	Utrecht University	Netherlands	514	U
10	University of British Columbia	Canada	513	U
11	Swedish University of Agricultural Sciences	Sweden	493	U
12	Michigan State University	United States	480	U
13	Delft University of Technology	Netherlands	477	U
14	University of Illinois, Urbana-Champaign	United States	476	U
15	Arizona State University	United States	470	U
16	Technical University of Denmark	Denmark	469	U
17	Council for Scientific and Industrial Research	India	456	R
18	Centre National de la Recherche Scientifique	France	451	R
19	University of Wisconsin, Madison	United States	431	U
20	Universiti Teknologi Malaysia	Malaysia	426	U
21	Iowa State University	United States	423	U
22	North China Electric Power University	China	419	U
23	Norwegian University of Science and Technology	Norway	419	U
24	University of Minnesota, Twin Cities	United States	419	U
25	Agricultural Research Service	United States	418	R
26	Shanghai Jiao Tong University	China	415	U
27	University of Tennessee, Knoxville	United States	413	U

[47] 'R' is for 'research organizations' and 'U' for 'universities'.

28	University of Tehran	Iran, Islamic Republic of	410	U
29	Imperial College London	United Kingdom	407	U
30	Katholieke Universiteit Leuven	Belgium	400	U
31	University of Cambridge	United Kingdom	398	U
32	University of Leeds	United Kingdom	392	U
33	University of Nottingham	United Kingdom	389	U
34	Zhejiang University	China	387	U
35	KTH Royal Institute of Technology	Sweden	383	U
36	Stanford University	United States	378	U
37	University of Lisbon	Portugal	378	U
38	VU University Amsterdam	Netherlands	378	U
39	University of Manchester	United Kingdom	377	U
40	Lund University	Sweden	372	U
41	Stockholm University	Sweden	371	U
42	Hong Kong Polytechnic University	China	369	U
43	Texas A&M University, College Station	United States	365	U
44	University of São Paulo	Brazil	364	U
45	Monash University	Australia	361	U
46	Consiglio Nazionale delle Ricerche	Italy	360	R
47	Purdue University, West Lafayette	United States	355	U
48	Australian National University	Australia	350	U
49	University of Oxford	United Kingdom	350	U
50	Spanish National Research Council	Spain	348	R

Source: Elaborated by the author from the CWTS in-house WoS database.

However, checking a bivariate plot with the 15 institutions most productive with the scientific output (y-axis) on sustainability and the AI (x-axis) as well as the scientific output of each country (size of the bubble) one can appreciate that the most productive institution in sustainability output (as well as the output of each country), namely Chinese Academy of Sciences, presents a lower specialization (2385 docs, 1.63 AI). However, Wageningen University and Research Centre, which has less scientific output, presents a higher AI (1,197 docs, 8.86 AI). Moreover, other institutions such as the Swedish University of Agricultural Sciences (493 docs, 7.28 AI), INRA National Institute for Agricultural Research (825 docs, 5.06 AI) or University of Malaya (635 docs, 4.94 AI) also present higher AI. Furthermore, other organizations that do not have high scientific output on sustainability but present a higher level of AI are listed below: Wuppertal Institute for Climate, Environment and Energy (234 documents; 73.21 AI);

BC3 Basque Centre for Climate Change (257 documents, 40 AI); and the Stockholm Environment Institute (296 documents, 34.73 AI) (Figure 18).

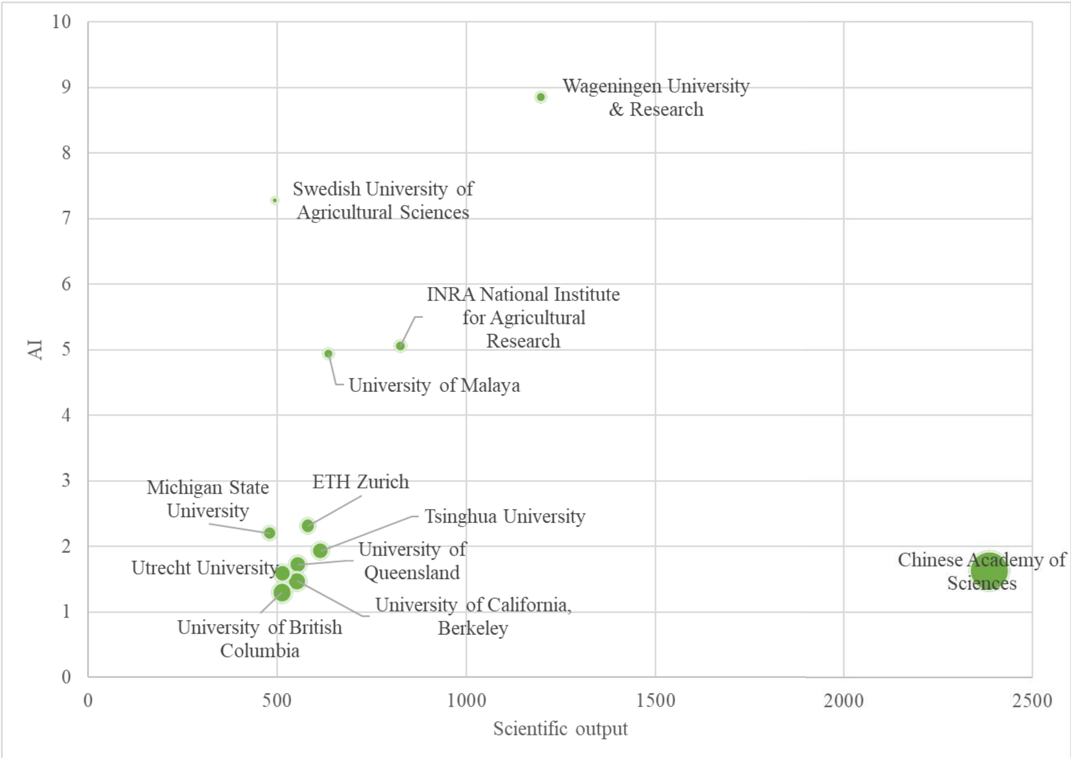


Figure 18. Bivariate plot with the AI (*y*-axis), scientific output (*x*-axis) and the size of the bubbles is the scientific production of each institution (2008–2017).
Source: Own elaboration from the CWTS in-house WoS database.

4.1.1.4.1. The role of sustainability at HEIs

Of the dataset, 81,105 documents (82.86%) were classified as having at least one signature by one HEI (that is, classified as university, federal university or university campus) during the period. From this dataset, 2,316 unique HEIs and 142,459 affiliations were found. Figure 19 shows its evolution in comparison with the sustainability scientific output delimitated on this research. The scientific output of HEIs has increased over time from 3,188 documents in 2008 to 15,511 in 2017. The average growth rate is higher among documents with HEI affiliation (17.38 HEIs vs 16 sustainability production) as well as among those with a high CAGR (19.22 HEIs vs 17.70 sustainability production).

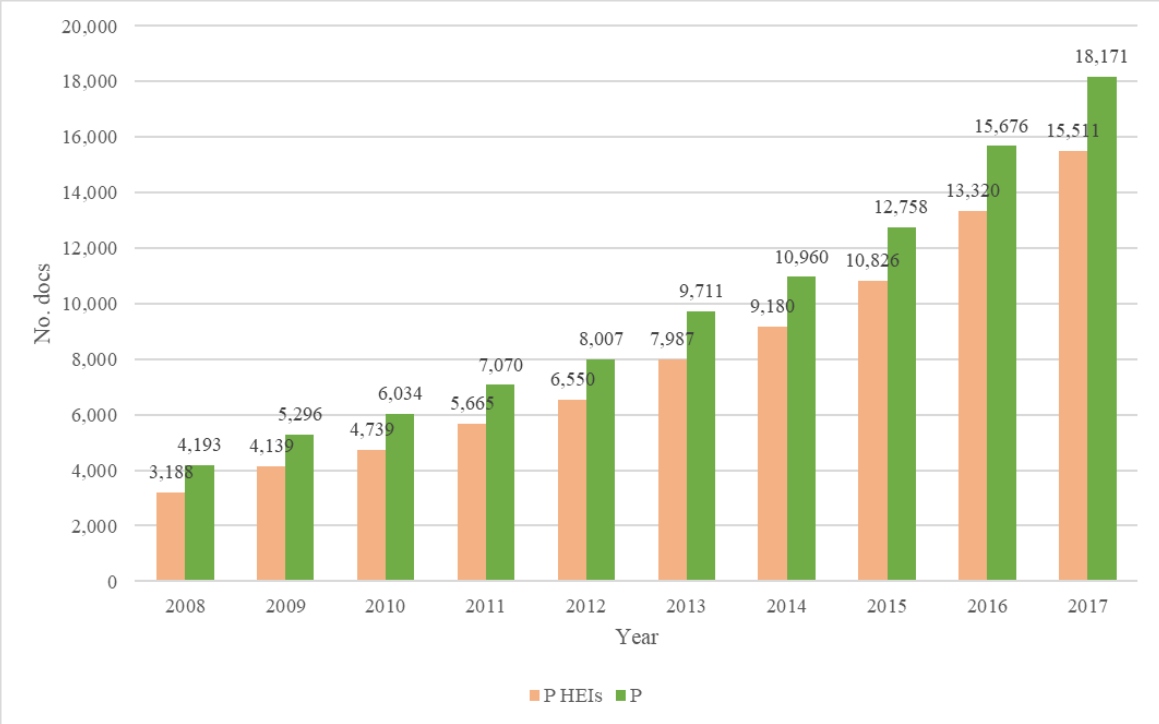


Figure 19. Evolution of the scientific output of sustainability (P) and the scientific output of HEIs (P HEIs) over the period (2008–2017).

Source: Elaborated by the author from the CWTS in-house WoS database.

Table 14 shows the top 100 HEIs with a higher scientific output. In this sense, Wageningen University Research Centre (the Netherlands) is the most productive, with 1,197 documents (4.39% of their country scientific output), followed by University of Malaya (Malaysia) with 635 documents (2.45% of their output), Tsinghua University (China) with 614 documents (0.96) and ETH Zurich (Switzerland) with 581 documents (1.15%). In this ranking, 24 HEIs are from the United States, 11 from China and the United Kingdom, 10 from Australia and 6 from Canada.

Table 14. Top 100 HEIs Ranked by a Higher Number of Documents (2008–2017)

Position	*HEIs*	*Country*	*P*	*% P/ P (Organization)*	*No. Affiliations*
1	Wageningen University & Research Centre	Netherlands	1,197	4.39	1,626
2	University of Malaya	Malaysia	635	2.45	881
3	Tsinghua University	China	614	0.96	753
4	ETH Zurich	Switzerland	581	1.15	677
5	University of Queensland	Australia	554	0.86	682
6	University of California, Berkeley	United States	552	0.73	688
7	Utrecht University	Netherlands	514	0.79	564
8	University of British Columbia	Canada	513	0.64	632
9	Swedish University of Agricultural Sciences	Sweden	493	3.61	623
10	Michigan State University	United States	480	1.09	732

11	Delft University of Technology	Netherlands	477	1.96	520
12	University of Illinois, Urbana-Champaign	United States	476	0.89	753
13	Arizona State University	United States	470	1.33	656
14	Technical University of Denmark	Denmark	469	1.87	522
15	University of Wisconsin, Madison	United States	431	0.57	594
16	Universiti Teknologi Malaysia	Malaysia	426	4.73	658
17	Iowa State University	United States	423	1.52	641
18	North China Electric Power University	China	419	6.14	472
19	Norwegian University of Science and Technology	Norway	419	1.75	506
20	University of Minnesota, Twin Cities	United States	419	0.52	602
21	Shanghai Jiao Tong University	China	415	0.57	470
22	University of Tennessee, Knoxville	United States	413	1.07	510
23	University of Tehran	Iran, Islamic Republic of	410	1.67	466
24	Imperial College London	United Kingdom	407	0.50	521
25	Katholieke Universiteit Leuven	Belgium	400	0.70	513
26	University of Cambridge	United Kingdom	398	0.44	472
27	University of Leeds	United Kingdom	392	1.09	469
28	University of Nottingham	United Kingdom	389	1.00	450
29	Zhejiang University	China	387	0.53	451
30	KTH Royal Institute of Technology	Sweden	383	1.68	442
31	Stanford University	United States	378	0.36	539
32	University of Lisbon	Portugal	378	0.97	446
33	VU University Amsterdam	Netherlands	378	0.73	422
34	University of Manchester	United Kingdom	377	0.58	431
35	Lund University	Sweden	372	0.77	419
36	Stockholm University	Sweden	371	1.56	440
37	Hong Kong Polytechnic University	China	369	1.62	400
38	Texas A&M University, College Station	United States	365	0.64	448
39	University of São Paulo	Brazil	364	0.36	461
40	Monash University	Australia	361	0.61	442
41	Purdue University, West Lafayette	United States	355	0.81	517
42	Australian National University	Australia	350	1.07	397
43	University of Oxford	United Kingdom	350	0.33	402
44	Chalmers University of Technology	Sweden	345	2.45	380

45	Beijing Normal University	China	342	1.70	404
46	UniversitatAutònoma de Barcelona	Spain	342	0.98	482
47	University of Melbourne	Australia	340	0.45	402
48	National University of Singapore	Singapore	339	0.53	406
49	University of Michigan	United States	339	0.29	451
50	Aarhus University	Denmark	338	0.94	395
51	University of Tokyo	Japan	338	0.38	425
52	University of California, Davis	United States	335	0.48	469
53	University of Waterloo	Canada	334	1.25	395
54	University of New South Wales	Australia	326	0.59	385
55	Cardiff University	United Kingdom	324	1.03	386
56	North Carolina State University Raleigh	United States	324	0.89	429
57	University of Florida	United States	321	0.44	418
58	Seoul National University	Korea, Republic of	311	0.42	421
59	University of Edinburgh	United Kingdom	310	0.59	336
60	Cornell University	United States	309	0.41	376
61	University of Groningen	Netherlands	308	0.61	336
62	University of Copenhagen	Denmark	305	0.48	343
63	University of Toronto	Canada	305	0.23	397
64	Pennsylvania State University	United States	301	0.45	381
65	Ghent University	Belgium	296	0.69	370
66	Aalto University	Finland	287	1.84	331
67	University of South Australia	Australia	286	2.18	335
68	University of Bologna	Italy	274	0.59	332
69	Aalborg University	Denmark	273	1.98	282
70	Dalian University of Technology	China	272	1.04	298
71	Griffith University	Australia	270	1.48	334
72	Chongqing University	China	268	1.52	351
73	Oregon State University	United States	268	1.25	323
74	Virginia Polytechnic Institute and State University	United States	266	0.92	331
75	University of Helsinki	Finland	265	0.54	298
76	University of Washington, Seattle	United States	262	0.25	321
77	McGill University	Canada	260	0.38	354
78	Politécnico di Milano	Italy	258	1.54	275
79	University of Exeter	United Kingdom	258	1.26	278
80	Colorado State University	United States	257	1.11	309
81	Curtin University	Australia	257	1.32	290
82	Newcastle University	United Kingdom	256	0.86	284
83	Tianjin University	China	256	0.97	323
84	Ohio State University	United States	252	0.34	300

85	Huazhong University of Science and Technology	China	250	0.59	304
86	Nanjing University	China	250	0.60	343
87	Universitat Politècnica de València	Spain	250	1.61	330
88	University of Alberta	Canada	250	0.42	296
89	University of Göttingen	Germany	250	0.76	301
90	University of Nebraska, Lincoln	United States	250	1.27	367
91	University of Sheffield	United Kingdom	247	0.69	294
92	Université de Montréal	Canada	245	0.53	287
93	University of Amsterdam	Netherlands	245	0.38	268
94	University of Sydney	Australia	245	0.32	266
95	Technical University of Madrid	Spain	244	1.77	281
96	James Cook University	Australia	242	2.05	303
97	BOKU)	Austria	242	3.24	307
98	Washington State University	United States	242	1.12	293
99	Universiti Sains Malaysia	Malaysia	240	1.55	291
100	King Abdulaziz University	Saudi Arabia	235	1.03	268

Source: Own elaboration from the CWTS in-house WoS database.

However, the results of a comparison of AI versus scientific production produce a different picture. Wageningen University and Research Centre (the Netherlands) is the most productive (*n* = 1,197) and presents the highest specialization (8.86% AI). With lower scientific output on sustainability (*n* = 635 documents), the Swedish University of Agricultural Sciences (Sweden) also presents high values of specialization (7.28%), followed by the University of Malaya in Malaysia (*n* = 635, 494% AI), Delft University of Technology in the Netherlands (*n* = 477, 3.95% AI) and the Technical University of Denmark (Denmark, *n* = 469, 3.77% AI). On the centre of the bivariate plot, a list of universities with higher production on the topic but lower specialization can be found (e.g. ETH Zurich in Switzerland, Tsinghua University in China, the University of Queensland in Australia).

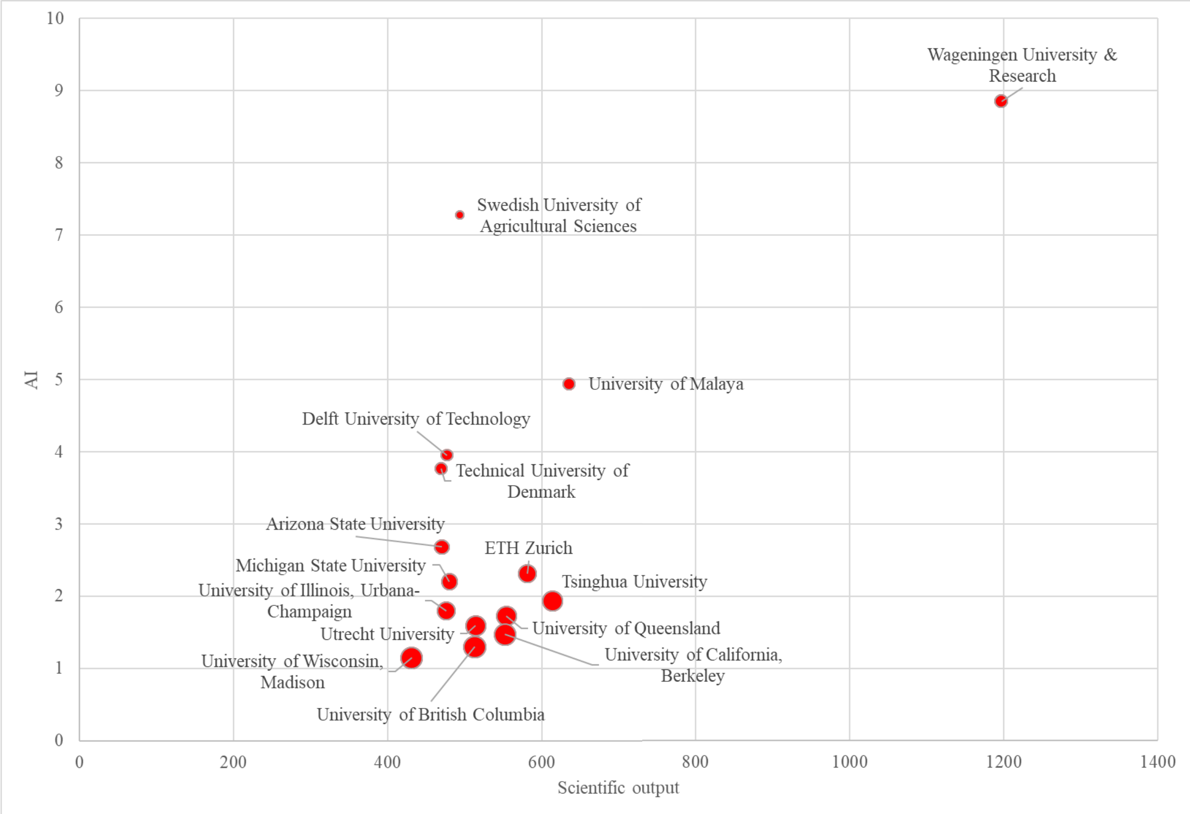


Figure 20. Bivariate plot of the top 15 institutions the AI (*y*-axis), scientific output (*x*-axis) and the size of the bubbles is the scientific production of HEIs (2008–2017).
Source: Own elaboration from the CWTS in-house WoS database.

Table 15 presents the most productive HEIs in Spain with sustainability research. The most productive university in this field is the Universitat Autònoma de Barcelona (UAB) with 342 documents (0.98% of their organization production), Universidad Politécnica de València (UPV) with 250 documents (1.61%), Universidad Politécnica de Madrid (UPM) with 244 documents (1.77%), Universidad de Zaragoza (UNIZAR) with 226 documents (1.20%), Universidad Politécnica de Catalunya (UPC) with 219 documents (1.36%), the Universidad del País Vasco (EHU) with 217 documents (1.04%) and Universidad de Santiago de Compostela (USC) with 203 documents (1.21%).

Table 15. Most Productive HEIs in Spain (2008–2017)

Position	*HEIs*	*P*	*% P/ P (Organization)*	*No. Affiliations*	*Total output*
1	UAB	342	0.98	482	34,760
2	UPV	250	1.61	330	15,492
3	UPM	244	1.77	281	13,791
4	UNIZAR	226	1.20	318	18,797
5	UPC	219	1.36	295	16,083
6	EHU	217	1.04	271	20,861
7	USC	203	1.21	219	16,786
8	UCO	194	2.26	219	8,593
9	UGR	189	0.79	212	23,804

10	UCLM	158	1.62	202	9,764
11	US	155	0.73	180	21,090
12	UAM	140	0.51	147	27,616
13	UNIOVI	130	0.97	151	13,399
14	UA	124	3.11	167	3,993
15	UVIGO	109	1.20	126	9,092
16	UB	108	0.25	120	42,981
17	UCM	107	0.30	114	36,021
18	USAL	102	0.84	115	12,170
19	URV	99	1.08	105	9,172
20	UNEX	94	1.41	140	6,659
21	UDL	94	2.30	98	4,085
22	UNICAN	90	1.24	101	7,267
23	UA	89	1.13	113	7,847
24	UV	84	0.29	107	28,977
25	UJI	82	1.55	88	5,288
26	UC3M	80	1.13	80	7,076
27	UJAEN	80	1.65	97	4,845
28	URL	80	3.45	90	2,316
29	UPO	76	2.23	85	3,406
30	UDG	71	1.17	86	6,058
31	URJC	67	1.21	73	5,547
32	UVA	65	0.83	80	7,847
33	UDC	56	1.01	68	5,536
34	UNILEON	56	1.37	70	4,078
35	UMA	55	0.60	61	9,126
36	UNED	55	1.39	61	3,957
37	UM	51	0.37	60	13,863
38	UPCT	48	1.69	61	2,845
39	ULL	45	0.51	64	8,793
40	UNIRIOJA	45	2.17	64	2,077
41	UPF	44	0.45	46	9,841
42	UNAVARRA	43	1.18	51	3,637
43	UAH	42	0.58	44	7,190
44	ULPGC	36	0.83	40	4,359
45	UHU	36	1.19	43	3,018
46	UNAV	33	0.29	39	11,443
47	UCA	30	0.64	36	4,657
48	UIB	28	0.45	28	6,170
49	UBU	28	1.52	30	1,845
50	UMH	19	0.36	26	5,227
51	COMILLAS	17	2.80	18	608
52	UIC	15	1.51	16	994
53	UOC	15	1.76	15	851
54	ULOYOLA	15	5.51	19	272
55	DEUSTO	11	1.06	13	1,035
56	UEM	10	0.71	12	1,413
57	CEU	6	0.41	6	1,451
58	UVIC	6	1.02	6	588
59	MUNI	6	1.94	6	309
60	IE	4	2.08	4	192
61	UCJC	3	0.86	3	347
62	ESIC	3	21.43	4	14

63	UCV	2	0.27	2	729
64	UAX	2	0.98	2	204
65	USJ	2	1.02	2	196
66	UEMC	2	1.33	2	150
67	UCAM	1	0.09	1	1,145
68	UCHCEU	1	0.13	1	773

Source: Own elaboration from the CWTS in-house WoS database.

Figure 21 shows a bivariate plot with scientific output vs AI of Spanish HEIs. The plot shows the top 15 institutions with a higher output on this topic with, at least, 100 documents on the topic. Universities such as UAB, which has a higher production (342 documents), present lower specialization (AI of 1.98%). On the other hand, universities with lower scientific output present a higher specialization. Examples of relationship between output and specialization can be seen in the following HEIs: the University of Almería (124 documents; 6.26% AI), the University of Cordoba (194 documents; 4.55% AI) and the Technical University of Madrid (244 documents; 3.57% AI).

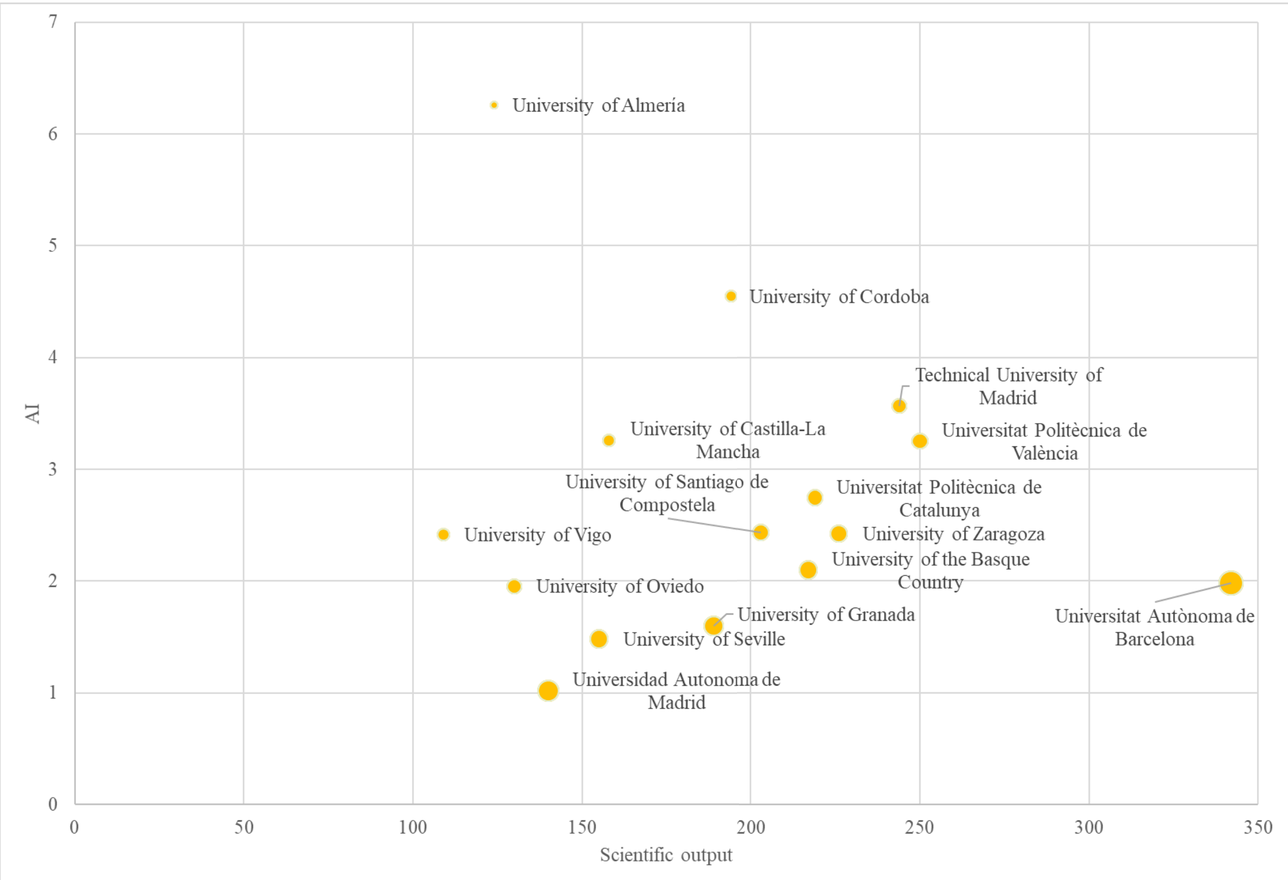


Figure 21. Bivariate plot of the scientific output vs AI of Spanish HEIs (2008–2017).

Source: Own elaboration from the CWTS in-house WoS database.

4.1.1.5. Subject categories

The JCR database assigns between one and four thematic categories to each indexed journal according to the topic. There are 254 WoS categories and, related to the topic, 221 categories (87%) were assigned to the topic. The subject category with a higher number of documents is "Green & Sustainable Science & Technology" with 59,374 documents (60.66%). This finding is aligned with the selection of this WoS category in the dataset. The next subject category is "Environmental Sciences" with 28,715 documents (28.79%), "Energy & Fuels" with 25,610 documents (26.17%), "Engineering environmental" with 15,799 documents (16.14%) and "Environmental studies" with 13,545 documents (13.84%). Moreover, the same pattern is observed at HEIs (Table 16). Moreover, the subject category with the most increase over the period is that of "Engineering, Chemical" (62.63%), "Environmental Sciences" (25.31%) and "Chemistry, Multidisciplinary" (24.16%).

Table 16. Number of Documents by WoS Category and Year (2008–2017)

WoS Category	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*Total*
Green & Sustainable Science & Technology	1,782	2,344	2,712	3,435	4,202	5,512	6,653	8,354	11,041	13,339	59,374
Environmental Sciences	935	1,121	1,219	1,448	1,779	2,388	2,955	3,824	5,381	7,125	28,175
Energy & Fuels	718	1,197	1,302	1,877	2,219	2,853	3,009	3,695	4,381	4,359	25,610
Engineering, Environmental	475	587	690	799	980	1,515	1,689	2,201	3,141	3,722	15,799
Environmental Studies	463	577	625	776	833	1,159	1,366	1,787	2,434	3,525	13,545
Chemistry, Multidisciplinary	371	476	623	721	892	1,026	1,427	1,543	2,060	2,601	11,740
Engineering, Chemical	21	133	95	131	206	521	689	795	1,220	1,671	5,482
Business	313	511	463	410	434	446	448	501	523	546	4,595
Economics	334	351	361	403	456	419	356	358	354	359	3,751
Ecology	211	224	270	274	270	348	351	412	427	454	3,241
Management	166	252	314	360	305	323	320	353	354	407	3,154
Water Resources	290	251	227	276	289	284	363	310	340	285	2,915
Agriculture, Multidisciplinary	158	179	230	230	197	244	265	278	257	281	2,319
Agronomy	105	112	177	158	192	217	221	271	238	271	1,962
Engineering, Electrical & Electronic	25	45	82	112	152	191	254	299	354	430	1,944
Marine & Freshwater Biology	204	193	166	195	190	169	239	224	221	138	1,939
Ethics	147	283	210	172	164	189	176	206	186	183	1,916
Geography	137	121	166	170	172	208	238	191	223	233	1,859
Regional & Urban Planning	129	125	148	151	154	165	182	197	226	244	1,721

Forestry	113	100	141	161	192	163	167	167	202	217	1,623

Source: Own elaboration from the CWTS in-house WoS database.

However, the intensity of a topic inside of the WoS category can be identified by relating "the number of papers identified in the dataset to the total number of papers on this subject category in the same period of time". Figure 23 shows the intensity of each subject category classified by its pillar. The subject categories with a higher intensity are as follows: Green & Sustainable Science & Technology (99.85%), Environmental Studies (17.33%), Engineering, environmental (13.16%), Agricultural economics & Policy (11.47%), Energy & Fuels (10.42%) and Regional & Urban Planning (7.22%). Figure 22 denotes that the greater intensity of research is in environmental and social sustainability and less in economic sustainability. This divergence may be explained by the inclusion in the search strategy of a whole WoS category (green and sustainable science and technology) dedicated to environmental sustainability.

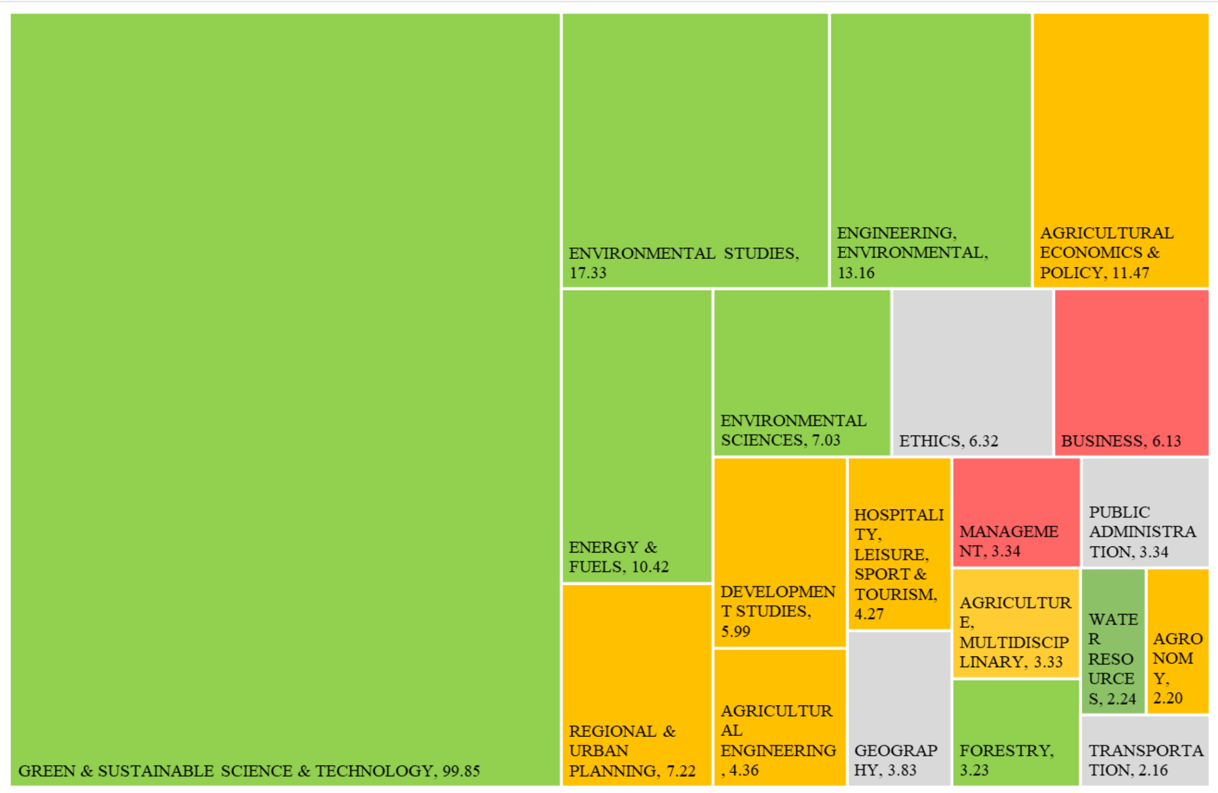


Figure 22. The intensity of each WoS category by the three pillars (green, environmental; red, economic; yellow, social; and grey, undetermined).[48]

Source: Elaborated by the author from the CWTS in-house WoS database.

4.4.1.6. Journals

From 2008–2017, of the 97,876 documents retrieved about sustainability, 3,270 were published in journals. The number of journals by year grew during the period, from 826 journals in 2008 to 1,182

[48] Colours of each pillar are assigned by personal judgment.

journals in 2016 (27.86%). However, the interannual growth between all the periods shows that the growth rate decreases over time (e.g. from 10.29% in 2008–2009 to 2.43% in the period 2015–2016). Some periods of this growth are even negative (i.e., 2014–2015 with a decrease of 1.37% and 2016–2017 with a decrease of 3.13%) (Table 17).

Table 17. Evolution of Number of Journals and Growth Rate about Sustainability over the Period (2008–2017)

Year	*No. of journals*	*Growth Rate*
2008	826	0
2009	911	10.29
2010	989	8.56
2011	1,043	5.46
2012	1,105	5.94
2013	1,133	2.53
2014	1,170	3.27
2015	1,154	−1.37
2016	1,182	2.43
2017	1,145	−3.13
Total	3,270	

Source: Own elaboration from the CWTS in-house WoS database.

If we check the top 20 journals published on the period, the journal with a higher number of documents is the *Journal of Cleaner Production* with 8,458 documents (8.85%), *Renewable and Sustainable Energy Reviews* with 7,202 documents (7.36%), *Renewable Energy* with 6,319 documents (6.36%) and *Sustainability* with 5,648 documents (5.77%). Regarding the journals from HEIs, it presents the same pattern of publications: *Journal of Cleaner Production* with 7,572 documents (9.34), *Renewable & Sustainable Energy Reviews* with 5,872 documents (7.24%) and *Renewable Energy* with 5,287 documents (6.52%) (Table 18).

Table 18. Top 20 Journals with Number of Papers Published (2008–2017)

Position	*Source*	*P*	*%*
1	*Journal Of Cleaner Production*	8,658	8.85
2	*Renewable & Sustainable Energy Reviews*	7,202	7.36
3	*Renewable Energy*	6,319	6.46
4	*Sustainability*	5,648	5.77
5	*Green Chemistry*	4,559	4.66
6	*Chemsuschem*	3,197	3.27
7	*Acs Sustainable Chemistry & Engineering*	3,099	3.17
8	*International Journal of Greenhouse Gas Control*	2,248	2.30
9	*Clean-Soil Air Water*	1,835	1.87
10	*Journal of Renewable and Sustainable Energy*	1,720	1.76
11	*Journal Of Business Ethics*	1,380	1.41
12	*Clean Technologies and Environmental Policy*	1,292	1.32
13	*Environmental Progress & Sustainable Energy*	1,285	1.31

14	*Biomass & Bioenergy*	1,008	1.03
15	*IEEE Transactions on Sustainable Energy*	959	0.98
16	*Journal of Industrial Ecology*	953	0.97
17	*Iet Renewable Power Generation*	942	0.96
18	*International Journal of Green Energy*	862	0.88
19	*Journal of Sustainable Tourism*	760	0.78
20	*Sustainable Cities and Society*	759	0.78

Source: Own elaboration from the CWTS in-house WoS database.

4.4.1.7. Identification of elite authors

Price and Yablonsky's index allows the identification of elite authors by productivity. In this regard, the Price index establishes that the number of authors who are most productive is linked with the square root of the total of authors. In the dataset of this study, the total authors are 97,876, and 312 are the authors that comprise this elite group; in the case of HEIs, this elite is composed of 284 authors. On the other hand, the Yablonsky index uses the square root of the authors with only one author. With the application of this index to our dataset, the following results are obtained: 112 authors (P sustainability) and 92 authors (P HEIs).

4.1.2. Scientific collaboration

In this section, indicators related to scientific collaboration have been obtained in order to determine the collaboration pattern in the documents retrieved about sustainability. With that aim, co-authorship and patterns of collaboration (national, international, or without collaboration) have been calculated by different levels of aggregation: countries and institutions (general and HEIs).

4.1.2.1. Co-authorship

This section analyses the productivity of the authors within the sustainability dataset. The average of number of authors per paper is 3 authors in the sustainability dataset, 4 authors with documents signed by HEIs. The documents signed without collaboration in scientific output (P) in sustainability are 12.87% and 10.32% in P(HEIs). Table 19 presents the distribution of the number of authors and the amount of scientific output. The great majority of papers in the sustainability dataset are signed by 3 authors (22.76%) followed by 2 authors (21.62%) and 4 authors (16.95%). Regarding HEIs' scientific output, 23.48% of the papers are signed by 3 authors, 21.52% by 2 authors and 17.60% by authors.

Table 19. Number of Authors by Documents in Sustainability Dataset (P) and HEIs (P HEIs) (2008–2017)

	P		***P(HEIs)***	
Number of authors	***No. Docs***	***%***	***No. Docs***	***%***
1	12,595	12.87	8,374	10.32
2	21,161	21.62	17,457	21.52
3	22,275	22.76	19,041	23.48

4	16,592	16.95	14,275	17.60
5	10,569	10.80	9,158	11.29
6	6,320	6.46	5,479	6.76
7	3,530	3.61	3,014	3.72
8	1,959	2.00	1,730	2.13
9	1,077	1.10	932	1.15
10–20	1,672	1.71	1,524	1.88
21–30	96	0.10	92	0.11
31–40	19	0.02	18	0.02
41–84	11	0.01	11	0.01
Total	97,876		81,105	

Source: Own elaboration from the CWTS in-house WoS database.

The co-authorship average on sustainability scientific output is 3.42 authors per document in the period 2008–2016. This ratio is 0.11 points (3.53) higher in output signed by HEIs. According to Figure 23, which shows the evolution of co-authorship as well as the number of authors and year of both strategies (P and P[HEIs]), it can be observed that co-authorship presents a growing tendency over the period, slightly higher in sustainability scientific output (CAGR of 4.34% sustainability and CAGR of 4.01% sustainability at HEIs).

In the sustainability dataset, the number of authors went from 11,509 authors in 2008 to 73,109 authors in 2017 (CAGR 22.8%); in sustainability at HEIs, the number grew from 9,194 authors to 63,370 authors (24% CAGR).

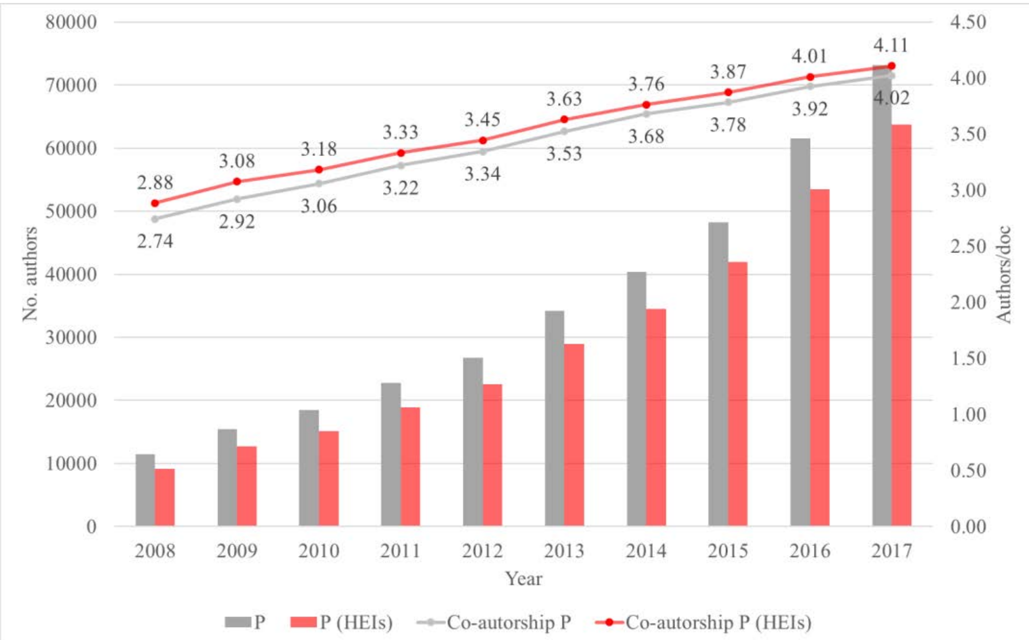


Figure 23. Evolution of the number of authors and co-authorship index in sustainability publications (2008–2017).

Source: Own elaboration from the CWTS in-house WoS database.

4.1.2.1.1. Co-authorship by country

In Table 20 can be observed the number of articles (P) and signatures, as well as the co-authorship of each country with, at least, 10 documents. The countries with a high co-authorship are France (2 authors/document), China (1.90 authors/document), United States (1.89), Brazil (1.85), South Korea (1.85), Taiwan (1.85) and Argentina and Chile (1.81).

Table 20. Co-authorship by Top 20 Countries (>10 documents) in the Period 2008–2017

Position	*Country*	*P*	*No. of signatures*	*Co-authorship*
1	France	3,866	7,734	2.00
2	China	13,479	25,617	1.90
3	United States	19,663	37,196	1.89
4	Brazil	2,289	4,244	1.85
5	Korea, Republic of	2,660	4,930	1.85
6	Taiwan, Province of China	1,597	2,947	1.85
7	Argentina	394	714	1.81
8	Chile	442	799	1.81
9	Portugal	1,329	2,398	1.80
10	Benin	35	62	1.77
11	Thailand	707	1,251	1.77
12	Serbia	419	734	1.75
13	Japan	2,296	3,999	1.74
14	Iran, Islamic Republic of	1,960	3,398	1.73
15	Mexico	833	1,441	1.73
16	Malaysia	2,229	3,818	1.71
17	Pakistan	664	1,130	1.70
18	Algeria	234	398	1.70
19	Madagascar	20	34	1.70
20	Iceland	79	132	1.67

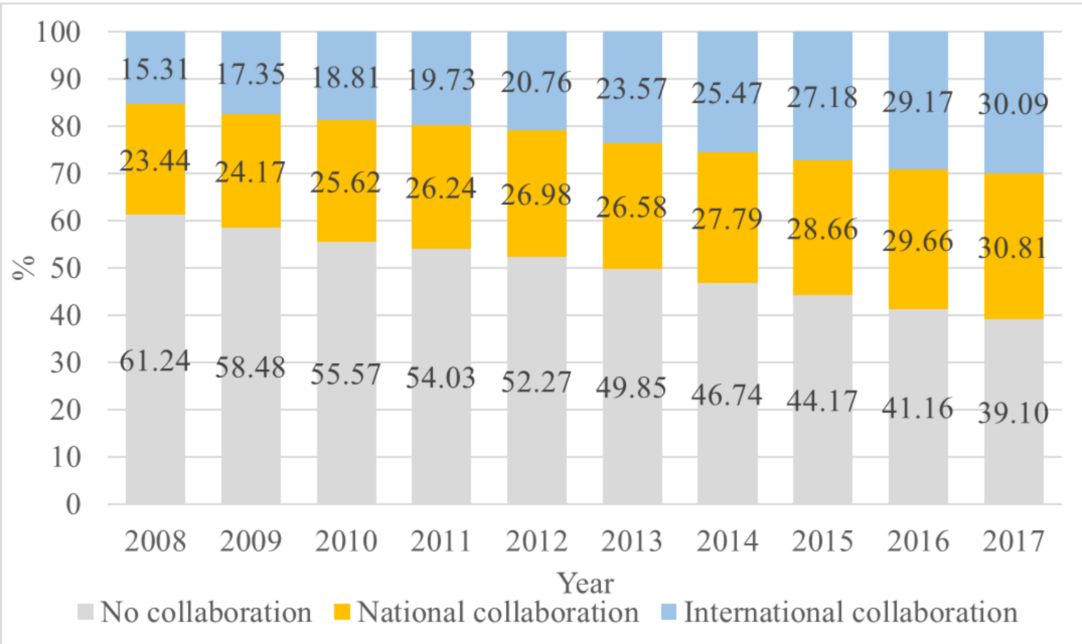
Source: Own elaboration from the CWTS in-house WoS database.

4.1.2.2. Patterns of collaboration

To analyse the patterns of collaboration, the affiliation or institutional level is considered. At this level, it is considered that there no collaboration exists when a document is signed by one or more authors that belongs to a single institution; national collaboration is considered present when the authors are from different institutions in the same country, and international collaboration is present when the document has authorial representation from institutions of two or more countries.

During the studied period, 46,180 documents (47.18%) had no collaboration, 27,356 documents (27.94%) had national collaboration, and 24,340 documents (24.87%) had international collaboration. The evolution by years is shown in Figure 24, a. It can be observed that the percentage of documents without collaboration has decreased over time (CAGR of decrease of 4.86%). In contrast, national collaboration and international collaboration have increased over time by 3.08% and 7.79%, respectively. Documents with HEI affiliation display a similar progression (Figure 24, b). From this perspective, documents without collaboration number to 34,691 (42.78%), with 23,507 documents having national collaboration (29%) and 22,890 documents having international collaboration (28.23%). Given the evolution of these trends over time, documents without collaboration present a negative CAGR of 4.61%, denoting their decrease over time. Documents with national and international collaboration show an increasing and positive evolution over time, but have more of the second type of collaboration (CAGR of 1.71% national collaboration vs CAGR of 6.67% international collaboration). The average proportion of documents with international collaboration is 22.74%; national collaboration, 27%; and no collaboration, 50.26%; these percentages are 25.95%, 28.45% and 45.60% in HEIs, respectively.

a)



b)

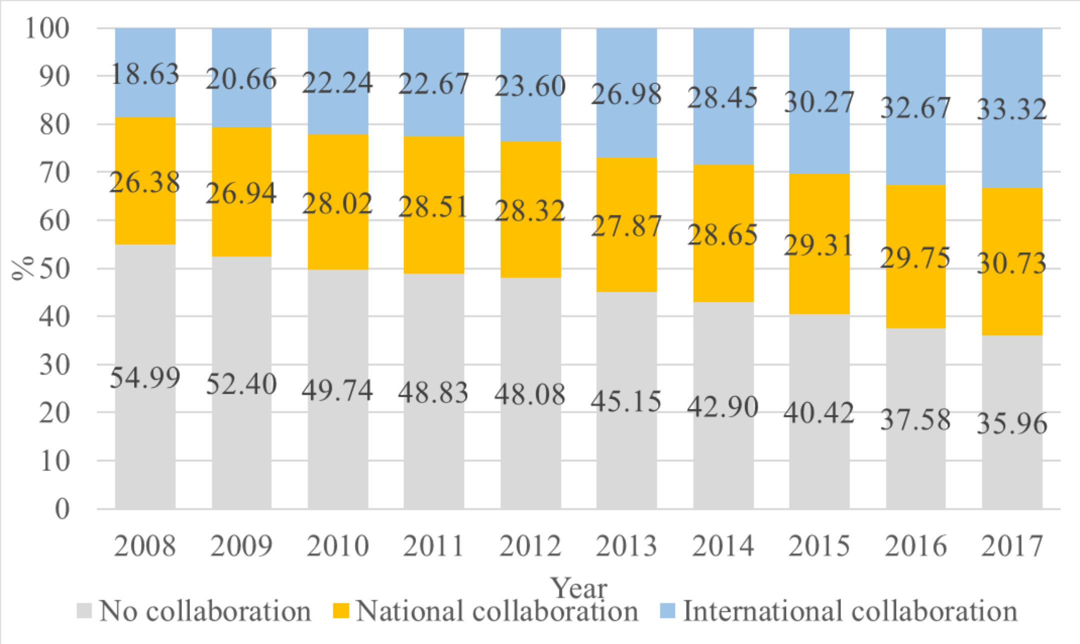


Figure 24. Evolution of documents with national, international and no collaboration of a) sustainability and b) sustainability at HEIs.

Source: Elaborated by the author from the CWTS in-house WoS database.

An institutional collaboration index (ICI) has been calculated with the equation of the number of institutions and the number of articles. During the period of analysis, the average of this indicator rose 0.02. From countries with more than 15 documents, 51 countries present an ICI higher to the average of the discipline. The countries with higher ICIs are Bulgaria (0.21), Ukraine (0.16), Latvia (0.15), Algeria (0.12), Russia (0.11) and Kazakhstan (0.11) (Table 21).

Table 21. Top 20 of Countries Ranked by the Index of Institutional Collaboration (ICI) (>15 docs)

Position	*Country*	*P*	*No. Organizations*	*ICI*
1	Bulgaria	84	18	0.21
2	Ukraine	67	11	0.16
3	Latvia	53	8	0.15
4	Algeria	234	28	0.12
5	Russian Federation	258	29	0.11
6	Kazakhstan	28	3	0.11
7	Romania	629	54	0.09
8	Macedonia, the former Yugoslav Republic of	24	2	0.08
9	Slovakia	215	14	0.07
10	Rwanda	16	1	0.06
11	Brazil	2289	126	0.06
12	Czech Republic	543	29	0.05
13	Israel	344	17	0.05
14	Lithuania	284	14	0.05
15	Hungary	406	20	0.05
16	Uruguay	41	2	0.05
17	Japan	2296	109	0.05

18	Turkey	1874	87	0.05
19	Philippines	241	11	0.05
20	Senegal	44	2	0.05

Source: Elaborated by the author from the CWTS in-house WoS database.

Figure 25 is shown the collaboration pattern at the country level, ranked in descending order by the number of publications. With regard to international collaboration with a great production on the area, the countries with more than 100 publications are as follows: Perú (89.11%), Indonesia (87.13%), Vietnam (84.21%), Kenya (82.69%) and Qatar (80.13%). If we consider the countries with more than 1,000 documents, the countries with a higher amount of international collaboration are Austria (62.16%), Denmark (60.78%), Switzerland (59.85%) and Belgium (57.06%). Moreover, considering the average of the documents with international collaboration in the area of sustainability (22.74%), 58 countries are below average value (with more than 100 publications). Regarding national collaboration, six countries (>100 publications) are below the average (27.94%): Taiwan (33.93%), South Korea (33.83%), China (32.15%), Brazil (30.19%), Serbia (29.83%) and Algeria (29.06%). With respect to documents without collaboration, Poland (60.12%), Romania (51.19%), Turkey (51.12%) and India (51%) present a percentage of documents with this type of collaboration higher than the average (50.26%).

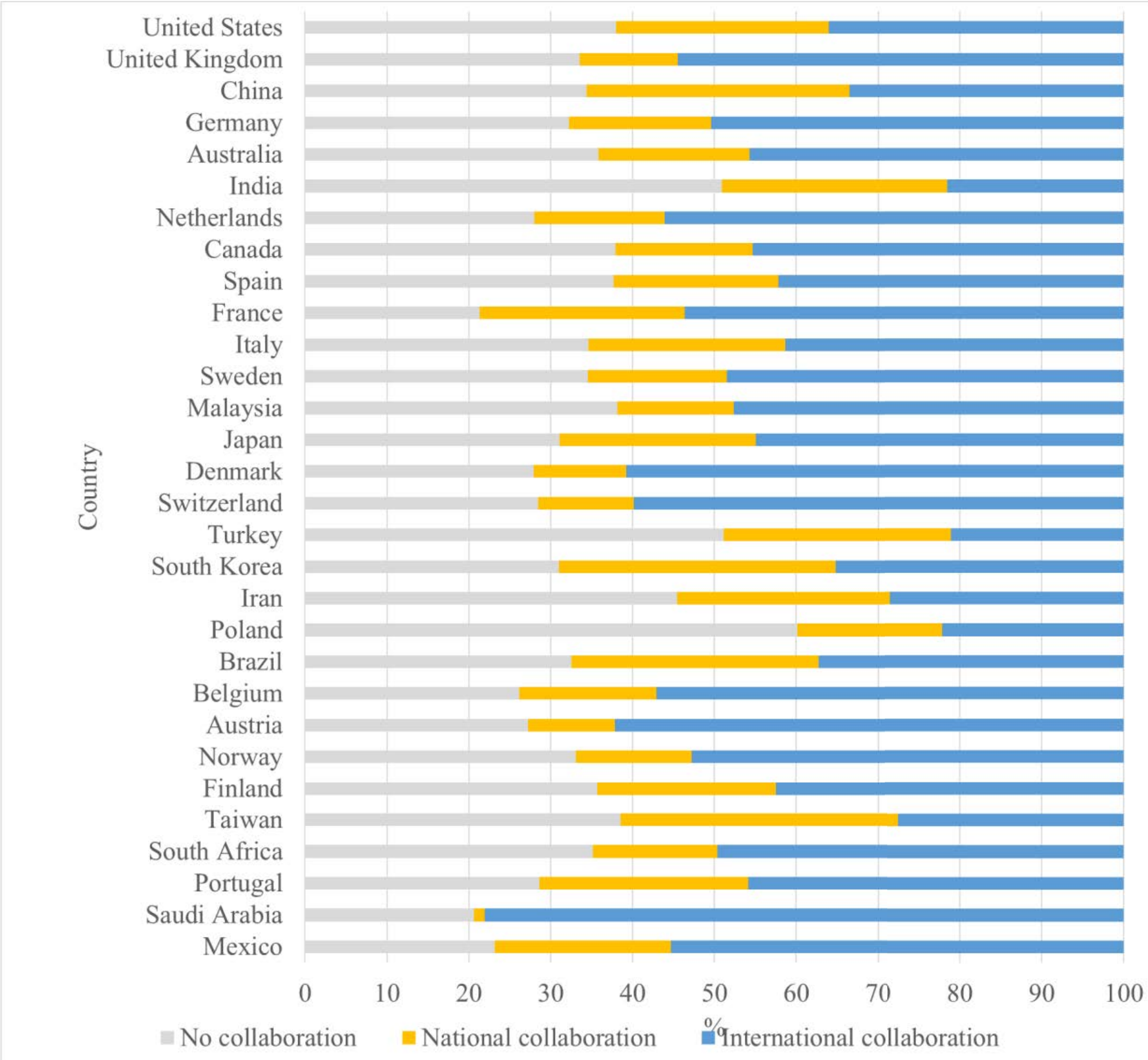


Figure 25. Distribution of the patterns of collaboration in the top 30 countries by scientific production (2008–2017).
Source: Compiled from the CWTS in-house WoS database.

Along these lines, Figure 26 presents the patterns of collaboration in the institutions with a scientific output higher than 100 documents. The institutions with a higher number of documents with international collaboration are King Abdulaziz University (93.61%), the International Institute for Applied Systems Analysis (IIASA) (90.29%), the Natural Environment Research Council (77.94%), the University of St Andrews (75.96%), King Saud University (75.33%) and University of Aberdeen (74.15%). In relation to national collaboration, the United States Department of Agriculture leads the ranking (66.31%), followed by the University of Idaho (63.71%), Mississippi State University (61.36%), the Beijing Institute of Technology (60.51%), the Agricultural Research Service (60.05%), "Consiglio per la Ricerca in Agricoltura e l'analisi dell'economia agrarian" (56.48%), and Korea University (55.06%). Regarding documents without collaboration, the leaders are the Indian Institute of Technology Roorkee (66.49%), the Bucharest Academy of Economic Studies (64.50%), the University of Salamanca (63.72%) and the University of Oviedo (51.54%).

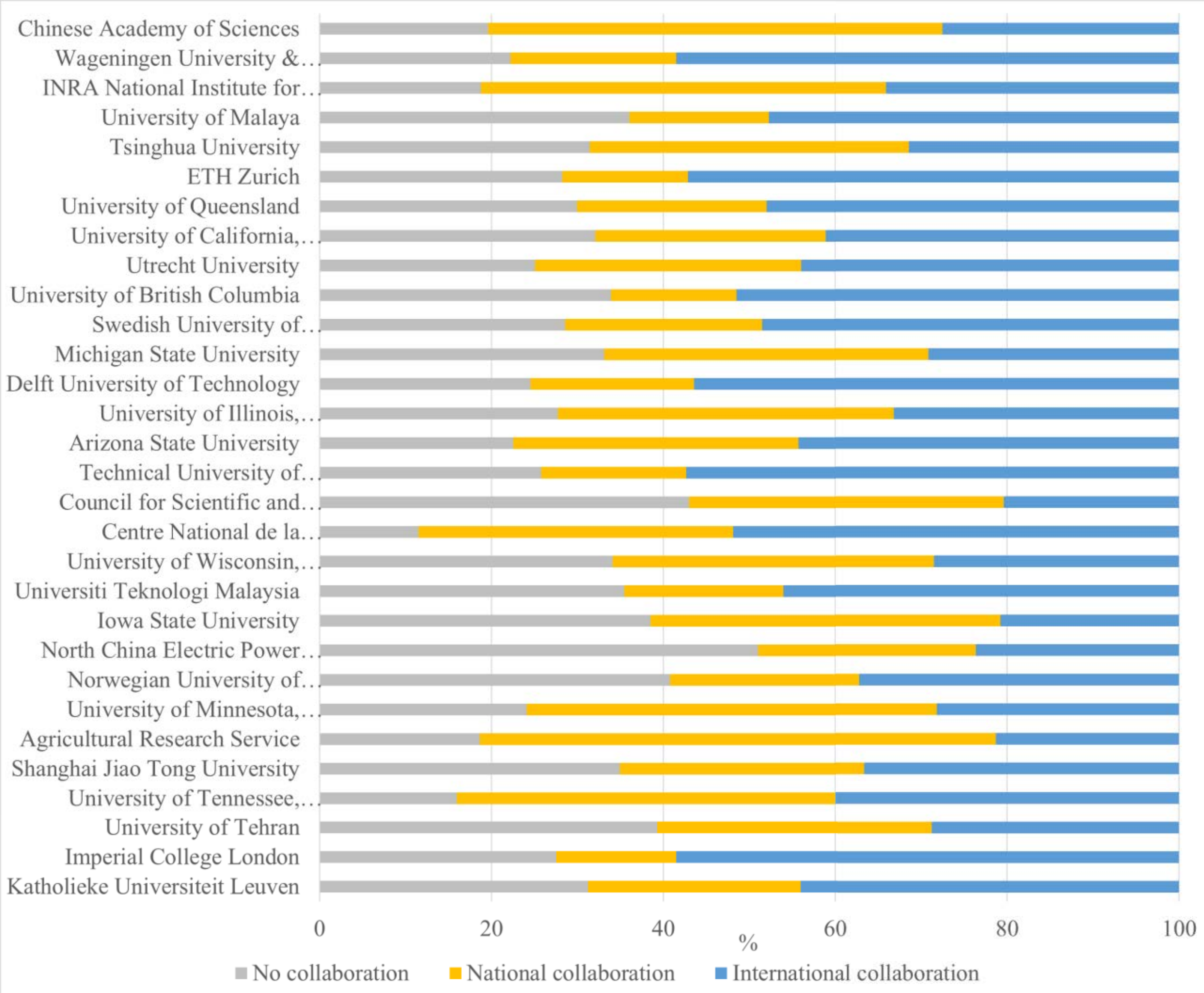


Figure 26. Distribution of the patterns of collaboration in the top 30 institutions by scientific production (2008–2017).

Source: Compiled from the CWTS in-house WoS database.

Figure 27 shows the patterns of collaboration by HEIs. On the basis of these results, 294 institutions are below the average with international collaboration (28.23%). From these, seven HEIs present a percentage of international collaboration higher than 70%. This fact includes the following institutions from the following countries: the United Kingdom (University of Sant Andrews 75.96%; the University of Aberdeen, 74.15%; Aberystwyth University, 73.15%), Saudi Arabia (King Abdulaziz University, 93.62%; the King Saud University, 75.33%), Norway (the Norwegian University of Life Sciences, 72.93%) and Belgium (Université Catholique de Louvain, 71.57%). Regarding national collaboration, 176 countries are below the average of 28.45%. The HEIs that present a higher proportion of documents with national collaboration are located in the following countries: the United States (University of Idaho, 63.71%; Mississippi State University, 61.36%; Clemson University, 52.21%), China (Beijing Institute of Technology, 60.51%; Lanzhou University, 52.42%), South Korea (Korea University, 55.06%) and France (AgroParisTech, 53.33%). About documents without collaboration, 20 countries are higher than the percentage average (45.60%). In this group, the leading position is held by the Indian Institute of

Technology Roorkee (66.49%), the Bucharest Academy of Economic Studies in Romania (64.50%), the University of Salamanca (63.73%), the University of Oviedo (51.54%) in Spain, and the North China Electric Power University in China (51.07%).

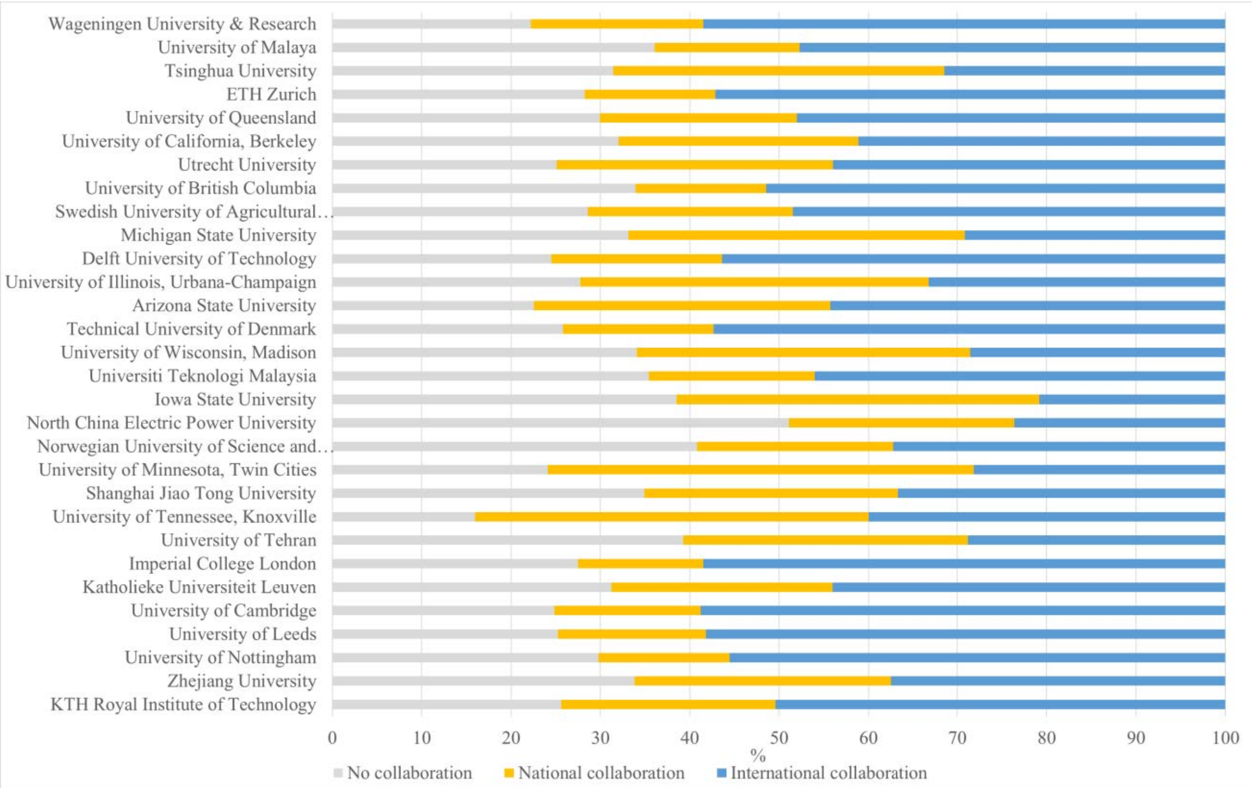


Figure 27. Distribution of the patterns of collaboration in the top 30 HEIs by scientific production (2008–2017).
Source: Compiled from the CWTS in-house WoS database.

4.1.3. Impact and visibility

4.1.3.1. Impact: Citation analysis

Table 22 displays the number of citations of sustainability dataset (P) and from the documents signed by HEIs (P[HEIs]). The number of citations is 1,275,833, with 167,525 self-citations (13.13%) in P, and 1,097,659 and 146,835 self-citations (13.38%) in P(HEIs). Following the classic distribution of citations, documents with a larger citation window receive a higher number of citations. That is, the variable citation window is used for each year. For instance, for documents from 2008, the citation window includes 2008–2017 (10 years), while for the documents in 2009 the window goes from 2009 to 2017 (9 years). Documents present more citations in previous years. For instance, P presents a higher number of citations in 2011 (n = 163,446), corresponding to a P(HEIs) peak in 2011 (n = 141,434).

Table 22. Number of Citations and Self-Citations of P and P(HEIs)

	P				***P(HEIs)***			
year	***n_cits***	***% cit***	***self_cits***	***% self_cits***	***n_cits***	***% cit***	***self_cits***	***% self_cits***

2008	128,974	10.11	10,606	8.22	107,318	8.41	8,973	8.36
2009	152,532	11.96	14,521	9.52	129,050	10.11	12,746	9.88
2010	161,945	12.69	16,840	10.40	140,247	10.99	14,541	10.37
2011	163,446	12.81	19,680	12.04	141,434	11.09	17,177	12.14
2012	156,744	12.29	20,388	13.01	134,132	10.51	17,772	13.25
2013	153,714	12.05	22,670	14.75	132,979	10.42	19,959	15.01
2014	140,876	11.04	22,650	16.08	122,780	9.62	20,050	16.33
2015	112,879	8.85	19,422	17.21	98,494	7.72	17,261	17.52
2016	78,515	6.15	14,712	18.74	68,195	5.35	12,933	18.96
2017	26,208	2.05	6,036	23.03	23,030	2.10	5,423	23.55
Total	1,275,833		167,525		1,097,659		146,835	

Source: Compiled from the CWTS in-house WoS database.

The distribution of the ratio of citations per document of P and P(HEIs) is shown in Figure 28. The average number of citations per document is higher, with documents signed by HEIs (P is 17.31 vs 18.56 in P[HEIs]).

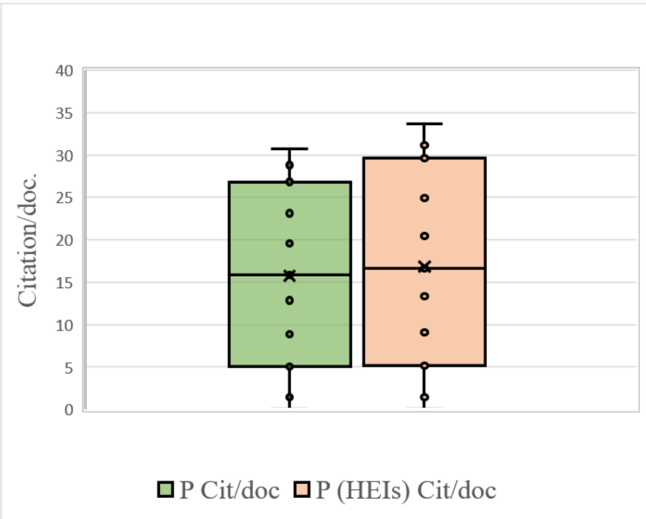


Figure 28. Distribution of the number of citations per document in P and P(HEIs).
Source: Compiled from the CWTS in-house WoS database.

Authors from the United States have gained the most citations, at 23.99% (*n* = 306,134), followed by China (*n* = 159,912, 12.53%), the United Kingdom (*n* = 139,962, 10.97%), Germany (*n* = 96,408, 7.56%) and the Netherlands (81,889, 6.42%). However, if we consider the number of citations per document (with documents of more than 100 documents), the results offer a different overview: 22.58 citations per document in Kenya, 19.53 citations per document in the Netherlands, 19.12 citations per document in Denmark and 18.13 citations per document in Malaysia. Regarding the percentage of non-cited articles, Vietnam (32.54%), Croatia (28.92%), Slovakia (26.05%), Ghana (25.32%) and Romania (25.12%) constitute the five countries with highest percentages (Table 23).

Table 23. Impact of the Publications (Number of Citations; Citations per Document and Non-cited Papers) by Top 30 Countries

Position	*Country*	*Citations*	*% Citation*	*Citation/doc.*	*Non-cited paper*	*% Non-cited*
1	United States	306,134	23.99	15.57	2,872	14.61
2	China	159,912	12.53	11.86	2,449	18.17
3	United Kingdom	139,962	10.97	15.85	1,092	12.36
4	Germany	96,408	7.56	16.93	779	13.68
5	Netherlands	81,889	6.42	19.53	455	10.85
6	Canada	77,563	6.08	15.62	691	13.91
7	Spain	76,428	5.99	14.45	771	14.58
8	Australia	75,709	5.93	13.92	757	13.92
9	India	71,031	5.57	14.94	765	16.10
10	Italy	58,451	4.58	13.33	579	13.20
11	France	56,510	4.43	14.62	543	14.05
12	Sweden	47,653	3.74	15.79	357	11.83
13	Malaysia	40,419	3.17	18.13	270	12.11
14	Denmark	32,279	2.53	19.12	204	12.09
15	Japan	30,991	2.43	13.50	364	15.85
16	Switzerland	28,306	2.22	17.48	216	13.34
17	Korea, Republic of	24,202	1.90	9.10	617	23.20
18	Belgium	23,595	1.85	17.00	160	11.53
19	Iran, Islamic Republic of	22,873	1.79	11.67	365	18.62
20	Brazil	22,701	1.78	9.92	465	20.31
21	Portugal	22,323	1.75	16.80	191	14.37
22	Turkey	22,108	1.73	11.80	323	17.24
23	Austria	18,501	1.45	15.15	148	12.12
24	Finland	18,306	1.43	11.92	190	12.37
25	Norway	17,724	1.39	13.41	197	14.90
26	Taiwan, Province of China	16,098	1.26	10.08	308	19.29
27	Greece	14,714	1.15	13.99	114	10.84
28	South Africa	13,416	1.05	10.90	246	19.98
29	New Zealand	11,479	0.90	12.38	165	17.80
30	Ireland	10,489	0.82	15.20	91	13.19

Source: Compiled from the CWTS in-house WoS database.

In analysis of the organizations that produce knowledge on sustainability, the most-cited institution is the Chinese Academy of Sciences (n = 35,593, 2,79%), followed by the Wageningen University and Research Centre (n = 25,527, 2%), the University of Malaya (n = 15,017, 1.18%) and the University of Minnesota, Twin Cities (n = 14,870, 1.17%). However, if we consider the citations per document, the organization with a highest value is the Max Planck Society (49.5 citations/document), followed by the Université Catholique de Louvain (47.19 citations/document), the University of East Anglia (47.04 citations/document), Princeton University (46.25 citations/document) and the University of Vermont (37.64 citations/document). If we consider the organizations with a higher percentage of documents that are not cited, the leading positions are held by Empresa Brasileira de Pesquisa Agropecuária (Embrapa)

(30.39%), China University of Geosciences (29.56%), Islamic Azad University Tehran Ambiguous (29.19%), the Wuhan University of Technology (28.85%) and Korea University (28.65%) (Table 24).

Table 24. Impact of the Institutions from the Publications by Top 30 Institutions

Position	*Institution*	*Citations*	*% Citation*	*Citation/doc.*	*Non-cited paper*	*% Non-cited*
1	Chinese Academy of Sciences	35,593	2.79	14.92	357	14.97
2	Wageningen University & Research Centre	25,527	2.00	21.33	140	11.70
3	University of Malaya	15,017	1.18	23.65	58	9.13
4	University of Minnesota, Twin Cities	14,870	1.17	35.49	54	12.89
5	Arizona State University	14,321	1.12	30.47	55	11.70
6	Stockholm University	12,432	0.97	33.51	37	9.97
7	University of California, Berkeley	12,273	0.96	22.23	52	9.42
8	ETH Zurich	12,245	0.96	21.08	52	8.95
9	INRA National Institute for Agricultural Research	10,945	0.86	13.27	105	12.73
10	Stanford University	10,878	0.85	28.78	42	11.11
11	University of Wisconsin, Madison	10,578	0.83	24.54	53	12.30
12	University of East Anglia	10,442	0.82	47.04	19	8.56
13	Utrecht University	10,288	0.81	20.02	48	9.34
14	University of Queensland	10,155	0.80	18.33	56	10.11
15	Technical University of Denmark	9,902	0.78	21.11	55	11.73
16	University of Oxford	9,719	0.76	27.77	40	11.43
17	Max Planck Society	9,702	0.76	49.50	18	9.18
18	Imperial College London	9,127	0.72	22.43	21	5.16
19	KTH Royal Institute of Technology	9,040	0.71	23.60	49	12.79
20	University of British Columbia	8,985	0.70	17.51	66	12.87
21	Australian National University	8,808	0.69	25.17	44	12.57
22	University of Illinois, Urbana-Champaign	8,667	0.68	18.21	54	11.34
23	Iowa State University	8,548	0.67	20.21	49	11.58
24	VU University Amsterdam	8,194	0.64	21.68	31	8.20
25	Delft University of Technology	8,152	0.64	17.09	51	10.69
26	University of Cambridge	8,077	0.63	20.29	43	10.80

27	University of Leeds	7,771	0.61	19.82	49	12.50
28	University of Nottingham	7,697	0.60	19.79	36	9.25
29	Michigan State University	7,508	0.59	15.64	70	14.58
30	Tsinghua University	7,483	0.59	12.19	95	15.47

Source: Compiled from the CWTS in-house WoS database.

The HEIs with the highest impact (in terms of citations) are the Wageningen University and Research Centre (n = 25,527, 2.33%), the University of Malaya (n = 15,017, 1.37%), the University of Minnesota, Twin Cities (n = 14,870, 1.35%), Arizona State University (14,321, 1.30%), Stockholm University (n = 12,432, 1.13%) and the University of California, Berkeley (12,273, 1.12%). On the other hand, regarding the number of citations per document, the organization with a highest value is the Université Catholique de Louvain (47.19 citations/document), followed by the University of East Anglia (47.04 citations/document), Princeton University (46.25 citations/document), the University of Vermont (37.64 citations/document), the University of Minnesota, Twin Cities (35.49 citations/document) and Ecole Polytechnique Federale de Lausanne (35.15 citations/document). Regarding the universities with a higher percentage of non-cited documents, the ranking is led by China University of Geosciences (29.56%), the Wuhan University of Technology (28.85%), Korea University (28.65%) and the University of Zagreb (27.73%) (Table 25).

Table 25. Impact of the Publications by HEIs

Position	***Institution***	***Citations***	***% Citation***	***Citation/doc.***	***Non-cited paper***	***% Non-cited***	***P***
1	Wageningen University & Research Centre	25,527	2.33	21.33	140	11.70	1,197
2	University of Malaya	15,017	1.37	23.65	58	9.13	635
3	University of Minnesota, Twin Cities	14,870	1.35	35.49	54	12.89	419
4	Arizona State University	14,321	1.30	30.47	55	11.70	470
5	Stockholm University	12,432	1.13	33.51	37	9.97	371
6	University of California, Berkeley	12,273	1.12	22.23	52	9.42	552
7	ETH Zurich	12,245	1.12	21.08	52	8.95	581
8	Stanford University	10,878	0.99	28.78	42	11.11	378
9	University of Wisconsin, Madison	10,578	0.96	24.54	53	12.30	431
10	University of East Anglia	10,442	0.95	47.04	19	8.56	222
11	Utrecht University	10,288	0.94	20.02	48	9.34	514
12	University of Queensland	10,155	0.93	18.33	56	10.11	554

13	Technical University of Denmark	9,902	0.90	21.11	55	11.73	469
14	University of Oxford	9,719	0.89	27.77	40	11.43	350
15	Imperial College London	9,127	0.83	22.43	21	5.16	407
16	KTH Royal Institute of Technology	9,040	0.82	23.60	49	12.79	383
17	University of British Columbia	8,985	0.82	17.51	66	12.87	513
18	Australian National University	8,808	0.80	25.17	44	12.57	350
19	University of Illinois, Urbana-Champaign	8,667	0.79	18.21	54	11.34	476
20	Iowa State University	8,548	0.78	20.21	49	11.58	423
21	VU University Amsterdam	8,194	0.75	21.68	31	8.20	378
22	Delft University of Technology	8,152	0.74	17.09	51	10.69	477
23	University of Cambridge	8,077	0.74	20.29	43	10.80	398
24	University of Leeds	7,771	0.71	19.82	49	12.50	392
25	University of Nottingham	7,697	0.70	19.79	36	9.25	389
26	Michigan State University	7,508	0.68	15.64	70	14.58	480
27	Tsinghua University	7,483	0.68	12.19	95	15.47	614
28	Universiti Teknologi Malaysia	7,280	0.66	17.09	47	11.03	426
29	Norwegian University of Science and Technology	7,278	0.66	17.37	53	12.65	419
30	University of Lisbon	7,090	0.65	18.76	53	14.02	378

Source: Compiled from the CWTS in-house WoS database.

4.1.3.2. Visibility: Documents in the first-quartile and top 3

One indicator related to the quality of the publications identified in the period is the number of documents in the first-quartile (1Q) according to the impact factor from the Journal Citations Reports (JCR). From the total of papers identified, 97,876 (94.96%) has quartile: from this group, 53,201 documents (54.36%) are in the 1Q. The higher percentage of 1Q documents is in 2017 (63.69%) and, considering the interannual growth, the higher the increase is from 2009–2010 (62.15%) and 2015–2016 (35.88%). The increasing evolution continues over the period, presenting a CAGR of 30.7%, denoting the significant increase of publications in the 1Q through all of the periods analysed (Figure 29).

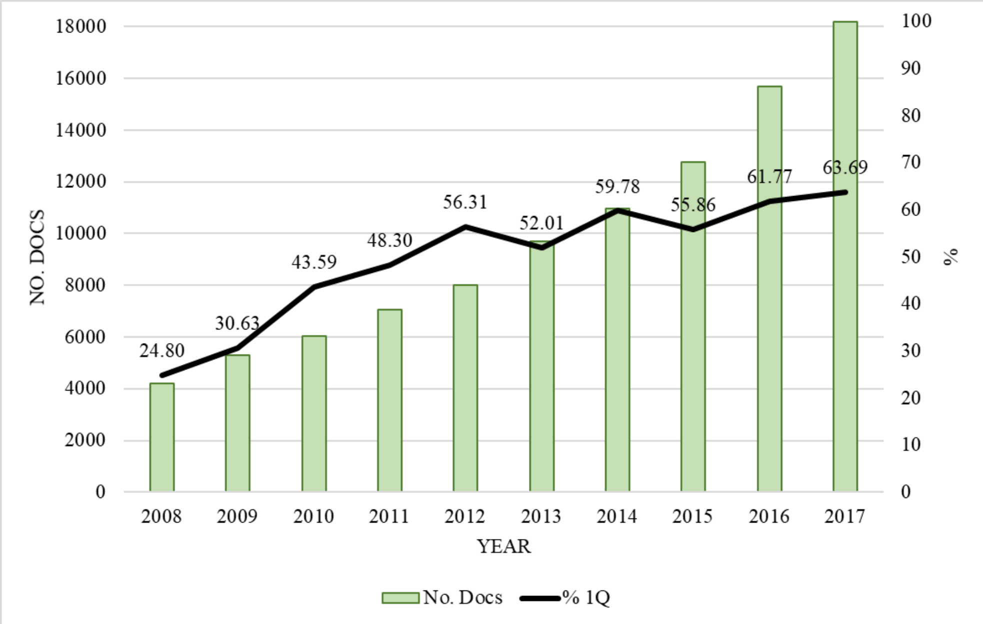


Figure 29. Evolution of the number of documents and percentage of 1Q documents (2008–2017). Source: Compiled from the IUNE and CWTS in-house WoS database.

Another indicator of quality is the percentage of Top 3 documents, which is to say, the number of documents in the three first positions in the JCR thematic classification. Overall, this dataset has 15,180 documents (15.51%) in the top 3. The CAGR presented in the period is 36.37%. The temporal evolution is regular (2008–2011) and even decreasing (2011–2014) in the first years of the analysis, with an important tendency to increase since 2014. This fact can be observed by assessing interannual growth, which shows the decline (28% from 2011–2012 and 12.62% from 2012–2013) and the major increase identified in 2014–2015 (433%). Following the same tendency as 1Q documents, the higher percentage of documents in the top 3 is also present in the last year of study, 2017 (31.24%) (Figure 30).

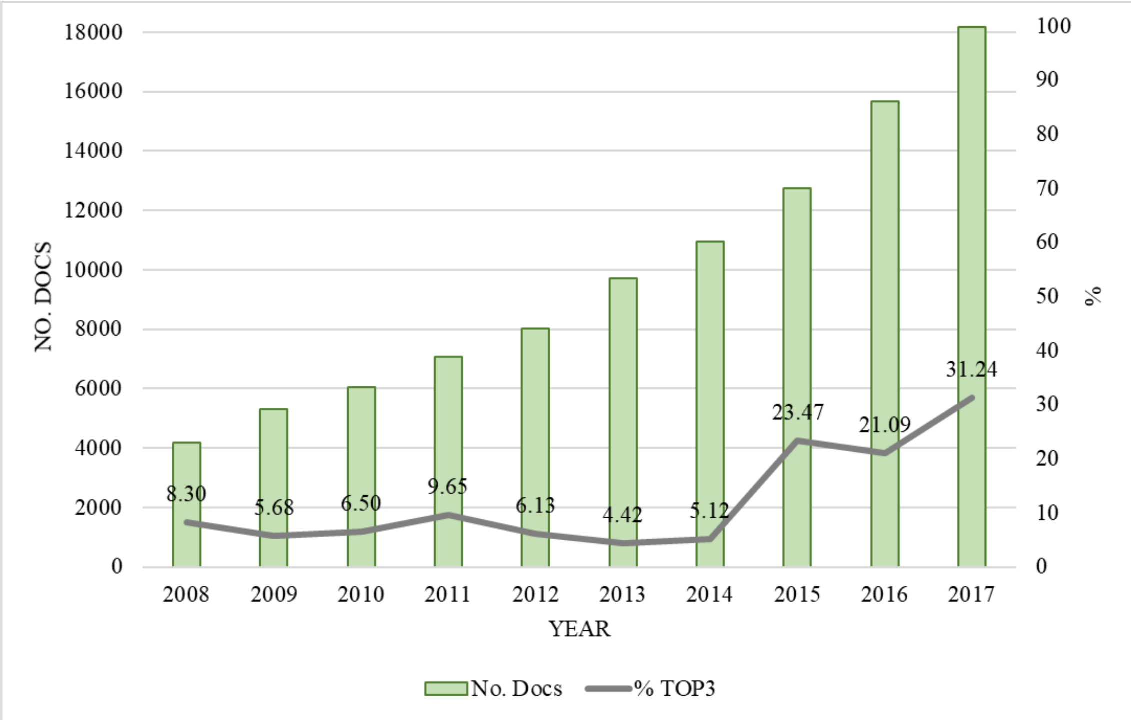


Figure 30. Evolution of the number of documents and percentage of top 3 documents (2008–2017). Source: Compiled from the IUNE and CWTS in-house WoS database.

4.1.4. Thematic analysis: Keywords

Burst is a concept associated with a "change of a variable's values in a relatively short time. In this framework, burst detection is an analytic method to find articles that receive particular attention from the related scientific communities in a certain period of time" (Zhou et al., 2018). In this section, the burst detection on the keywords of "sustainability research" is illustrated to show articles that have received rapidly increasing attention and citations. In this regard, "keyword citation bursts can show the emergence of topics in a certain field or journal". In the period analysed, there have been 42 different bursting keywords in sustainability scientific output according to CiteSpace software burst analysis. Table 26 lists these keywords with the strongest citations burst, with their strength and time span. In this sense, "burst strength is an indicator that denotes the change in usage frequency, which can be derived from the burst detection algorithm by Kleinberg" (Kleinberg, 2003). According to the data, the following terms have the strongest citation burst: "organization" (146.57), "ethics" (144.346), "industrial ecology" (131.58), "economics" (122.65), "CO_2 emission" (122.02), "energy consumption" (109.47) and "electricity" (103.55). However, if we check this information temporally, a different overview emerges. Keywords such as "risk", "environment", "Europe", "ecology", "sustainable development", "social responsibility" and "globalization", among others, have more importance at the beginning of the period (2008–2011). In contrast, terms like "CSR", "dynamics", "CO_2 emissions", "energy consumption" and "supply chain" have attracted attention more recently (2014–2017). In contrast, certain terms that have the longest time span bursts (in red), denoting that their concepts have seen keen interest during the sample period. That is the case for "environmental management" (2008–2014) and "politics" (2008–2015).

Table 26. Top 42 Keywords with the Strongest Citation Bursts

Keywords	*Year*	*Strength*	*Begin*	*End*	*2008 - 2017*
environmental management	2008	57.3243	2008	2014	
politics	2008	52.7475	2008	2015	
risk	2008	18.4753	2008	2009	
environment	2008	41.8215	2008	2009	
Europe	2008	91.6319	2008	2011	
ecology	2008	50.0681	2008	2009	
business	2008	66.1807	2008	2013	
economics	2008	122.6477	2008	2012	
ethics	2008	144.346	2008	2012	
firm	2008	64.6463	2008	2012	
industrial ecology	2008	131.5803	2008	2012	
globalization	2008	45.1204	2008	2009	
united states	2008	80.1694	2008	2012	
nitrogen	2008	48.1166	2008	2010	
financial performance	2008	38.4431	2008	2012	
sustainable development	2008	23.3011	2008	2010	
agriculture	2008	26.2472	2008	2010	
social responsibility	2008	90.1762	2008	2011	
australia	2008	77.4313	2008	2010	
organization	2008	146.5683	2009	2013	
switchgra	2008	57.7533	2009	2010	
biofuel	2008	51.7903	2009	2011	
responsibility	2008	50.1011	2009	2010	
fair trade	2008	52.3911	2009	2010	
turkey	2008	75.4565	2010	2011	
resilience	2008	36.9028	2010	2011	
education	2008	84.6828	2010	2011	
CO_2	2008	52.7935	2010	2011	
productivity	2008	47.8676	2011	2013	
landscape	2008	63.2955	2012	2013	
soil	2008	25.3507	2013	2015	
stakeholder	2008	71.0348	**2013**	2014	
CSR	2008	14.7502	**2014**	2017	
supply chain	2008	35.3985	**2014**	2017	
plant	2008	58.9793	**2014**	2017	
dynamics	2008	22.662	**2015**	2017	
integration	2008	84.7598	**2015**	2017	
energy consumption	2008	109.4729	**2015**	2017	
co2 emission	2008	122.0193	**2015**	2017	
city	2008	102.4317	**2015**	2017	
electricity	2008	103.5527	**2015**	2017	
waste	2008	74.7611	**2015**	2017	

Source: Elaborated by the author from CiteSpace.

"Analysis of keywords is an effective way to show emerging trends and hot topics of research over time because it gives a succinctness and accurate high-level summarization of a document" (Zhou et al., 2018). A timeline of yearly fluctuations in research specialties based on keywords and based on keywords and references together is offered in this section. The research specialties are created according to keywords using the log-likelihood ratio, and the clusters are arranged on a horizontal timeline and ranked by frequency in descending order (Chen, 2014). Table 27 and Figure 28 show the top 6 clusters based on references and keywords and show an overview of the development of a field. In this timeline, the references are shown as circles, and the red nodes contain references with high burst values. Moreover, large nodes are of particular interest, because they are highly cited or have citation bursts or both (Olmeda-Gómez, 2019). According to the visualization, the largest cluster is governance (#0), followed by biofuels (#1), CSR (#2), energy consumption (#3) and heterogeneous catalysis (#4); Table 27 summarizes the main keywords for each. According to the timeline, "policy" and "sustainability management" are significant keywords in the governance cluster (#1); "biomass", "impact", and "energy" for #2; "CSR" or "strategy" for cluster #3; "design", "model" or "system" for cluster #3; and "oxidation" or "carbon dioxide" for cluster #4. It can be observed that the second cluster (i.e., CSR) is a pioneering specialty, and the rest of the clusters were formed later. Moreover, it can be observed that some clusters are short-lived (e.g. biofuels cluster), while others last longer (e.g., governance).

This timeline was also calculated with only keywords (not references) in Table 28 and Figure 32. Some clusters created were the same as in the previous analysis (i.e., #1 biofuels, #2 CSR, and #3 heterogeneous catalysis), but additionally, new ones were created (#0 ecosystem services, #4 wind energy and #5fair trade). For these new clusters, the significant keywords identified are as follows: “policy” or “sustainability management” for #0 ecosystem services (this cluster is similar to #0, governance in Table 26, but has been tagged differently); “design”, “model” or “system” for #4 wind energy (similar to #3 “energy consumption”) and the not particularly remarkable keyword for #4, fair trade. In this overview, biofuels have a more long expansion over time and others like #fair trade are more short-lived.

Table 27. Clusters Based on Keywords and References on Sustainability Dataset (2008–2017)

Cluster	***Keywords***
#0 governance	management; sustainability; analysis; risk; source environmental; social; innovation; institutional; ecoinnovation
#1 biofuels	assessment; cycle; life; environmental; impact energy; biomass; supply; rotation; forestry
#2 CSR	corporate; social; responsibility; stakeholders; communication environmental; management; strategic; legitimacy; orientation
#3 energy consumption	energy; renewable; efficiency; development; policy solar; cycle; assessment; life; consumer
#4 heterogeneous catalysis	carbon; dioxide; kinetics; absorption; modelling acid; water; chemistry; ionic; liquid

Source: Elaborated by the author from CiteSpace.

Table 28. Clusters Based on Keywords on Sustainability Dataset (2008–2017)

Cluster	***Keywords***
#0 ecosystem services	management; sustainability; analysis; risk; source environmental; stakeholder; forestry; eden; narrative
#1 biofuels	energy; biomass; supply; willow; rotation assessment; cycle; life; environmental; production
#2 CSR	corporate; social; responsibility; stakeholders; communication environmental; management; legitimacy; orientation; strategic
#3 heterogeneous catalysis	chemistry; acid; water; ionic; liquid catalysis; heterogeneous; oxidation; hydrogenation; enzymes
#4 wind energy	energy; renewable; sources; engineering; technologies power; heat; biomass; simulation; bioenergy
#5 fair trade	trade; fair; ethics; coffee; networks environmental; standards; sustainability; eco-labels; karl

Source: Elaborated by the author from CiteSpace.

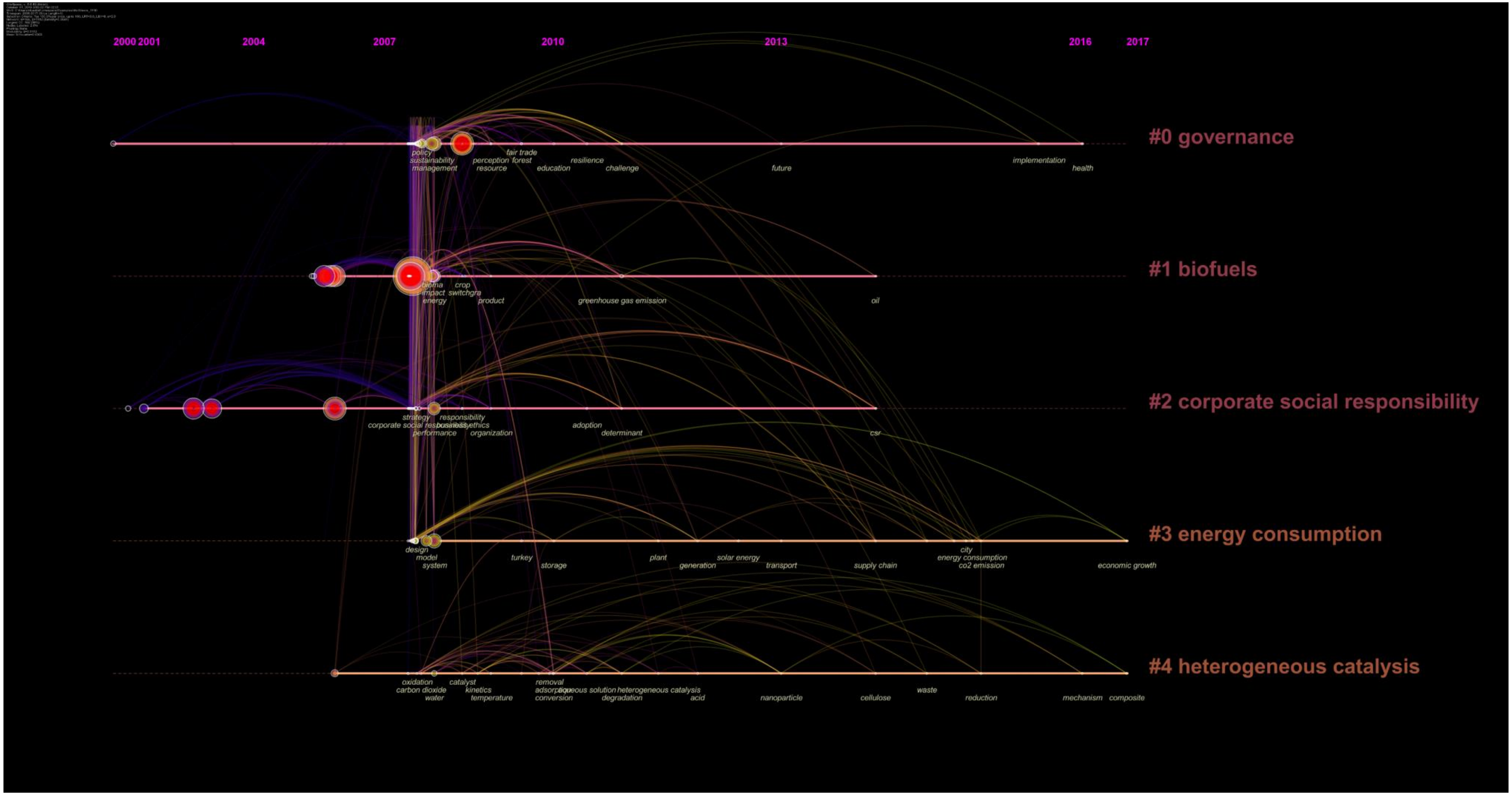


Figure 31. Horizontal timeline of research specialities (labels based on keywords and references in citing papers using the log-likelihood ratio).

Source: Elaborated by the author from CiteSpace.

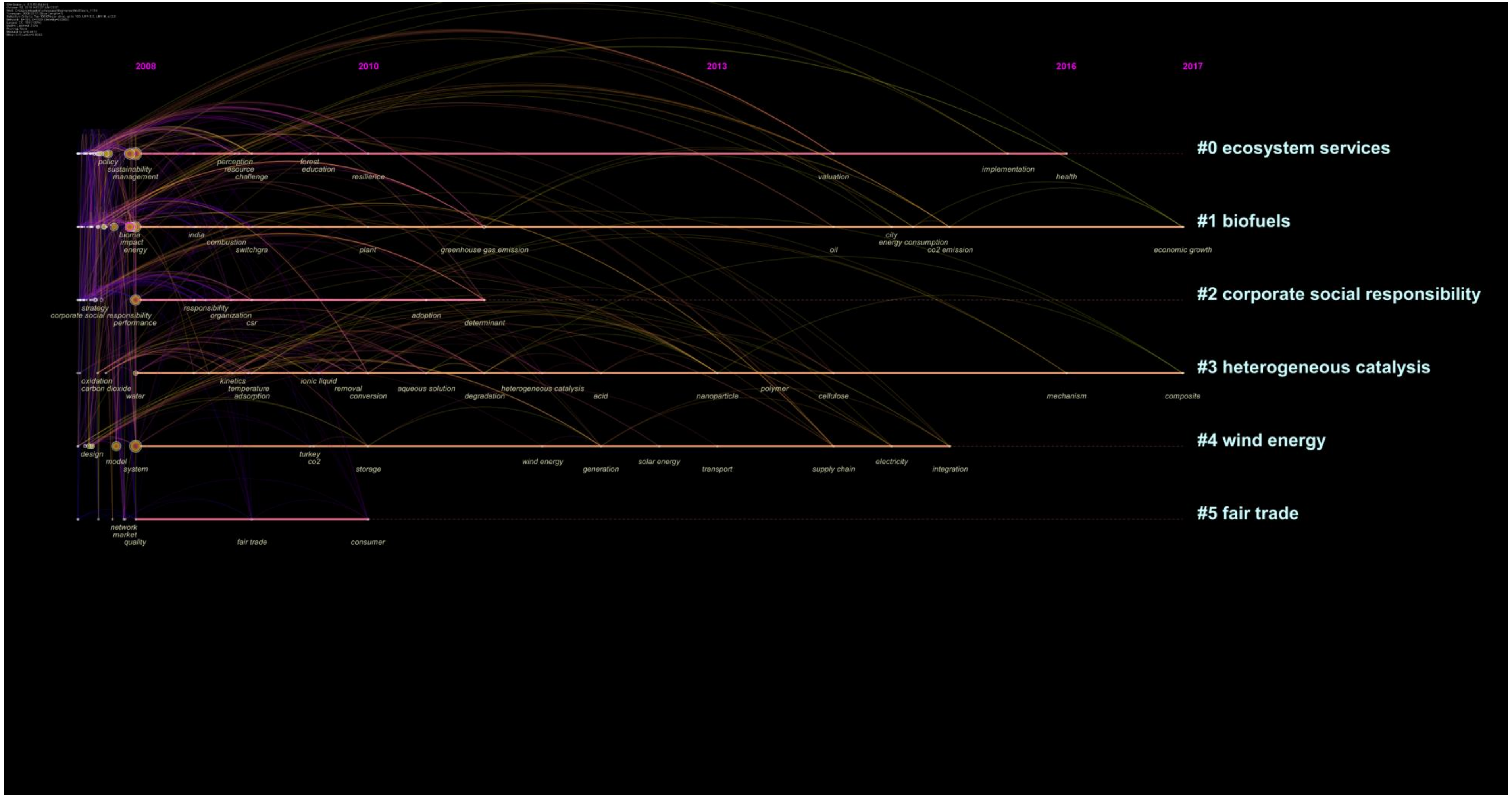


Figure 32. Horizontal timeline of research specialities (labels based on keywords in citing papers using the log-likelihood ratio).

Source: Elaborated by the author from CiteSpace.

4.1.5. Acknowledgments information

Acknowledgments in research publications express gratitude to the different entities who funded or contributed somehow to the research (Tang et al., 2017). These offer an overview of the funding landscape in which inputs and outputs form different researchers active in an area can be identified (Grassano et al., 2016). In addition, this information is considered one of the points of the reward triangle, along with authorship and citation (Costas and Leeuwen, 2012). Several studies have analysed acknowledgments patterns from different fields: medical (Butler, 2001); nanotechnology (Shapira and Wang, 2010) or library and information science (Zhao, 2010). Certain limitations have been highlighted from the literature as well: these acknowledgments are collected only when they include funding information (Costas and Leeuwen, 2012) or the lack of standardization (Grassano et al., 2016; Alvarez-Bornstein et al., 2017). Analysing the acknowledgments information in WoS allows us to explore the relationship between funding and research output. This information has been collected in WoS since 2009. From the sustainability dataset identified in this study, 40,782 documents (41.67%) have funding acknowledgments. This percentage is even higher in documents signed by university (44.03%). Observing the evolution over time, the CAGR of sustainability dataset rise to 46.03 over the period and 0.84 percentage points higher (46.87%) at HEIs. However, if we observe the percentage of the documents with funding acknowledgments regarding the total number of documents in the year, it can be observed the percentage is higher in recent years, denoting that more research explicitly indicates sources of funding. For instance, in 2017, the percentage of documents with funding acknowledgments was 54.17% P and 55.95% P(HEIs) (Table 29).

Table 29. Evolution of Documents with Funding Acknowledgments (FA) Evolution in P and P(HEIs) over the Period (2008–2017)

	P		***P(HEIs)***	
Year	***No. Docs with FA***	***%***	***No. Docs with FA***	***%***
2008	326	7.77	273	8.56
2009	1,279	24.15	1,095	26.46
2010	1,636	27.11	1,370	28.91
2011	2,227	31.50	1,902	33.57
2012	2,788	34.82	2,419	36.93
2013	3,664	37.73	3,176	39.76
2014	4,591	41.89	4,005	43.63
2015	6,245	48.95	5,546	51.23
2016	8,182	52.19	7,246	54.40
2017	9,844	54.17	8,679	55.95
Total	40,782	41.67	35,711	44.03

Source: Elaborated by the author from CWTS in-house WoS database.

Table 30 shows the main funding sources of this dataset, divided also by P and P(HEIs). A total of 1,632 funding sources have been identified for P and 1,597 for P(HEIs). Considering the sustainability output, the main sources are the National Natural Science Foundation of China, with 7,463 documents; the

Ministry of Science and Technology of China, with 3,433 documents; the European Commission, with 3,267 documents; and the Ministry of Education of China, with 2,524 documents. Regarding production at HEIs, results create a similar pattern: however, the European Commission (*n* = 2,903) and Ministry of Science and Technology of China (*n* = 2,868) switched their positions to the second and third place, respectively.

Table 30. Top 30 Main Funding Sources of P and P(HEIs) in the Period 2008–2017

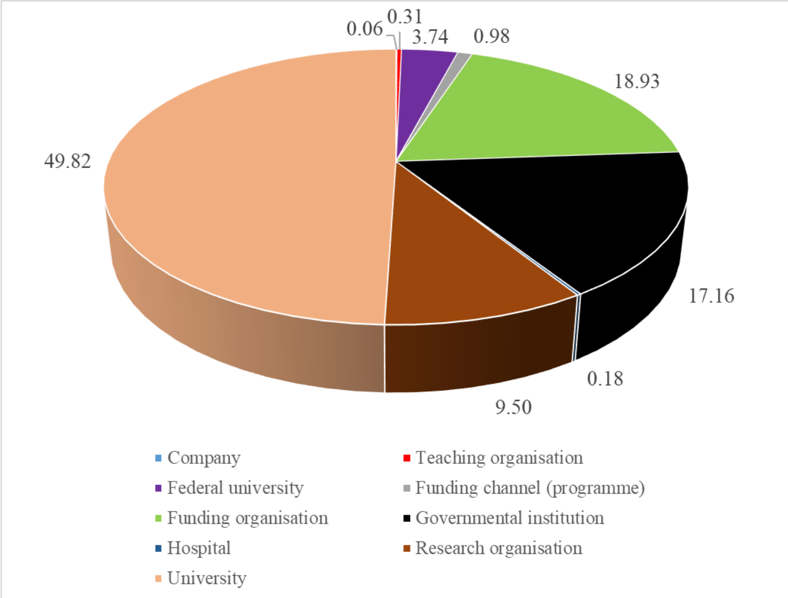
	P		**P(HEIs)**	
Position	***Funding source***	***No. docs***	***Funding source***	***No. docs***
1	National Natural Science Foundation of China	7,463	National Natural Science Foundation of China	6,502
2	Ministry of Science and Technology of China	3,433	European Commission	2,903
3	European Commission	3,267	Ministry of Science and Technology of China	2,868
4	Ministry of Education of China	2,524	Ministry of Education of China	2,463
5	United States Department of Energy	1,767	European Union	1,504
6	European Union	1,746	Government of Spain	1,485
7	Government of Spain	1,624	United States Department of Energy	1,415
8	National Science Foundation	977	National Science Foundation	948
9	Natural Sciences and Engineering Research Council of Canada	907	Natural Sciences and Engineering Research Council of Canada	889
10	Chinese Academy of Sciences	891	Engineering and Physical Sciences Research Council	850
11	Engineering and Physical Sciences Research Council	872	National Research Foundation of Korea	803
12	National Research Foundation of Korea	847	National Institute for Food and Agriculture	789
13	National Institute for Food and Agriculture	815	Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq	688
14	Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq	711	Foundation for Science and Technology Portugal	638
15	Foundation for Science and Technology Portugal	656	Coordenadoria de Aperfeiçoamento de Pessoal de Nível Superior	509
16	Ministry of Science and Technology of Taiwan	612	Ministry of Science and Technology of Taiwan	499
17	Ministry of Education	535	Ministry of Education	494

18	Coordenadoria de Aperfeiçoamento de Pessoal de Nível Superior	526	Chinese Academy of Sciences	483
19	Jiangsu Province	497	Jiangsu Province	479
20	United States Government	486	China Scholarship Council	460
21	Postdoctoral Science Foundation	483	United States Government	435
22	Department of Science & Technology	470	Postdoctoral Science Foundation	431
23	China Scholarship Council	469	Australian Research Council	430
24	Federal Ministry of Education and Research	468	Deutsche Forschungsgemeinschaft	428
25	United States Environmental Protection Agency	455	Japan Society for the Promotion of Science	409
26	Deutsche Forschungsgemeinschaft	453	Government of South Korea	387
27	Japan Society for the Promotion of Science	451	United States Environmental Protection Agency	387
28	Australian Research Council	436	Federal Ministry of Education and Research	379
29	Government of South Korea	421	United States Department of Agriculture	370
30	United States Department of Agriculture	399	Swedish Energy Agency	367

Source: Elaborated by the author from CWTS in-house WoS database.

Pie graphs from Figure 33 show the profile of the funding sources according to the CWTS organization classification. Similar patterns are reflected in both graphs. Universities are the main funding sources (49.82% in sustainability output P vs 50.16% in P[HEIs]), followed by funding organizations (18.93% P vs 19.10% P[HEIs]) and governmental organizations (17.16% P vs 17.53% P[HEIs]).

a)



b)

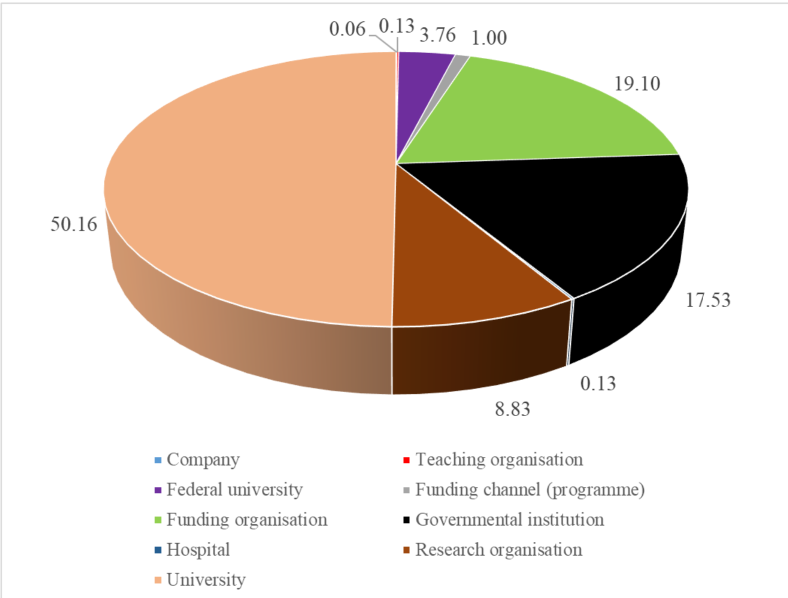


Figure 33. Funding sources of P (a) and P(HEIs) (b) in the period (2008–2017).
Source: Elaborated by the author from CWTS in-house WoS database.

4.1.6. Technological

4.1.6.1. Evolution of green patents in HEIs

Figure 34 presents the evolution of the volume of green patent families requested by universities (by the oldest priority) during the period of study. The number of families is 130,512. As can be seen, there is a growing tendency for innovative activity during the period. Only the patents growth in the period (2008 to 2017) rises to 209%. For applicant country of residence, in the top 50 the main producer is China (41 institutions), followed by Japan (3 institutions) and South Korea (2 institutions). The leading university is the University of Tsinghua (China) with 3,116 documents, followed by the University

Zhejiang (China) with 2,811 documents, University South China Tech with 2,029 documents and the University of Tianjin with 1,971 green patents requested (Table 31).

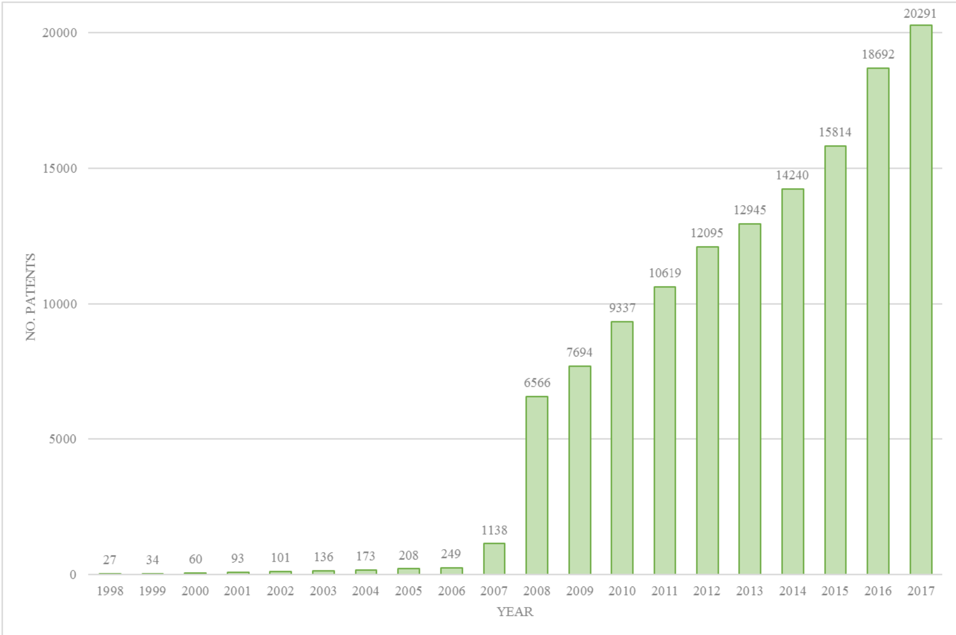


Figure 34. Evolution of green patents by the "oldest priority" in HEIs in the period.
Source: Elaborated by the author from EPO (2019)

Table 31. Applicant of Green Patents in HEIs

No.	***Applicant***	***Country***	***Docs.***
1	Univ Tsinghua	China	3,116
2	Univ Zhejiang	China	2,811
3	Univ South China Tech	China	2,029
4	Univ Tianjin	China	1,971
5	Univ Southeast	China	1,668
6	Univ Shanghai Jiaotong	China	1,601
7	Univ California	United States	1,294
8	Univ Kunming Science Tech	China	1,202
9	Univ Nanjing	China	1,190
10	Univ Dalian Tech	China	1,175
11	Univ Beijing	China	1,107
12	Univ Jiangnan	China	1,027
13	Univ Fudan	China	1,023
14	Univ Huazhong Science Tech	China	1,014
15	Univ Korea Res Bus Found	South Korea	975
16	Univ Tohoku	Japan	962
17	Univ Jilin	China	939
18	Univ Shanghai	China	900
19	Univ Xidian	China	897
20	Univ Shandong	China	890
21	Univ Beijing Technology	China	852
22	Univ Tongji	China	827
23	Univ Electronic Science Tech	China	796
24	Univ East China Science Tech	China	766
25	Univ China Petroleum	China	749
26	Univ Chongqing	China	725
27	Univ Wuhan Tech	China	717
28	Univ Peking Founder Group Co	China	691
29	Univ Central South	China	691
30	Univ Tokyo	Japan	678
31	Univ Jiangsu	China	676
32	Univ Xi An Jiaotong	China	670

33	Shenzhen Founder Microelectronics Co Ltd	China	657
34	Univ Shanghai Science Tech	China	601
35	Univ Yonsei Iacf	Korea	598
36	Univ Xiamen	China	589
37	Univ Guangdong Technology	China	588
38	Hon Hai Prec Ind Co Ltd	Taiwan	586
39	Univ Zhejiang Ocean	China	570
40	Univ North China Elec Power	China	570
41	Centre Nat Rech Scient	France	558
42	Univ Changzhou	China	555
43	Univ Sungkyunkwan Res Bus	South Korea	550
44	Univ China Agricultural	China	544
45	Univ Zhejiang Technology	China	539
46	Univ Taiyuan Technology	China	534
47	Univ Tianjin Commerce	China	525
48	Univ Osaka	Japan	523
49	Univ Zhejiang Normal	China	519
50	Univ Guangxi	China	509

Source: Elaborated by the author from EPO (2019)

Table 32 synthesis the IPC classes of the green patents selected. The great majority ($n = 47{,}481$ documents) are from IPC Class H01: fuel cells. In second place is inorganic chemistry (C01 class, $n = 22{,}155$), and in third, biochemistry (C12 class, $n = 15{,}460$).

Table 32. Documents IPC Class of the Green Patents Selected

No.	*IPC class*	*No. Documents*	*IPC class*
1	H01	47,481	Fuel cells
2	C01	22,155	Inorganic chemistry
3	C12	15,460	Biochemistry; beer; spirits; wine; vinegar; microbiology; enzymology; mutation or genetic engineering
4	F24	12,043	Heating; ranges; ventilating
5	B01	11,996	Physical or chemical processes or apparatus in general
6	A01	9,557	Agriculture; forestry; animal husbandry; hunting; trapping; fishing
7	H02	9,286	Generation, conversion, or distribution of electric power
8	C07	8,059	Organic chemistry
9	C10	7,102	Petroleum, gas or coke industries; technical gases containing carbon monoxide; fuels; lubricants; peat
10	F25	5,591	Refrigeration or cooling; combined heating and refrigeration systems; heat pump systems; manufacture or storage of ice; liquefaction or solidification of gases

Source: Elaborated by the author from EPO (2019)

4.1.6.2. Evolution of green patents in Spanish HEIs

This section focusses on Spanish HEIs. The overview is different. The evolution of Spanish HEIs presents a more irregular trend. A total of 534 patents have been identified over the period. The CAGR is negative over the period (3.91%). Table 32 summarizes the application of HEI of green patents in

Spanish HEIs. Six institutions are below 20 applications: Consejo Superior Investigaciones Científicas (CISC) (75), UPM (73), Universidad de A Coruña (UDC) (35), UPV (34), US (33) and UPC (22) (Table 33). The IPC classes are related to basic electric elements (C01, 133), basic electric elements (H01, 116) and physical or chemical processes or apparatus in general (B01, 101) (Table 34).

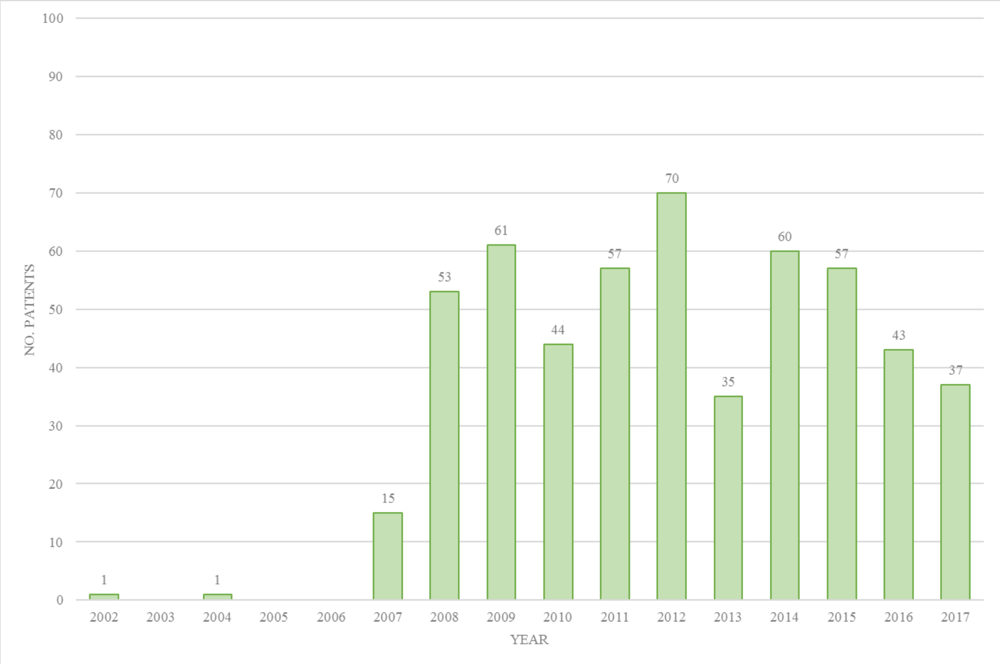


Figure 35. Evolution of green patents by date of priority in HEIs in the period. Source: Elaborated by the author from EPO (2019).

Table 33. Applicant of Green Patents in Spanish HEIs (<10 documents)

No.	*Applicant*	*Documents*
1	CSIC	75
2	UPM	73
3	UDC	35
4	UPV	34
5	US	33
6	UPC	22
7	UCA	18
8	UA	18
9	UCM	17
10	EHU	15
11	UAM	14
12	USC	13
13	CSIC	13
14	UNIZAR	12
15	UPM	12
16	UGR	11
17	UVA	10
18	UV	10
19	UPV	10
20	UNED	10

Source: Elaborated by the author from EPO (2019)

Table 34. Documents IPC Class of the Green Patents Selected

Value	*IPC*	*Group*	*Documents*
1	C01	Inorganic chemistry	133
2	H01	Basic electric elements	116
3	B01	Physical or chemical processes or apparatus in general	101
4	F24	Heating; ranges; ventilating	72
5	C12	Biochemistry; beer; spirits; wine; vinegar; microbiology; enzymology; mutation or genetic engineering	57

6	F03	Machines or engines for liquids; wind, spring, or weight motors; producing mechanical power or a reactive propulsive thrust, not otherwise provided for	51
7	C07	Organic chemistry	37
8	F25	Refrigeration or cooling; combined heating and refrigeration systems; heat pump systems; manufacture or storage of ice; liquefaction or solidification of gases	29
9	C10	Petroleum, gas or coke industries; technical gases containing carbon monoxide; fuels; lubricants; peat	29
10	A61	Medical or veterinary science; hygiene	29

Source: Elaborated by the author from EPO (2019)

4.1.7. Mathematical models applied to bibliometric indicators

As noted in the methodology section, a state-space model was applied to predict trends in different dimensions of the dataset analysed in this study.

4.1.7.1. Scientific output

Figure 36 shows the evolution of the sustainability dataset, as well as its division between environmental dataset and social and economic sustainability. Moreover, it presents a three-year prediction estimated by the model. As mentioned before (4.1.1. section), the overall CAGR is 17.78%: however, the major CAGR is in the environmental pillar (25.06%) in comparison with social and economic sustainability (9.85). For 2018–2020, the model predicts 62.36% growth. A 3-year prediction (2018–2020) is given by the model, considering the input (2008–2017) (represented with grey colour in the graph). This predicted trend (2018–2020) is even higher in environmental sustainability (91.73%) and is estimated to exceed 4,632 documents in 2020, in comparison to the main dataset. That is, the model estimates growth especially for environmental sustainability. Social and economic sustainability are projected to have a more moderate increase (15.65%) (Figure 36).

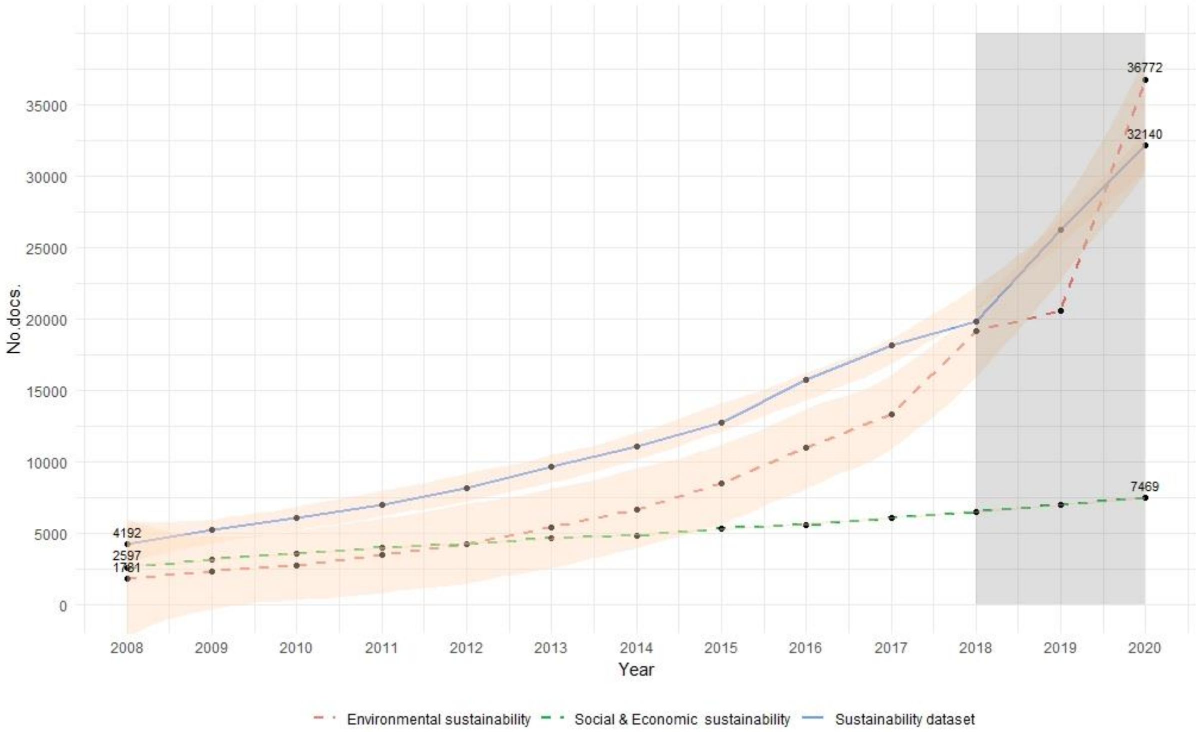


Figure 36. Evolution of sustainability dataset and pillars divided (environmental vs social and economic sustainability in 2008–2017) and 3-year prediction (2018–2020) (loess curve fitting; CI = 95%).
Source: Elaborated by the author from CWTS in-house WoS database and MATLAB software.

The mean residual error (i.e., a measure of model goodness of fit) varied from −105 to 80 for the sustainability dataset (−89 and 117 in environmental sustainability and −80 and 137 in social and economic sustainability) (Figure 37).

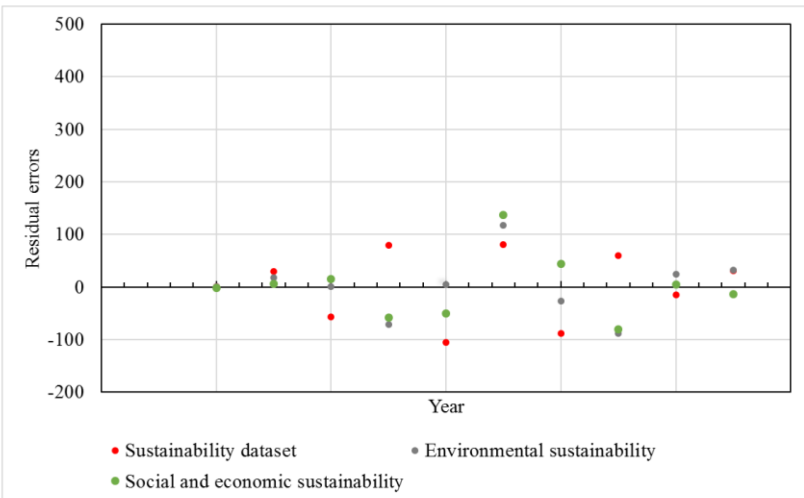


Figure 37. Residual error for the state-space model, 2008–2017.
Source: Elaborated by the author from CWTS in-house WoS database and MATLAB software.

4.1.7.1.1. Scientific output by countries

The model has also been tested for the scientific production of the top 10 countries with the highest output. The model predicts positive growth for 2018–2020 for the majority of countries, with two exceptions that present a negative tendency: the United States (−1.71%) and Australia (−4.58%). China is at the centre of the predicted growth in 2018–2020 (133.68%), followed by India (55.65%). The United Kingdom, despite its lower CAGR (13.78%), is predicted to have a positive growth trend (51.93%). The rest of the countries presented an increase of between 15–44% (Figure 38). Figure 39 summarizes the residual errors over the study period. These errors lie from −85 to 98. Canada (−6 to 7), United Kingdom (−12 to 22) and Spain (−17 and 18) present the lowest residual errors, attesting a good fit between the model and the data.

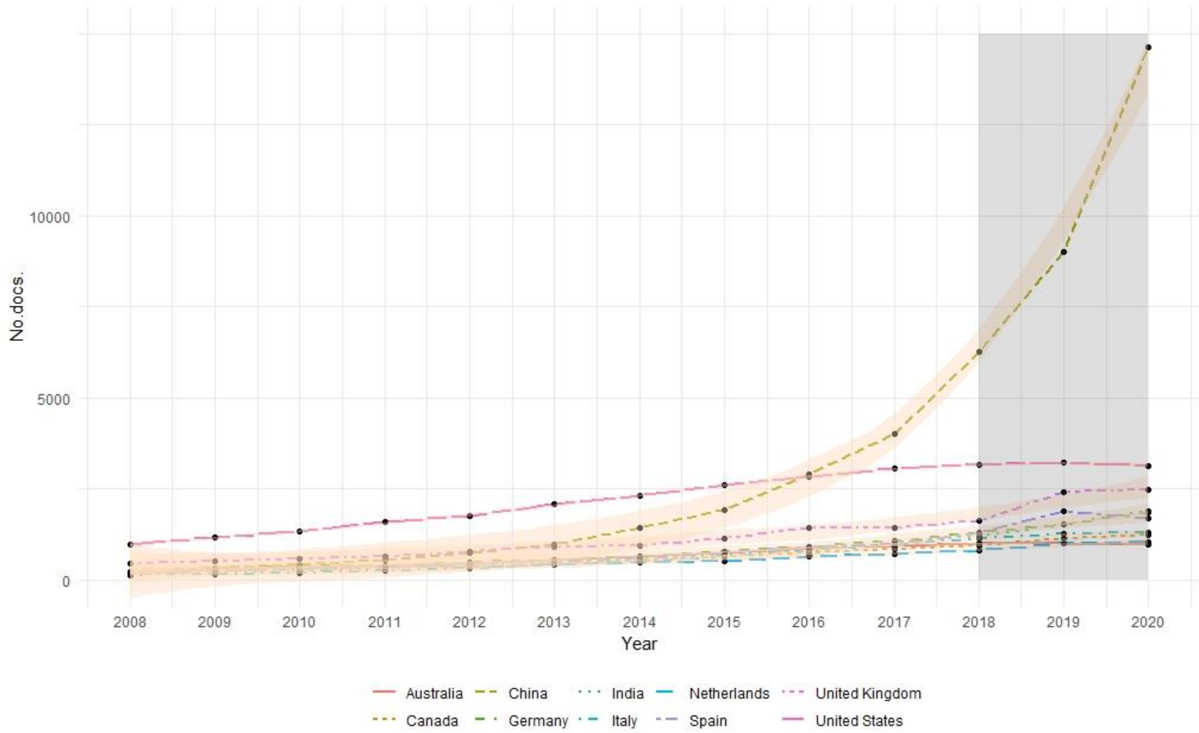


Figure 38. Evolution of top 10 countries and 3-year prediction (2018–2020) (loess curve fitting; CI = 95%).

Source: Elaborated by the author from CWTS in-house WoS database and MATLAB software

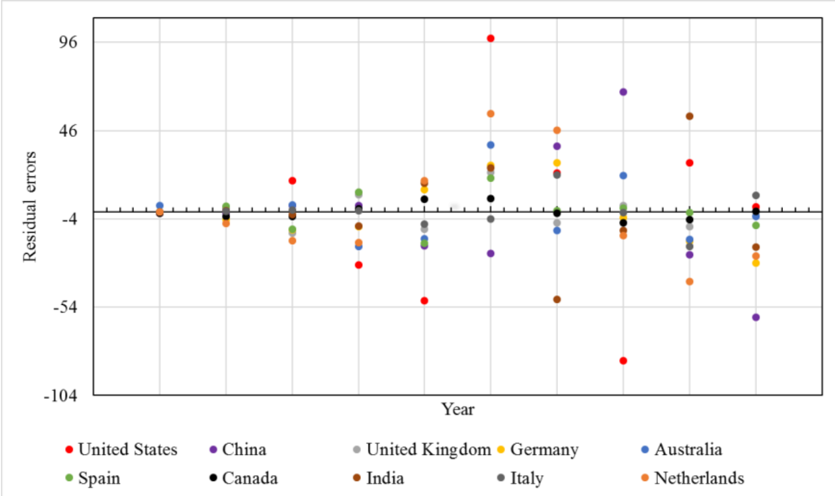


Figure 39. Residual error for the state-space model, 2008–2017.
Source: Elaborated by the author from CWTS in-house WoS database and MATLAB software.

4.1.7.2. Subject categories

Figure 40 shows the top 10 WoS categories (from 254 identified) scientific output evolution and a 3-year prediction (2018–2020). The major growth is expected to happen in "Chemical engineering" (1114%), "Environmental Studies" (183.34%) and "Environmental sciences" (93.58%). In contrast, economics, with a smaller CAGR over the period (0.81%), along with energy and fuels (CAGR, 22.19%), exhibit a negative trend (−8.8% and −2.8%) (Figure 41). In this case, the range of residual errors is broader (−221 to 266). The WoS categories business and economics are the most adjusted categories in the model, from −12 to 12 (Figure 42).

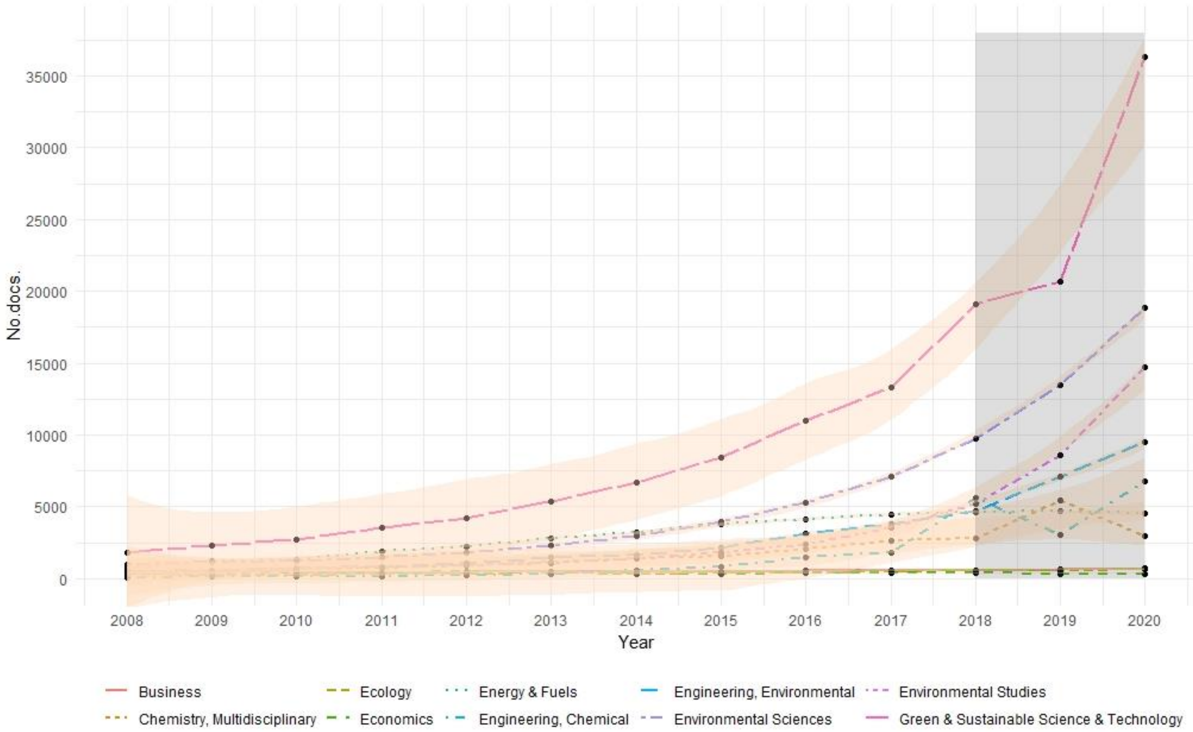


Figure 40. Evolution of top 10 subject categories and 3-year prediction (2018–2020) (loess curve fitting; CI = 95%).
Source: Elaborated by the author from CWTS in-house WoS database and MATLAB software.

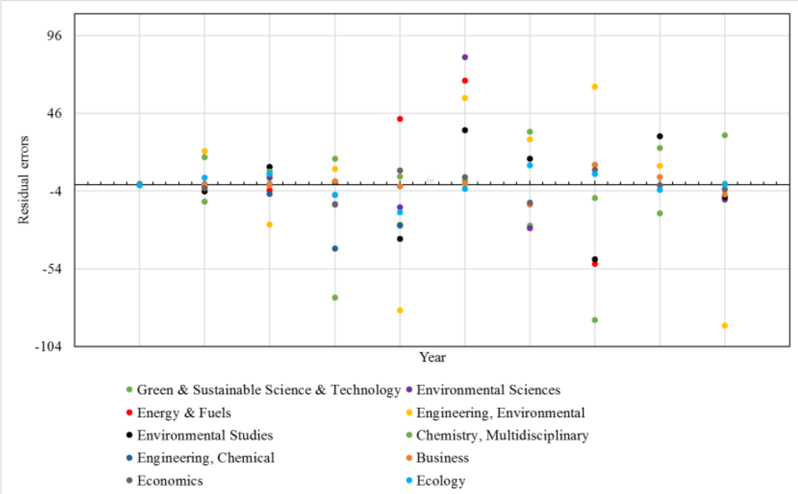


Figure 41. Residual error for the state-space model, 2008–2017. Source: Elaborated by the author from CWTS in-house WoS database and MATLAB software.

4.1.7.3. Collaboration

A state-space model is also applied to patterns of collaboration (national, international and no collaboration). Overall, with this time series, CAGR is higher in international collaboration (26.87%); the CAGRs of national collaboration and no collaboration are 21.33% and 11.97%. The estimated trend in 2018–2020 is higher for national collaboration (77.66%), international collaboration (61.77%) and documents with no collaboration (24.03%) (Figure 42). The model that presented the minimum residual errors is national collaboration (−52 to 47). The residual errors for international collaboration are −58 to 83 and for documents with no collaboration are −106 to 119 (Figure 43).

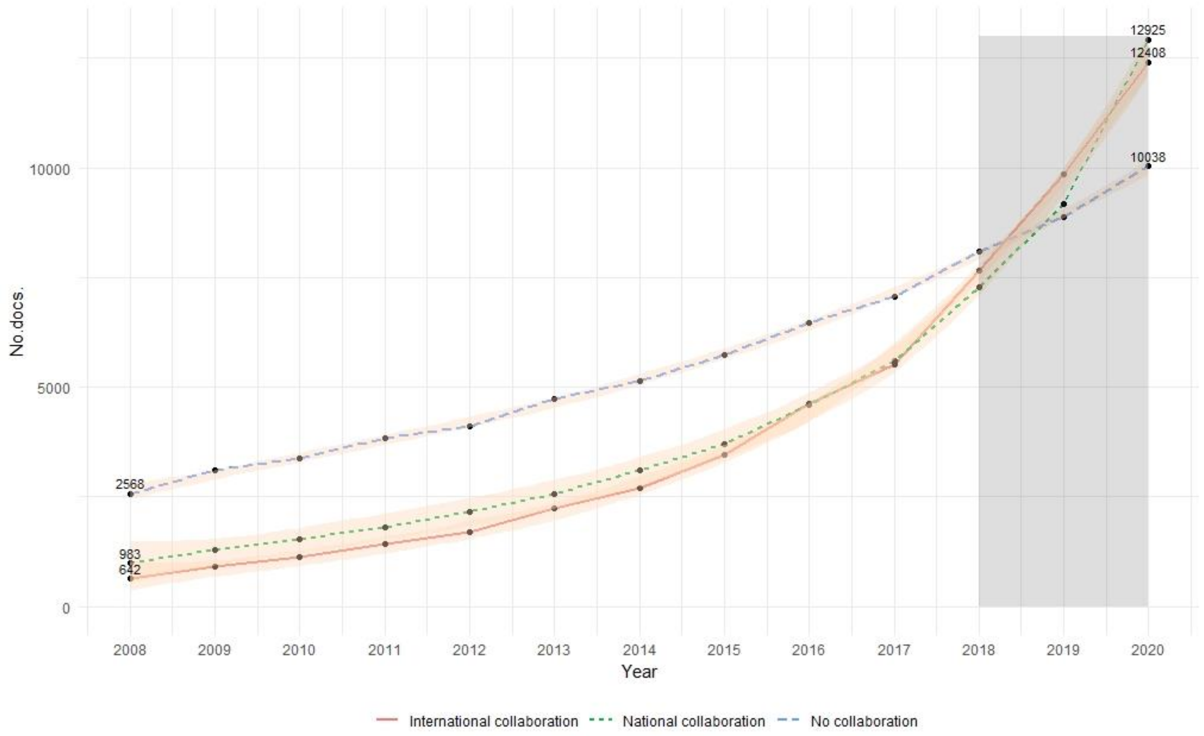


Figure 42. Evolution of national, international and no collaboration over 3-year prediction (2018–2020) (loess curve fitting; CI = 95%).

Source: Elaborated by the author from CWTS in-house WoS database and MATLAB software.

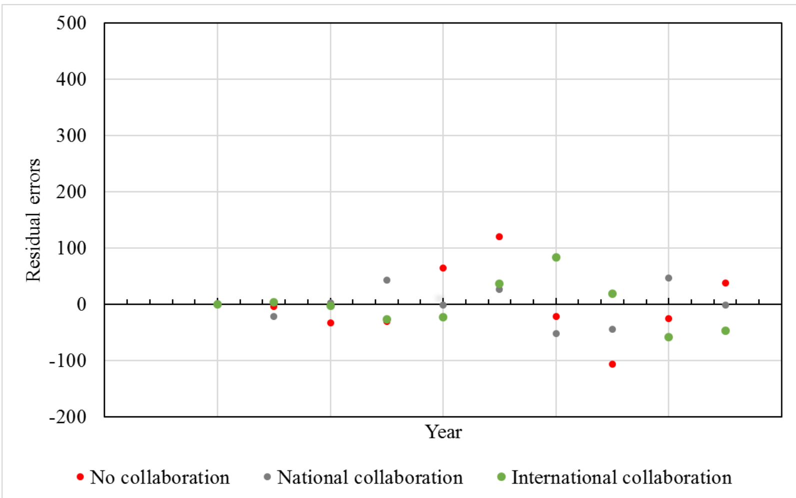


Figure 43. Residual error for the state-space model, 2008–2017. Source: Elaborated by the author from CWTS in-house WoS database and MATLAB software.

4.1.7.4. Visibility

The final dimension analysed with the state-space model is visibility and, more particularly, 1Q documents and top 3 documents. Considering the CAGR estimated (30.7 1Q vs 36.37% top 3), the highest estimated trend for 2018–2020 is 151.23% in the Top 3 (vs 54.3% in 1Q) (Figure 44). Residual errors (Figure 45) are relatively high (−1,026 to 979). That difference in pattern (i.e., with the model predicting lower values than actually observed in the time series) suggests that this indicator has a greater impact than expected.

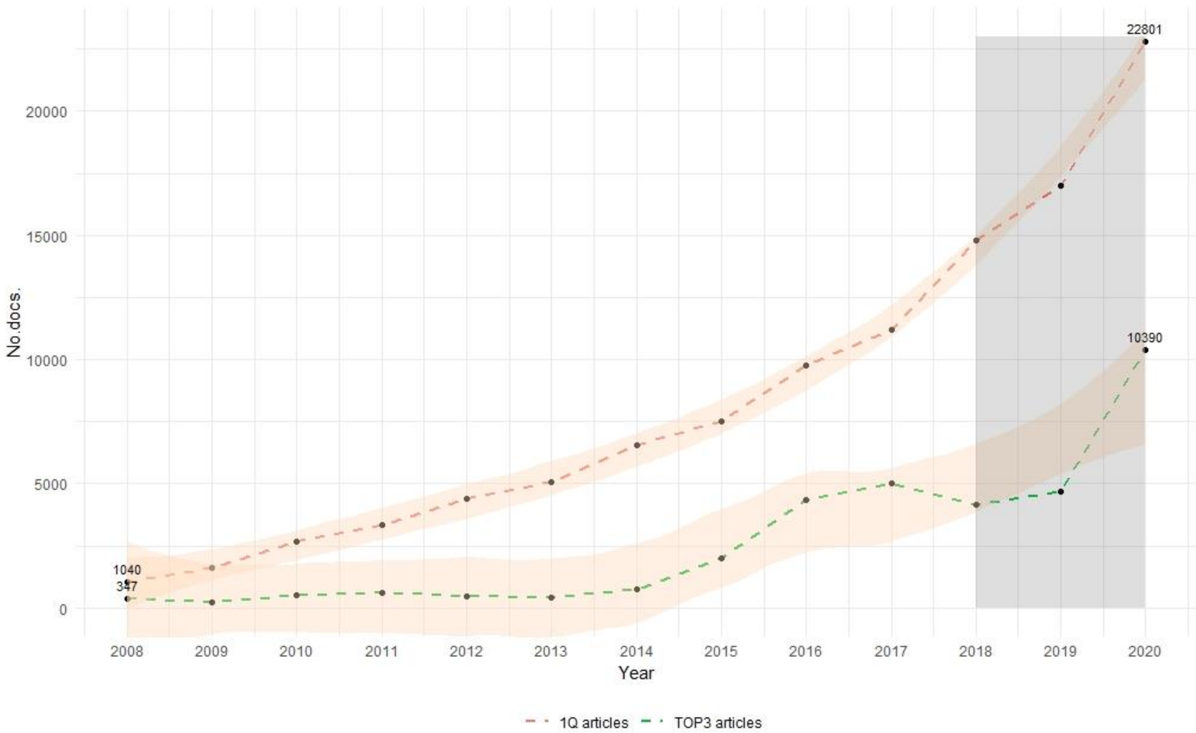


Figure 44. Evolution of first quartile (1Q) and top 3 documents and 3-year prediction (2018–2020) (loess curve fitting; CI = 95%).

Source: Elaborated by the author from CWTS in-house WoS database and MATLAB software.

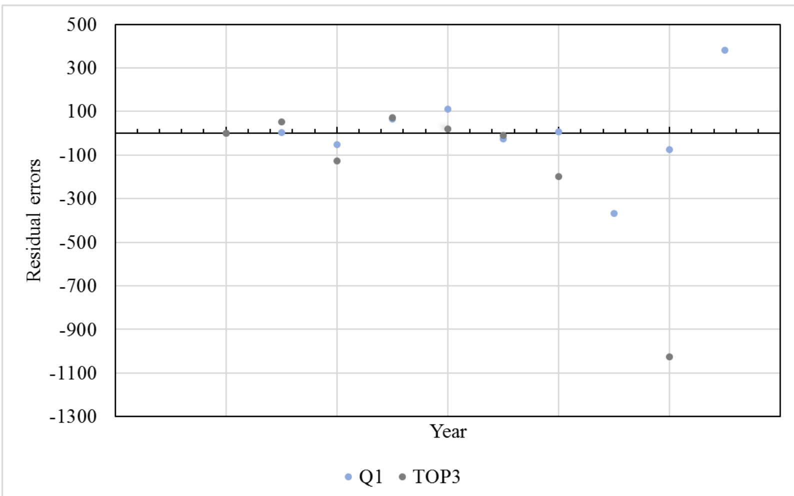


Figure 45. Residual error for the state-space model, 2008–2017.

Source: Own elaboration from CWTS in-house WoS database and MATLAB software.

4.1.7.5. Performance analysis

Before any conclusions can be drawn from the model results, the estimates must be validated. The values for RMSE, R^2, and r, given in Table 35, provide a measure of model accuracy. The 3-year predictions for scientific output and productivity were acceptably accurate: This accuracy circumstance was confirmed by the determination coefficient (R^2) that goes from 0.958 to 1. In other words, 95% of the variation in the state-space model estimates was explained by the observed values, denoting a very high correlation between the two (only 0.9% at most would be unexplained). Moreover, the mean Pearson's correlation coefficient for the four dimensions was 0.994, a value close to 1, which means the variables were linearly correlated. The RMSE, in turn, is a measure of the accuracy of model predictions. The findings show that the model predicts visibility (Top 3, RMSE = 498) and scientific output by WoS categories (e.g. "Business" category, RMSE = 464) least accurately (Table 35).

Table 35. Statistical Parameters for the State-Space Model Used

Dimension	*Indicator*	*RMSE*	R^2	*r*
Scientific output	Sustainability dataset	63.559	1.000	1.000
	Environmental sustainability	54.123	1.000	1.000
	Social and economic sustainability	57.783	0.997	0.998
Scientific output by countries.	United States	46.709	0.995	0.998
	China	33.374	0.999	1.000
	United Kingdom	9.851	0.999	1.000
	Germany	17.205	0.996	0.998
	Australia	16.916	0.995	0.998
	Spain	9.837	0.999	0.999
	Canada	4.241	1.000	1.000
	India	541.927	0.990	0.995
	Italy	516.474	0.999	0.999
	Netherlands	29.157	0.966	0.983
Subject categories	Green & sustainable science & technology	53.658	1.000	1.000
	Environmental sciences	61.317	0.999	1.000
	Energy & fuels	112.322	0.992	0.996
	Engineering, environmental	49.045	0.998	0.999
	Environmental studies	24.903	0.999	1.000
	Chemistry, multidisciplinary	16.443	0.999	1.000

	Engineering, chemical	111.931	0.970	0.985
	Business	463.844	0.990	0.995
	Economics	376.644	0.958	0.979
	Ecology	8.064	0.990	0.995
Collaboration	No collaboration	58.664	0.998	0.999
	National collaboration	31.495	1.000	1.000
	International collaboration	39.365	0.999	1.000
Impact	1Q	175.274	0.997	0.999
	Top 3	498.032	0.959	0.920

Source: Elaborated by the author from CWTS in-house WoS database, MATLAB and Xlstat software.

Higher education for sustainable development: The case of Spanish HEIs

This section intends to offer an overview of the commitment to sustainability in HEIs. While the documents retrieved offer a broad overview of universities worldwide, this section is focussed on Spanish HEIs. To analyse these HEIs' commitment to sustainability, the following sustainability elements based on reporting and assessment are analysed: internationalization (participation in GreenMetric ranking and participation in European projects), inclusion of sustainability in the strategic plans of the university or sustainability plans, a green campus and green offices at the university.

4.1.8. Internationalization

4.1.8.1. GreenMetric ranking

GreenMetric World University Ranking is a global sustainability ranking for universities developed by UI since 2010. The aim is "to provide the result of an online survey regarding the current condition and policies related to green campuses and sustainability in universities all over the world", and it is expected that by "drawing the attention of university leaders and stakeholders, more attention will be given to combating global climate change, energy and water conservation, waste recycling and green transportation". The ranking is worldwide and voluntary, and the procedure consists of submitting data by completing an online survey. It assesses the following six categories: setting and infrastructure, energy and climate change, waste, water, transportation and education. In comparison with the first edition, more indicators were added, and verification methods were included to check data validity, among others metrics of quality (Suwartha and Sari, 2013). The participation has increased from 95 universities in 2010 to 718 in 2018, an increase of 129.47%. The participation of Spanish HEIs has also been increasing since its creation. Thus, while in 2010 a total of five universities participated, in 2018, this figure amounts to 28, marking an increase of 460% (Table 36).

Table 36. Participation of Universities and Spanish HEIs in GreenMetric Ranking

Year	*Participation of universities*	*Spanish HEIs*

2010	95	5 (5.26%)
2011	178	6 (3.37%)
2012	215	8 (3.72%)
2013	301	14 (4.65%)
2014	361	21 (5.82%)
2015	407	22 (5.41%)
2016	516	27 (5.23%)
2017	617	27 (4.38%)
2018	718	28 (3.9%)

Source: Elaborated by the author from GreenMetric website.

Table 37 shows the Spanish universities that are on the ranking with its position by years. In addition, it shows the evolution of the position over time. In 2010, the university with best position (16th) was the Universidad Alcalá de Henares (UAH), followed by UPV in 42nd, Universidad de Valencia (UV) in 44th, la Universidad de Navarra (UNARRA) in 60th, and USC in 68th. Remarkably, at the national level, the UAH maintained its leadership from 2010 to 2014 with positions between 12 (in 2013) and 31 (in 2011), while in 2015 and 2016, the list was headed by the UAB, in positions 20 and 14, respectively.

Table 37. Position of Spanish Universities in GreenMetric Ranking with Its Evolution (Red = Decrease; Green = Increase; Yellow = Maintains Position)

HEIs	***2010***	***2011***	***2012***	***2013***	***2014***	***2015***	***2016***	***2017***	***2018***
UAB			88	126	45	20	14	50	37
UAH	16	31	31	12	28	37	26	16	16
UV	44	76	127	179	171	152	28	178	113
UAM				24	34	62	47	91	55
UB				90	111	112	59	180	127
UNIOVI					124	86	72	112	75
URJC					213	148	78	82	85
UJI				95	102	99	79	141	155
UDG							96	109	106
UPV	42	47	39	45	64	64	118	104	88
UCLM					210	174	127	273	240
UNAVARRA	60	145	135	187	250		132	130	104
UDC							149	87	94
UVIC							191	236	233
UVA					190	289	218	157	200
USAL					282	203	230	359	369
USC	68	125	95	96	150	210	234	283	269
ULPGC				176	228	245	247	237	224
UGR					295	237	248	417	302
URV				233	271	259	250	188	120
UMH						239	260	124	124
UA							262	330	392
UNIZAR					90	126	263	310	299
UVIGO						209	321	118	118
UIB					336	373	418	466	547
ULL				192	257	298	425	529	512
UJAEN		146	169	230	273	311	465	267	202
UPC			81	110				350	291

Source: Elaborated by the author from GreenMetric website.

Figure 46 shows a correspondence analysis between the universities with more than 70 documents with their score on the six areas of the GreenMetric Ranking 2018. The size of the nodes shows the number of documents according to the search strategy developed in this study. A high number of universities which also have a high number of documents were also closed associated with energy and climate change. This positioning can be interpreted as indicating a higher score in this area. Examples of these universities include the University of Nottingham, Hokkaido University and the University of Malaya. Regarding education and research, some universities that presented a higher score in this area were the University of Connecticut and Kyoto University. Prominent in the area of transportation were universities such as University Kebangsaan Malaysia or the University of Technology Malaysia. The categories “setting and infrastructure” and “water” are not closely associated with any universities. However, Stockholm University and King Abdulaziz University could be as associated with water, and Ferdowsi University of Mashad, with setting and infrastructure. The last area, waste, is closely linked to more universities. For instance, National Chiao Tung University and the University or Maribor are among ‘Waste’ score. Some universities are located in the centre, such as the University of Ottawa, denoting a similar score in all areas.

Figure 47 puts focuses on the 27 Spanish universities that appear on the 2018 ranking. Some universities, such as Universidad Jaume I (UJI) or Universidad de Navarra (UNAVARRA) are near to setting and infrastructure, with scores of 1,150 and 1,125, respectively; UAH has a score of 1,400; Universidad de las Illes Balears (UIB), 50; Universidad de Jaén (UJAEN), 1,075; and Universidad de Vic (UVIC), 900, close to transportation. Universidad de Girona (UDG) and Universidad Miguel Hernández (UMH) are close to the category “water”, with 600 and 775, respectively; Universidad de las Palmas de Gran Canaria (ULPGC) presents a score of 1,275, close to education and research. Universidad de Barcelona (UB), UV and Universidad Rovira i Virgili (URV), with scores of 1,200, 1,425 and 1,650, respectively, are close to waste. In this case, few universities are close to energy and climate change.

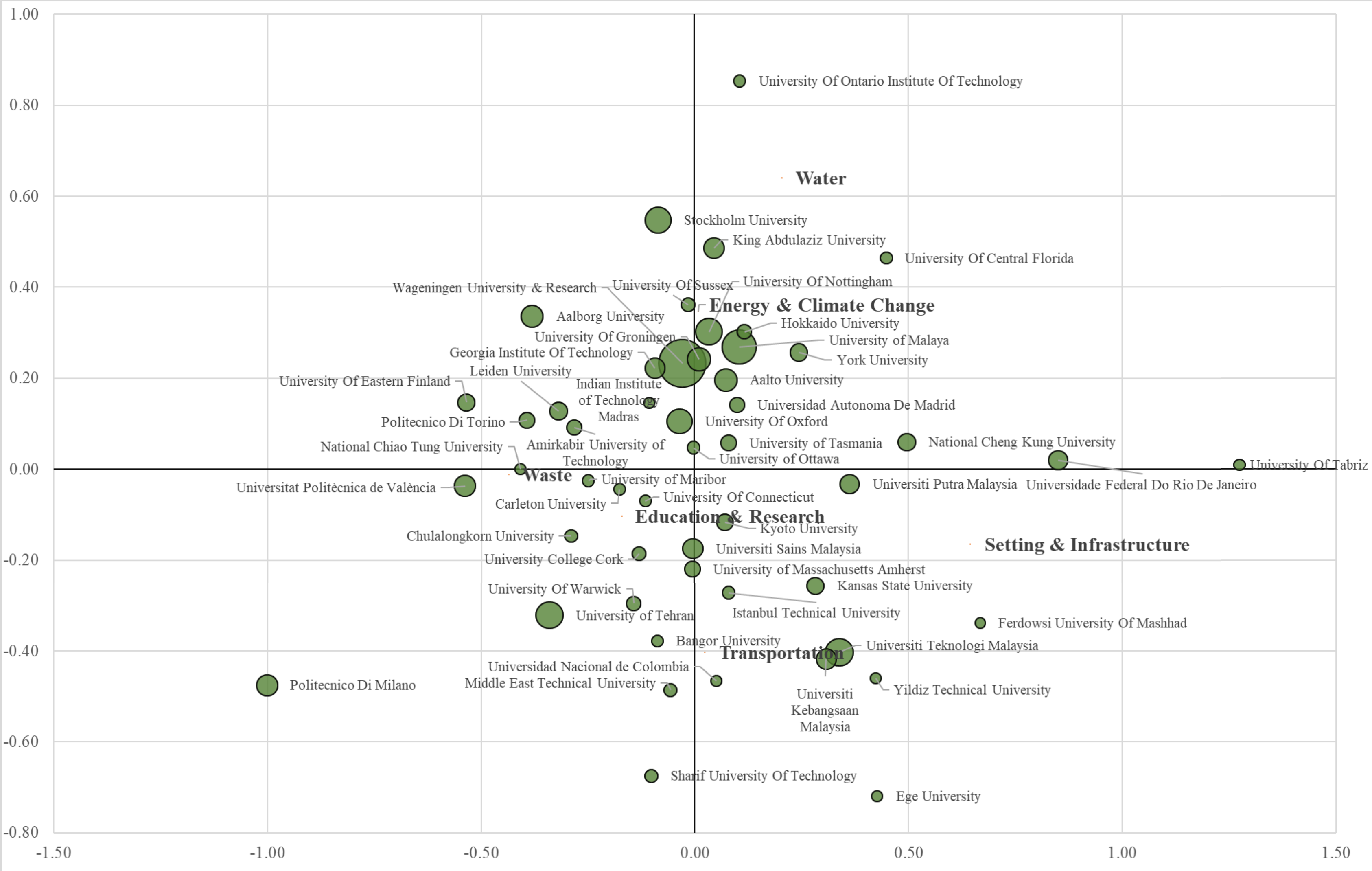


Figure 46. Correspondence analysis between the universities with more than 70 documents on the period and the areas of GreenMetric ranking 2018. Source: Compiled by the author from GreenMetric website.

Figure 47. Correspondence analysis of Spanish universities in GreenMetric 2018.

Source: Compiled by the author from GreenMetric website.

4.1.8.2. Participation in projects related to sustainability

The participation of HEIs in European projects has been analysed. In this regard, two programme frameworks that coincide with the period of study have been considered: FP7 (2007–2013) and FP8, more popularly known as the H2020 programme (2014–2020). Considering that sustainability is a transdisciplinary topic, a few representative subprogrammes for its relation with the topic have been selected in order to analyse the participation of HEIs. These programmes can be summarized as follows:
- *FP7: Cooperation-specific programme.* This sub-programme constitutes one of the principal building blocks of this programme. The subprogrammes selected are as follows:

- *Environment subprogramme.* This specific programme wanted to generate knowledge about "environment and climate change and identify environmentally friendly technologies, tools and services, with the aim to improve management of natural and man-made resources and address policy needs such as sustainability impact assessment of European Union policies".[49] It is composed of the following "activities and areas: climate change, pollution and risks; sustainable management of resources; environmental technologies and earth observation and assessment tools".
- *Energy subprogramme.* Energy systems were considered one of the main challenges considering the alarming trends in global energy demand. This program aimed to mitigate the consequences of climate change by establishing "more affordable energy costs or more efficient use of energies."[50]
- *Transport subprogramme.* Considering that transport is responsible for 25% of EU emissions of CO^2, the objective of this programme was to "transform the current energy system into one that is more sustainable and less dependent on fossil fuels."[51]
- *Social sciences and humanities subprogramme.* This subprogramme tackled socio-economic issues related to topics such as demographic change and quality of life; education and employment; cultural diversity and values, and so forth.

Within the H2020 programme, there are specific subprogrammes in which societal challenges and sustainability are addressed (called "societal challenges"). For the purposes of this study, we have selected the following subprogrammes:

- *The food security, sustainable agriculture, and forestry, marine, maritime, and inland water research, and the bioeconomy.* This programme arose with the need for a "transition towards a more optimal and renewable use of biological resources and towards sustainable primary production and processing systems". This system's

[49] Information extracted from the following link: https://cordis.europa.eu/programme/rcn/855/en.
[50] Information extracted from the following link: https://ec.europa.eu/research/fp7/index_en.cfm?pg=energy.
[51] Information extracted from the following link: https://ec.europa.eu/research/fp7/index_en.cfm?pg=transport.

purpose is to produce more food while minimizing inputs, environmental impacts, and so on.[52]

- *Secure, clean, and efficient energy*. The main aim of this subprogramme is to "support the transition to a "more reliable, sustainable and competitive energy system". In this regard, the main priorities were energy transition, low-carbon technologies or smart cities and communities.[53]
- *Smart, green, and integrated transport*. As described in the programme, this "Challenge aims to boost the competitiveness of the European transport industries and achieve a European transport system that is resource-efficient, climate-and-environmentally-friendly, safe and seamless for the benefit of all citizens, the economy and society". These activities are grouped by the following topics: "mobility for growth, automated road transport, small business and fast track innovation for transport."[54]
- *Climate action, environment, resource efficiency, and raw materials*. The activities of this subprogramme are intended to increase "European competitiveness, raw materials security and improve wellbeing while assure environmental integrity, resilience and sustainability with the aim of keeping average global warming below 2°C".

In the 7th FP, a total of 25,778 projects were identified.[55] A total of 1,841 projects were identified as considering the selected subprogrammes. The call that gas received the most for higher participation is transport, with 720 projects, followed by environment, with 494 projects; energy, with 374 projects; and 253 projects in the social sciences and humanities. Within this group, 1,495 of the projects have seen representation from at least one university involved as a coordinator or as partner.[56] The call in which HEIs have the most participation is transport, with 535 projects. If their participation is compared with the total number of projects in the call, HEIs have a significant presence in the social sciences and humanities, with 238 projects (94.07%), followed by the environment programme, with 437 projects (88.46%). Moreover, the number of Spanish HEIs has been checked. In this regard, Spanish HEIs have participated in 292 projects, with a higher weight in the social sciences and humanities, with 74 projects (31.1%) followed by 100 projects (22.9%) in the environment programme (Figure 48). The Spanish institutions involved with a higher number of projects are as follows: UPM with 50 projects, Universidad Autónoma de Madrid (UAM) with 30 projects, UPC with 25 projects and UB with 24 projects (Figure 48).

[52] Information extracted from the following link: https://ec.europa.eu/programmes/horizon2020/en/h2020-section/food-security-sustainable-agriculture-and-forestry-marine-maritime-and-inland-water.
[53] Information extracted from the following link: https://ec.europa.eu/programmes/horizon2020/en/h2020-section/secure-clean-and-efficient-energy.
[54] Information extracted from the following link: https://ec.europa.eu/programmes/horizon2020/en/h2020-section/smart-green-and-integrated-transport.
[55] The number of projects identified are from the Cordis Open Data Portal. FP7 projects are collected from the following link https://data.europa.eu/euodp/es/data/dataset/cordisfp7projects; H2020 projects are from here: https://data.europa.eu/euodp/es/data/dataset/cordisH2020projects.
[56] The query used to search the Universities involved were by searching 'Univ*'.

From this call, it should be mentioned there is a FP7-4-SD[57] website that monitors the contributions of FP7 to sustainability goals (and is related by experts to the SDGs). Despite that the interactive database and the information is no longer available, some results are available. For instance, in the different calls analysed in this section, environment and energy have a proportion of more than 85%, with a positive impact. Transport and the social sciences and humanities have a low proportion of topics assigned positively (62–68%).

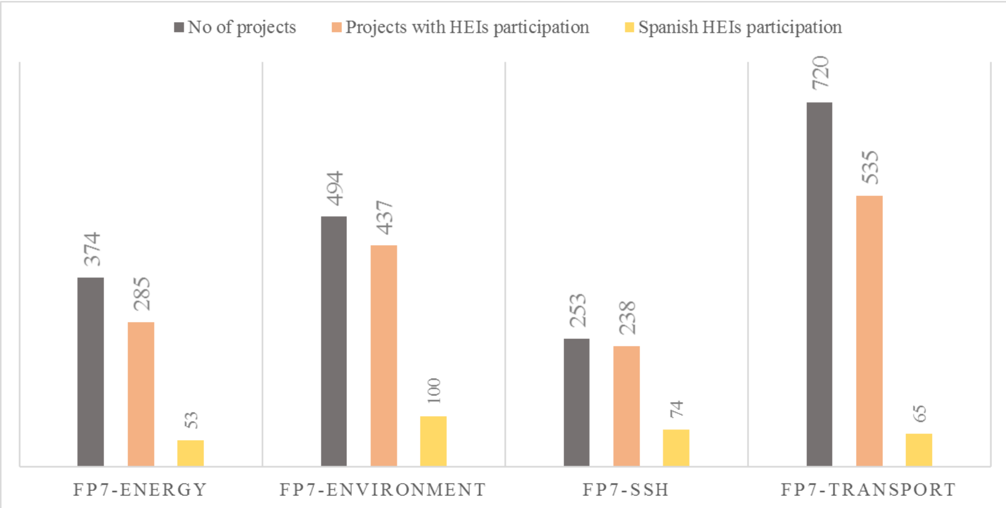


Figure 48. Number of FP7 projects on each programme and projects with HEIs participation. Source: Elaborated by the author from CORDIS website.

The topics of the projects have been analysed by using a subject index classification (SIC) code facilitated by CORDIS. This classification is composed by 71 terms (in German [de], English [en], Spanish [es], French [fr], Italian [it] and Polish [pl]) into different groups: industry and technology; energy; physical and exact sciences; biological sciences; agriculture and marine resources and products; measurements and standards; protecting humanity and its environment; social and economic concerns; and RTD horizontal topics.[58] This content analysis has been used for the Spanish HEIs' projects. Figure 49 shows its word cloud according to each one. The subjects more directly addressed by these organizations are environmental protection (92 projects), social sciences and humanities (65 projects), scientific research (51 projects), transport (40 projects) and policies (26 projects).

[57] Information on the platform for monitoring the contribution to the renewed EU SD strategy. Information available at https://www.fp7-4-sd.eu/fp7view.html#expert-filter accessed 7 December 2019.
[58] More information on this classification available at https://cordis.europa.eu/guidance_old/sic-codes_en.html accessed 7 December 2019.

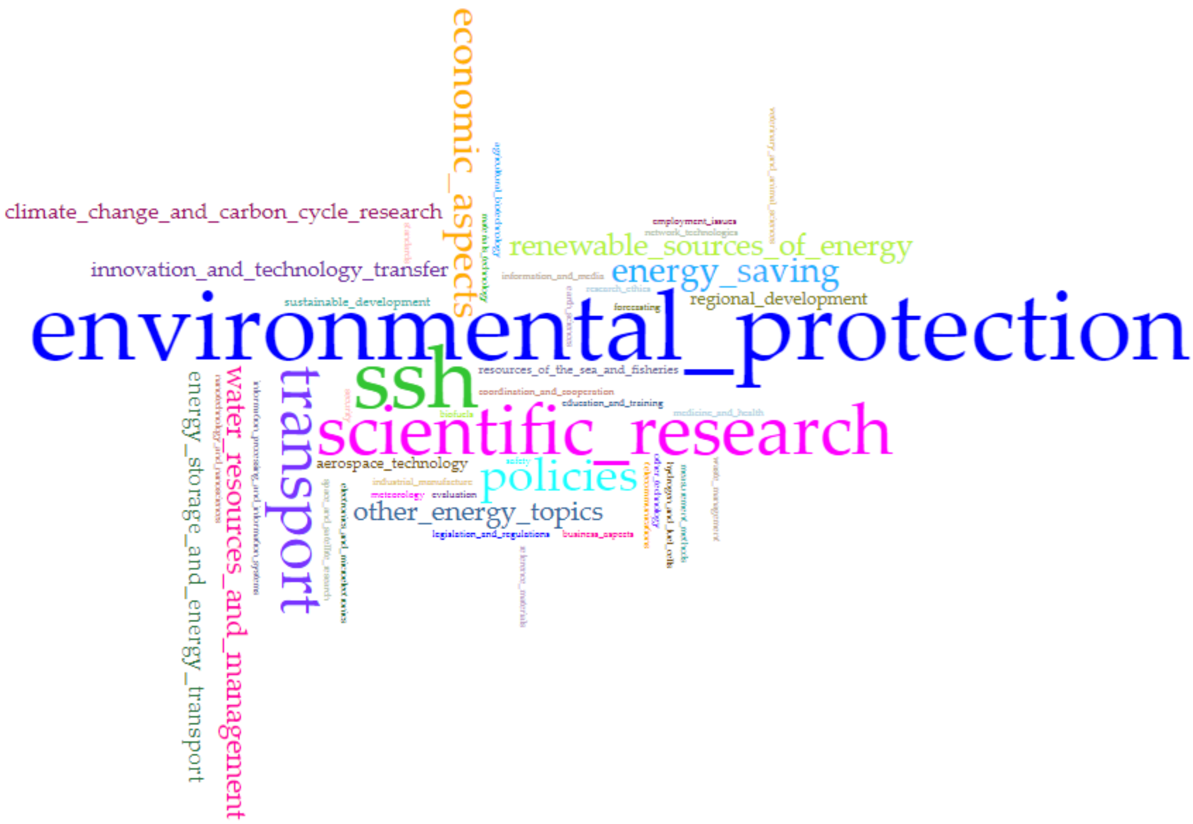


Figure 49. Word cloud of the SIC projects in Spanish HEIs from FP7.

Source: Elaborated by the author from CORDIS and VoyantTool website.

Regarding the H2020 programme, 25,019 projects are identified. However, the project continues. The differences of participation on the programmes selected, as well as the HEIs and the Spanish case, are shown in the Figure 50. From the subset of programmes selected, the one that has included more projects is 3.4. (smart, green and integrated transport) with 1,376 projects, followed by 3.3 (secure, clean and efficient energy) with 1,146 projects and 3.5. (climate action, environment, resource) and 3.2 (food security, sustainable agriculture) with 592 and 591, respectively. From this total, 3,705 involved one HEI. The calls for higher HEIs participation are answered with respect to food security programmes with 325 projects (54.99%) and to climate action with 267 projects (45.10%); the other two programmes selected (3.3. and 3.4) present a participation of HEIs close to 40%. Spanish HEIs participated in 336 projects (21.54% of the projects with HEIs participation). Technical universities led 116 projects (UPM, UPV, UPC). Subsequently, 22 projects were led by the US, 19 by the UAB, 16 by the USC, and 12 by the ULPGC (Table 38).

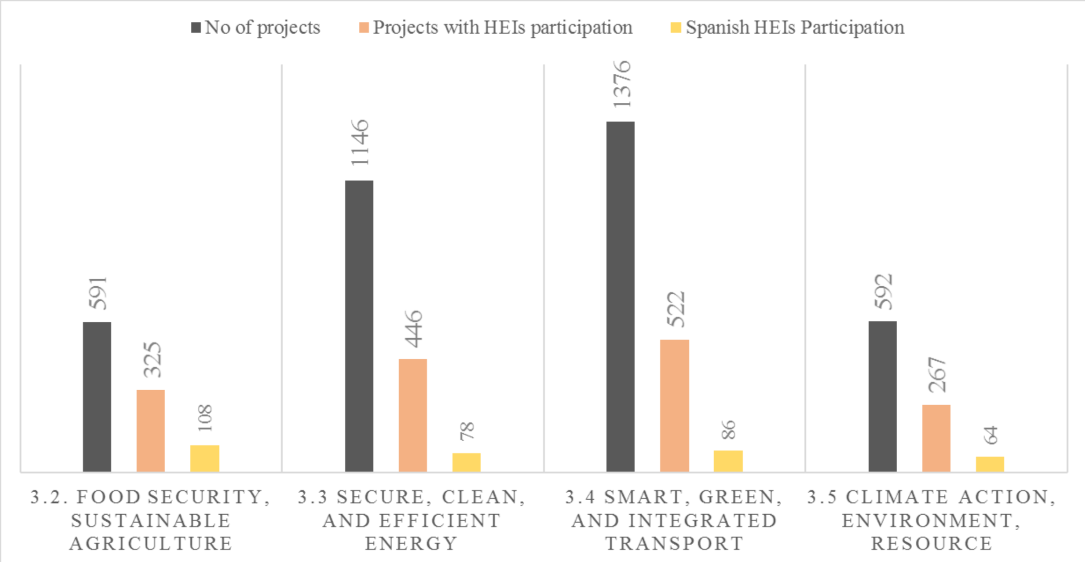


Figure 50. Number of FP7 projects on each programme and projects with HEI participation.

Source: Compiled by CORDIS.

Table 38. Spanish Universities Participating in FP7 and H2020 projects

HEIs	*FP7*	*H2020*	HEIs	FP7	H2020
UPM	50	47	URV	5	4
UPV	15	35	UM	3	4
UPC	25	34	UNAV	3	4
US	9	22	UNILEON	0	4
UAB	30	19	UVIGO	0	4
USC	6	16	UPCT	0	4
ULPGC	4	12	UNIOVI	7	3
UBU	24	11	UAM	5	3
UNICAN	8	11	UDC	5	3
UA	4	11	UIB	3	3
UCO	6	10	UCA	0	3
UV	10	9	UC3M	8	2
UDL	2	9	UJI	6	2
UAL	0	9	UAH	3	2
EHU	7	8	UMA	2	2
UDG	0	8	UBU	0	2
UCM	13	7	UCUENCA	0	2
COMILLAS	12	7	UMH	0	2
UCLM	7	7	USAL	2	1
UGR	12	6	UNAVARRA	2	1
UNIZAR	8	6	ULL	0	1
UVA	2	6	UPF	7	0
URJC	2	6	UPO	3	0
DEUSTO	3	5	UNED	2	0
			Total	325	377

Source: Elaborated by the author from CORDIS.

SIC codes were not available for these projects. In this case, the title and abstracts from the projects were analysed. The most frequently used words are as follows: "project" (frequency of 454 words), "energy" (406 words), "based" (340 words), "new" (329), and "European" (263).

Figure 51. Word cloud of H2020 projects with Spanish HEIs participation. Source: Compiled by CORDIS and VoyantTools.

4.1.9. University governance and assessment and reporting

4.1.9.1. Inclusion in strategic plans and sustainability plans

A strategic plan is a document that summarizes what an organization wants to accomplish in order to achieve its mission and vision. In this context, within this document HEIs are defined not only by their mission, vision, and scope but also their strategies of action. The great majority of Spanish universities have strategic plans published on their websites, more predominantly in public than in private universities. According to a Fundación Compromiso y Transparencia (Cavanna & Medina, 2017) report, in 2016, forty-one public universities (83.67%) had a public strategic plan, versus 12 private universities (46.15%). In our study, we have identified 58 HEIs that have strategic plans: 14 are private and 44 are public. Of those, 41 universities (35 public and 6 private) mentioned sustainability (Table 39). Some of them included this information in the sections devoted to their missions (Universidad de Alicante [UA], Universidad de Murcia [UMU]), Values (Universidad de Burgos [UBU], UMH, UV, Universidad Nacional de Educación a Distancia [UNED]), or as strategic axes (Universidad de Córdoba [UCO], UAB). It should be remarked that, despite "social responsibility" usually being considered synonymous with "sustainability" and "sustainable development", only sustainability mention has been considered the present work, since "social responsibility" is a broader term. Sustainability is mentioned in different ways: some highlighted environmental sustainability (Universidad Carlos III of Madrid (UC3M), UAH, UCO); others, economic sustainability (UJI). Still others mentioned the three pillars of sustainability.

However, the most often mentioned concept is "environmental sustainability". Another fact that should be highlighted is the limited mentions of the SDGs from some universities (e.g., UNED). In public universities, more commitment can be observed than in private universities (in private universities, only six mentioned sustainability in their strategic plans) (Table 39).

Table 39. Mention of Sustainability in the Strategic Plans of Public and Private Universities of Spain

Acronym	***Typology***	***Document revised***	***Mention (X = Yes)***
EHU	Public	Plan Estratégico (2012–2017)	X
UA	Public	Plan Estratégico (2014–2019)	X
UAB	Public	Plan Estratégico (2018–2030)	X
UAH	Public	Plan Estratégico (2014–2018)	X
UAL	Public	Plan Estratégico (2016–2019)	X
UAM	Public	Estrategia UAM 2025	X
UB	Public	* Not found	
UBU	Public	Plan Estratégico De La Universidad De Burgos (Estrategia En Materia Educativa UBU)	X
UC3M	Public	Plan Estratégico (2010–2015) Y Plan Estratégico (2016–2020)	X
UCA	Public	II Plan Estratégico De La Universidad De Cádiz 2015–2020	X
UCLM	Public	Estrategia UCLM 2020	X
UCM	Public	Plan Estratégico 2015–2019	X
UCO	Public	Plan Estratégico Uco 2016–2020	X
UDC	Public	Plan Estratégico de La UDC 2013–2020	X
UDG	Public	Udg2030 X	
UDL	Public	Pla Estrategic Udl 2013/2016	X
UGR	Public	Plan Estratégico Rrhh Pas 2016–2019	
UHU	Public	Plan 2010–2015	X
UIA	Public	Plan Estratégico 2010–2014	X
UIB	Public	Plantejament Estratègic UIB (2016–2019)	
UIMP	Public	* Not found	
UJAEN	Public	II Plan Estratégico De La Universidad De Jaén	X
UJI	Public	Pla Estratègic De La Universidad Jaume I 2018	X
ULL	Public	Plan Estratégico De La Universidad De La Laguna 2008	X
ULPGC	Public	Plan Estratégico Institucional De La Universidad De Las Palmas De Gran Canaria (2015/2018)	X
UM	Public	Plan Estratégico 2020	X
UMA	Public	Plan Estratégico 2009–2012	X
UMH	Public	Plan Estratégico 2016–2019	X
UNAVARRA	Public	IV Plan Estratégico 2016–19	X
UNED	Public	Plan Estratégico 2019–2022	X
UNEX	Public	Plan Estratégico 2014/2018	X
UNICAN	Public	Plan Estratégico 2019/2023	X
UNILEON	Public	Plan Estratégico En Materia De Transferencia De Conocimiento 2016–2018 Y Líneas Estratégicas 2017–2018	
UNIOVI	Public	Propuesta De Plan Estratégico 2018–2020	X

UNIRIOJA	Public	Plan Estrategico Internacional Horizonte 2020 (2014–2020)	
UNIZAR	Public	Plan Estratégico 2002–2005	X
UPC	Public	* Not found	
UPCT	Public	* Not found	
UPF	Public	Pla Estratègic 2016–2025 - Upf	
UPM	Public	* Not found	
UPO	Public	Plan Estratégico 2018–2020	
UPV	Public	Plan Estratégico UPV 2015–2020	X
URJC	Public	URJC Líneas Estratégicas 2014–2016	
URV	Public	II Pla Estratègic De Recerca I Innovació	X
US	Public	Plan Estratégico 2020	X
USAL	Public	Plan Estratégico General 2013 2018	X
USC	Public	Plan Estratégico De Desarrollo Sostenible (2003)	X
UV	Public	Plan Estratégico 2016–2019	X
UVA	Public	Plan Estratégico 2008–2014	
UVIGO	Public	* Not found	
CEU	Private	Plan Estrategico 2015–2019	
COMILLAS	Private	Plan Estrategico 2014–2018	X
DEUSTO	Private	Plan Estratégico DEUSTO 2022	X
IE	Private	* Not found	
MUNI	Private	Plan Estratégico 2017–2020	
NEBRIJA	Private	Plan Estratégico 2016–2022	
SANDAMASO	Private	* Not found	
UAO	Private	Plan Estratégico 2018–2022	
UAX	Private	* Not found	
UCAM	Private	Plan Estratégico	X
UCAVILA	Private	* Not found	
UCHCEU	Private	Plan Estratégico 2015–2019	
UCJC	Private	* Not found	
UCV	Private	* Not found	
UDIMA	Private	* Not found	
UEB	Private	* Not found	
UEC	Private	* Not found	
UEM	Private	* Not found	
UEMC	Private	* Not found	
UEV	Private	* Not found	
UFV	Private	* Not found	
UI1	Private	* Not found	
UIC	Private	Plan Estratégico 2015–2022	X
ULOYOLA	Private	Plan Estratégico	X
UNAV	Private	Iv Plan Estratégico 2016–2019	X
UNEATLANTICO	Private	* Not found	
UNIR	Private	Plan Estratégico	
UOC	Private	Plan Estratégico 2014–2020	
UPSA	Private	* Not found	
URL	Private	* Not found	
USJ	Private	Plan Estratégico 2015–2020	
UVIC	Private	* Not found	
VIU	Private	* Not found	

Source: Elaborated by the author from HEIs website.

Table 40 summarizes sustainability plans from public and private Spanish universities. Only official documents on the universities' websites were considered. Thirty-six public universities (72%) have sustainability plans, versus 6 private universities, denoting the increased activity of public universities on this topic. Regarding sustainability plans in public universities, there are different typologies: sustainability plans or action sustainability plans (UAH, Universidad de Salamanca [USAL], UPM, UAB, UCA, UAL, UB); transport or mobility plans (UGR, UPV, UNAVARRA); energy plans (UPC, UNIOVI); declarations from deans about university commitments (UC3M); and best practices guidelines (UIB, URJC). The main focus and actions are related to environmental sustainability. Examples of documents from private universities documents are as follows: "*Declaration of Environmental Sustainability of the University of Deusto*" (DEUSTO), the framework document for the sustainability and commitment from UIC Barcelona in sustainability policy (International University of Catalonia [UIC]), the Memory for sustainability (Ramon Llull University [URL]), and a sustainability plan (UVIC).

Table 40. List of Sustainability Plans Identified in Public Universities in Spain

Acronym	***Sustainability plans identified***
EHU	Two Reports "Memoria Dirección De Responsabilidad Social" (14/15 Y 15/16)
UA	Agenda 21; Plan De Movilidad Sostenible
UAB	Pla De Campus Saludable I Sostenible (2018–2022); Pla De Sostenibilitat 2013–2017; Plan De Acción Para La Sostenibilidad Ambiental 2011–2015
UAH	Plan De Sostenibilidad Ambiental (2017); Programa De Calidad Ambiental; Programa De Excelencia Ambiental (Pea)
UAL	Plan De Acción De Sostenibilidad Ambiental De La Ual (2018)
UAM	Agenda 21; Plan De Implementación De La Agenda 2030 Para El Desarrollo Sostenible En La Universidad Autónoma De Madrid
UB	Pla Ambiental Ub (2003–2004); Política De La Sostenibilidad De La Uab (2016); Plan De Sostenibilidad (2012) (With Monitoring Reports)
UBU	No information
UC3M	Declaración De La Política Medioambiental Del Rector
UCA	Plan De Sostenibilidad 2016/2017; Plan De Sostenibilidad 2017/2018; Politica Ambiental Uca 2006
UCLM	No information
UCM	Informe Preliminar Sobre Sostenibilidad En La Universidad Complutense De Madrid (2016); Plan De Movilidad Urbana Sostenible De La Ciudad Universitaria (Pmus-Cu); Plan De Movilidad Urbana Sostenible De La Ciudad Universitaria (Pmus-Cu)
UCO	Declaración De Política Ambiental De La Universidad Del Rector (2006 Y 2008); Plan De Gestión Integral De Residuos (2007); Sistema De Gestión Ambiental (2011)
UDC	No information
UDG	Pla Estratègic D'ambientalització (1998)
UDL	No information
UGR	Política De Movilidad Y Accesibilidad En La Universidad De Granada
UHU	No information
UIA	No information

UIB	Codi De Conducta Ambiental (1996)
UIMP	No information
UJAEN	Declaración De Política En Sostenibilidad Ambiental De La Universidad De Jaén (2014)
UJI	No information
ULL	No information
ULPGC	Política Del Sistema De Gestión Ambiental (2015); Política De Calidad Y Ambiental (2016)
UM	Programa De Gestión Ambiental De Campus Sostenible De Campus Sostenible (2007)
UMA	Sistema De Gestión Ambiental Uma
UMH	Plan De Calidad Ambiental De La Universidad Miguel Hernández De Elche (2010); Política Ambiental De La Oficina Ambiental De La Universidad Miguel Hernández De Elche (2017)
UNAVARRA	Plan De Transporte Y Movilidad Para La Universidad Pública De Navarra (2009)
UNED	No information
UNEX	No information
UNICAN	Plan De Gestión Ambiental De La Universidad De Cantabria (2011–2015); Plan De Movilidad Ciclista (2015)
UNILEON	No information
UNIOVI	Plan De Ahorro Energético Y Sostenibilidad (2010)
UNIRIOJA	Declaración De Política Medioambiental De La Universidad De La Rioja (2009); Aprobación De La Política De Desarrollo Sostenible (2017)
UNIZAR	Memoria De Responsabilidad Social De La Uz (2015–2016); Informe De Política Y Resultados En Materia De Energía De La Universidad De Zaragoza (2013–2014)
UPC	Pla Upc 2020 De Sostenibilitat Energètica; Pla D’estalvi Energètic; Política De Mobilitat Sostenible De La Upc
UPCT	No information
UPF	Agenda 21 (Comisión De Medio Ambiente De 2007); Documento De Buenas Prácticas Ambientales
UPM	Plan Sostenibilidad Ambiental (2018)
UPO	No information
UPV	Plan De Movilidad Sostenible Upv 2015–2020
URJC	Guías De Buenas Prácticas
URV	Plan De Medio Ambiente De La Universidad Rovira I Virgili (Tarragona Y Reus) 2011–2015
US	Libro De Las Buenas Maneras; Planta De Reciclaje De Residuos
USAL	Plan De Gestión Ambiental Y Sostenibilidad (2015)
USC	Plan De Desarrollo Sostenible
UV	Campus Sostenible Uv (2011)
UVA	Plan De Calidad Ambiental De La Universidad De Valladolid; Plan De Sostenibilidad Enérgetica En Los Campus De La Universidad De Valladolid (2009)...
UVIGO	Plan De Sostenibilidad Y Medio Ambiente De La Universidad De Vigo (Suma) (2008)

Source: Elaborated by the author from HEIs website.

4.1.9.2. Network participation

Table 41 summarizes the participation of public universities in two Spanish networks: CRUE sustainability and its working groups and the Sustainable Solutions Development Network (i.e., REDS). According to León-Fernández (2015), apart from CRUE there are also other networks like the Catalan Network of Education for Sustainability Research (EduSost), but such alternatives have not been considered in this study because of their regional level. The CRUE Sustainability Working Group was created in 2009, and its "objective is to gather the experience of universities in environmental management, advances in the environmentalisation of the university community and work in risk prevention, while fostering cooperation in these areas for the exchange of experiences and the promotion of good practices".[59] It is composed by the following sub-groups: "a) university sustainability assessment; b) environmental improvements in university buildings; c) participation and volunteering; d) prevention of occupational hazards; e) curricular sustainability; f) university and sustainable mobility; g) healthy universities; h) university planning and sustainability and, i) gender policies". REDS is the Spanish network of the SDSN and was created in 2015 with a mission "to mobilize and sensitize Spanish society, public institutions and the private sector so that they know in a more rigorous and committed way the SDGs, as well as favouring their incorporation of public policies, business environment and in the behaviour of society in general."[60] In the first network (CRUE), 52 (78.78%) HEIs belong to the network; in the second network (REDS), this value rises to 36 (54.54%).

Table 41. Participation of Public Universities in Networks

Acronym	*CRUE*	*REDS*
UAH	x	x
UAB	x	-
UAM	x	x
UDC	x	-
UA	x	x
UB	x	x
UCLM	x	x
UDG	x	x
UGR	x	x
UJAEN	x	-
ULL	x	x
UIB	x	-
ULPGC	x	-
UNIOVI	x	x
USAL	x	x
USC	x	x
UV	x	x
UVA	x	x
UVIC	x	-
UVIGO	-	x
UNIZAR	x	x
UJI	-	x
UMH	x	-
COMILLAS	-	x
UNAVARRA	x	x
URJC	x	x
URV	x	-
IE	-	x
UAX	-	-
UCJC	-	-
UC3M	x	x
UCV	-	-
UCAM	-	-
UCM	x	x

[59] Information extracted from CRUE website: http://www.crue.org/SitePages/Crue-Sostenibilidad.aspx accessed 27 November 2019.
[60] Information extracted from REDS website: http://reds-sdsn.es/quienes-somos/red-espanola-desarrollo-sostenible accessed 27 November 2019.

UAL	x	-
UBU	-	-
UCA	x	-
UNICAN	x	x
UCO	x	x
DEUSTO	x	x
UNEX	x	x
UHU	x	-
UNIRIOJA	x	-
UNILEON	x	-
UDL	x	-
UMA	x	x
MUNI	x	-
UM	x	x
UNAV	x	-
US	x	x

Source: Elaborated by the author from CRUE and REDS website.

4.1.10. Campus operations

4.1.10.1. Green campus and green offices

Another important aspect that shows university commitment is to have a "green" office or environmental office. In the public universities that the SUE has analysed, 31 (62%) have this kind of office. Each is called the "Green Office" (UNIZAR, USAL), "Environment Office" (UAB, Universidad de Vigo [UVIGO]), or "Sustainability Office" (UCA, University de la Rioja [UNIRIOJA]). However, 19 of the universities do not have this kind of office, although some of these have a "Sustainability Classroom" (University of Huelva [UHU]), International University of Andalucía [UIA]). Only three private universities (9.1%) have green offices (DEUSTO, University San Jorge [USJ], UVIC) (Figure 52).

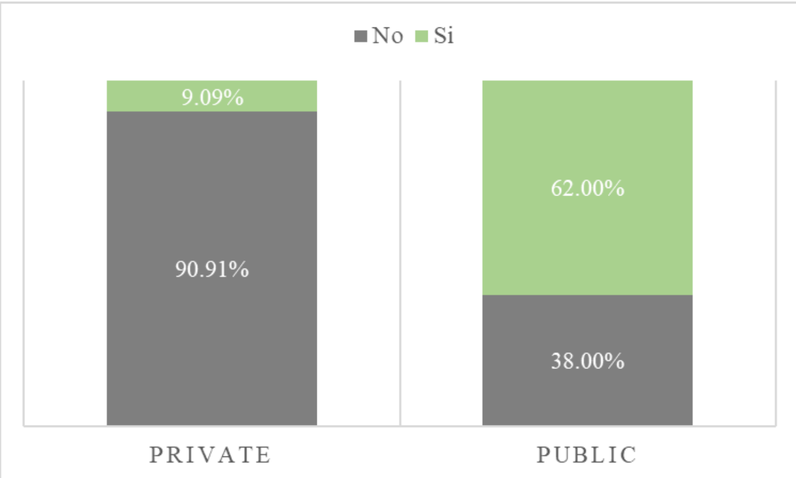


Figure 52. Percentage of green offices in private and public HEIs.

Source: Elaborated by the author from HEIs website.

4.1.11. Relation analysis between variables in the HEIs in Spain

A chi square test (namely Chi-2) is used to analyse categorical data and allows us to determine the degree of association between variables in a contingency table. Table 42 shows the test results of the chi-square values and their *p*-value of the 21 categorical values. Each test represents a 2×2 table with Yates correction and is calculated with contingency tables. Considering the abuses of the *p*-value,[61]

[61] Information on *p*-value misuses available at https://www.nature.com/articles/d41586-019-00874-8; https://www.nature.com/articles/d41586-019-00857-9.

particularly when it is used as a rule to separate results into two groups—those that are statistically acceptable (or significant) and those that are not—in this section, *p*-value was not used as an inequality but by expressing its exact value and to validate the degree of association from the value obtained for Chi-square. This type of contingency table allows one to identify whether the differences between two categoric variables are or not random. The relation is shown in a general mode, without determining whether relations exist or not (or to what degree) between two variables. According to the *p*-values, if a $p > .05$ is obtained we reject H0 and we accept H1, denoting significative differences: however, when $p > .05$, we fail to reject the H0. These significant differences are not random. For instance, there are associations between the following variables: strategic plan versus typology ($p = .04$); typology versus GreenMetric ($p = .01$); sustainability plan versus network 2 (REDS); sustainability plan versus GreenMetric ($p = .01$); and network 1 versus green office ($p = .01$). A stronger association exists between $p = .000$ and the following variables: sustainability plan versus typology; green office versus typology; sustainability plan versus green office. It should be considered that in Table 42, only 66 Spanish HEIs have been considered (only the ones with data retrieved by the search strategy).

Table 42. Association between variables

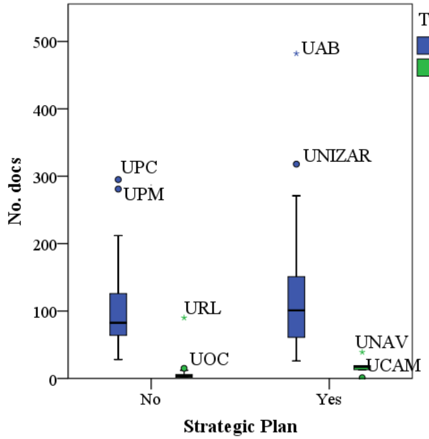
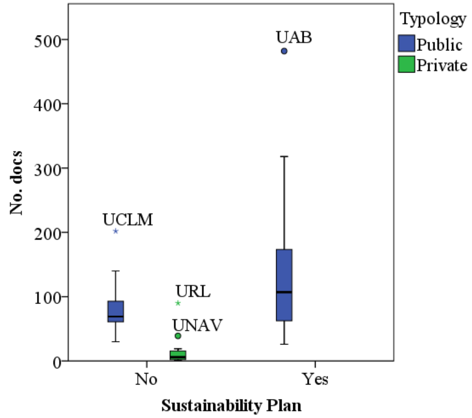
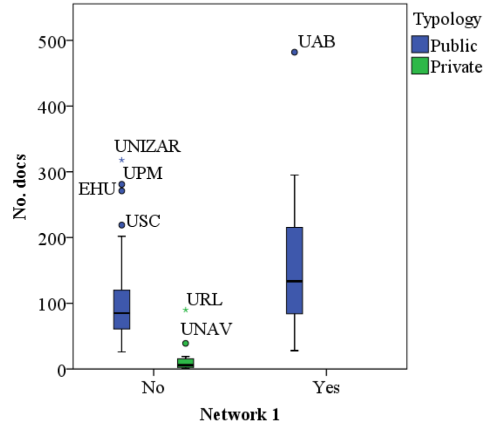
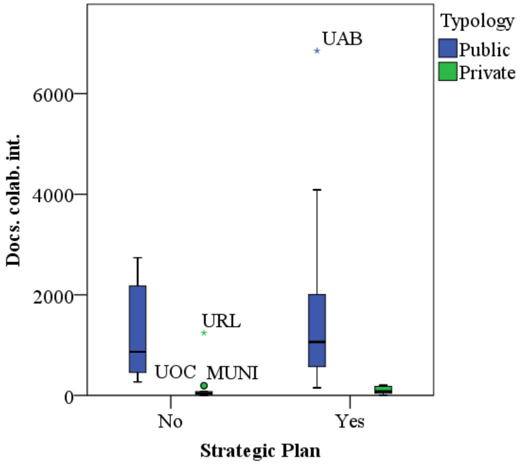
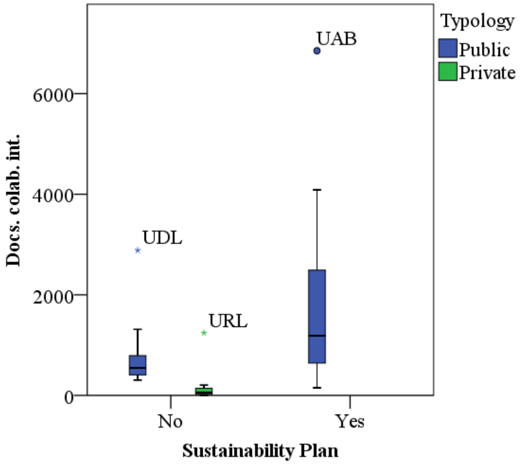
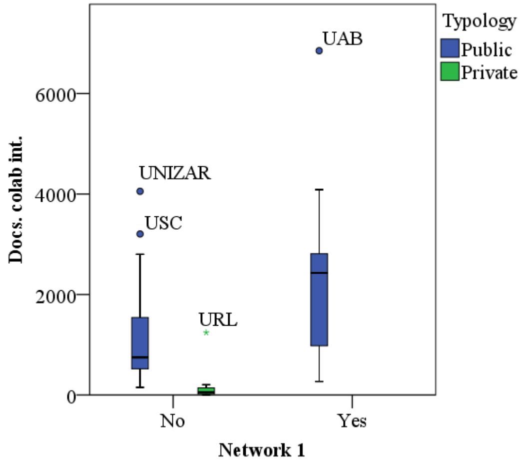
	Typology	Strategic plan	Sustainability plan	Network 1	Network 2	Green office	GreenMetric
Typology	1						
Strategic plan	8.354[a] .004*	1					
Sustainability plan	30.124[a] .000*	2.771[a] .096	1				
Network 1	5.929[a] .015	.033[a] .953	5.407[a] .020	1			
Network 2	5.676[a] .017	1.880[a] .170	8.567[a] .003*	.085[a] .771	1		
Green office	12.490 .000*	1.567[a] .211	17.580[a] .000*	10.185[a] .001*	2.200[a] .138	1	
GreenMetric	10.189[a] .001*	2.405[a] .121	11.235[a] .001*	1.842[a] .175	4.615[a] .032	3.071 [a] .080	1

H0 is rejected with $p < .05$ *.
Source: Elaborated by the author from data collected in HEIs website and SPSS.

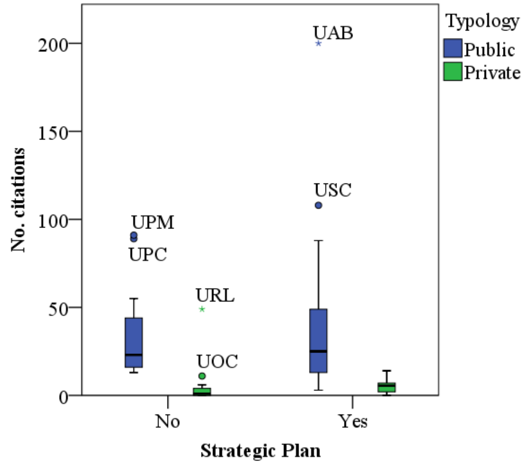
Tables 43 and 44 show the box-and-whisker plots of the different categoric variables (strategic plan, sustainability plan, network 1, network 2, green office and GreenMetric) versus the numeric variables (number of documents, documents with international collaboration, number of citations and number of 1Q documents). Major variability exists between the public universities in all the categories analysed, revealing differences between public and private universities in all categories. Certain HEIs are commonly outliers (e.g. UAB, UNIZAR in public universities; URL, UNAV, in private universities).

Considering the numeric variable "number of documents" with the categoric variables selected, the median is higher in public documents, especially in the "yes" division in all the variables. That is, when public universities have a higher number of documents, when mentioning sustainability in their strategic plans and when they have a sustainability plan, they are linked to a network (CRUE and REDS), have a Green office or campus or participate in GreenMetric ranking. The documents with international collaboration present a similar pattern: major variability in public HEIs, and the medians are higher in the affirmative part. This difference between public and private is even more pronounced difference in network 1. In terms of the number of citations, presents the same tendency. However, it should be remarked that the higher median in public HEIs belongs to the network 1. That is, the number of citations that public universities receive if they belong to the CRUE network is higher than is otherwise the case. The impact dimension measured by the 1Q documents also demonstrates the same tendency. Regarding the strategic plan, among private HEIs, some (UEM, UOC, URL) stand apart from the average.

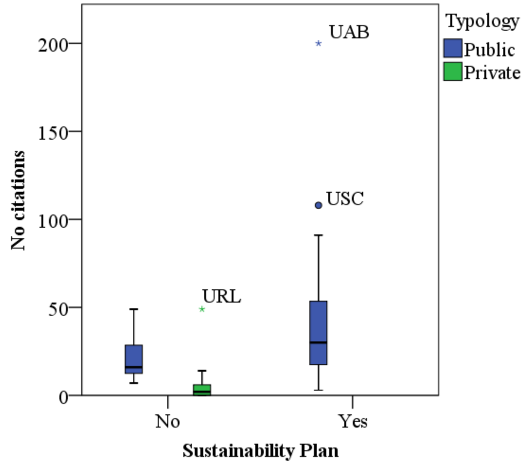
Table 43. Boxplots of quantitative vs qualitative variables in Universities

	Strategic plan	***Sustainability plan***	***Network 1***
No. docs	 No (pub. = 14; priv. = 13) Si (pub. = 33; priv. = 6)	 No (pub. = 12; priv. = 19) Si (pub. = 35; priv. = 0)	 No (pub. = 35; priv. = 19) Si (pub. = 12; priv. = 0)
Docs. colab. int.	 No (pub. = 14; priv. = 13) Si (pub. = 33; priv. = 6)	 No (pub. = 12; priv. = 19) Si (pub. = 35; priv. = 0)	 No (pub. = 35; priv. = 19) Si (pub. = 12; priv. = 0)

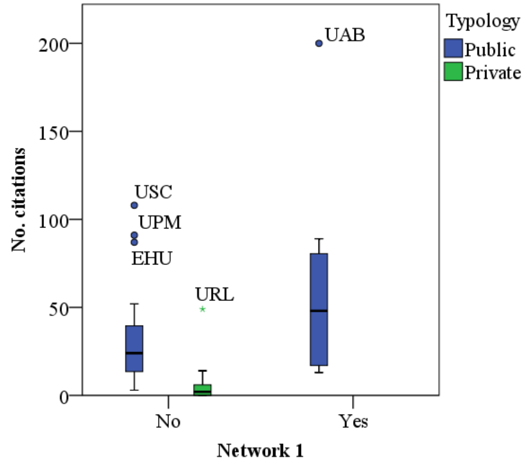
No. citations



No (pub. = 14; priv. = 13) Si (pub. = 33; priv. = 6)

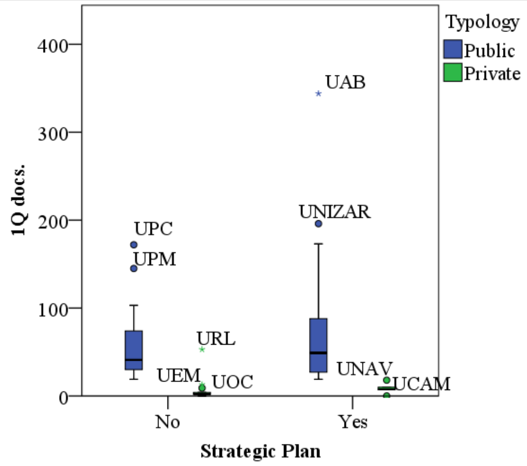


No (pub. = 12; priv. = 19) Si (pub. = 35; priv. = 0)

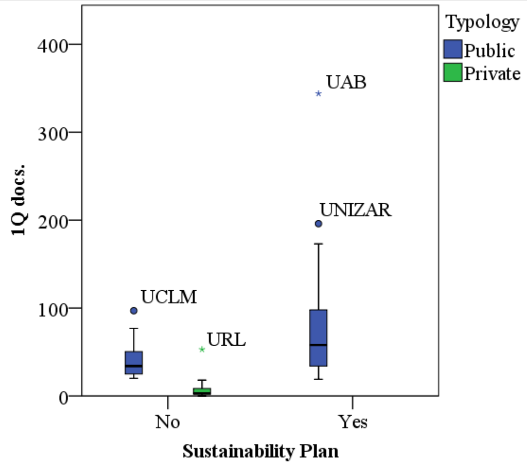


No (pub. = 35; priv. = 19) Si (pub. = 12; priv. = 0)

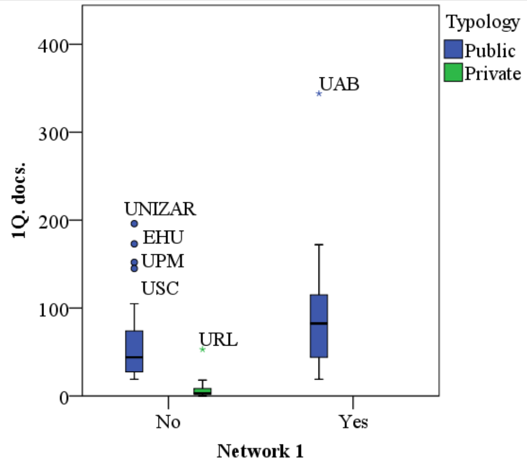
1Q. docs.



No (pub. = 14; priv. = 13) Si (pub. = 33; priv.= 6)



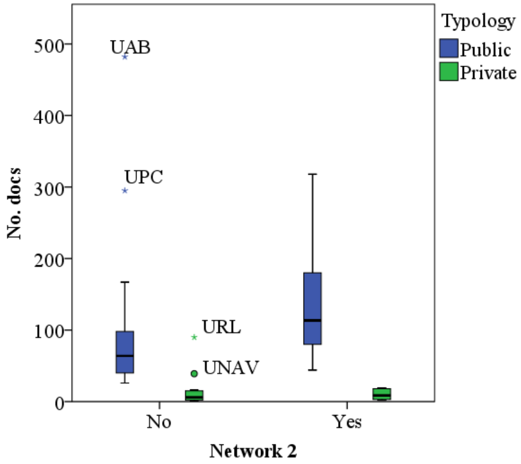
No (pub. = 12; priv. = 19) Si (pub. = 35; priv. = 0)

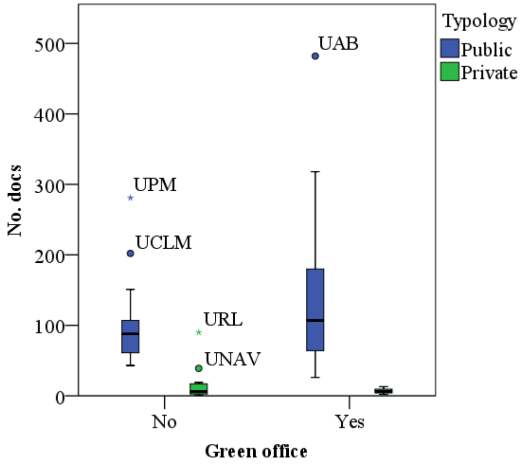


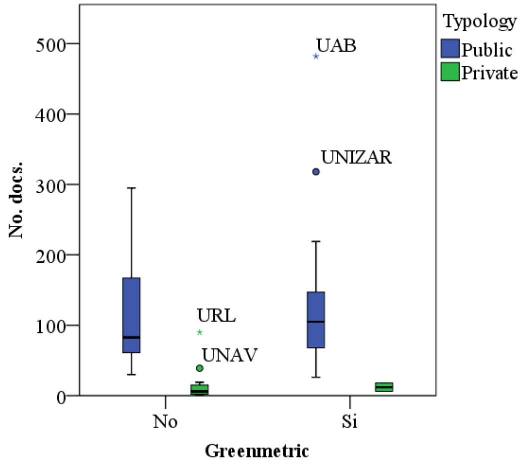
No (pub. = 35; priv. = 19) Si (pub. = 12; priv. = 0)

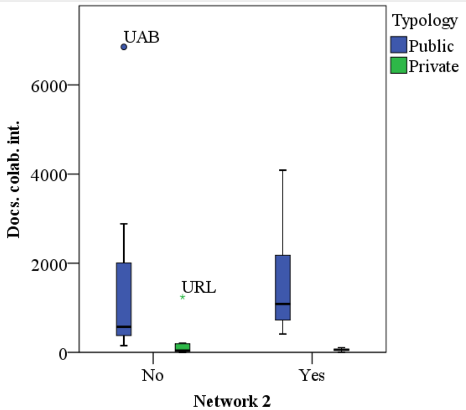
Source: Elaborated by the author from data collected in HEIs website and SPSS.

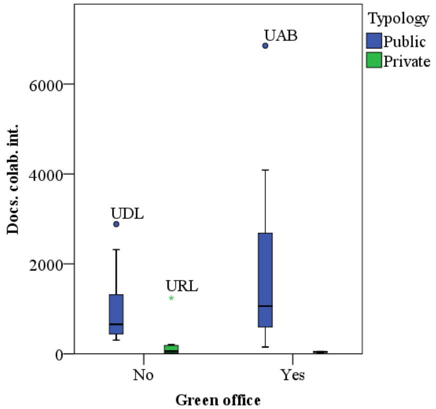
Table 44. Boxplots of quantitative vs qualitative variables in Universities

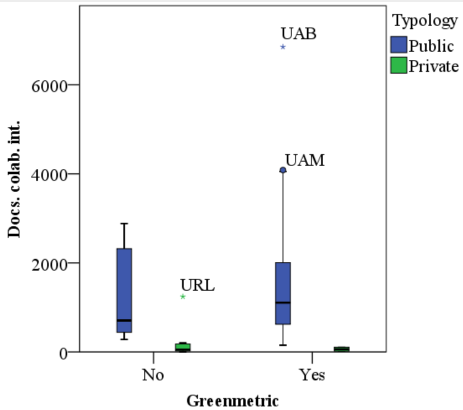
<table>
<tr><th></th><th>Network 2</th><th>Green Office</th><th>GreenMetric</th></tr>
<tr><td>No. docs.</td>
<td>

No (pub. = 17; priv. = 13) Si (pub. = 30; priv. = 3)</td>
<td>

No (pub. = 17; priv. = 16) Si (pub. = 30; priv. = 3)</td>
<td>

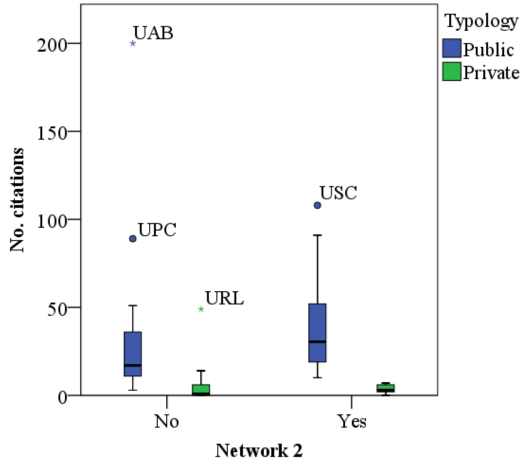
No (pub. = 22; priv. = 17) Si (pub. = 25; priv. = 2)</td></tr>
<tr><td>Docs. colab. Int.-</td>
<td>

No (pub. = 17; priv. = 13) Si (pub. = 30; priv. = 3)</td>
<td>

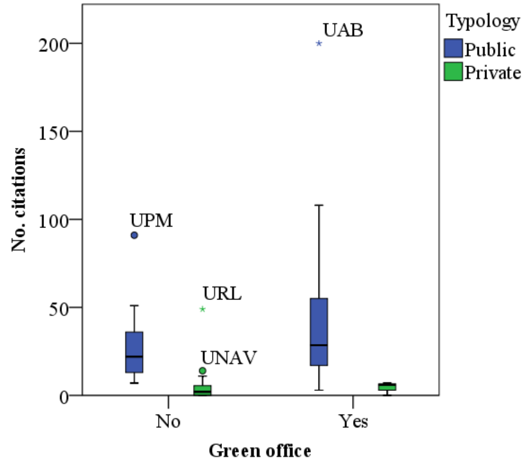
No (pub. = 17; priv. = 16) Si (pub. = 30; priv. = 3)</td>
<td>

No (pub. = 22; priv. = 17) Si (pub. = 25; priv. = 2)</td></tr>
</table>

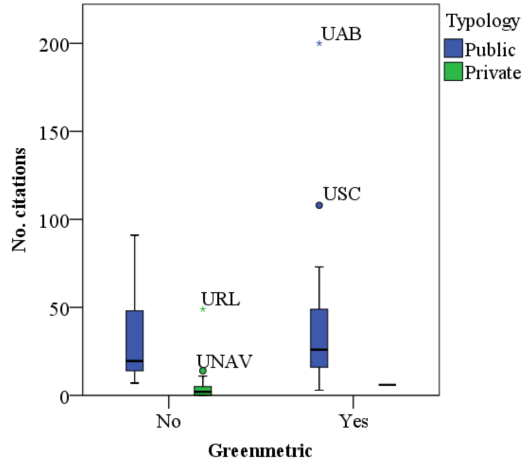
No. citations



No (pub. = 17; priv. = 13) Si (pub. = 30; priv. = 3)

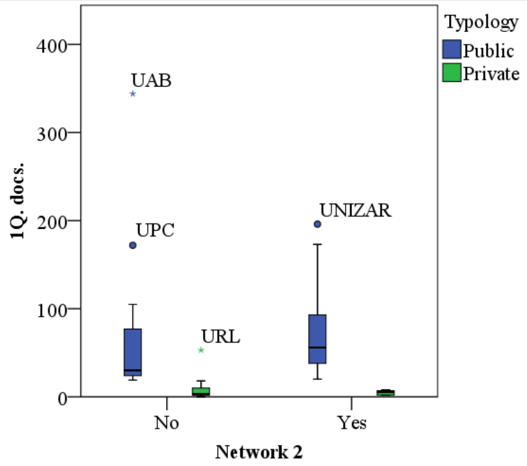


No (pub. = 17; priv. = 16) Si (pub. = 30; priv. = 3)

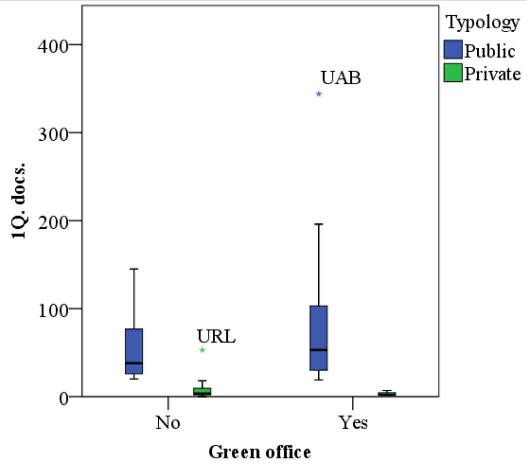


No (pub. = 22; priv. = 17) Si (pub. = 25; priv. = 2)

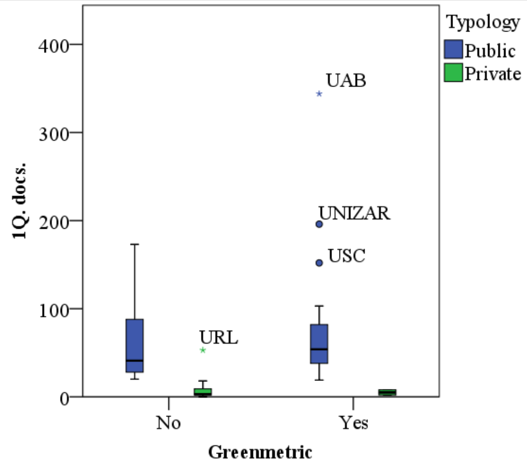
1Q. docs



No (pub. = 17; priv. = 13) Si (pub. = 30; priv. = 3)



No (pub. = 17; priv. = 16) Si (pub. = 30; priv. = 3)



No (pub. = 22; priv. = 17) Si (pub. = 25; priv. = 2)

Source: Elaborated by the author from data collected in HEIs website and SPSS.

4.2. Connexionist indicators: Visualization

4.2.1. Countries

The keyword co-occurrence map from which the five aforementioned clusters and the relationships among them across the entire period (2008–2017) were drawn is reproduced in Figure 53. The graph has been constructed with VOSviewer software, with the Ling/Long Modularity algorithm. Node size is indicative of the number of documents, while the lines identify inter-document relationships and their thickness and intensity. The first cluster (red) is composed of 32 countries. The country with the most documents is the United Kingdom (*n* = 8,833), followed by Germany (*n* = 5,695), Italy (*n* = 4,385 docs), the Netherlands (*n* = 4,194 docs.), Sweden (*n* = 3,018 docs.), Denmark (*n* = 1,688 docs.) and Switzerland (*n* = 1,619 docs). A strong relation exists between countries such as Germany and United Kingdom (link strength of 518) or the Netherlands and the United Kingdom (link strength of 505). That relation means collaboration in the scientific output is intensive. The second cluster (green) is composed of 26 countries. The majority of countries in this group are located in South-Europe and North-Africa and Spanish-speaking regions of South-America: Spain (*n* = 5,288), France (*n* = 3,866), Brazil (*n* = 2,289), Portugal (*n* = 1329), Mexico (*n* = 833) and Chile (*n* = 442). Strong relations can be observed in countries of other clusters: for example, between Spain and the United Kingdom (link strength of 408), France and the United Kingdom (link strength of 356), Spain and the United States (318), and France and the United States (315). The third cluster (blue) constitutes an aggrupation of 19 countries and includes some of the countries with the highest scientific output on sustainability. From this group, the countries with a higher node size are as follows: the United States (*n* = 19,663), China (*n* = 13,479), Australia (*n* = 5,438), Canada (*n* = 4,966), India (*n* = 4,753) and South Korea (*n* = 2,660). In this cluster, there is a strong relationship between countries: for example, the United States and China (a strength of 1,676) and Canada and the United States (link strength of 815). Moreover, it also has strong connections with countries from other clusters (e.g. the United States and the United Kingdom, with a strength of 866). The fourth cluster (yellow) is formed by 18 countries, and it contains countries ranked by scientific output such as Malaysia (*n* = 2,229), Iran (*n* = 1,960), Turkey (*n* = 1,874) or Saudi Arabia (*n* = 761). There are strong relations within some countries of the cluster (e.g. Malaysia-Saudi Arabia, strength of 82) or within other clusters (Malaysia and the United Kingdom, 114). Last, the fifth cluster (purple) is grouped by 14 countries, and higher nodes include South Africa (*n* = 1,231), Nigeria (*n* = 329), Kenya (*n* = 260), Ghana (*n* = 154) or Ethiopia (*n* = 120). In this group, there is a strong relationship between the following binomials: South Africa and the United States (strength of 135) and South Africa and Austria (link strength of 97).

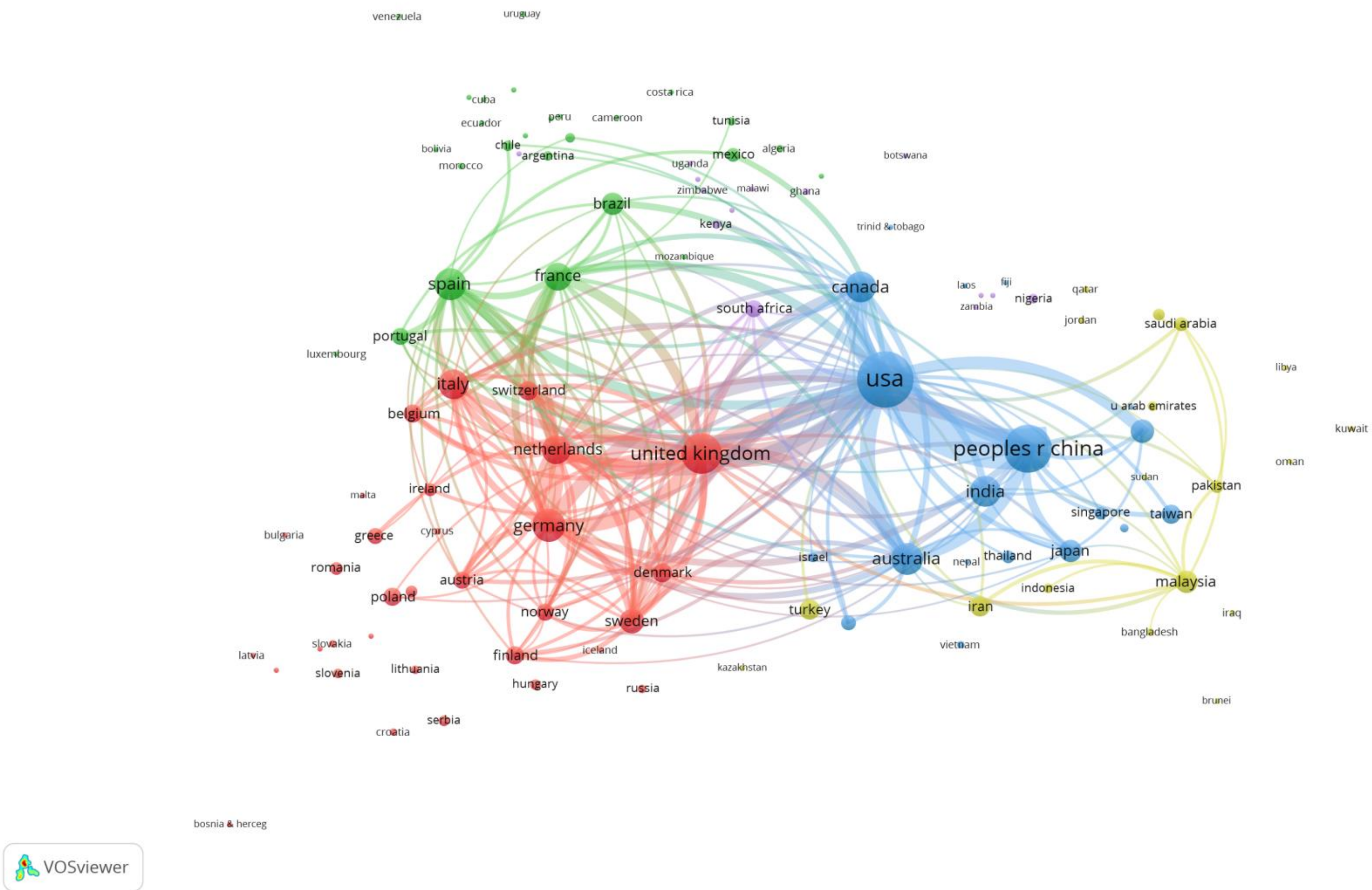


Figure 53. Co-authorship by countries in sustainability research (<20 documents).

Source: Elaborated by the author from CWTS in-house WoS database and VOSviewer.

4.2.2. Institutions

Figure 54 presents the co-occurrence map of institutions. According to their relations, 8 clusters have been identified. The first cluster (red) is composed of 70 institutions, and the higher nodes are United-States based: the University California Berkeley (*n* = 552), the University Illinois (*n* = 476), the University of British Columbia (*n* = 513), Michigan State University (*n* = 480) or the University of Wisconsin (*n* = 431). The second cluster (green) on the map is composed by 66 institutions that are North European (from the Netherlands, Denmark and Sweden): Wageningen University and Research Centre (*n* = 1,197), the University of Utrecht (*n* = 514), Delft University of Technology (*n* = 477), the Technical University of Denmark (*n* = 469) and the Swedish University of Agricultural Sciences (*n* = 493). Fifty-six clusters constituted the institutions from the third cluster (blue) and are mainly located in Asia. For instance, the Chinese Academy of Sciences (*n* = 2,385), Tsinghua University (*n* = 614), Shanghai Jiao Tong University (*n* = 415), and Zhejiang University (*n* = 387).

The fourth cluster (yellow) is composed of 52 institutions, and there are research centres from France (e.g. INRA with 825 documents), Brazil (University São Paulo with 364 documents), Spain (Spanish National Research Council CSIC with 348 documents), Italy (Politécnico di Milano with 258 documents, University of Bologna with 274 documents) and Portugal (University of Lisbon, 378 documents). The fifth cluster (purple) is mainly United Kingdom-based institutions: for example, the University of Cambridge (*n* = 398), University of Leeds (*n* = 392), University of Nottingham (*n* = 389) and University of Manchester (*n* = 377). It is composed of 40 institutions. The sixth cluster (light blue), which includes 35 institutions, comprises mainly Australian institutions: for example, the University of Queensland (*n* = 554), Monash University (*n* = 361), Australian National University (*n* = 350) and the University of Melbourne (*n* = 340).

The seventh cluster (orange) is formed of 25 institutions, mainly from South-West Asia: for instance, the University of Malaya (*n* = 635), Universiti Teknologi Malaysia (*n* = 426), the University of Tehran (*n* = 410) or Islamic Azad University (*n* = 394). The eighth and final cluster (brown) is composed of 18 institutions: the University of Waterloo (*n* = 334), University of Toronto (*n* = 305), McGill University (*n* = 260) and University Alberta (*n* = 250).

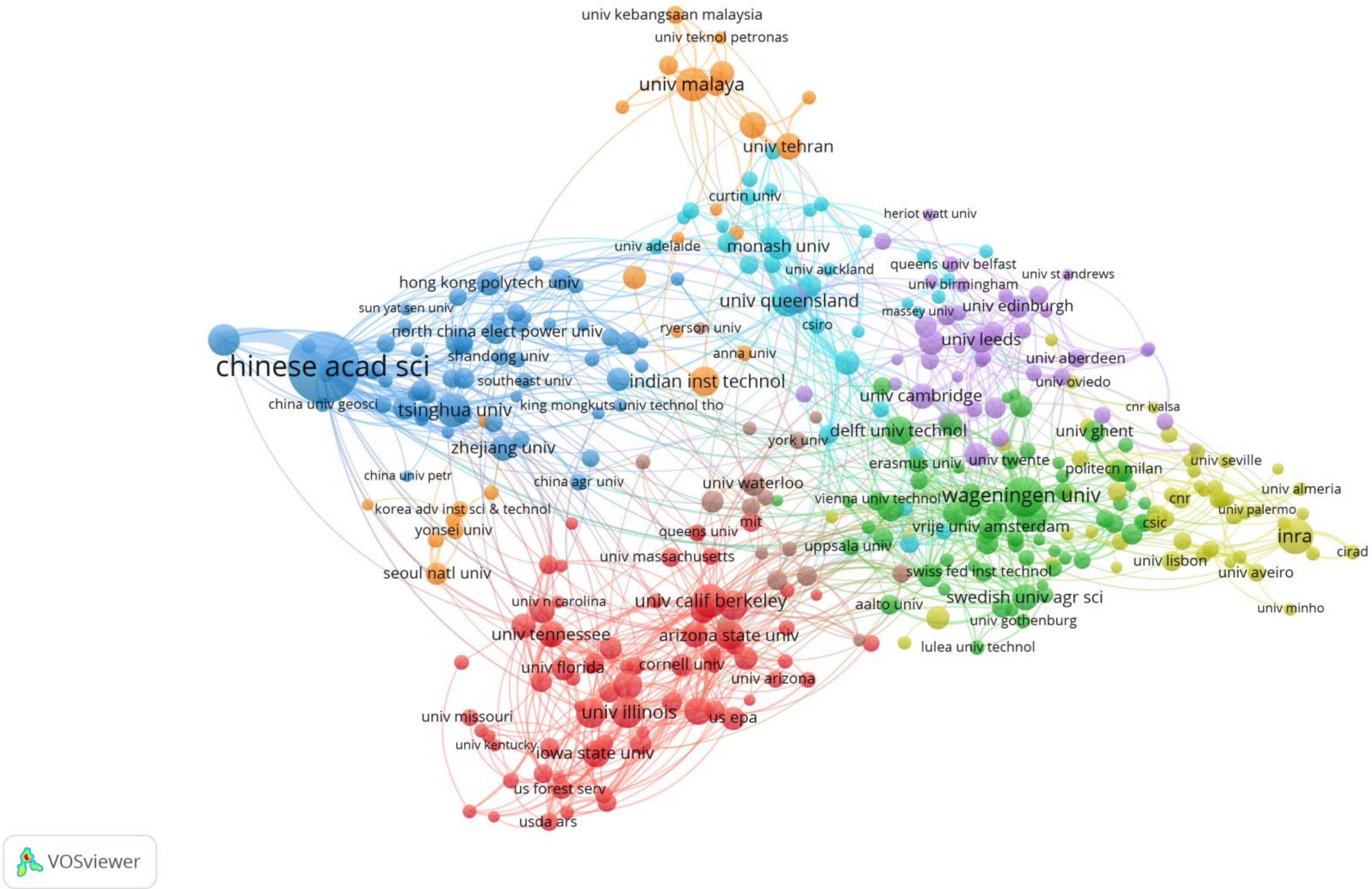


Figure 54. Co-occurrence by countries in sustainability research in 2008–2017 (>100 docs).

Source: Elaborated by the author from CWTS in-house WoS database and VOSviewer.

4.2.3. Topics

4.2.3.1. Keywords

A thematic network based on keywords (author keywords and Keywords Plus) with ≥50 occurrence is shown in Figure 55. The size of the nodes equals the number of documents collected, and the amount of variation in the lines indicates the frequency at which two keywords appears together. Moreover, the colour allows one to determine clusters of related keywords. The network of this topic contains five clusters, whose keywords by occurrence are summarized in the Table 45 (a, b). The largest cluster is #1 "Energies" and the second largest is #2 "Management and policy of the sustainability". However, the number of links per paper (#$link_{avg}$) is higher for clusters #3, energy systems, and #4, life cycle assessment of the energy. In addition, it is observed that in several clusters, the $year_{avg}$ is later than 2013. This fact leads to the conclusion that those clusters were published in the last three years of the study (Table 45a). Related to the topics, the first cluster, energies, includes keywords such as "biomass" (occurrence of 4,565), "water"; (2,491), "biodiesel" (1,336), "carbon" (1,282) and "conversion" (1,277). The second cluster, management and policy of sustainability, includes keywords such as "management" (6,954 occurrences), "sustainability" (6,203), "policy" (2,354), "SD" (2,914), "framework" (2,877) and "governance" (2,639). The third cluster, energy systems, is composed of keywords such as "systems" (4,844), "energy" (4,842), "model" (4,088), "China" (3,004), and "renewable energy" (2,779). The fourth cluster,"life cycle assessment of the energy", and includes keywords such as "life cycle assessment" (4,265), "emissions" (2,178), "biofuels" (1,910), "bioenergy" (1,900) and "United States" (1,476). The fifth cluster, impact and economic and social sustainability, includes keywords such as "performance" (6,600), "impact" (2,667), "perspective" (2,365) and "industry" (2,029) along with terms related to social and economic sustainability ("CSR", "business", "ethics", etc.). The first cluster has a higher average of citations (18.68 citations), followed by the fourth cluster (15.14 citations).

Table 45. Clusters Identified on the Period and Frequency of Keywords Ranked by Occurrence (O)

a)

No.	***Cluster name***	***#nodes***	***#link$_{avg}$***	***#year$_{avg}$***
1	Energies	286	300.43	2014.22
2	Management and policy of the sustainability	264	397.19	2013.83
3	Energy systems	174	406.33	2014.44
4	Life cycle assessment of the energy	150	397.94	2013.83
5	Impact and economic and social sustainability	126	360.05	2013.89

b)

Clust. 1	***O***	***Clust. 2***	***O.***	***Clust. 3***	***O***	***Clust. 4***	***O***	***Clust. 5***	***O***
biomass	4,565	management	6,954	systems	4,844	life-cycle assessment	4,265	performance	6,600
water	2,491	sustainability	6,203	energy	4,842	emissions	2,178	Impact	2,667

biodiesel	1,336	policy	3,254	model	4,088	biofuels	1,910	Perspective	2,365
carbon	1,282	sustainable development	2,914	china	3,004	bioenergy	1,900	industry	2,029
conversion	1,277	framework	2,877	renewable energy	2,779	united-states	1,476	CSR	3,422
adsorption	1,226	governance	2,639	design	2,665	lca	1,472	strategy	2,183
storage	1,176	climate change	2,375	system	2,620	impacts	1,434	innovation	1,387
temperature	1,124	conservation	2,289	optimization	2,452	growth	1,426	financial performance	1,243
removal	1,072	agriculture	2,163	consumption	2,005	ethanol	1,404	green	1,027
nanoparticles	1,058	ecosystem services	2,049	efficiency	1,813	quality	1,404	business	1,014

Source: Elaborated by the author from CWTS in-house WoS database and VOSviewer.

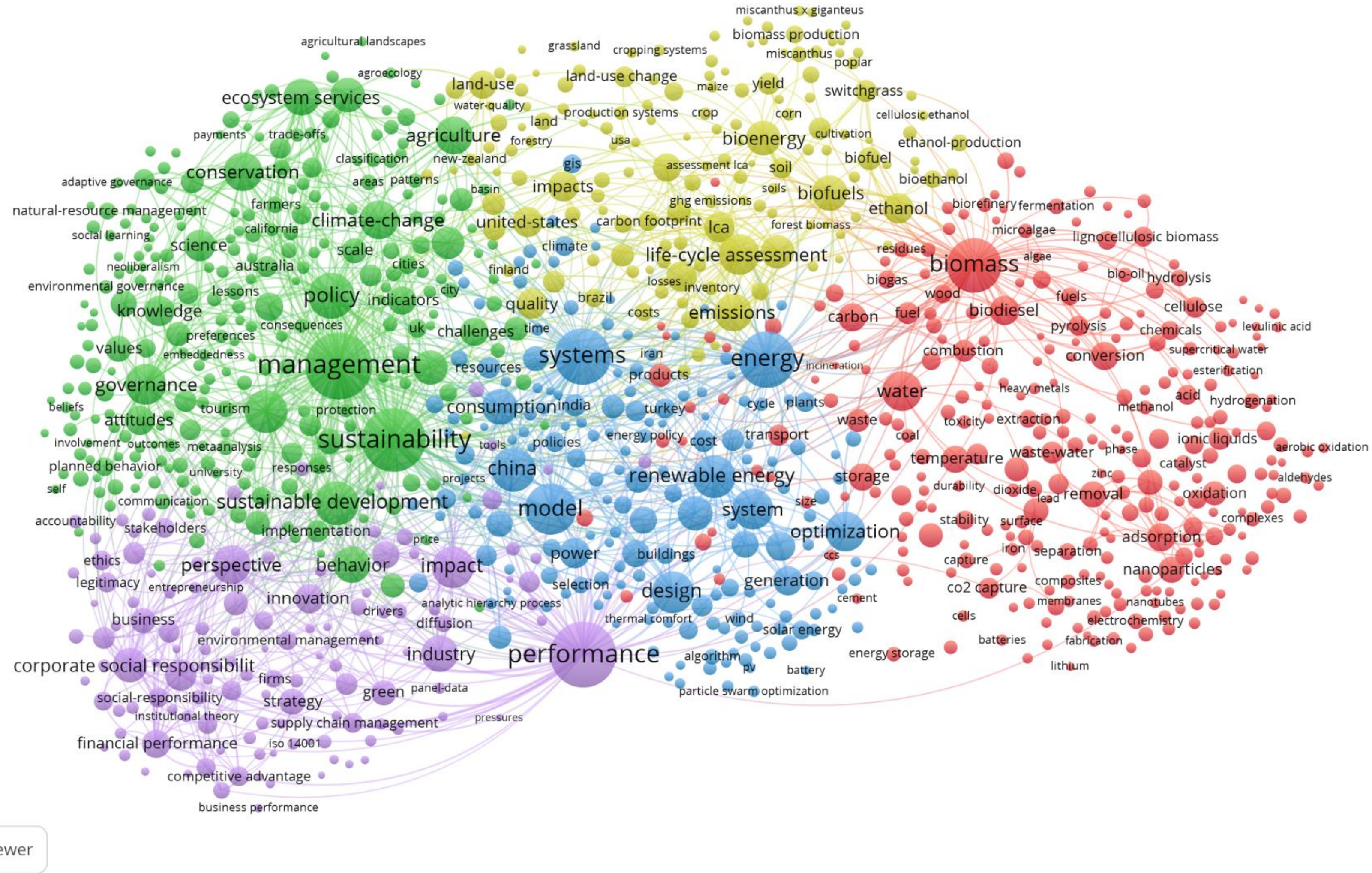


Figure 55. Co-occurrence keywords (author keywords and keywords plus) map (>50 occurrence).

Source: Elaborated by the author from CWTS in-house WoS database and VOSviewer.

Table 46 and Figure 56 summarize the information on the clusters, sorted by period: 2008–2010, 2011–2014 and 2015–2017. This analysis allows one to visualize the evolution of the topics over the period. The map (Fig. 56, a) is composed of four clusters. The first one (red) is one related to sustainability management and includes terms like “policy” (484 occurrences) or “governance” (317) or “agriculture” (415 occurrences). It constitutes the biggest cluster, with 91 nodes. The second cluster (green) is related to energy ($n = 597$) and includes terms (e.g., “biofuels”, 369; “bioenergy”, 22) related to the environment and to emissions. In the third cluster (blue) are prominent terms such as “performance” ($n = 673$), “sustainable development” ($n = 533$), and “CSR” ($n = 434$) that, jointly with words like “performance”($n = 673$) or “model” ($n = 465$), denote the concern of science for this topic. Cluster 4 is also associated with energy (“biomass”, 655; “water”, 346; “system”, 276, and “biodiesel”, 203). The papers in those clusters were published in the last year of the subperiod (an average year is 2009), and cluster #3 has a strong links, denoting that is more connected with the other clusters.

In the period 2011–2014 (Figure 56, b), the management of sustainability is maintained in the red cluster. There are terms that also have increased occurrence (“management”, 2385; “sustainability”, 2160; “policy”, 1118; “SD”, 1065 or “governance”, 948). Cluster number 2 (green) is the evolution of cluster number 4 from the first period: however, it includes other terms such as “processes” (e.g. heterogeneous catalysis). In this period, cluster 3 (blue) is also related with energy and incorporates terms such as “biofuels” ($n = 895$), “life-cycle assessment” ($n = 814$), “bioenergy” ($n = 801$) and “emissions” ($n = 757$). The final clusters, 4 (yellow) and 5 (purple), are also related to energies: “renewable energy” and, in practice, terms like “impact”. In this case, the $year_{avg}$ is at the beginning of the sub-period (average year is 2012) and the clusters with the strongest links are performance and management.

Finally, in the 4-year period (2015–2018), there are some energy-related clusters that are the evolution of the previous groups. Life-cycle (purple) has been constituted as a cluster that is also associated with other prominent keywords such as “emissions” ($n = 1198$), “bioenergy” (879), “agriculture” ($n = 867$), “growth” ($n = 801$) and “greenhouse gas emissions” ($n = 727$). Moreover, “China” ($n = 1{,}628$) has become the keyword with a highest frequency in cluster 6 (light blue) and is associated with “urbanization” ($n = 339$), “consumption” ($n = 1{,}275$) and “CO_2 emissions” ($n = 684$), denoting the global concern for the sustainability model and urbanization in this country. The $year_{avg}$ is at the beginning of the sub-period (average year is 2016). In this sub-period are the strongest links with cluster 3 (biofuels) and cluster 2 (biomass).

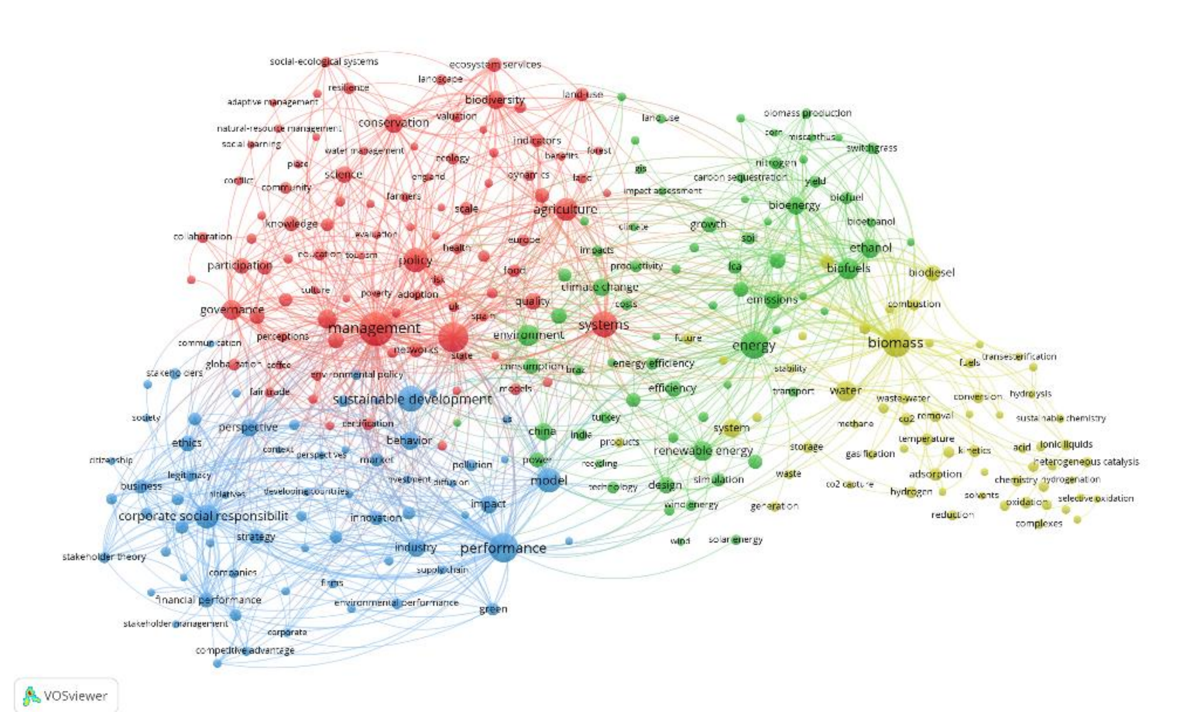
One fact observed between the different clusters is an increase in the nodes and the average link. As such, there are more topics, and these nodes about sustainability have gained connection over time. That is, they are more closely connected.

Table 46. Sub-clusters on Sustainability Research over the Period (2008–2017)

Period	*No.*	*Cluster name*[62]	*#nodes*	*#link$_{avg}$*	*#year$_{avg}$*
2008–2010	1	Management	91	491.36	2009.15
	2	Energy	71	431.65	2009.20
	3	Performance	66	501.48	2009.15
	4	Biomass	61	274.25	2009.20
2011–2014	1	Management	264	887.55	2012.71
	2	Biomass	246	593.67	2012.80
	3	Biofuels	128	914.70	2012.70
	4	Energy	117	888.97	2012.75
	5	Performance	103	1120.94	2012.67
2015–2017	1	Management	294	890.00	2016.14
	2	Biomass	209	1371.39	2016.14
	3	Biofuels	174	1389.73	2016.13
	4	Energy	132	1437.28	2016.15
	5	Life-cycle	114	1278.84	2016.11
	6	China	77	1051.42	2016.20

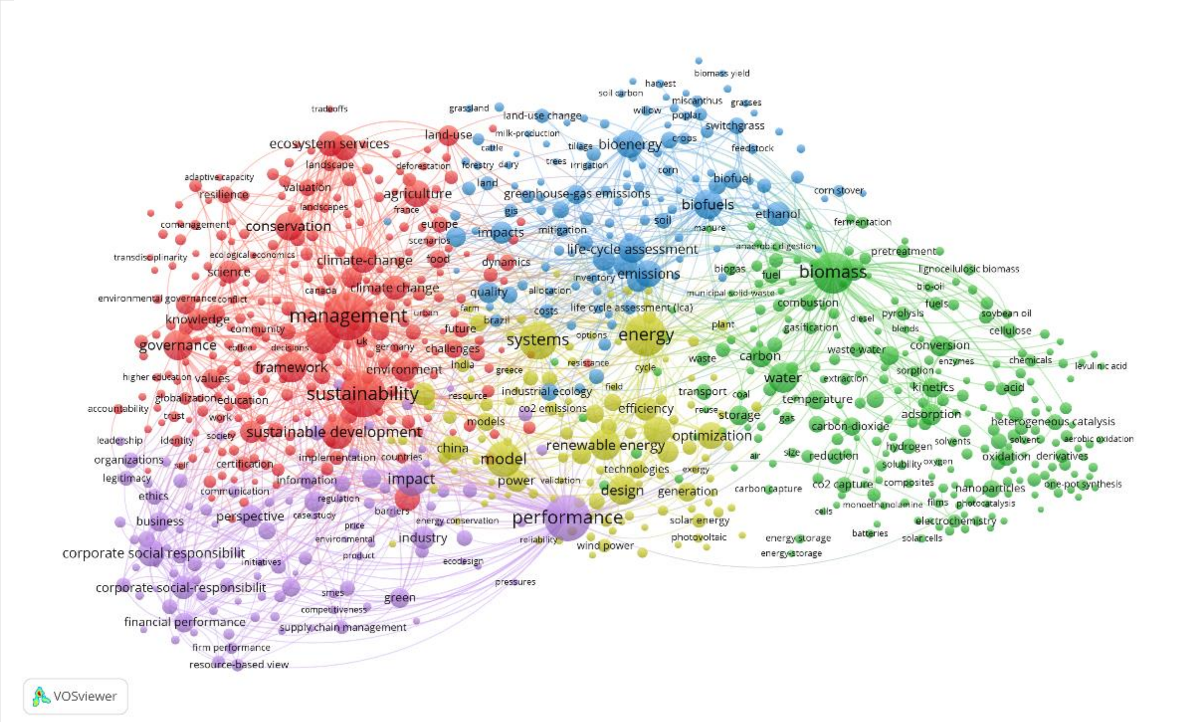
Source: Elaborated by the author from CWTS in-house WoS database and VOSviewer.

a)



b)

62 Cluster name has been labelled according the term with the highest frequency.



c)

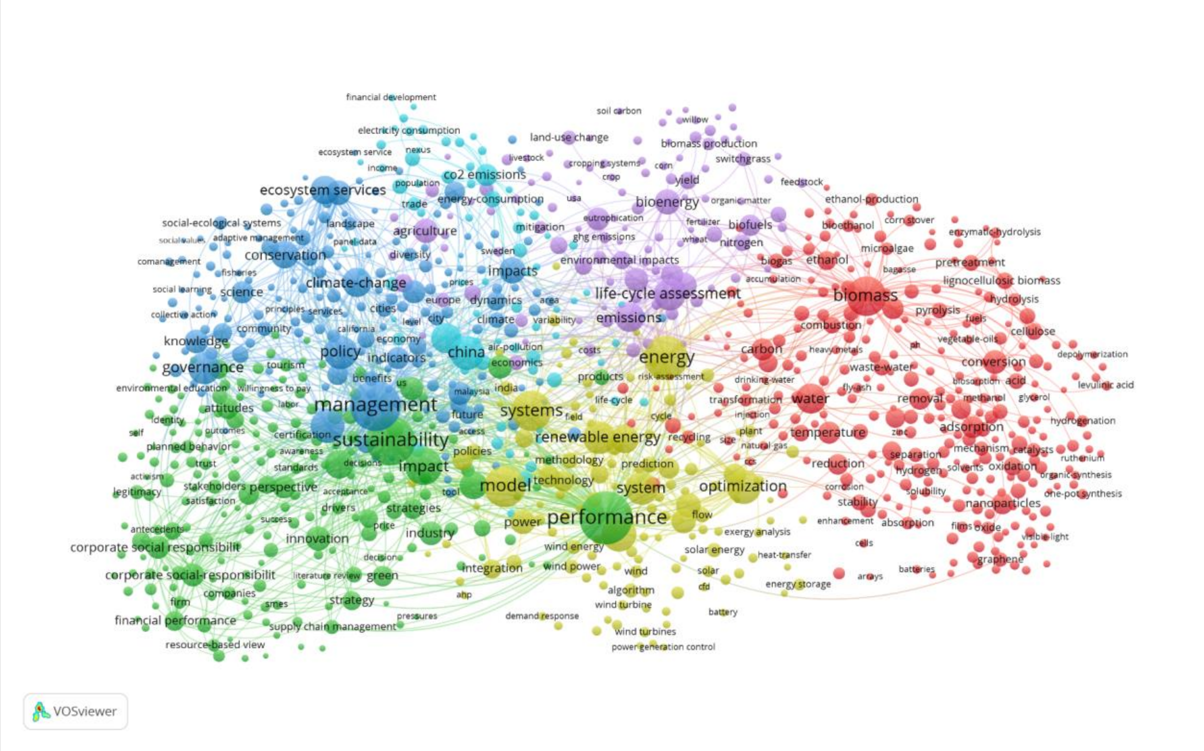


Figure 56. Co-occurrence of keywords by periods: a) 2008–2010 b) 2011–2014 c) 2015–2018 (>50 occurrence).

Source: Elaborated by the author from CWTS in-house WoS database and VOSviewer.

4.2.3.2. Subject categories

Figure 57 displays co-occurrence by subject categories and shows the relations between the subject categories. In this respect, six clusters have been identified. The first cluster (in red) is composed by a wide variety of 117 WoS categories: “Environmental studies”, (*n* = 13,545), “Business”’ (*n* = 4,595) “Economics”’ (*n* = 3,751), “Ecology” (*n* = 3,241) or “Management” (*n* = 3,154). The second cluster (green), is composed by 13 WoS categories. More than 1,000 documents can be found in the following categories: “Environmental Sciences” (*n* = 28,175), “Engineering, environmental” (*n* = 15,799), “‘Water resources”’ (*n* = 2,915) and “Marine & freshwater biology”’ (*n* = 1,939). The third cluster (Blue), with only eight categories, highlights “Agronomy” (*n* = 1,962), “Biotechnology & applied microbiology” (*n* = 1,505) and “Agricultural engineering” (*n* = 1,480). The fourth cluster (yellow), with 11 WoS Categories, is related to engineering and environmental sustainability and collects the higher number of documents (“Green & sustainable science & technology”, 59,374; “Energy & Fuels”, 25,610; “Chemistry, multidisciplinary”, 11,740). In this cluster, there are strong relations: “Green & sustainable science & technology” with“Environmental Sciences” (strength link of 21,068); environmental “Engineering, environmental” and “Green & sustainable science & technology” (strength of 14,436);“Environmental sciences” to “Engineering, environmental” (link of 13,480). The fifth cluster (purple) includes seven categories, linked to engineering: “Engineering, manufacturing”, 529 or “Operations research & management science”, 407. The last cluster (light blue), includes five categories associated with materials (“Polymer science”, 294; “Materials science, composites”, 197). However, if we check the heat map for average publications it can be observed that cluster 4 (yellow) is more recent than the average (2014).

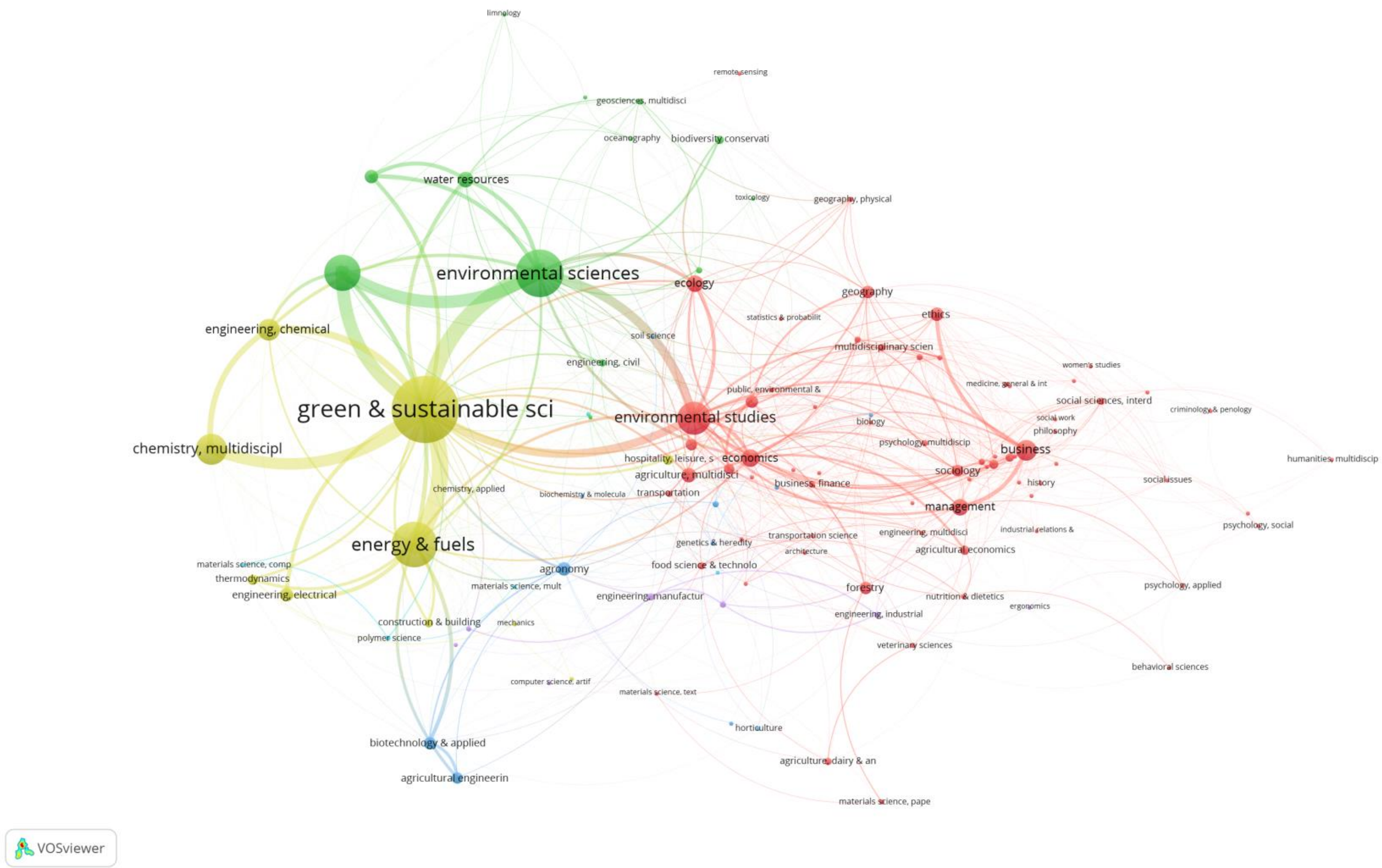


Figure 57. Co-occurrence by subject categories in sustainability research in 2008–2017 (>20 docs).

Source: Elaborated by the author from CWTS in-house WoS database and VOSviewer.

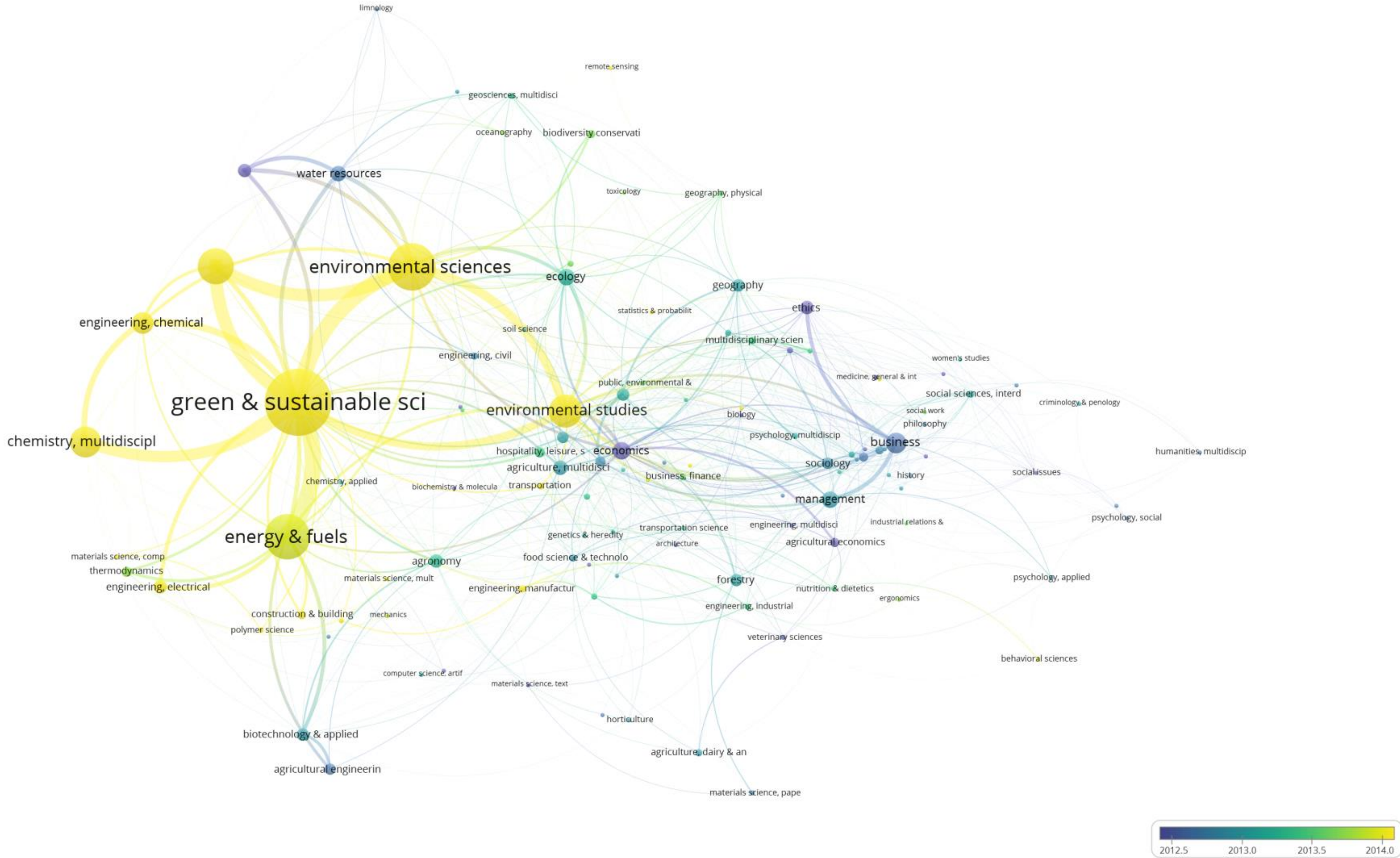


Figure 58. Heat map with average year by subject categories in sustainability research in 2008–2017 (>20 docs).

Source: Elaborated by the author from CWTS in-house WoS database and VOSviewer.

4.2.3.1. SDGs Classification

The documents related to the dataset of sustainability (P) and sustainability at HEIs (P[HEIs] have been classified by using the ontology SDG based on the different SDGs. It should be considered that a paper could be multiply classified into different SDGs, and 83,948 documents (85.77%) were classified with at least one SDG. Regarding documents from HEIs, 78,717 documents (97.06%) were classified with the glossary.

The co-occurrence map of SDGs from the sustainability dataset shows six clusters. The biggest cluster is the first cluster, related to the following SDGs relations: building partnerships (SDG17, occurrence of 11,601); reducing inequalities (SDG10, 12,881); peace, justice and strong institutions (SDG16, 21,418); and cities (SDG11, 19,254)—and with weaker connections, SDG1, no poverty (833), and SDG5, gender equality (1,330). Cluster 2 is related to economic aspects (SDG8 and SDG9) and has bigger nodes: $n = 21{,}388$ in SDG8, and $n = 24{,}292$ in SDG9. Cluster 3 is related to energy (affordable and clean energy, SDG7), climate action (SDG13) and responsible consumption (SDG12). SDG7 constitutes the SDG with a higher occurrence ($n = 28{,}988$). Is it especially remarkable the link between SDG7 and SDG13 (link strength of 12,598). Cluster 4 is linked with food, health, and land (SDG2, SDG3, SDG15). Cluster 5 is composed only of one node related to education (SDG4). Finally, there is a cluster related to water (SDG6 and SDG14). The goals most often addressed were SDG7 (28,988), SDG9 (24,292), SDG15 (23,116), SDG16 (21,418) and SDG8 (21,388). The clusters created with the HEIs subset present the same pattern of SDG clusters.

However, the average publications on each SDG present some differences between the datasets: SDG11, related to cities, and SDG7, to affordable and clean energy, are more recently emphasized in HEIs publications (Figure 60, b).

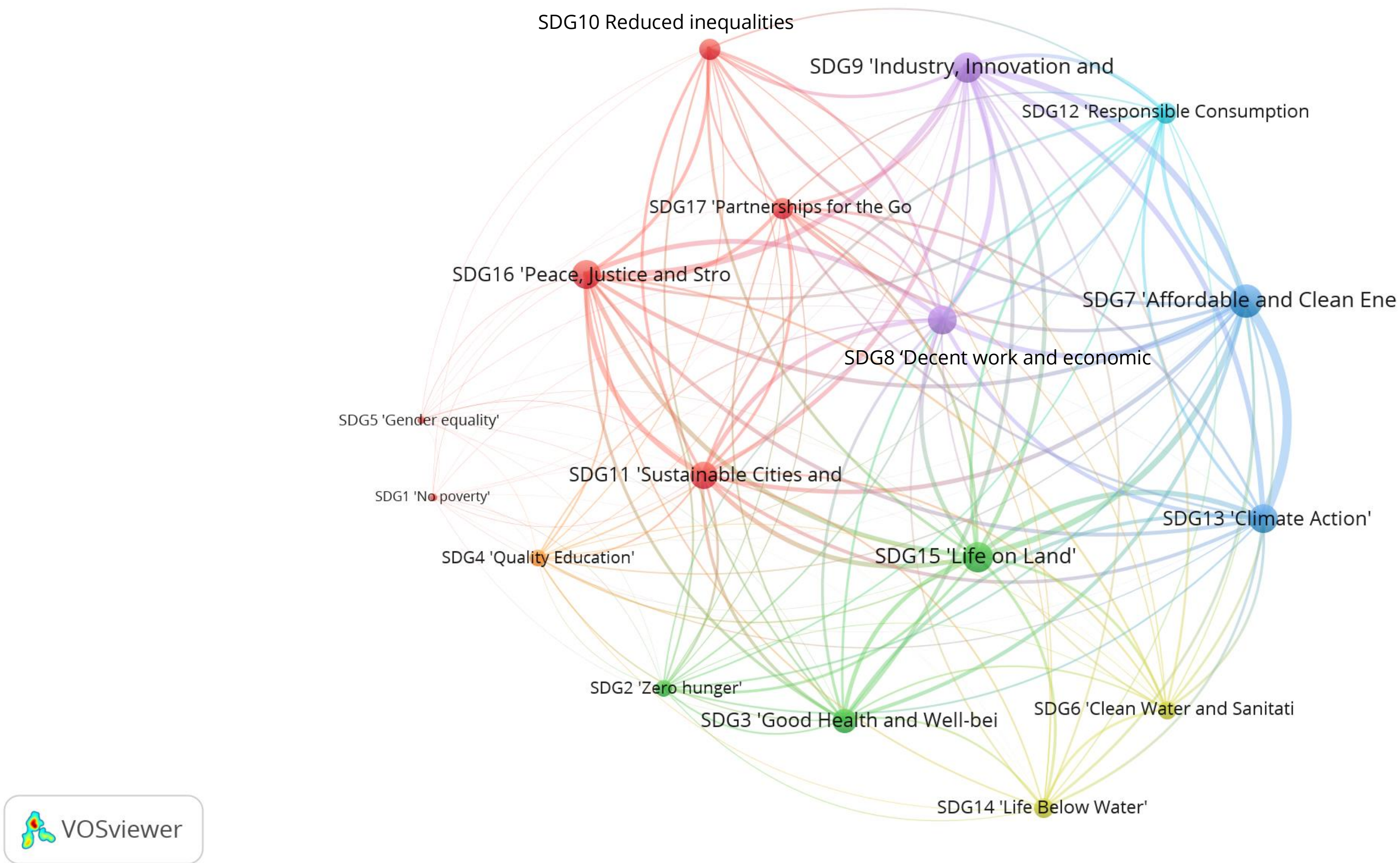
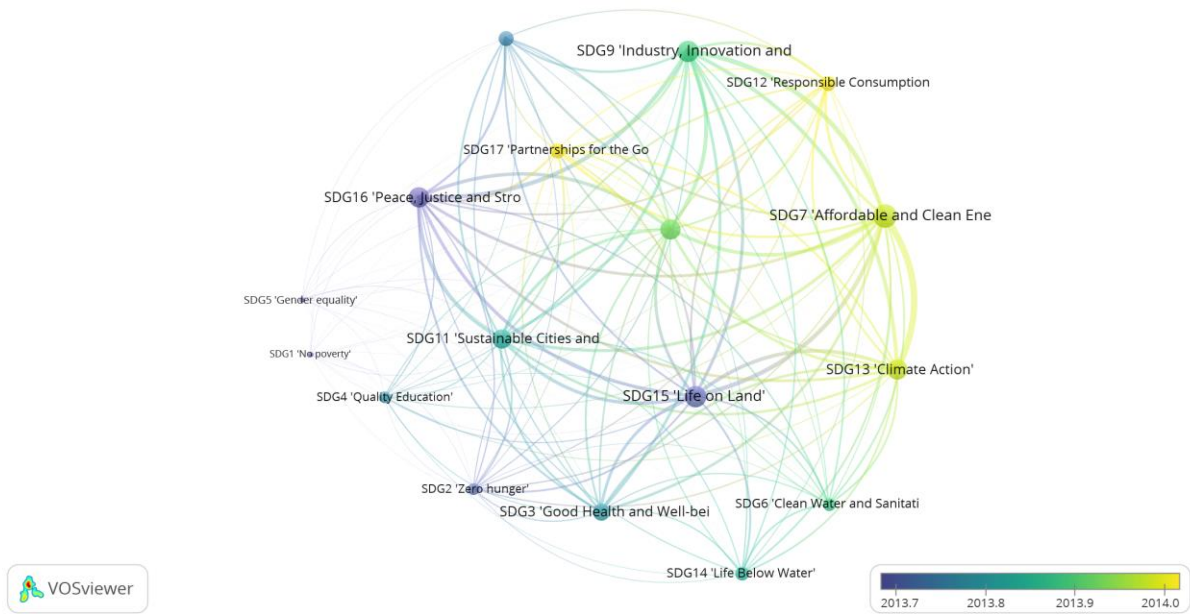


Figure 59. Co-occurrence map of SDGs of sustainability dataset (2008–2017).

Source: Elaborated by the author from CWTS in-house WoS database and VOSviewer.

a)



b)

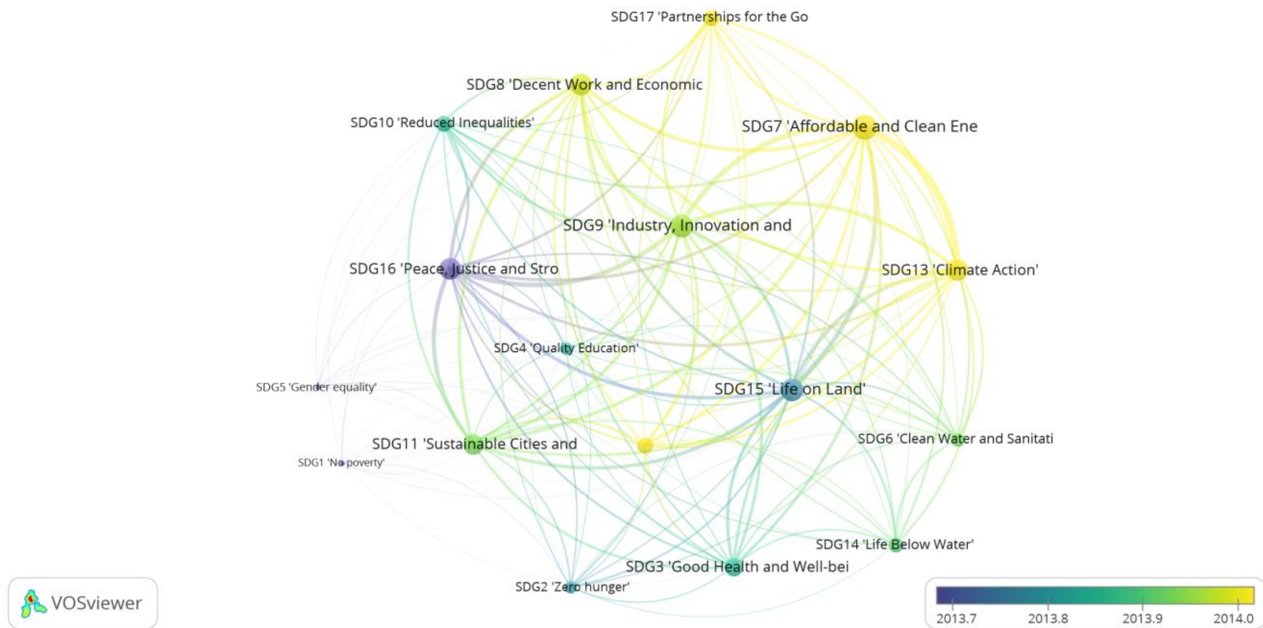


Figure 60. Co-occurrence map of SDGs at a) sustainability dataset and b) HEIs with average number of publications (>50).

Source: Elaborated by the author from CWTS in-house WoS database and VOSviewer.

4.3. Multidimensional indicators

4.3.1. Countries and years

Figure 61 shows a correspondence analysis of the countries' in relation to the years of publications of the papers. Only countries with a production of more than 100 documents during the period of study have been considered. This representation analysis shows both variables (countries and years) in the coordinate axis and can determine whether the scientific production of a country in the sustainability field has been continuous over time or there are variations (represented in peaks). Moreover, countries tend to increase their research output with each year that passes. The size of the spheres is proportional to the publications during the period of study.

The overall analysis leads to the following conclusions. The graph is divided into four periods: 2008–2010 (quadrant II), 2011–2013 (quadrant III), 2014–2016 (quadrant IV) and 2017 (quadrant I). The scientific output presents peaks that can be interpreted as a higher scientific effort in 2008 (n = 4,193), 2009 (n = 5,296), 2010 (n = 6,034), 2016 (n = 15,676) and 2017 (n = 18,171). The great majority of the countries are located in quadrants II and III. There are not many countries close to 2008 or 2009 (although Turkey is close to it). Regarding the second period, the Netherlands, the United States and Canada are close to 2011, Israel to 2012, and Argentina and Finland to 2013. In quadrant IV, regarding 2014, we can find countries such as Taiwan, while in 2015, India and Lithuania, or Italy in 2016. Finally, in the most recent period, certain countries have gained prevalence, such as Chile or Ghana. At the centre we can find countries that had sustained over the period, such as Belgium or Cyprus.

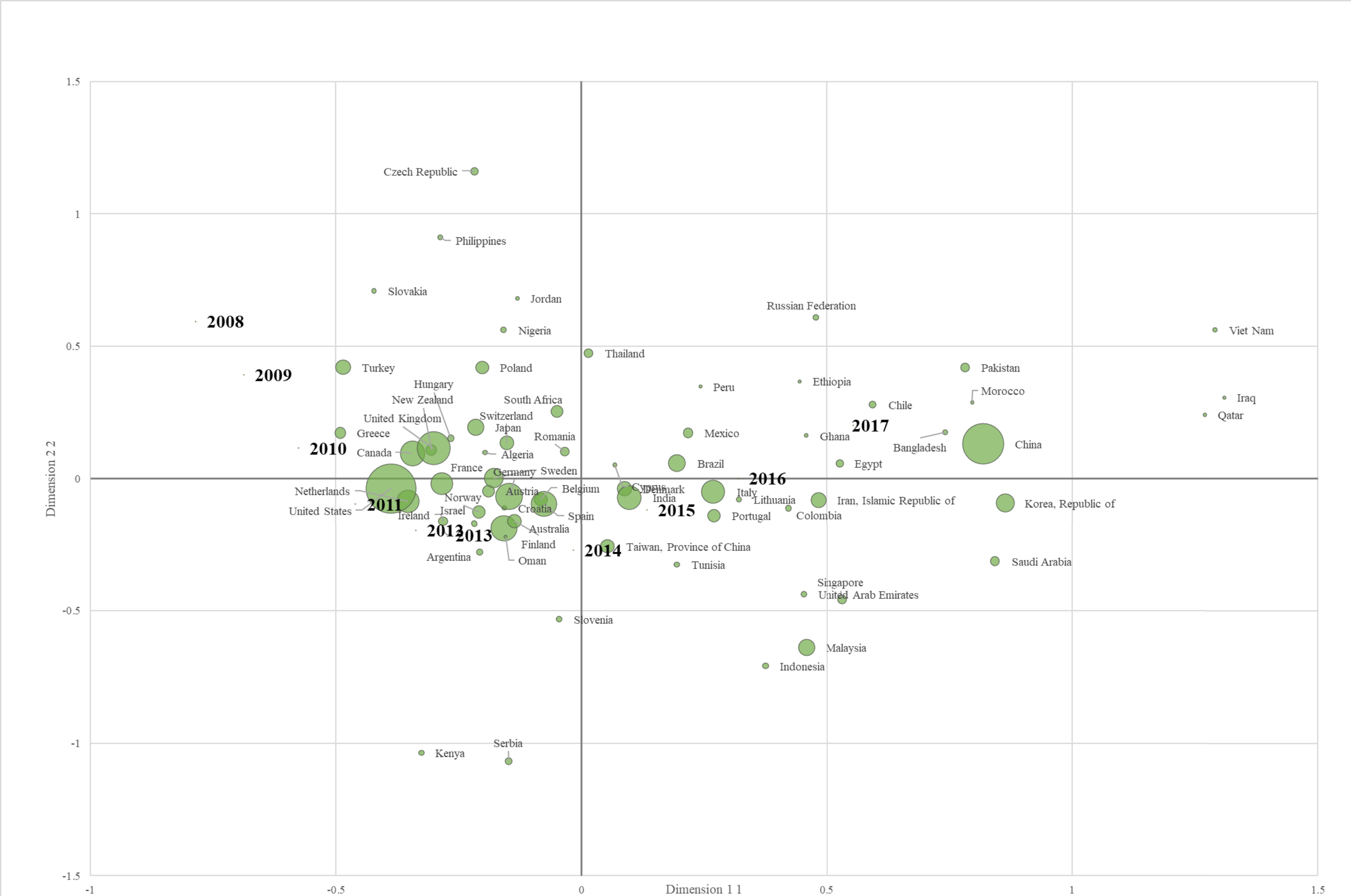


Figure 61. Correspondence analysis of sustainability by countries and years (2008–2017).

Source: Own elaboration from CWTS in-house WoS database and Xlstat.

4.3.2. Organizations and years

Figure 62 shows the correspondence analysis of organizations retrieved from the scientific output detected. In this case, only organizations with more than 300 documents have been included in the analysis. From the graph, it can be observed that organisations such as Consiglio Nazionale delle Richeche, ETH Zurich, Cornell University and the Agricultural Research Service are closer to 2008. Moreover, it is presented as a peak in the period. As happened with the countries, no organizations are closer to the first period. The year 2010 is surrounded by the University of California, Davis or INRA National. Closer to it, 2011 includes organizations such as Utrecht University, the Swedish University of Agricultural Sciences, and the Norwegian University of Science and Technology, while 2013 includes VU University Amsterdam and the University of Copenhagen, among others. For more recent years, some of the more central organizations are as follows: Centre National de la Recherche Scientifique, the University of Leeds, and the University of Edinburgh, in 2014; Stockholm University or the Council for Scientific and Industrial Research in 2015; the University of New South Wales or KTH Royal Institute of Technology in 2016; and the University of Malaya, Hong Kong Polytechnic University, and the University of Lisbon in 2017.

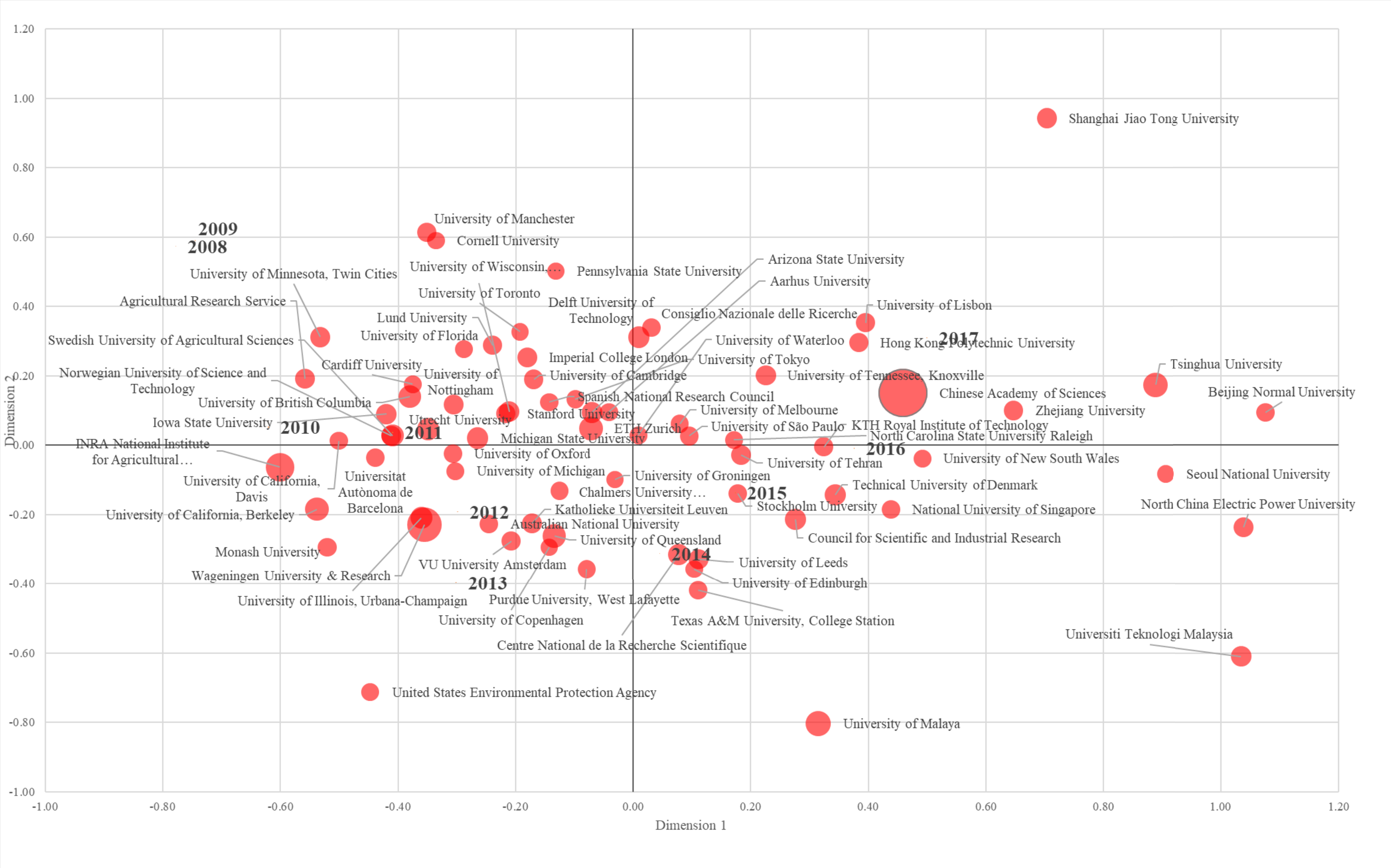


Figure 62. Correspondence analysis of sustainability by countries and years.

Source: Elaborated by the author from CWTS in-house WoS database and Xlstat.

4.3.3. WoS categories and years

Figure 63 shows the correspondence analysis of WoS categories and years of the sustainability dataset, and Figure 64 shows the same analysis for only HEIs.

In the first period of analysis (2008–2010), different WoS categories are distributed over the period. In this sense, in 2008, WoS categories such as “Ethics” are located closer to centre; in 2009, “Business, “Development Studies” or “Water resources” are predominant; in 2010 “Sociology” or “Ecology” are proximate to the year, denoting relation to the year.

In quadrant III are topics related to social sustainability (e.g. “Education & Educational Research”; “Agronomy, “Agriculture, diary & animal science”, “Geography)..) and economic sustainability (e.g. “Management”, “Business, finance”…). Furthermore, social topics were more prevalent in the first part of the period (2011), while economic concerns are broader in this period (2011–2013). Moreover, categories such as energy and fuels have gained importance in this period, close to 2013. In the quadrant IV, in 2015, appear subject categories such as “Green & Sustainable Science & Technology” or “Chemistry, multidisciplinary” . Finally, in the most recent period, 2016–2017, appear topics such as “Engineering, environmental”, “Environmental studies” or “Environmental sciences”, denoting the interest in these topics at the end of the period. The topics at the centre of the axis show a presence over the whole period. They are particularly related to agriculture, denoting the importance of this topic for the whole period (e.g. hospitality, leisure and sport and tourism).

In the second correspondence analysis of HEIs can be observed the following differences. Diverging from the other correspondence analysis, in the first years of the period (2008–2010) the predominant topics were “Business”, “Development studies” or “Agricultural economics & Policy”. Later, in 2011–2014, categories such as marine and freshwater biology (close to 2012 vs 2009 general) or “Food Science & Technology” (close to 2012–2012 vs 2011 general) were more prevalent. In recent years, the WoS categories are similar to the general overview.

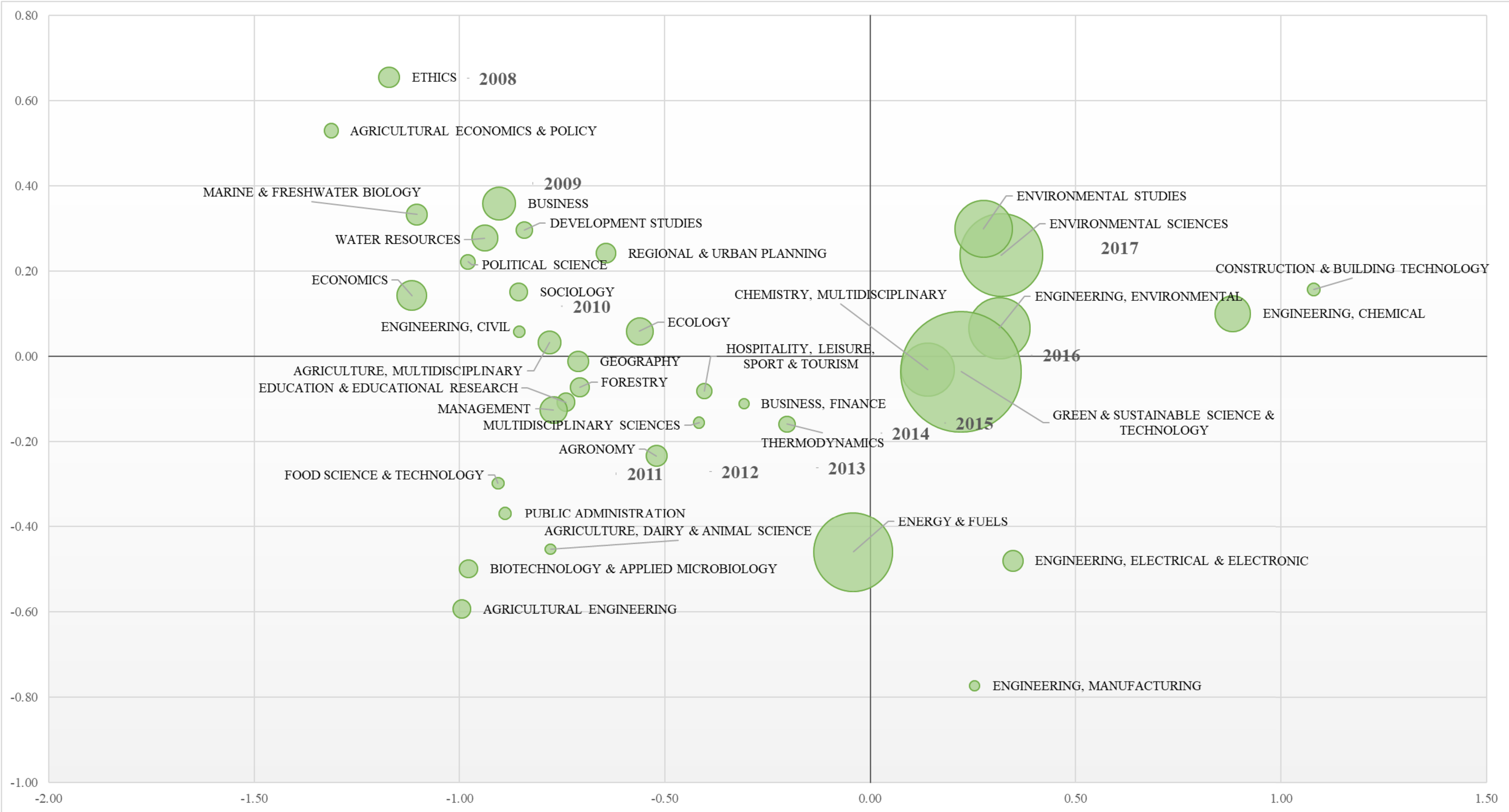


Figure 63. Correspondence analysis between WoS categories and years in P (> 500 docs).

Source: Elaborated by the author from CWTS in-house WoS database and Xlstat.

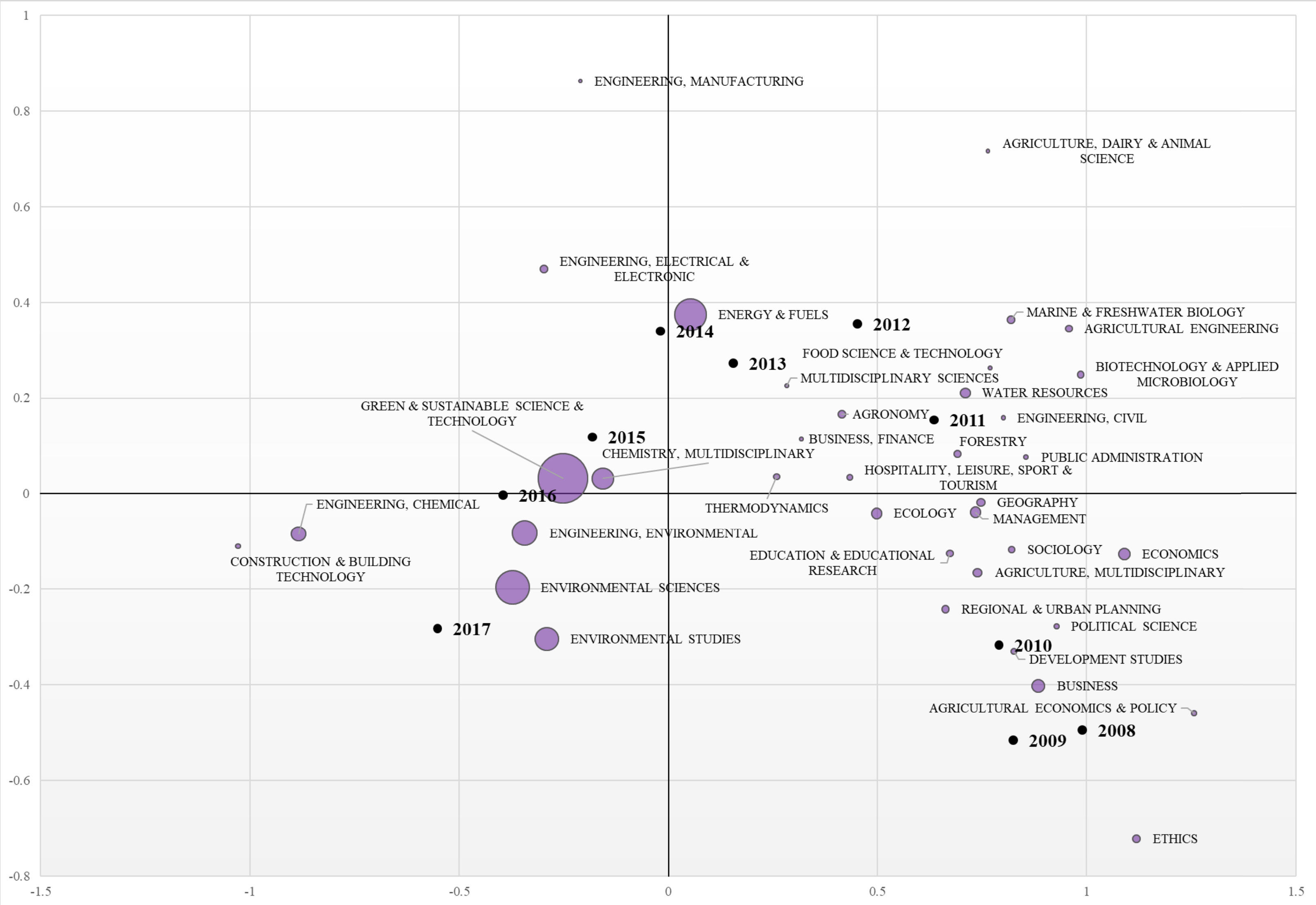


Figure 64. Correspondence analysis between WoS categories and years in P(HEIs).

Source: Elaborated by the author from CWTS in-house WoS database and Xlstat.

4.4. An overview of HEIs and SDGs

4.1. Research output and main actors

By checking the HEIs and RC involved in scientific papers related to sustainable goals, during the period of study, 21,587 documents were detected, with 84.18% of the documents in the same period (*n* = 25,645) (Figure 65). This evolution shows an tendency of increase towards growth of 825% over the period and a CAGR of 13.98%. It is especially remarkable that since the launch of the SDGs (2015–2017), the scientific production of this period rose to the 31.6% of the scientific production for the period. This evolution of the scientific production of the HEIs and RC leads to the conclusion that HEIs play a key role in the scientific output of the M&SDG.

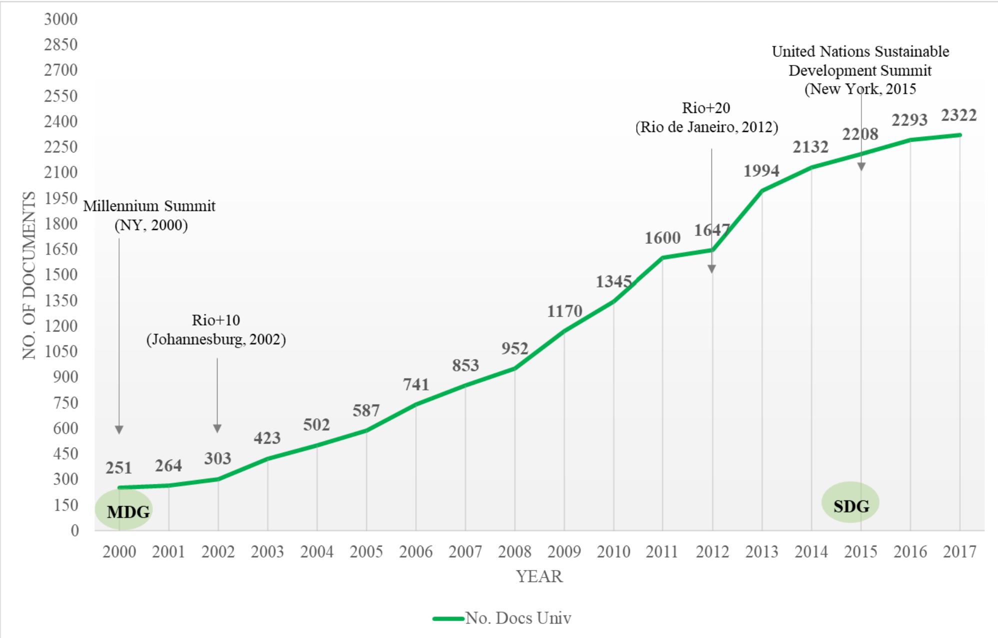


Figure 65. Yearly output of the scientific production of development goals of the HEIs and RC (2000–2017).
Source: Own elaboration from CWTS in-house WoS database.

If we consider the participation of HEIs and RC in the research about M&SDG, 1,965 organizations were detected during the period. The most productive institution encompassed by this topic was the London School of Hygiene and Tropical Medicine, with 1,957 documents (9.07%), followed by the WHO, with 1,672 documents (7.75%), Johns Hopkins University with 1,319 (6.11%) and Harvard University with 1,075 documents (4.98%). However, if we consider periods in blocks of six years, different tendencies can be shown over time. That is, in the first 6-year (2000–2005), the number of documents was 2,330, and 660 organizations participated. The most productive organizations in this period were the WHO, with 293 documents (12.58%), followed by the London School of Hygiene and Tropical Medicine with 272 documents (11.67%) and Johns Hopkins University with 157 documents (6.74%). In the second period (2006–2011), 6,661 documents were collected from 1,245 organizations. During this period, the London School of Hygiene and Tropical Medicine led the ranking with 680 documents (10.21%), followed by the WHO with 579 documents (8.69%) and Johns Hopkins University with 439 documents (6.59%). In the third period (2012–2017), 12,596 documents were retrieved from 1,771 organizations. This period has the same rankings as the second period: The London School of Hygiene and Tropical Medicine leads with 1,005 documents (7.98%), followed by the WHO with 800 documents (6.35%) and Johns Hopkins University with 723 documents (5.74%) (Table 1). Only HEIs such as the University of Cape Town or the University of the Witwatersrand in South Africa, Makerere University from Uganda, Aga Khan University from Pakistan or the Federal University of Pelotas in Brazil are from other developing countries in this ranking of the top most productive.

Table 47. 6-year Period Evolution of the Top 20 Organizations Participating in Sustainability Goals Research

2000–2005			***2006–2011***			***2012–2017***		
Org.	***P***	***%***	***Org.***	***P***	***%***	***Org.***	***P***	***%***
WHO	293	12.58	London School of Hygiene & Tropical Medicine	680	10.21	London School of Hygiene & Tropical Medicine	1,005	7.98
London School of Hygiene & Tropical Medicine	272	11.67	WHO	579	8.69	WHO	800	6.35
Johns Hopkins University	157	6.74	Johns Hopkins University	439	6.59	Johns Hopkins University	723	5.74
Harvard University	117	5.02	Harvard University	315	4.73	Harvard University	643	5.10
University of Oxford	69	2.96	University of Oxford	246	3.69	University of Washington, Seattle	476	3.78
Columbia University	67	2.88	University College London	210	3.15	University of Oxford	423	3.36

University of California, Berkeley	52	2.23	Columbia University	202	3.03	University College London	383	3.04
University College London	47	2.02	Imperial College London	192	2.88	Columbia University	377	2.99
University of Liverpool	44	1.89	University of Cape Town	177	2.66	University of the Witwatersrand	359	2.85
Imperial College London	44	1.89	University of Liverpool	163	2.45	University of Cape Town	355	2.82
Cornell University	42	1.80	University of Washington, Seattle	142	2.13	Imperial College London	344	2.73
University of Cape Town	41	1.76	International Centre for Diarrhoeal Disease Research, Bangladesh	131	1.97	University of Toronto	328	2.60
Swiss Tropical & Public Health Institute	40	1.72	Aga Khan University	130	1.95	University of Queensland	299	2.37
University of East Anglia	39	1.67	University of California, San Francisco	128	1.92	Aga Khan University	298	2.37
University of North Carolina, Chapel Hill	38	1.63	University of California, Berkeley	126	1.89	University of Melbourne	297	2.36
University of Sussex	36	1.55	University of the Witwatersrand	120	1.80	University of North Carolina, Chapel Hill	295	2.34
Yale University	36	1.55	University of Queensland	111	1.67	University of Liverpool	293	2.33
University of Toronto	34	1.46	Swiss Tropical & Public Health Institute	109	1.64	Makerere University	265	2.10
International Centre for	34	1.46	Makerere University	107	1.61	Emory University	250	1.98

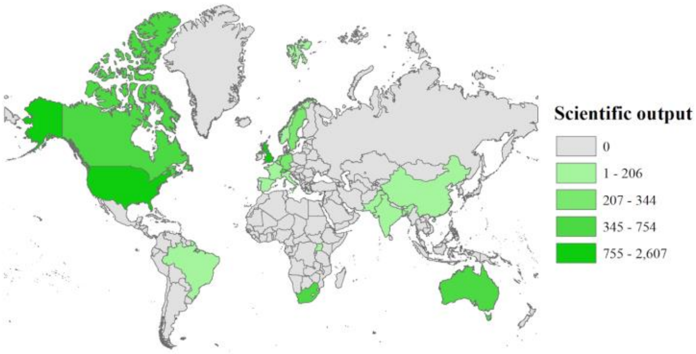
Diarrhoeal Disease Research, Bangladesh								
Federal University of Pelotas	33	1.42	Emory University	102	1.53	Stanford University	241	1.91
Total docs.	2,330			6,661			12,596	

Source: Own elaboration from CWTS in-house WoS database.

The most productive country was United States (8,444 docs, 39.12%), followed by the United Kingdom (6,031 docs, 27.94%), Switzerland (2,225 docs, 10.31%) and Australia (1,950 documents, 9.03%). This trend is maintained over the duration of the output analysis. In the first period, 67 countries participated, and the most productive country was the United States, with 936 documents (40.17%), followed by the United Kingdom with 743 (31.89%), Switzerland with 328 (14.08%) and Canada with 120 (5.15%). In the second period (2006–2011), 86 countries participated, and the United States was the main producer, with 2,607 documents (39.14%), followed by the United Kingdom with 2001 (30.04%), Switzerland with 754 (11.32%) and Canada with 490 (7.36%). In the last period, 95 countries participated and, the country the most participation from its institutions was the United States, with 4,901 documents (38.91%), followed by the United Kingdom with 3,287 (26.10%), Australia with 1,381 (10.96%) and Canada with 1,144 (9.08%) (Figure 66).

a)

b)



c)

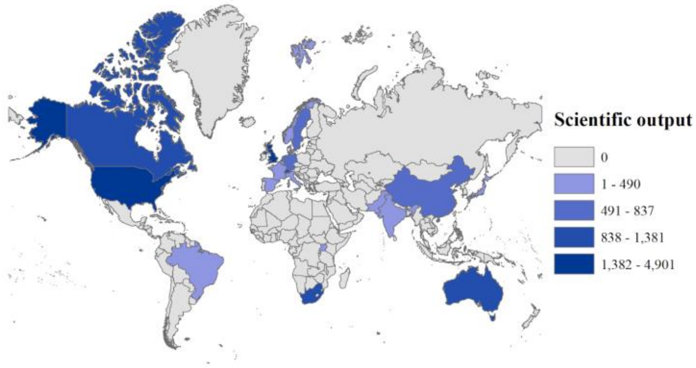


Figure 66. Geographic distribution of scientific documents in the top 20 institutions in the following periods: a) 2000–2005; b) 2006–2011; c) 2012–2017.
Source: Own elaboration from CWTS in-house WoS database and ArcGIS.

In order to determine also the most specialized countries with respect to this topic, an AI based on M&SDGs has been created. Figure 3 shows a scatter plot with the relation between the institutions with a higher scientific output on SDGs and the AI (SDG). The size of the bubble indicates the number of documents in the WoS of its institution, indicating their production size. If we check with the most productive institutions on the topic, the graph shows that institutions with higher scientific output such as Johns Hopkins University (*n* = 1,319) or Harvard University (*n* = 1,075) present a lower AI (8.71 and 3.89, respectively). However, the WHO (*n* = 1,672) and London School of Hygiene and Tropical Medicine (*n* = 1957) present a high AI of more than 88%. Moreover, if we check the institutions in terms of specialization, other institutions appear, such as the Stockholm Environment

Institute (AI 191.10), Aga Khan University (AI 142.26) or the International Centre for Diarrhoeal Disease Research, Bangladesh (AI 132.66) (Figure 3).

Figure 67. Scatter plot of the Top 20 organizations ranked by AI (SDGs).

Source: Own elaboration from CWTS in-house WoS database.

4.2. Thematic specialization

4.2.1. Keyword co-occurrence analysis

With the aim to analyse the topics of this research, keyword co-occurrence-based clustering was conducted (Figure 5). According to the terms identified in each cluster, the following five clusters were identified: #1 millennium development goals inheritance and policy framework; #2 maternal mortality and care; #3 health systems: diagnosis, treatment; #4 Africa health ecosystem and #5 developing countries landscape: health, community, water, and so on. Table 2 summarizes information in the cluster (e.g. the most frequent keywords, the average year, average links, core papers). It can be observed that the largest is cluster 2, maternal mortality and care, and the second largest is cluster 3, health systems. The number of links per paper ($\#link_{avg}$) is higher in those clusters, denoting that is more connected with the other clusters. In addition, it is observed that in several clusters, the $year_{avg}$ is 2011–2012. This fact leads to the conclusion that those clusters were published in the last three years of the study. The percentage of core documents on each cluster are presented. For instance, cluster 1 includes more core documents (21.85%), so it could be interpreted as a cluster that includes papers related to the precursor of SDGs, MDGs, so it grouped with core documents.

Table 48. Summary of 5 Thematic Clusters on SDG Research, Label, Size, Core Papers and Most-Frequent Keywords and Frequency

Cluster	***Label***	***#nodes***	***Core papers***	***% core papers***	***#link$_{avg}$***	***#year$_{avg}$***	***Most-frequent keywords and frequency***
#1	Millennium development goals inheritance and policy framework	8,960	1,958	21.85	169.13	2012.19	management (962); policy (694); poverty (657); millennium development goals (640); climate change (512)
#2	Maternal mortality and care	9,905	1,459	14.73	196.58	2012.45	care (1,586); countries (1,349); services (882); maternal mortality (875); India (837)
#3	Health systems: diagnosis, treatment	9,504	1,185	12.47	192.24	2012.31	mortality (2,435); health (2,068); systematic analysis (774); risk factors (726); disease (722)
#4	Africa health ecosystem	8,073	1,050	13.01	178.00	2011.42	Africa (1,257); sub-Saharan Africa (1,135), impact (1,126); children (1,053), South-Africa (741)
#5	Developing countries landscape: health, community, water	6,777	932	13.75	186.91	2012.09	developing countries (1,892); intervention (928); randomized (763); middle-income countries (597); growth (529); community (458)

Source: Elaborated by the author from CWTS in-house WoS database.

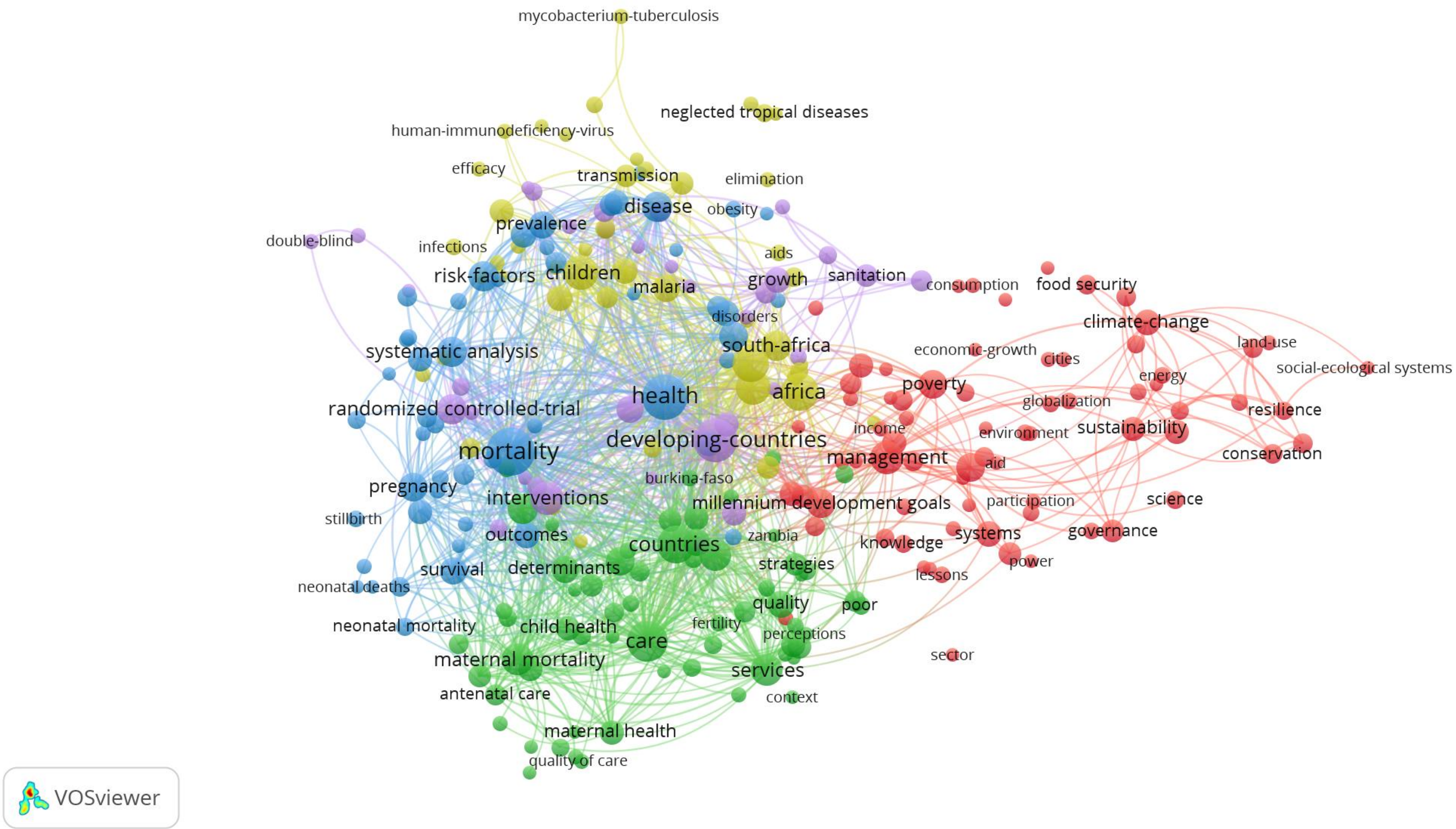


Figure 68. Co-occurrence map (<100 keywords) based on keywords of production related to SDGs.

Source: Own elaboration from CWTS in-house WoS database.

Burst is a concept associated with a change of a variable's value in a relatively short time. In this section, burst detection for keywords of sustainability research are illustrated to show articles that have received rapidly increasing attention through citations and to explore research directions intensively. In the period analysed, there have been 60 different bursting keywords in sustainable goals publications. Table 3 lists these keywords with the strongest citation bursts, along with their strength and time span. In this sense, burst strength is an indicator that denotes change in usage frequency, which can be derived by the burst detection algorithm from Kleinberg (2003). It shows that "middle income country" has the strongest citation burst with a burst strength of 75.13, in the period, followed by "tuberculosis" with 66.52 and "maternal health" with 64.98. Some keywords have a time span of only the beginning of the period (e.g. low birth weight, 2000–2003; economic growth, 2000–2001; and rural Bangladesh, 2000–2001). However, in recent years, bursting citation keywords include "newborn" (16.65, time span of 2015–2017), "middle income country" (75.13, time span of 2014–2017), "maternal health" (64.98, time span of 2014–2017) and "delivery" (36.38, time span of 2014–2017). It is consistent with the fact that more efforts are devoted to these critical research themes, which have become more relevant over time (Table 49).

Table 49. Top 60 Keywords with the Strongest Citation Bursts Sorted by Opening Year

Kw	*Str.*	*Begin*	*End*	*2000 - 2017*
infant mortality	41.0873	**2000**	2008	
income	15.9272	**2000**	2003	
low birth weight	11.4649	**2000**	2003	
trial	22.5934	**2000**	2004	
inequality	48.7206	**2000**	2008	
nutrition	6.0144	**2000**	2001	
globalization	16.9567	**2000**	2006	
health care	18.6416	**2000**	2006	
antenatal care	9.5531	**2000**	2003	
transmission	40.9383	**2000**	2007	
aid	31.8646	**2000**	2007	
cost	17.542	**2000**	2006	
human immunodeficiency virus	6.6829	**2000**	2001	
economic growth	8.02	**2000**	2001	
prenatal care	11.092	**2000**	2004	
rural Bangladesh	5.346	**2000**	2001	
anaemia	6.0144	**2000**	2001	
randomized trial	8.1832	**2001**	2004	
malaria	14.4421	**2001**	2006	
safe motherhood	8.1832	**2001**	2004	
tuberculosis	66.5183	**2001**	2011	
fertility	12.3561	**2001**	2003	
growth	30.4484	**2001**	2008	
infection	20.8902	**2002**	2008	
Uganda	9.8743	**2002**	2003	
cost effectiveness	17.0745	**2002**	2006	
gender	9.6188	**2002**	2004	
Tanzania	8.7135	**2002**	2004	
malnutrition	33.955	**2003**	2009	
education	10.544	**2003**	2004	

public health	42.1686	**2004**	2012	
morbidity	53.5406	**2006**	2011	
poverty	20.0308	**2006**	2009	
randomized controlled trial	52.8332	**2006**	2013	
Kenya	18.7307	**2007**	2008	
strategy	45.8455	**2007**	2012	
population	34.6716	**2007**	2011	
neonatal mortality	11.2422	**2007**	2008	
model	22.6023	**2008**	2010	
HIV	19.8909	**2009**	2013	
sustainabili ty	6.7965	**2009**	2011	
survival	12.697	**2010**	2013	
challenge	9.4519	**2011**	2012	
child mortality	49.1852	**2011**	2014	
United States	8.4907	**2011**	2012	
prevention	16.4552	**2012**	2013	
systematic analysis	60.5619	**2013**	2017	
burden	27.8308	**2013**	2017	
millennium developme nt goal	28.3765	**2013**	2014	
community	8.0114	**2013**	2014	
equity	33.994	**2013**	2015	
trend	30.5064	**2013**	2017	
epidemiolo gy	5.7865	**2013**	2014	
maternal health	64.9803	**2014**	2017	
access	57.4133	**2014**	2017	
middle income country	75.1318	**2014**	2017	
delivery	36.3786	**2014**	2017	
infant	14.7382	**2014**	2015	
outcome	38.0628	**2015**	2017	
newborn	16.6561	**2015**	2017	

Source: Own elaboration from CWTS in-house WoS database and CiteSpace.

With the use of an *ad hoc* ontology (Annex 1), 20,825 documents were classified (96.5%) on each of the 17th SDGs. It should be remarked that a paper could be integrated into more than one SDG. In this regard, the following SDGs were most prevalently represented: SDG3, good health and well-being, with 16,101 papers (77.32%); followed by SDG16, peace, justice and strong institutions, with 11,953 (57.40%); SDG11, sustainable cities and communities, with 9,877 documents (47.73%); and SDG10, reduce inequalities, with 6,317 documents (30.33%). On the other hand, the least represented SDGs are the following: SDG 12: responsible production and consumption, with 939 papers (451%); and SDG7: affordable and clean energy, with 1,095 documents (5.26%) (Figure 7).

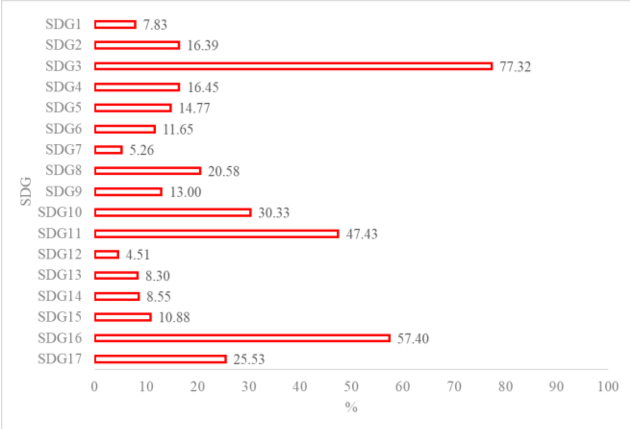


Figure 69. Percentage of documents classified by each SDG (*n* = 20,825).

Source: Own elaboration from CWTS in-house WoS database and ontology-based.

Table 4 shows which SDGs are in research by continent, based on the distribution for the total of each SDGs (left) and based on the total of scientific output on each continent (right). The country selected is based on first-author affiliation. The results show that all goals have higher production in Europe and the North America. Considering all scientific output goals (Table 4, left), it can be observed that in Europe the highest percentage is in SDG2, zero hunger (37.68%), and SDG5, gender equality (37.50%); in America, it is in SDG13, climate action (46.21%), and SDG15, life on land (44.15%). In Africa, the higher production of HEIs and research centres is in SDG5, gender equality (15.61%); SDG4, quality education (14.24%); and SDG11, sustainable cities and communities (13.81%). In Asia, it is in SDG17, partnership for the goals (13.94%); SDG5, gender equality (13.59%); and SDG4 (13.28%). Finally, in Oceania, the higher production of these institutions is in SDG13, climate action (8.44%); SDG15, life on land (6.80%) and SDG17, partnership for the goals (6.58%). From a global perspective, if we consider the distribution of the documents on each goal by continent to determine their profile (Table 4, right), the approach of the different SDGs by HEIs and research centres exhibit more similar patterns, although some SDGs—such as good health and well-being (SDG3); peace, justice and strong institutions (SDG16); and reducing inequalities (SDG10)—stand out from the others.

Table 50. Distribution of Papers per SDGs by Continent Based on the Total of Each SDGs (left) and on the Total/Continent (right)

SDG1	10.36	33.42	9.99	40.34	5.89
SDG2	9.52	37.68	11.37	34.95	6.48
SDG3	13.33	36.75	11.53	33.11	5.28
SDG4	14.24	35.55	13.28	31.61	5.31
SDG5	15.61	37.50	13.59	27.90	5.40
SDG6	10.72	33.59	10.35	40.93	4.41
SDG7	4.57	32.33	12.97	43.84	6.30
SDG8	10.92	35.11	10.36	37.24	6.37
SDG9	9.53	35.89	10.41	37.78	6.39
SDG10	9.69	34.89	10.29	39.31	5.83
SDG11	13.81	34.88	13.04	32.94	5.34
SDG12	5.75	30.14	11.50	45.37	7.24
SDG13	4.68	31.98	8.68	46.21	8.44
SDG14	8.54	32.70	10.62	42.87	5.28
SDG15	7.51	32.32	9.23	44.15	6.80
SDG16	12.60	35.71	11.48	34.38	5.83
SDG17	10.31	30.45	13.94	38.72	6.58

SDG1	1.85	1.99	1.79	2.34	2.11
SDG2	3.56	4.68	4.26	4.24	4.87
SDG3	23.50	21.55	20.39	18.97	18.72
SDG4	5.34	4.44	5.00	3.85	4.01
SDG5	5.26	4.20	4.59	3.05	3.66
SDG6	2.85	2.97	2.76	3.53	2.36
SDG7	0.55	1.29	1.56	1.71	1.52
SDG8	5.13	5.48	4.88	5.68	6.01
SDG9	2.83	3.54	3.10	3.64	3.81
SDG10	6.70	8.03	7.14	8.83	8.10
SDG11	14.94	12.55	14.14	11.57	11.61
SDG12	0.59	1.03	1.19	1.52	1.50
SDG13	0.89	2.01	1.65	2.84	3.22
SDG14	1.66	2.12	2.08	2.71	2.07
SDG15	1.86	2.67	2.29	3.56	3.39
SDG16	16.49	15.55	15.07	14.62	15.35
SDG17	6.00	5.90	8.14	7.33	7.71

Source: Own elaboration from CWTS in-house WoS database and ontology-based.

In terms of involvement in the research of each SDG, Table 5 presents the number of unique institutions involved in each SDG. The average of HEIs and RC that participated in the research production of each goal is 1,101 (of 1,965 institutions in total), denoting interest in this topic. The SDG that presented a higher number of institutions involved is SDG3, wellbeing and health, with 1,674 (85.19%). It is followed by SDG16, peace, justice and strong institutions, with 1,536 institutions (78.17%); and SDG11, sustainable cities with 1,515 institutions (77.10%).

Table 51. Approach of the 17 SDGs by the Institutions Analysed

SDG	***Number of institutions involved***	***%***
SDG1	735	37.40
SDG2	1,055	53.69
SDG3	1,674	85.19
SDG4	1,041	52.98
SDG5	897	45.65
SDG6	973	49.52
SDG7	687	34.96
SDG8	1,171	59.59
SDG9	1,107	56.34
SDG10	1,395	70.99
SDG11	1,515	77.10
SDG12	642	32.67

SDG13	974	49.57
SDG14	900	45.80
SDG15	1,022	52.01
SDG16	1,536	78.17
SDG17	1,396	71.04
Total institutions	1,965	

Source: Own elaboration from CWTS in-house WoS database and ontology-based.

4.2.2. SDGs interconnections

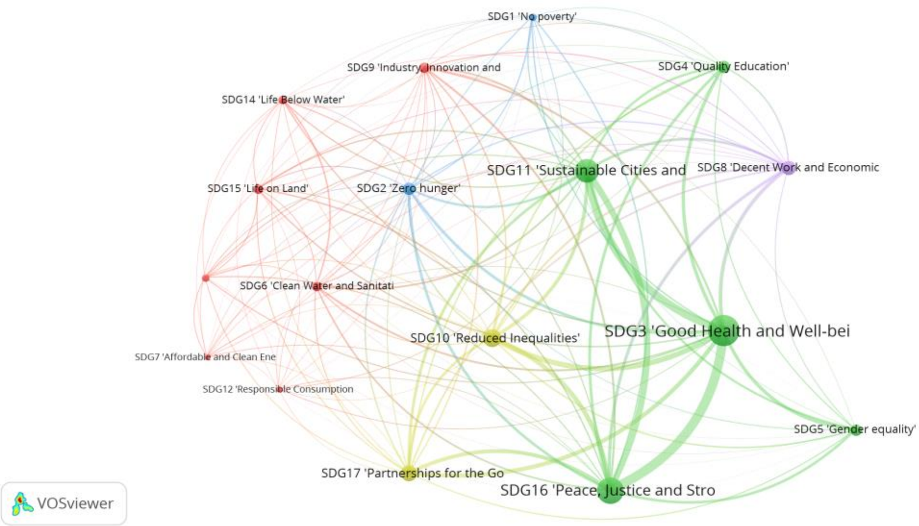
Although the interlinked nature of SDGs has been stressed, their interactions are "not explicit in the description of the goals" (Griggs et al., 2017). For instance, SDG11, sustainable cities and communities, contains targets related to economic dimensions (e.g. financial and technical assistance for developed countries, expenditure on the conservation on cultural and natural heritage), social (e.g. number of deaths per disaster and urban population living in slums) or environmental dimensions (e.g. reduce the adverse per capita environmental impact of cities and proportion of urban solid waste) and can be linked with other SDGs (e.g. SDG6, clean water and sanitation). To reveal their relations in the research, a co-occurrence map has been created with VOSviewer software. The proximity between SDGs nodes indicates their similarity in terms of SDGs co-occurrence. The size of the nodes reflects the frequency of SDGs, and the thickness of the edges denotes how often these goals are co-cited. Figure 6 shows the SDGs map. The following clusters are defined:

- Cluster 1 (red) is formed by SDG6, clean water and sanitation; SDG7 affordable and clean energy; SDG9, industry, innovation and infrastructure; SDG14, life below water; and SDG15, life on land. It is composed of SDGs related to the environment (e.g. SDG15; SDG14), energy and industry (SDG9). Within this group, there is a strong connection between SDG6 and SDG14 that could be associated, for instance, with developing management strategies to reduce fluvial erosion and pollution (International Council for Science, 2015).
- Cluster 2 (blue) is grouped by SDG1, no poverty, and SDG2, zero hunger, two of the most important SDGs inheritance of MDGs. SDG1 is directly and indirectly related to all other SDGs, but dependent on SDG2 (International Council for Science, 2015).
- Cluster 3 (yellow) includes two SDGs: SDG10, reduce inequalities, and SDG17, partnership for the goals. For instance, one linkage of these two SDGs could be that data should be collected of all groups of population and analysed in the disaggregated form to ensure targets are being met for everyone (International Council for Science, 2015).
- Cluster 4 (green) is composed of SDG3, good health and well-being; SDG4, quality education; SDG 5, gender equality; SDG11, sustainable cities and communities; and SDG16, peace, justice and strong institutions. Within this group, strong connections between SDGs can be shown. For

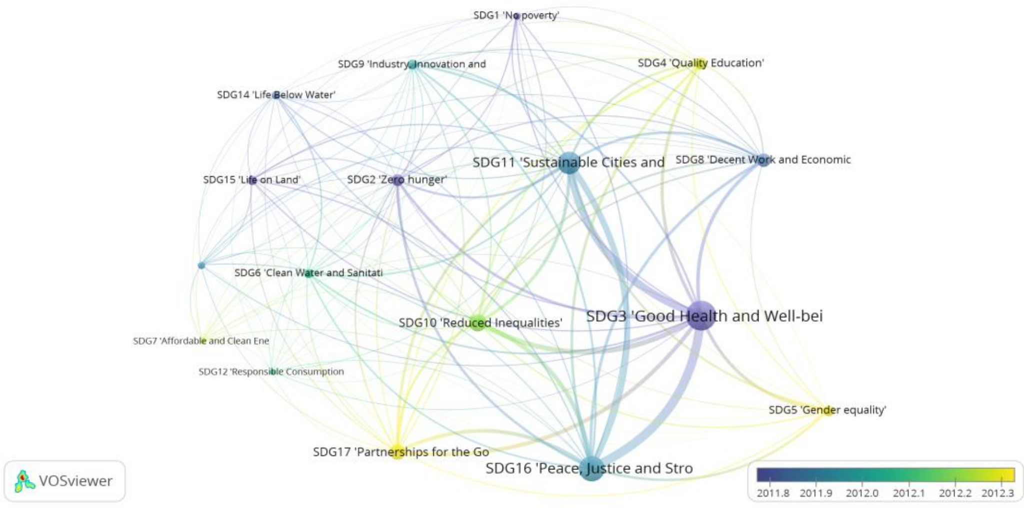
instance, SDG11 and SDG3 have a strong connection (link strength of 8,062). Moreover, SDG3, related to health, also presents a strong connection with SDG16 (strength of 9,840). Health is a crucial SDG that also can be associated with peace and justice in the world. SDG16 and SDG11 also have a strong connection (strength of 6,243). In comparison with MDGs, urbanization has become one of the main challenges in the SDG framework.

- Cluster 5 (purple) is composed of only one SDG, which is SDG8, decent work. However, this goal has links with SDG9, industry, innovation and infrastructure, and SDG11, sustainable cities and communities, or SDG3, good health and wellbeing, among others.

Figure 8b shows the evolution of the keywords in each cluster from the average publication year (2011–2012). In earlier years there are topics more related to health (SDG3). Later, SDG17, partnership for the goals; SDG10, reduced inequalities; SDG5, gender equality; and SDG4, quality education, start to appear as more "recent". This development proves more recent awareness of topics related to education or gender, as well as a partnership for achieving the goals.



a)



b)

Figure 70. Co-occurrence map of (a) SDGs and (b) by average publication year.

Source: Own elaboration from CWTS in-house WoS database, ontology-based and VOSviewer.

4.4.3. SDGs retrieval in social networks

According to Bautista-Puig and Dudek (2019c), research can be a response to topics that are considered societal challenges and that are multi-faceted, such as the SDGs. In addition, the delineation of a field is crucial for decision-support studies: it allows one to understand actors involved and to analyse the dynamics of a field. This study proposes a delineation procedure to retrieve scientific publications centred around the SDGs. Our goal is to complement an ontology-based approach with an approach based on Twitter data. Twitter is seen as a relevant resource in the dissemination of scientific literature (Robinson et al., 2014), and one interesting point related to Twitter platform is the use of hashtags. Previous studies have analysed hashtag usage (Romero et al., 2011), but not applied this element to field delineation. We seek to understand how hashtags might be used for field delineation through the question, Can Twitter be used to identify and delineate publications related to the 17 SDGs?

This study is based on records of scientific production in the WoS; as a second source, we referred to the database of Altmetric.com for Twitter records of scientific publications. The test of delineation of publications according to the 17 SDGs followed two different steps:
First, we identified publications in the WoS of SDGs as a seed of publications on this topic. These publications were determined by searching SDGs and MDGs for title, abstract and keywords. Then, an *ad hoc* ontology was created for each SDG with a total of 3,825 terms. This ontology was based on the selection of key terms from the description of the SDGs by the United Nations (United Nations, 2019), as well as the keywords taken from the initial seed of publications. In the second part, we searched for tweets containing the hashtags "#MDG" and "#SDG" as well as hashtags referring to the different goals

(e.g., "#SDG1") in the Twitter data by Altmetric.com. Consequently, any publication referred to in those tweets was collected.

Hashtags as a retrieval element

Using the search strategy in the WoS, 4,725 documents were retrieved from 2000 to 2017. In the Twitter hashtag approach, 1,300 unique documents could be collected. Considering the different SDGs, the hashtags that retrieved the most publications were SDG1, no poverty, and SDG3, well-being and health, denoting the importance of these topics in social networks (Table 1). The overlap between the results of both retrieval methods included 333 distinct documents, meaning that 75% of publications identified based on hashtags were not included in the set of publications identified with the seed.

Table 52. Publications per Hashtag (Publications Can Be Assigned Multiple Hashtags)

Hashtag	***P***	***SDGs seed***
#SDG	994	224
#MDG	381	137
#SDG1	114	9
#SDG2	22	1
#SDG3	68	10
#SDG4	26	4
#SDG5	14	1
#SDG6	52	8
#SDG7	10	3
#SDG8	2	0
#SDG9	2	0
#SDG10	9	0
#SDG11	10	1
#SDG12	10	0
#SDG13	17	0
#SDG14	35	5
#SDG15	3	0
#SDG16	15	1
#SDG17	18	3

Source: Own elaboration from CWTS in-house WoS database.

Topical comparison of retrieval methods

Regarding the classification of scientific publications according to the first approach, most occurrences were found with 2,472 documents (52.32%) classified as SDG17, partnership for the goals). This is followed by 2,075 documents (43.92) in SDG3, health and well-being; 1,831 (38.75%) in SDG16, peace, justice and strong institutions; and 1,208 (25.57%) in SDG11, sustainable cities and communities. It should be considered that each paper could be classified by more than one SDG.

Regarding documents collected by the hashtag strategy, of the 1,300 documents, 933 documents (71%) were assigned to one or more specific SDGs (i.e., not only to a general hashtag like "#SDG"). Considering the different goals, 557 were classified into SDG3, health (42.85%); 424 documents (32.62%) into SDG16, peace, justice and strong institutions; 392 (30.15%) into SDG17, partnership for the goals; and 290 (22.31%) into SDG10, reducing inequalities. Health seems a prominent topic in both scientific production and apparent interest on Twitter; however, peace and justice seem to have more relevance on Twitter than in the research community. Partnership for the goals (SDG17) seems to be the most prominent topic among the scientific publications included.

Comparing labelling accuracy

In order to determine whether hashtags were properly assigned, the SDGs from hashtags were compared with the SDG-labels assigned based on the ontology. For this validation, only specific hashtags (e.g., "#SDG1") were considered ($n = 280$ unique documents). From this consideration, 36% of the documents were positively classified to the same goal according to the ontology. By checking differences by goals, SDG3, health and well-being, was classified positively (41 documents), followed by SDG6, clean water and sanitation (31 documents), and SDG4, quality education (19 documents). See Table 2 for all results.

Table 53. Documents Positively Assigned

Hashtag	***No Match***	***Match***
#SDG1	111 (39.64%)	3 (1.07%)
#SDG2	12 (4.29%)	10 (3.57%)
#SDG3	27 (9.64%)	41 (14.64%)
#SDG4	7 (2.50%)	19 (6.79%)
#SDG5	9 (3.21%)	5 (1.79%)
#SDG6	21 (7.50%)	31 (11.07%)
#SDG7	5 (1.79%)	5 (1.79%)
#SDG8	2 (0.71%)	0
#SDG9	4 (1.43%)	0
#SDG10	8 (2.86%)	1 (0.36%)
#SDG11	9 (3.21%)	1 (0.36%)
#SDG12	10 (3.57%)	0
#SDG13	8 (2.86%)	9 (3.21%)
#SDG14	19 (6.79%)	16 (5.71%)
#SDG15	1 (0.36%)	2 (0.71%)
#SDG16	7 (2.50%)	8 (2.86%)
#SDG17	13 (4.64%)	5 (1.79%)

Source: Own elaboration from CWTS in-house WoS database and ontology-based.

Chapter V: Discussion

In the previous chapter, the results of this study were presented according to various dimensions and corresponding indicators. This section focusses on the analysis and discussion of the research results obtained from the sustainability scientific output from this study.

5.1 Scientific output

The search for scientific output in sustainability during the period 2008–2017 has retrieved a total of 97,876 documents at WoS based on the search strategy proposed in this study. The CAGR for the period is 15.92%, and the interannual growth shows a similar trend, with an average of 17.78% during the period (vs 3.57% observed in WoS in the same period). The results of this study suggest that although one may presume this topic would have a long tradition, it can be observed that the research on this topic has developed considerably in recent years. One fact that supports this statement is that the number of documents published since 2015 represents 58% of the total scientific output.

This output and growth carries forward the findings of previous research studies on sustainability research or sustainability science. As Nučič (2012) has analysed the "interdisciplinary nature of research in sustainability science from 1991 to 2011 using the term sustainability in the title and abstract and keywords", he identifies 24,487 articles (1991–2011), stating that the output has increased exponentially (average of 70.8% on the period). Kajikawa (2007) shows the evolution of articles with "sustainability" or "sustainable" in their bibliographic papers and determines that "12,000 papers on sustainability were published annually", up to the end of 2014 (Kajikawa, Tacoa, and Yamaguchi 2014). According to the results obtained in this study in a recent 10-year period (2008–2017), the average of publications by year is 17,795 documents, leading to an increase in the average of publications on sustainability research. Pulgarín et al. (2015) analyses the structure of SD from 1900 to 2013 and identifies 13,093 articles. Their study shows an exponential evolution in which the annual growth rate is 22%, versus the 17.78% detected in this study. It also points out that the most recent scientific output (in the last five years, 2009–2013) represents 50% of the scientific output. On the other hand, Ramírez et al. (2016) analyse the publications by using sustainability in title, abstract and keywords (labelled by the authors as "sustainability discourse" scientific output) in Scopus database in all areas (with the exception of health sciences) from 1970 to 2015. Regarding the scientific output evolution, a regular and upward trend to 15,000 documents can be observed in 2015 (vs 12,578 documents observed in the same year in our study).

Olawumi and Chan's (2018) study analyses the "global trend and structure of sustainability research by using the terms sustainability and SD" from 1991–2016. These authors identified 2,094 records with a growth of 197.58% in the last five years of the study (2012–2016). Despite the scientific output is different, the growth in this study in the same period rose to 95.78%. Zhu and Hua (2017) have also analysed SD scientific output (by searching "sustainable development") from 1987 to 2015 and collected 59,926 records. The difference obtained by the search strategy proposed in this study retrieved 27,379 more documents than their study (36,650 documents from 2008–2015).

This growth in sustainability research has been discussed in the scientific literature. One aspect that should be remarked upon is the emergence of a new scientific field in the 21st century called "sustainability science" (Kates et al., 2001; Komiyama and Takeuchi 2006; Kajikawa et al; 2007; Kajikawa, 2008; Kajikawa et al., 2014; Nučič, 2012). Sustainability science was originally created at the World Congress "Challenges of a Changing Earth 2001" (Mochizuki, 2015). This congress is focussed on the "dynamic interactions between nature and society, with equal attention to how social change shapes the environment and how environmental shapes society" (Clark & Dickson, 2003). Sustainability science investigates "complex and dynamic interactions between natural and human systems: it aims to bridge the gap between science and society and limit its knowledge to the actions for sustainability" (Wiek et al., 2012; Disterheft et al., 2013). As Kajikawa et al. (2014) have stated, sustainability science is a "rapidly expanding field caused by global ecological crises". Although there is no consensus on its definition, many topics (e.g. renewables, sustainability) have been analysed from this perspective, and its characteristics have been widely described in the literature. Concepts such as transdisciplinarity or its being action-oriented have been used to characterize this new field (Kates et al., 2001; Disterheft et al., 2013). The structure of this new field has been explored qualitatively (Miller, 2013; Jerneck et al., 2011). Similarly, a bibliometric approach has been adopted to "examine the development of sustainability science through the analysis of citations" (Kajikawa et al., 2007, 2014; Buter and Van Raan, 2013) or journal interdisciplinarity (Bettencourt and Kaur, 2011; Buter and Van Raan, 2013) or its dynamics, such as patterns of collaboration (Yarime et al., 2010). According to Quental et al. (2011) "regarding the evolution of scientific approaches to the concept of sustainability, it has passed from the following phases":

1) Ecological economics (1990s) in which the motto was the following: "transdisciplinary research about interactions between human economies and natural ecosystems".

2) Sustainability transition (1999) as a transition in which a "world population comes to meet its needs by moving away from the action that degrades planet's life support systems and living resources while moving towards those that sustain and restore these systems and resources".

3) Sustainability science (2000s): "dynamic interaction between nature and society, with equal attention to how social change shapes the environment and how environmental change shapes society". This phase affects institutions and decision making and implies "resilience" as a principle.

However, regarding how this field is delineated, bibliometric studies on sustainability science have commonly used terms such as "sustainability" or "sustainable" as a search strategy. Buter and Vaan Raan (2013) identified 10,594 publications by using a mixed methodology (they selected a seed set with "sustainab" search in title, publications cited by those and strongly cited publications, known as highly cited knowledge-based dataset). Kajikawa (2014), for their study on sustainability science, use "sustainability" or "sustainable" in the titles, abstracts, and keywords and use the maximum connected component, which resulted in 51,390 papers found. The methodology proposed centres on studies that address sustainability science. Although the combined search strategy proposed in this study suggested a traditional approach based on the three main pillars (i.e., TBL) in sustainability, it combines the delineation based on a WoS category (for the environmental) and a direct citations (or seed+expand) methodology (for social and economic sustainability). This fact constitutes a scientific contribution to sustainability science due to this retrieval methodology fitting its definition. The main decision to propose this approach was supported by the fact that these three pillars remain important in the conception of sustainability science. Despite its limitations, it offers an overview of the scientific output of this concept using a different approach.

On the approach of the three pillars of sustainability, certain bibliometric studies have focused on this differentiation in those three approaches. Some bibliometric studies have focused on analysing specific topics: Fu and Zhang et al. (2017) study the trajectory of urban sustainability concepts; Feng et al. (2017), CSR; and Ruhanen et al. (2015), sustainable tourism research. In Bautista et al., (2019a) the core of the three pillars of sustainability are analysed: 1,683 documents were retrieved on economic sustainability; 1,302 documents, on social sustainability; and 6,107 documents, on environmental sustainability. It is stated that environmental sustainability saw greater increases over the period (CAGR of 20.81%), showing that the research has gained more interest in this pillar. Regarding social sustainability, as pointed out by some studies (Ramírez et al., 2016), the "growth can be related to the emergence of urban sustainability studies". According to Nučič (2012), by applying a "meta-disciplinary perspective with a six-factor grouping of WoS Categories the sustainability lies in the disciplinary fields of environmental science and technology in first hand and social sciences in the second". The results obtained in this study suggest that environmental sustainability has a pivotal role to play in scientific output (20.81 growth rate for environmental sustainability vs 8.06 social and economic sustainability). This assumption is also confirmed by previous studies, which have stated that environmental issues lie at the core of SD, despite social and economic needs to be addressed in a balanced manner (Pulgarín, 2015). In Schoolman et al.'s (2012) study of sustainability science, the tripartite model was considered. These authors used a search strategy ("sustainability" in title or keywords) in Scopus (1996–2009) and selected basic categories for each pillar (e.g. for economics, they selected the following categories: economics, econometrics, and finance; business, management and accounting; and decision sciences). This study also determined that environmental sustainability is richest in terms of articles but poorest in terms of connections. The further state that discussion of this subject "is less widespread within economics and that the social sciences researchers affiliated with these pillars reach out, through citations, both to each other and to the environmental sciences".

Previous studies have discussed the evolution of the scientific output and its growth, along with its possible reasons. As Pulgarín (2015) has stated, this growth can be explained because "the impact of human activity on the environment is leading to this area of research being studied from ever more different fields". In this regard, many disciplines of science and technology have contributed to developing a sustainable society, increasing scientific output (Pulgarín, 2015). Moreover, as Ramirez (2016) points out, this "growth can be explained by the emergence of the concept of sustainable development", which introduced a new reflection on structural changes and how societies should deal with the TBL approach. Olawumi and Chan (2018) consider that this increase could be linked to "more efforts and resources" being devoted to this topic. Considering that sustainability and SD are interdisciplinary, multidisciplinary and transdisciplinary subjects, one controversial issue is to determine to what extent this nature has led sustainability to progress as a scientific discipline. For Nučič (2012), this increasing growth could be associated with "sustainability science as a highly interdisciplinary research field". This hypothesis is also corroborated by Schoolman et al. (2012), who demonstrate that "sustainability research is more interdisciplinary than other scientific research".

Moreover, another aspect that could explain this growth is the emergence and fostering of the MDGs and SDGs in 2000 and 2015, respectively. Considering Nakamura et al.'s (2019) study focussing on the scientific output of SDGs, a scientific output of 2,800 documents was identified in the core and 10,300 expanded by using direct citations. Bautista-Puig and Mauleón (2019b) identified 4,532 documents about the core of scientific output in development goals. Moreover, it can be observed from this study the remarkable scientific interest within the SDGs strategy, in contrast with the MDGs. The methodology proposed in section 4.4., which constitutes an expansion of this previous study, is similar to that of Nakamura et al. (2019) and retrieved a total of 25,645 documents with a CAGR of 13.98. Considering Nakamura study (2019) that focusses on the scientific output on SDGs by using the same methodology, more documents were retrieved in the present study (2,800 in the core and 10,300 expanded in cited/citing vs 4,685 in the core and 25,185 expanded). This difference may arise because in the present study, we also have included MDGs in the search query, considering them as a precursor that maintains the same philosophy of SDGs.

5.1.1. Scientific output at HEIs

From documents retrieved with this search strategy, 81,105 documents (82.86%) are related to HEIs during the period with a CAGR growth slightly higher than the average (19.22 HEIs vs 17.70 P). Similar bibliometric studies have also analysed the scientific output of these institutions. Hallinger and

Chatpinyakoop (2019) analyse 1,459 documents (1998–2018) related to higher education for SD in Scopus (by searching "higher education", "sustainable development" and "sustainability" in titles, abstracts and keywords). From their analysis, the authors suggested there is an "accelerating growth stage" from 2012 to 2018 with 998 documents published (68.40%). Even, they suggested that the "HESD [higher education for sustainable development] knowledge base will more than double in size in the year 2025". This "accelerating" growth coincides with the evolution of scientific output in this research (63,374 documents in 2012–2017, 78% of the output and a growth of 136.80%). In Alejandro Cruz et al.'s (2019) study of SHE (by searching terms in titles, abstracts and keywords, such as "sustainability" or "sustainable", "higher education" or "academic career") in WoS and Scopus, they identified 5,074 records from 1991 to 2018 and also showed this exponentially increasing trend. They stated that the period between 2010–2018 is the most productive in the area of SHE. These authors also consider that "this field is still in a stage of growth" because they related this growth with the "appearance of new author's keywords, that continues to boost year after year".

Bizerril et al. (2018) identify 1,228 publications in Scopus from 2004 to 2015, all focussed on SHE (through a search for the keywords "sustainability" and "higher education" or "university", or "sustainable university"). Their study shows a significant increase in 2013 (in this study, this year is associated with a growth of 21.28% in P and 22% in P[HEIs]). Veiga-Ávila et al. (2018) analyses sustainability and education for sustainability publications and identified 5,924 documents from 2005–2014. The publications also show an increase (422.6%) during the period from 212 in 2005 to 1,108 in 2013. Despite that the number of documents of their study is low in comparison with the present study, one can nevertheless observe the upward trend. Findler et al. (2018) analysed journal articles from 2015–2018 and collected 113 articles discussing the discourse on the impacts of HEIs in SD. These authors, based on an inductive content analysis, determined a strong focus on outreach and assessment and reporting. Despite the growing interest in this subject, we find that there is very little analysis of sustainability at HEIs in Spain from a bibliometric point of view. However, some studies had focussed on this overview from an environmental perspective. In a previous study, Bautista-Puig et al. (2019d), using the environmental category green and sustainable science and technology, identified 3,140 documents from 1994 to 2017 at Spanish HEIs; however, with the expanded search strategy of this thesis (by adding social and economic), this number has increased. De Filippo (2019) has also analysed scientific publications of HEIs in the same subject category, identifying 79,014 papers (1994–2018). Among these papers, 4,129 papers are from Spain, and 3,881 are identified in the same period as this study (n = 5,288). This difference (n = 1,407) can be explained because of the expansion of the dataset. León-Fernández's (2015) dissertation carried an analysis of participation actions in Spanish and Latin American Universities and stated that the universities are active on the issue of participation in environmental questions and sustainability, but in general, the involvement of the university community needs a boost to make it really effective. Some other studies have analysed sustainability at HEIs from other approaches: namely virtual laboratories (Salmerón-Manzano and Manzano Agugliario, 2018) and theses and dissertations on sustainability education (Leetch et al., 2017).

Considering only the role of HEIs in SDGs output, a methodology based on seed and expansion by direct citation has been carried out in order to determine the core scientific production and its extension in section 4.4.. The findings reveal the important participation of HEIs and research centres in this research (85.71%). In this regard, 21,587 unique documents with at least one signature of HEIs or RC were collected in WoS from 2000 to 2017. If we compare this scientific output with other studies that analyse the output of sustainability or SD in HEIs, we find the results of this analysis are more numerous: 1,228 in Scopus from 2004 to 2015 (Bizerril, 2018); 1,459 documents from 1998–2018 (Hallinger and Chatpinyakoop, 2019); 5,074 documents from 1991 to 2018 (Alejandro Cruz et al., 2019); and 5,924 documents from 2005–2014 (Veiga-Ávila et al., 2018). Moreover, only since the launch of the SDGs in 2015 has the scientific production identified by these actors represented 31.6% of the period. This trend accords with Olawumi and Chan's (2018) bibliometric analysis of SD: only the scientific output of 2015 to 2016 represents a 36.27% (vs 23.36% on SDG output of this study). Growth in the period is calculated by the cumulative average growth rate (CAGR) rising to 13.98% (vs 3.82% in WoS in the same period). Moreover, the results of this study suggest that despite MDGs having a long tradition, since 2000, the number of documents is concentrated in recent years, denoting more recent interest (31.61% from 2015 to 2017 vs 21.83% in WoS in the same period).

5.2. Actors: Countries and institutions

5.2.1. Countries

Throughout this chapter, results by countries are analysed. According to the National Science Board's 2018 Science and Engineering Indicators, the countries that produce the majority of publications in Elsevier's Scopus database are the United States, the European Union and developed countries. However, Toffelson (2018) argues that according to United States National Science Foundation, China became a larger producer of scientific output in 2016 than the United States was, although with lower numbers than the European Union. This author also highlight the upward trend of other developing countries (e.g. Brazil), for which raising their investments in science and technology has increased their output. This claim is supported by Chinchilla Rodríguez et al. (2010), who report on the rapid growth of China between 1998 and 2007 (3.1% vs 10.6%) and that of countries such as India (1.9% vs 2.4%).

Previous studies have shown the country's distribution of the scientific output in sustainability research. Hassan, Haddawy and Zhu (2014) in their study of SD and its subareas, identified the main producers: the United States and China with a significant growth leading the rankings, followed by the United Kingdom. However, if we take into consideration the different sub-areas identified for the authors, the distribution differs by topic: In climate change, the leaders are the United States, the United Kingdom, and Germany; in renewable energy, the countries with the highest output are the United States and China, which are very close, and Japan; for forestry, the United States leads, followed by Canada and China. Pulgarín (2015) has identified 166 countries from which the top 35 have 90% of the total output. The United States of America, with 1,979 publications, leads the ranking, followed by China (*n* = 1,400) and the United Kingdom (*n* = 1,386), following the same pattern as in the previous study. For Zhu and Hua (2016), who ranked countries according to betweenness centrality (BC) to identify pivot nodes within knowledge networks distribution, the country distribution is as follows: the United States, followed by the United Kingdom and the Netherlands. According to the authors, this value “indicates the extent of a country’s predominance and impact at the historical and macroscopic levels”. However, in terms of absolute values in the scientific output, China (*n* = 10,463) and the United States (*n* = 6,770) are on the top. Olawumi and Chan (2018), in their study of SD, identified the following countries as most productive: the United States (428 articles, 20.44%), China (275 articles, 13.13%), the United Kingdom (258 articles, 12.32%), Canada (157 articles, 7.50%), Germany (132 articles, 6.30%), the Netherlands (131 articles, 6.26%), Australia (128 articles, 6.11%), and Sweden (124 articles, 5.92%). The author also suggests that the United States and the United Kingdom have the most articles in the field; the most building energy simulation software and devices are reported in the United States. Moreover, this could be caused by the building rating system.

This study follows a similar ranking to that of previous studies. The main producers are the United States (*n* = 19,663), China (*n* = 13,479), the United Kingdom (*n* = 8,833 documents) and Germany (*n* = 5,695 documents). However, according to the AI, some others show higher specialization, such as Malaysia (*n* = 2,229, 4.71% AI) and Finland (*n* = 1,536 documents, 2.26%). Results obtained through the country collaboration network exhibit patterns of collaboration in which the geographic factor (and the language) has a prominent importance. Moreover, it shows non-evident links of collaboration. In this regard, the intense collaboration of the United States with countries like China (strength of 1,676) or South Africa (strength of 135) is observed. For Bettencourt and Kaur (2011), who analyse the evolution and structure in sustainability science over the period 1974–2010, the participation of nations with traditional strength in science is remarkable (e.g. the United States, Western Europe and Japan) but also among countries (Australia, the Netherlands, the United Kingdom, Brazil, China and India, and most especially South Africa, Nigeria, Kenya and Turkey). According to their study, these nations, present a “large presence in terms of publications but also in citations”. In our study, these other countries are located in top 50 positions. Kenya (AI of 2.99), Nigeria (AI of 2.28), and South Africa (AI of 1.95) have also an AI below the average (1.91), denoting higher specialization.

If the results from previous studies about scientific output at HEIs are compared, the countries involved are similar. Hallinger et al. (2016) has mentioned that countries such as the United States, the United Kingdom, Canada, and Australia have produced 55% of the HESD literature. Moreover, these authors highlight the prevalence in Northern European Countries (Germany, the Netherlands, and Sweden, with 13% in the scientific output). They further mention that 16% of this literature has been authored in developing societies (e.g. China with 47 documents, Malaysia with 40 and South Africa with 40). Veiga Ávila et al. (2018) have identified the following countries: the United States of America, England, China, Australia and Canada. The authors justified their presence because they have "defined their strategies for implementing the DESD". Moreover, these authors have noted that Brazil is ranked 14th, which can be explained because the "relationship between education and sustainability is present as a requirement in the Brazilian Federal Constitution". Adomßent et al.'s (2014) study states that in the sustainability research in HEIs published in "international peer-reviewed journals there is a strong focus on development in such countries as the United States, the United Kingdom Australia, Canada, Sweden, Spain, Japan and Germany". Finally, Alejandro-Cruz et al. (2019) have identified the United States ($n = 945$), the United Kingdom ($n = 613$), China ($n = 471$) and Australia ($n = 417$), representing the 40.58% of the documents. In our study, the top 100 institutions in sustainability research from HEIs are from the United States (with 24 institutions), China (with 11 institutions), the United Kingdom (with 11 institutions) and Australia (with 10 institutions).

With the SDGs dataset, regarding the countries in which these institutions are based, the number of countries has risen (from 67 countries in the period 2000–2005 to 95 countries in the period 2012–2017). This fact is associated with Yarime et al.'s (2010) study, which stated "that an increasing number of countries are engaged in research on sustainability". Moreover, the distribution also confirmed that higher scientific production is concentrated mainly in developed countries (e.g. the United States, the United Kingdom and Canada). Special focus and importance should be placed on South Africa, the leading African country in this sense (production of 1,849 documents in 2012–2017), located in the 19th position on the SDG index (Stiftung and SDSN, 2019).

5.2.1. Institutions

Results at the institutional level show the typologies more predominant in this research are HEIs (73.94%), research organizations (19.17%), teaching organizations (3.99%), hospitals (1.13%) and governmental institutions (0.81%) (based on the addresses). Higher education institutes are responsible for 82.86% of the scientific output in this study. As the results determined, the main producers are the Chinese Academy of Sciences (China, $n = 2{,}385$), Wageningen University Research Centre (the Netherlands, $n = 1{,}197$), the INRA National Institute for Agricultural Research (France, $n = 825$), the University of Malaya (Malaysia, $n = 635$) and Tsinghua University (China, $n = 614$). However, the AI offers a different ranking: Wageningen University Research Centre (1,197 docs, 8.86 AI), Swedish University of Agricultural Sciences (493 docs, 7.28 AI), the INRA National Institute for Agricultural Research (825 docs, 5.06 AI) and the University of Malaya (635 docs, 4.94 AI). That is, despite not having the highest production, has a specialization on the topic. Moreover, the results obtained through the institutional collaboration networks (section 4.2.2.) allow us to identify patterns of collaboration. From the eight clusters identified, the geographical factor is of outstanding importance.

Previous studies have also identified institutions involved in the research. Ramírez et al.'s (2016) study has identified production at very early stages since the 1980s. In this regard, the main producers identified were Wright Patterson AFB, the University of Newcastle Australia, the World Bank, the University of Wisconsin Madison and Imperial College London. The authors suggest that the World Bank was one of the leaders in scientific discourse. From 1988 to 2015, in a period that the authors tagged as essential "to the SD concept and the economic crisis", the Wageningen University and Research Centre, Delft University of Technology, the University of British Columbia and Arizona State University lead the ranking. Furthermore, the Chinese Academy of Science or the University of San Paulo appear on the list, denoting the presence of emerging countries characterized by annual economic growth rate, urbanization, and industrialization. In the final period, called the "recent evolution", the production comes from the universities and Chinese organizations (Chinese Academy of Sciences, Tsinghua University, North China Electric Power University, Wageningen University and Research Centre, Delft University of Technology, etc.). The authors also point to the emphasis on urban sustainability, of which the main proponents are Arizona State University, Beijing Normal University, UCL, the University of Toronto, the Chinese Academy of Sciences and the University of Tokyo. That finding coincides with the institutions identified in this study.

Hassan, Haddawy and Zhu's (2014) bibliometric study identified as the main institutions the Chinese Academy of Sciences and Tsinghua University. This identification coincides with the first position and fifth position in our study, although their overview is differs from ours. In climate change, the National Centre for Atmospheric Research is the foremost institute, followed by the United States National Oceanic and Atmospheric Administration and the University of Colorado (Boulder). In the renewable energy sub-area, Tsinghua University is the first ranked, followed by the United States National Renewable Energy Center. In the third sub-area, forestry, the Forest Service (United States), the Swedish University of Agricultural Sciences and Helsingin Yliopisto (Finland) are the most highly productive organizations. This fact may be linked to two institutions identified in this study and their potential specializations. In this respect, according to their study, Tsinghua University is more specialized in renewable energies, and the Swedish University of Agricultural Sciences is specialized in Forestry. For Olawumi and Chan (2018), research on sustainability is more productive in institutions like the Chinese Academy of Sciences (67 articles), Delft University of Technology (Netherlands; 37 articles), the University of British Columbia (Canada; 30 articles) and Wageningen University Research Centre (the Netherlands; 28 articles), the University of Tennessee Knoxville and the Tennessee Universty System with 25 articles, ETH Zurich (Switzerland) and Lund University (Sweden; 24 articles), the United States Environmental Protection Agency and the University of Leeds (United Kingdom; 23 articles). Most of these institutions are captured in ways that coincide with our study, but some of the institutions are not identified (e.g. United States Environmental Protection Agency, United States).

5.2.1.1. HEIs participation

Regarding involvement of HEIs, the main producers identified are also included in the top 10: ETH Zurich (*n* = 581), the University of Queensland (*n* = 554), the University of California (*n* = 552), Utrecht University (*n* = 514), the University of British Columbia (*n* = 513) and Michigan State University (*n* = 480). Veiga-Ávila et al. (2018) have identified the most productive institutions from Canada and Australia: the University of Toronto (Canada), Monash University (Australia), the University of Sydney (Australia), Griffith University (Australia) and the University of British Columbia (Canada). The results of this study point out the growth can be associated with Australian, Canadian and American HEIs. However, in our results, stands out HEIs from America, China, and the United Kingdom. Alejandro-Cruz et al. (2019) estimate that there are around 2,996 institutions involved in the topic. This finding is similar to those of this study: The institutions involved in our study numbered 3,104, of which 2,295 are from HEIs. It can be observed that from 2000 to 2009, the countries with higher production were the University of Technology (Australia), Leuphana University of Luneburg (Germany) and Griffith University (Australia). In contrast, from 2010 to 2018, Metropolitan University (in the United Kingdom), the University of Technology (Australia), Griffith University (Australia), Leuphana University of Luneburg (Germany) and Arizona State University (United States) were the most prolific. These institutions are also identified in our dataset, although not as most prolific.

Regarding Spanish HEIs, this study has identified 68 institutions. From this selection, the most productive universities in sustainability research were UAB (*n* = 342), UPV (*n* = 250), UPM (*n* = 244), UNIZAR (*n* = 226), UPC (*n* = 219), EHU (*n* = 217) and USC (*n* = 203). In line with these results, Bautista-Puig (2019) identified technical universities as the main producers in environmental research (UPC, UPM and UPV). An F-measure analysis, which measures the specialization in a field, showed that these universities are the most specialized in this topic; however, other universities have a higher impact (UNIZAR), even if they are less specialized (UB, UDL, UAL and USC). These results are aligned with those of Romo-Fernández et al. (2012) on renewable energy, sustainability and environmental research output in the Scopus database, where UPM was also found to be one of the most productive and specialized, and UNIZAR was reported to have an impact higher than average. De Filippo (2019) identified as the main producers UAB (*n* = 235) and technical universities (UPV with 217 docs., UPM with 213 docs., UPC with 203 docs), similar to top 5 obtained in our study.

HEIs involved in the SDG *core* research revealed an increase in the number of the institutions (660 institutions in 2000–2005 to 1771 institutions in 2012–2017). In terms of the distribution of the publications on sustainability, the majority of the journal articles originated from the London School of

Hygiene and Tropical Medicine (1,965 documents), the WHO (1,672 documents) and Johns Hopkins University (1,319 documents). Their positioning changes slightly over a 6-year period (e.g., the WHO passes from first place in 2000–2005 to second place in 2012–2017). However, one can presume that this distribution is logical when compared to the size of these institutions. However, this pattern does not correspond with these most productive institutions (i.e., the WHO has a production of 11,273 documents from 2000 to 2017 and London School of Hygiene and Tropical Medicine has 26,778 documents in the same period). An AI analysis based on the M&SDGs confirms that these institutions also are highly specialized on this topic. In this framework, the London School of Hygiene and Tropical Medicine is a university that belongs to the University of London and is specialized in public health and tropical medicine, and the WHO is a specialized agency of the United Nations that is focussed on international public health. The WHO also provides health statistics for monitoring health in the SDGs.[63] This fact is aligned with Nakamura's (2019) study, which stated that the largest institutions are not always those that set the agenda and pace in a specialty area, but rather key players could include others (e.g. Stockholm University, University of London, Wageningen University Research Centre). In our study, with the AI (SDG), we also have detected other organizations that show specialization on this topic: Stockholm Environment Institute (AI 191.10), the Aga Khan University (AI 142.26) and the International Centre for Diarrhoeal Disease Research, Bangladesh (AI 132.66).

5.3. Thematic analysis

5.3.1. Subject categories and journals

5.3.1.1. Subject categories

The subject categories that are predominant on this research are "Green & Sustainable Science & Technology" (*n* = 59,374),"Environmental Sciences" (*n* = 28,715), "Energy & Fuels"(*n* = 25,610), "Engineering environmental" (*n* = 15,799) and "Environmental studies" (*n* = 13,545). In previous studies, WoS Categories have also been analysed. Nučič (2012) analysed a "meta-disciplinary perspective with a six-factor grouping of WC". This author determines from this analysis that "sustainability science lies in the disciplinary fields of environmental science and technology in the first hand and in social sciences in the second". One point that is remarkable is the positioning of sustainability science, not only in the environmental aspect, but also in the field of social sciences. This fact is supported also by the results obtained through this study in which social WoS categories present appear with greater intensity on this topic. In addition, "Geography", a category remarked for its link with the topic, appeared in only 18th position in our study.

In Pulgarin et al.'s (2015) study, the main subject categories identified by the authors are "Environmental Sciences"'(*n* = 3,507, 26.27%) and "Environmental Studies" (*n* = 2,480,

[63] Information available at https://www.who.int/sdg/en/.

18.57%).“Environmental Sciences” is the core category and the most linked with other areas (the greatest interdisciplinary according to the authors). Moreover, the relation of sustainability with “Engineering, civil engineering” subject category has been noted. With less presence (<8%), other categories can be found: “Ecology”, “Engineering environmental”, “Economics” or “Energy Fuels”. According to its map of the co-occurrence WoS category, the author determined this is a picture of the interdisciplinary nature of this topic (75% of the categories have some relation with others). This interconnection is shown also in our dataset. For instance, 221 WoS (87%) categories (from the total of 254) with more than 20 documents are connected.

Ramírez et al. (2016) have characterized the roots of SD. In the first early stage of sustainability (1977–1988), research is more focussed on technical aspects, with an ecological emphasis (environmental sciences) related to the belief in the mitigation of environmental impacts. In this period,“Environmental Sciences” (48.4%) was the leader subject category, followed by earth and planetary sciences (35%). Since 1989, the authors suggested, engineering with social sciences has acquired relevance in this integral vision of sustainability (“Engineering”, 35.6%;”Environmental Sciences”, 30.8% and “Social Sciences”, 20%), and of n their most recent period of study (1991–2015), they highlight the prevalence of urban sustainability. In this study, Environmental sciences” has a central role and is a cluster connected with strong links (section 5.3.1.1). In contrast, the Environmental studies” category presented the bigger cluster, with more WoS categories connected. The average publication year is 2012 in some categories (e.g. “Engineering, civil”) and 2014 in others (e.g., “Environmental sciences” or “Envrionmental studies”). In these previous studies, “Green & Sustainable Science and Technology” did not appear as an important subject category.

Zhu and Hua (2016) have highlighted also “Environmental Science” as the subject category with the highest publication count. Moreover, these authors detected engineering as a relevant category, followed by others such as “Psychology” (286 publications). Authors suggested that most of the categories identified in their study “have an affiliation with socio-economic pillar and the economy is still accorded primacy in policy and decision making”. By a burst detection analysis, it was remarked bursts of seven disciplines were noted (e.g. “Materials Science”, “Operation Research & Management Science”, “Management, Social Sciences”, “Business”, and “Computer Science”). This authors also remarked that “Materials Sciences” and “Social Sciences” have a high value and affirmed that these are “promising disciplines (or fields) that revealed precisely where the frontiers of sustainable development lie”. These categories also appeared in the strategy developed in this dissertation but do not have a higher scientific output. Buter and Van Raan et al. (2013) demonstrate the prevalent fields in sustainability science, and ranked in top position fields related to economic and environmental research (e.g. Environmental Sciences”, “Economics” or “Ecology”), with less emphasis on the social sciences. Further down, other categories are found (e.g. “Agriculture multidisciplinary”, “Multidisicplinary sciences” or “Sociology”).

Olawumi and Chan's (2018) study identifies eight subject categories with 100 or more articles:"Environmental sciences" (*n* = 1327 articles); "Green & Sustainable Science Technology" (*n* = 1294); "Environmental Engineering" (*n* = 925); "Civil Engineering" (*n* = 410);"Environmental Studies" (*n* = 376); "Construction & Building Technology" (254 articles); "Ecology" (203 articles), and "Water resources" (161 articles). "Environmental studies" and "Water resources", among others, received citation bursts. Those are the most active areas in the evolution of sustainability. However, the network and their links reveal increasing publications in areas such as urban studies, computer science, and interdisciplinary applications. In comparison with the results of our study, some WoS categories do not appear as the most productive (e.g. civil engineering). In relation to "Construction & Building Technology" the WoS category suggests this field appears as a recent trend, close to 2017 (Figure 63). From their results, the nodes related to urban can be understood as emerging nodes, while in this study, the average publication year of subject categories related with urban is in 2013.

Despite being more focussed on HEIs, Veiga-Ávila et al. (2018) have detected the WoS categories with more publications as "Education, educational research" (*n* = 2,102, 31.15%), "Environmental sciences, ecology" (*n* = 1,227, 18.18%), "Engineering" (*n* = 908, 13.54%), and "Business and economics" (*n* = 682, 10.11%). These categories are linked with other subjects (e.g. health, education and management). Moreover, an index to detect "hot topics" (based on Banks, 2006 methodology) in these categories was calculated. The hot topic was defined as "a topic within those categories that are likely to be of significant interest and study as presented a considerable growth." Within that approach, the authors identified WoS categories such as "Education educational research", "Business", "Economics", "Environmental sciences", "Ecology", "Environmental studies" and "Management". Those categories are likely to be of significant interest, with studies in those areas seeing considerable growth. With the exception of the "Educational research" subject category (the search strategy was created with a different purpose than the one defined in this study), the rest of the categories appeared in the top 10 positions.

5.3.1.2. Journals

The sustainability research retrieved with this study comprises 3,720 journals. Fifty-six percent of the papers are published in top 20 journals The journals with a higher number of documents are the *Journal of Cleaner Production* (*n* = 8,658), *Renewable & Sustainable Energy Reviews* (*n* = 7,202), *Renewable Energy* (*n* = 6,319) and *Sustainability* (5,648). These journals, based on their website description, are focused on interdisciplinary research, sustainability science and renewable energies. For instance, the *Journal of Cleaner Production* defines its scope as that of "an international, transdisciplinary journal focussing on cleaner production, environmental, and sustainability research and practice". *Renewable and Sustainable Energy Reviews* is a "peer-reviewed scientific journal covering research on sustainable energy with the aim to share problems, solutions, novel ideas and technologies to support the transition to a low carbon future and achieve our global emissions targets as established by the United Nations".[64] "Renewable energies" are focussed on various topics and technologies of renewable energy systems and components. Finally, *Sustainability* is an "international, cross-disciplinary, scholarly, peer-reviewed and open-access journal of environmental, cultural, economic, and social sustainability of human beings".

Pulgarín et al. (2015) found 36 journals (>50 articles) that represent 30% of the total output. The journals with a higher production are the *Journal of Cleaner Production* ($n = 328$), *International Journal of Sustainable Development and World Ecology* ($n = 262$), *Ecological Economics* ($n = 259$), *Sustainable Development* ($n = 241$) and *Energy Policy* ($n = 236$). Olawumi and Chan (2018) collected a 138 journals, from which 37 have at least 10 documents. *Journal of Cleaner Production* (United States, $n = 496$), *Sustainability* (Switzerland, $n = 371$) and *International Journal of Sustainable Development and World Ecology* (United States, $n = 176$), *Sustainability Science* (Japan, $n = 56$), *Ambio* (Sweden, $n = 52$) and *Water Science and Technology* (United Kingdom, $n = 46$) are located at the top. In this regard, the authors stated that the publishers in the United States and Netherlands account for 6 of the top 20 journals. Our study placed the following in the top list of journals: *Renewable and Sustainable Energy Reviews*, *Renewable Energy*, *Green Chemistry* and *Chemsuschem*. According to their results, by a "co-citation frequency of the top most co-cited journals," the *Journal of Cleaner Production*, *Ecological Economics*, the *Journal of Environmental Management Science* and *Energy Policy* stand out. This denotes these journals made a signification contribution to sustainability studies and are more often cited by researchers in the field.

In HEIs focus, Hallinger (2019) detected 152 journals, denoting a broad dispersion form the cross-disciplinary in journals that includes education, education policy or architecture. Top journals include the *International Journal of Sustainability in Higher Education* ($n = 268$), *Journal of Cleaner Production* ($n = 129$), *Sustainability* ($n = 81$) and *Environmental Education Research* ($n = 35$). They identified the most active journals, and the *International Journal of Sustainability in Higher Education* and *Journal of Cleaner Production* were identified at the top two HESD journals. In this case, the top 20 journals published 54% of the research (vs 56% in our study). Veiga-Ávila et al. (2018), on the other hand, identified *Procedia—Social and Behavioural Science*, the *Journal of Cleaner Production*, *Environmental Education Research International*, *International Journal of Sustainability in Higher Education*, *International Journal of Engineering Education*, and *WITTransactions on Ecology and the Environment*. Among the journals with the highest number of publications were *Procedia—Social and Behavioural Science* and the *Journal of Cleaner Production*, followed by *Environmental Education Research International* and the *International Journal of Sustainability in Higher Education*.

[64] Information on the journal and scope in following website: https://www.journals.elsevier.com/renewable-and-sustainable-energy-reviews Accessed 18 November 2019.

From these results, the predominant position of the *Journal of Cleaner Production* can be observed not only in the sustainability dataset but also in HEIs subgroup. This finding confirms the interdisciplinarity of this journal. However, from the HEI subgroup, some journals appear here that were not identified previously (e.g. the *International Journal of Sustainability in Higher Education* is more prominent).

5.3.2. Keywords

Thematic analysis has been completed through a co-occurrence network of keywords, their strongest citation burst analysis (and horizontal timeline representation). From the co-occurrence network, five clusters have been detected (Figure 55) related with energy, management and policy of the sustainability, energy systems, life cycle assessment of the energy, and impact and economic and social sustainability. In periods of three to four years, the increase of the heterogeneity of the concepts and the emergence of concepts related to social and economic sustainability can be seen. In addition, it can be observed that is a rapidly expanding and diversifying field, as Kajikawa (2007) has suggested. Within the clusters created by the CiteSpace software, the following can be noted: ecosystem services, biofuels, CSR, heterogeneous catalysis, wind energy and fair trade. Considering also the references burst, one can add “energy consumption”. With the citation burst analysis, certain keywords had a strong citation burst: “organization” (146.57), “ethics” (144.346), “industrial ecology” (131.58), “economics” (122.65), “CO_2 emission” (122.02), “energy consumption” (109.47) and “electricity” (103.55). Moreover, it has been observed from the results that these terms have attracted attention more recently (2014–2017) (e.g. CSR), while others remain prominent in the initial period (“ecology” or “globalization”). Finally, certain keywords were relevant over the whole period of time analysed (e.g. “environmental management” or “politics”).

In the co-word analysis completed by Olawumi and Chan (2018), a set of the keywords were listed with the highest frequency. The terms identified are listed below according to their frequency of occurrence and are compared with the results obtained in our study. “Sustainability” (frequency of 778 vs 6,203 obtained in our study), “sustainable development” (frequency 472 vs 2,914), “management” (frequency 212 vs 6,954), “system” (frequency 193 vs 2,620), “indicator” (frequency 141 vs 1,399), “framework” (frequency 112 vs 2,877), “China” (frequency 89 vs 3,004), “model” (frequency 89 vs 4,088), “energy” (frequency 88 vs 4,842), “performance” (frequency 84 vs 6,600), “impact” (frequency 82 vs 2,667) and “climate change” (frequency 53 vs 1,596). In comparison, in the results obtained in our study, certain keywords such as “Management”, “Performance”, “Energy” or “Model” have gained interest. It is also remarkable that certain keywords are located in our study in bottom positions (e.g. “SD” is located in the 10^{th} position or “indicator” in the 57^{th} position). Olawumi and Chan (2018) also conducted a keywords citation bursts analysis and identified the following terms: “environment” (14.15), “climate change” (13.82), “design” (13.01), “city” (11.82) and “policy” (10.34). These authors point out that “more efforts are devoted to these critical research themes in achieving a sustainable urban development". Moreover, other keywords identified by these authors have high BC scores (e.g. "sustainability", "sustainable development", "indicator", "system" or "China"), and according to the authors, these have influenced the development of sustainability research.

Zhu and Hua (2018) have conducted a "keyword co-occurrence network, generated under the minimum spanning tree algorithm in CiteSpace". From this analysis, the authors ranked "valuable keywords" (based on the juxtaposition of betweenness centrality [BC] and citation burst [CB]). According to this analysis, the authors identified terms such as "management" (frequency of 2,760), "policy" (1,483), "environment" (1,422) or "conservation" (1,106), with higher frequencies but, in terms of BC+CB, were led by "resource", "development", "agriculture" and "conservation". The first keyword with a highest frequency also coincides with our results ("management"). The authors also consider these keywords to provide a perspective on which to "construct a concept network on SD and to achieve consensus on SD". Moreover, as can be observed in their analysis, there are pioneering concepts such as "agriculture" (with data from 1987) and some environmental terms related to early sustainability discourse (e.g. "environment", "ecology", "biodiversity" or "management"). This fact also coincides with our results: The time span for "agriculture" starts in 2008–2010; "environment", 2008–2009; and "ecology", 2008–2009.

By a citation network approach, Kajikawa (2008) identified 10 clusters related "to economic development, forestry, climate, agriculture, energy and resources, health, fishery, biodiversity, lifestyle and water in three selected core journals of sustainability science". The most significant ones are economic development, agriculture and fishery. These clusters are created by considering the papers published in the three selected core journals of sustainability science. In a later study, Kajikawa, Tacoa and Yamaguchi (2014) showed a comparison of sustainability research between 2007 and 2014 based on the same approach. The difference between the two periods is fewer nodes in 2014, new clusters (e.g. Education and Sustainable Human Development) and an increase of the connection between the clusters. As in this study, energy issues are a relatively recent development. Their study shares other similarities with our study: Management and environmental issues are clusters connected in both. One fact that should be remarked from our study is the interconnections in the research landscape yielded by analysis of the information by periods. Research clusters that were previously separated in 2008–2010 become a more interconnected topics in the latest period (2015–2018). For instance, link strengths have passed from 418.95 in the early period to 1097.57 in the second period. This finding is aligned with those of Kajikawa, Tacoa and Yamaguchi (2014), who compared 2007 to 2013, finding that clusters were becoming more integrated into coupling systems.

In HEIs studies, the keyword overviews are different. For Hallinger and Chatpinyakoop (2019), a co-word analysis was conducted to identify key topics. Three main themes were identified in the HESD research front: managing for sustainability in higher education (that is, sustainability of HEIs); teaching, learning, and capacity development in HESD (management processes that enable HEIs to achieve the outcomes); and research and development in HESD (core processes of education for SD as it impacts teachers and learners). For Alejandro-Cruz et al. (2019), the author's keywords analysis with the top 500 authors determined that in a first period (2000–2009), "topics were related to environmental issues and the development of academic competences (education and SD)". However, during the second period (2010–2018), higher education was linked "to environmental awareness, innovation and guidance to achieve sustainability goals in HEIs, society and government (they are connected to engineering education, curricula, curriculum, leadership, etc.)". In our dataset, the education node is linked with SD and sustainability, and in the second period (2011–2014, Figure 56b) appears the node ESD (with an occurrence of 68). This fact also support Veiga-Ávila et al.'s (2018) study, which determined that terms such "education" and "sustainability" appear as emerging areas. In our study, this link has become stronger over time: education versus sustainability (13 link strength in 2008–2010; 51 in 2011–2014; 75 in 2015–2018) and education versus SD (18 link strength in 2008–2010; 43 in 2011–2014; 48 in 2015–2018).

Regarding SDGs dataset, if we consider the topics of interest in HEIs for answering the question "What are the main topics studied by the SDGs?" this information has been analysed in three ways: co-occurrence maps by keywords, burst citation keywords, and classification of the scientific output into the different SDGs by ontology. Related to the co-occurrence map, five clusters are addressed: 1) millennium development goals inheritance and policy framework; 2) maternal mortality and care; 3) health systems: diagnosis and treatment; 4) African health ecosystem and 5) developing countries' landscape: health, community and water. It can be observed that many of the challenges outlined SDG3 are related to health and "play a central role in the achievement of SD" (Pettigrew et al., 2015). Moreover, checking the average publication year of the topics, in order to know their relevance in time, certain topics appeared to be more recent (e.g. preterm birth, maternal health). This recency could be explained by the fact that, in spite of the progress during the MDGSs, major challenges remain, such as maternal or child mortality (World Health Organization, 2016). This finding accords with the keyword citation burst, which denotes that some keywords like "newborn" (16.65), "maternal health" (64.98) or "delivery" (36.38) became hot topics in the last period. In contrast, other words became more outdated (e.g. income, low birth weight, nutrition, human immunodeficiency virus or economic growth, among others). This finding leads to the conclusion that research on SDGs by HEIs is focussed mainly on health, as compared to sustainability research.

5.3.3. SDGs classification

Scientific output on SDGs has been classified in each SDG by using an ontology, and 85.77% of the papers were classified with at least one SDG; regarding the papers of HEIs, this percentage is even higher (97.06%). The co-occurrence map of SDGS shows six clusters labelled as follows: 1) SDGs relations (SDG17, SDG10, SDG16 and SDG11, among others); 2) economic aspects (SDG8 and SDG9); 3) energy (SDG7, SDG13 and SDG12); 4) food health and land (SDG2, SDG3, SDG15); 5) education (SDG4); and 6) water (SDG6 and SDG14). The goals more directly addressed were SDG7, clean energy (28,988); SDG9, industry (24,292); SDG15, life on land (23,116); SDG16. peace, justice and strong institutions (21,418); and SDG8. decent work (21,388). It is noteworthy that water-related goals appears as an individual cluster. This cluster follows Nakamura et al.'s (2019) analysis and is located as a global concern that even connects environment and health.

If we compare these results with the scientific output related to the core of SDGs (20,825 documents, 96.5%, were classified), the results offer a unique picture. The goals more addressed by HEIs and RC are SDG3, good health and well-being (77.32%); SDG16, peace, justice and strong institutions (57.40%); SDG11, sustainable cities and communities (47.73%); and SDG10, reduce inequalities (30.33%). SDG16, peace, justice and strong institutions, is a goal addressed by both datasets. The co-occurrence map of SDGs of the research output allows one to see the connections between SDGs. It can be observed that all SDGs have connections. According to Nilsson et al. (2016), the SDGs are more – "connected than their predecessors, the MDGs". This connectivity has led to SDGs being labelled enablers for integration (Le Blanc, 2015). In this regard, it should be remarked that certain strong connections exist between the following SDGs: SDG16–SDG13, SDG3–SDG11, and SDG16–SDG11. For instance, regarding the relation between SDG3 and SDG11, considering that 30% people live in urban areas, this fact could be associated with providing safe housing, which reduces exposure to diseases (Griggs et al., 2017).

Regarding SDGs dataset, by classifying the topics by each SDG, 20,825 documents were classified (96.5%). The goals more addressed by HEIs and RC are SDG3, good health and well-being (77.32%); SDG16, peace, justice and strong institutions (57.40%); SDG11, sustainable cities and communities (47.73%); and SDG10, reduce inequalities (30.33%). This classification coincides with the higher percentage of institutions involved on this research. Despite that all goals had higher production in Europe and the North America, checking the SDG-based output by countries presents a similar pattern (more intensive in SDG3, SDG11 and SDG16).

The co-occurrence map of SDGs of the research output allows one to see the connections between SDGs. It can be observed that all SDGs have connections. According to Nilsson (2016), SDGs are more connected than are their predecessors, the MDGs. This connection has led SDGs to be labelled as an enablers for integration (Le Blanc, 2015). In this regard, certain strong connections between the following SDGs should be noted: SDG16–SDG13, SDG3–SDG11, and SDG16–SDG11. For instance, regarding the relation between SDG3 and SDG11, considering that 30% people live in urban areas, this relation could be associated with providing safe housing, which reduces exposure to diseases (Griggs et al., 2017).

5.4. Patterns of collaboration

In the scientific output of sustainability in this study (2008–2017), we have detected that the percentage of papers written by different authors (co-authorship) is 65.51% and the average of authors per paper is three authors in the sustainability dataset and four authors with documents signed by HEIs. Moreover, the average of signatures in all period is 35,240 in P and 30,107 in P(HEIs).

About patterns of collaboration, the global results of this study have determined that 46,180 documents (47.18%) are published without collaboration; 27,356 documents (27.94%) involve national collaboration; and 24,340 documents (24.87%) entail international collaboration. Documents with international collaboration have increased over time (15.31% in 2008 to 30.09% to 2017). Documents with HEI affiliation are similar: 42.78% documents without collaboration, 29% with national collaboration and 28.23% with international collaboration. By considering HEIs involved, the international collaboration increased from 18.63% in 2008 to 33.32% in 2017. In a previous study, in which only the green WoS category was considered, as well as being limited to scientific output in Spanish HEIs, the number of documents published with international collaboration adds up to 43.8%, with 37.6% involving national collaboration and 36.94% involving no collaboration (Bautista-Puig et al., 2019d). Despite that the international collaboration percentage detected in this study (24.87%) could be interpreted as low, it should be highlighted that different subject categories are involved in the search strategy that could have an effect on it.

Regarding international collaboration, Olawumi and Chan (2018) have stated that the countries with the most international collaboration are the United States, China, the United Kingdom, Canada, Sweden, South Korea, the Netherlands, Australia and Switzerland. In our dataset, despite the average being 24.87%, certain countries have the most collaboration. For instance, the percentage of documents involving international collaboration are as follows: United States, 36.07%; China, 33.50%; the United Kingdom, 54.47%; Canada, 45.35%; Sweden, 48.48%; South Korea, 35.19%; the Netherlands, 56.10%; Australia, 45.70%; and Switzerland, 59.9%. In our particular case, Spain, international collaboration rises to 42% in the sustainability dataset. According to the last report of CSIC (Bordons et al., 2018) in the period 2013–2017 the percentage of international collaboration in Spain is 27.57%.

This information by institutions offers a different approach. In this regard, the institutions with a higher number of documents with international collaboration are King Abdulaziz University (93.61%), the IIASA (90.29%), the Natural Environment Research Council (77.94%), the University of St Andrews (75.96%), King Saud University (75.33%) and the University of Aberdeen (74.15%). In the case of

HEIs, seven institutions present a percentage of international collaboration higher than 70%. This fact includes the following institutions from the following countries: in the United Kingdom, the University of Saint Andrews (75.96%), the University of Aberdeen (74.15%) and Aberystwyth University (73.15%); in Saudi Arabia, King Abdulaziz University (93.62%) and King Saud University (75.33%); in Norway, the Norwegian University of Life Sciences (72.93%); and in Belgium, Université Catholique de Louvain (71.57%).

5.5. Impact and visibility

Citations are a proxy for the visibility of scientific output. For this analysis, the number of total citations and the citations per document have been considered. The number of citations is 1,275,833 in P and 1,097,659 in P(HEIs), with a decreasing tendency observed over the period, which corresponds to normal patterns in citations. The average number of citations per year in the data set is 127,583 in P and 109,766 in P(HEIs). In relative terms, by citations per document, the value presented is higher in P(HEIs), with 18.56 citations per document (vs 17.31 in P). However, as Olawumi and Chan (2018) have stated, areas such as "environmental sustainability have received significant citations in recent years (2014–2016)".

The countries from which the most-cited studies appear are the United States, China and the United Kingdom. However, in relative terms, the figures are higher in the Netherlands (19.53 citations/document), Denmark (19.12 citations/document) or Malaysia (18.13 citations/document).

In terms of organizations, Wageningen University Research Centre, the University of Malaya and the University of Minnesota are the most cited, but the University of East Anglia (47.04 citations/document), the University of Minnesota (47.04 citations/document), Twin Cities (47.04 citations/document), Stockholm University (47.04 citations/document) and Arizona State University (47.04 citations/document) are those with the most citations per document.

Regarding visibility, 53,201 documents (54.36%) are in the 1Q, and 15,180 documents (15.51%) in the top 3. However, this should be analysed cautiously because it is a very heterogeneous area in which different specializations co-exist. If we compare with, for example, SUE according to the observatory that monetizes the scientific and technological activity of Spanish Universities (IUNE, 2019), these averages are higher in the same period (53.56% in 1Q and 9.02% in top 3) (IUNE, 2019). In De Souza (2018), 7.15% of the scientific publications in Brazil were in the top 3 in the period of 2003–2015. In the period 2008–2015, similar to our study, the average in Brazil is 32.31% and 31.60% in the Brazilian University System versus 15.51% obtained in our study.

5.6. Other unidimensional indicators

5.6.1. Acknowledgments

Differences between these three major pillars in the funding data for acknowledgements do exist and constitute relevant information concerning impact and collaboration patterns. From the sustainability dataset identified in this study, 40,782 documents (41.67%) have funding acknowledgments. This percentage is even higher in documents signed by the university (44.03%). Compared with Díaz and Bordons' (2014) study, despite that its analysis is based on Spain in 2010, their results record funding acknowledgments percentages as higher in the social sciences but not in the rest of the fields. In Yan et al. (2018), who have analysed environmental journals, in environmental sciences area the average number of funding sources is 2.39 (in comparison with other fields of study, such as astrophysics with 4.10 or medicine with 4.18) and the percentage of funding support is thus 85.81%, higher than the percentage detected in this study (41.67%).

In this study, the main funding sources are from the National Science Foundation of China, the Ministry of Science and Technology of China, the European Commission and the Ministry of Education of China. Given only HEI production, the first funding source is the European Commission and Ministry of Science and Technology of China. These sources can be linked to the European Projects in which these institutions are involved. However, by checking the funding sources according to typology, universities are the main funding sources, followed by funding organizations and governmental organizations. The ranking denotes that FA information in these articles are mainly from this typology of organizations. If we compare with Bautista-Puig et al. (2019e), which analyses "the core of environmental, social and economic sustainability, it is considered that in environmental sustainability, most documents are governmental institutions (e.g. European Commission) or research councils (e.g. National Natural Science Foundation)". In economic sustainability, the funding organizations are councils (Chinese Academy of Sciences, CNR) and HEIs or research centres (Wageningen university research, State University System of Florida). For social sustainability, councils (National Science Foundation of China) or governmental organizations (European Commission) are highlighted. These findings correspond to the same funding sources established in our dataset.

Regarding acknowledgments information, a limitation should be noted, namely that funding sources are not always acknowledged by authors: nevertheless, this analysis could lead to a general overview of how funding affects scientific papers in sustainability research. In addition, further research will be necessary to study more deeply the role of funding agencies (e.g. type of organization) in scientific publications.

5.6.2. Technological activity

Indicators based on patents allow one to determine the innovation capacity of a knowledge area. In this context, it is understood that a higher number of patents implies a higher number of innovations (OECD 2009b). Schiermeie (2010) considers that patents “let you know about what the actual science is”. In this regard, the search strategy used to identify green patents has been an area of great inventive activity, with a total of 130,512 families through the period and a CAGR of 41.70. In the case of HEIs, the number of families rises to 534 documents, with an increasing trend of 27.22. This upward trend is similar to the one detected in previous studies of green patents. For instance, Schiermeie (2010) and Fabrizi et al. (2018) demonstrate a similarly growing trend. Sánchez et al. (2012) have confirmed that “green patents” represented 3.09% of the patents requested between 1995 and 2009 in the OEPM, showing a positive tendency. Moreover, according to Fabrizi et al. (2018), the role of university is relevant. In fact, due to the complexity of environmental innovations, the presence of high-profile scientific entities is required (e.g. HEIs and research centres) outside of the business world. This fact is also supported by Cainelli et al. (2012), “who consider that for the implementation of clean technologies the role of HEIs and research centres in environmental networks is important, as compared to other types of innovation”.

Regarding Spanish green patents, Bautista Puig et al. (2016) analyses green patents from 1985 to 2014, obtaining a total of 4,368 registers. If we consider a period similar to that of our study (2008–2014), there is an abrupt decrease observed that is appreciated in our study in the 2009 data. In this study, this patent output is linked with the Spanish legislation on the topic. This drop is presented between the period within the first Renewable Energy Plan (2005–2010) (the second plan was initiated in 2011 and is planned to last until 2020). About the applicants on this previous study, our results coincide with those of Peñasco, Martínez and Del Río (2016), who analysed the green patents in Spain. CSIC and UPM lead and has a very broad range of patents for each technology. For instance, in comparison with companies such as Acciona, which have requested patents from five technology areas (eolic energy, solar energy, water pollution reduction and biofuels) while CSIC and UPM have 12 and 7 areas, respectively.

5.6.3. Mathematical models applied to bibliometric indicators

Mathematical models have been applied in different dimensions of this study: scientific output (by pillars and countries), subject categories, collaboration and impact. The mean residual errors for the predictions for 2008–2017 were 58.49 for research output by pillars and 122.57 by countries, 127.82 in subject categories, 43.18 in collaboration and 336.65 in impact. The impact dimension was specified where the indicators of the differences between the predicted and observed values were widest (i.e., where the real values had the heaviest impact with the predicted). That may suggest a substantial change in reality relative to model predictions, denoting a “change” in the trend of the model. Regarding scientific output, in India and Italy, the output that was predicted to be higher than it actually proved to be. Business and economics in the subject categories also were above the average. About collaboration, documents with no collaboration exceeded the average (58.66), and regarding impact, top 3 documents were beyond the average. On the grounds of estimate errors, for instance, the model delivered better results on average for the scientific output and collaboration dimensions. However, these findings must be interpreted cautiously for the possible other factors that could explain this increase.

About the use of the engineering models applied to bibliometric indicators, in this study state-space models were used to predict trends in scientific output. Other bibliometric studies have also applied mathematical approaches such as vector autoregressive modelling to predict such trends (Bildosola et al., 2017; Monroy and Díaz, 2018). Previous studies were found in the literature in which state-space modelling was applied to bibliometric data (Bautista-Puig et al., 2019a). Based on the residual error and model performance data, the predictions delivered were acceptably accurate, although the state-space approach was more accurate for some indicators and periods than others. The mean coefficient of determination for the state-space model run in this study, 0.992, was similar to the 0.996 reported by Monroy and Díaz (2018) and indicative of an adequate level of accuracy. This coefficient is higher in some dimensions (e.g. scientific output by fields and collaboration with 0.999).

The data must be interpreted with caution, however, in light of certain limitations affecting the study. The number of observations in the 10-year time series analysed with the state-space model was not long enough to test and reliably predict long-term results. With more input data, the model would have delivered a better fit to the empirical data. A further limitation was the use of the WoS, for in fields such as law and the humanities, other databases are available (e.g., Latindex and Scopus).

5.7. Commitment of HEIs with SD: The Spanish case

This section analyses the results obtained of the overview of Spanish HEIs.

5.7.1. Regarding internationalization

This section analyses the overview to sustainability in Spanish HEIs. Regarding the internationalization dimension, two indicators have been analysed: GreenMetric ranking and participation in European projects, from the 7th and 8th framework programmes.

Regarding the GreenMetric ranking, which is open to global participation, an overview of HEIs and, more precisely, Spanish HEIs is analysed. Some studies have criticized this ranking by arguing its simplicity in terms of “categories and indicators in comparison with other systems and that the demands of the data types required are generally low for participants and less empirical than those used in other systems “(Lauder et al., 2015). Despite its limitations, it is the only ranking in the world that assesses sustainability at the world level. An increase can be observed in the participation of Spanish universities.

The participation of HEIs has risen from 95 HEIs in 2010 to 718 in 2018 (growth of 655.79%) versus 5 to 28 Spanish HEIs (growth of 460%). This rise indicates the interest of these HEIs in assessing their policies and actions in relation to their efforts towards sustainability and green campuses. If we check this information by the six areas established in the GreenMetric ranking, the great majority of universities are closer to energy and climate change (e.g. University of Malaya). This fact indicates the involvement of these HEIs in the area of sustainability. In contrast, other areas such as setting and infrastructure, or water, are not in focus for many universities. Certain universities are central (e.g. University of Ottawa or University of Tasmania), which means they have equal scores in different areas.

In Spanish HEIs, there are more HEIs closer to waste (e.g. UB, Universidad de València) or transportation (e.g. UIB, UAH) or setting and infrastructure (e.g. UJI). Energy and climate change are not in central focus for these HEIs, however. Their ranking is aligned with previous results that suggest Spanish universities have made a greater progress in actions related to waste and teaching and, to a lesser extent, have implemented measures on social responsibility, environmental impact assessment, water and green purchasing (Hidalgo et al., 2012).

As far as the participation of HEIs in European projects related to SD is concerned, more than 1,495 projects (5.8%) were identified by HEIs in FP7, and 1,560 projects (6.2%) were identified in H2020. Among these projects, 292 (19.53%) of Spanish universities participated in FP7 and 336 (21.54%) in H2020. This participation denotes that the results attained in ongoing H2020 activities were substantially better than those in the preceding edition. In addition, the structure of the H2020 framework programme indicates that an independent line of research has been opened that reflects the political priorities of the Europe 2020 strategy, where sustainability plays a central role. Results indicate that the universities in the Spanish framework that take part in a higher level are UAB, UB, and the technical institutions (UPM, UPC, and UPV). These universities have certain common features: They are highly specialized (technical universities) and are located in large cities (UAB, UB) (Manzano et al., 2016). Bautista-Puig et al. (2019d) have analysed the participation in Spanish Projects in FP7 and H2020. The strategy was slightly different from that carried out in this search strategy and was based on the search engine. Data in this dissertation have been obtained from the European Union Open Data Portal from CORDIS.[65] In FP7, a lower number of projects in comparison to this study were selected. Of those, 96 projects with Spanish participation were selected (vs 292 projects obtained in this study), and in the call for environmental, the participation of HEIs was more remarkable. The universities with the most participation were UAB (15 projects), UB (11 projects) and UPM (10 projects), and their main topics were water and management. In this study, the universities with a higher number of projects are UPM, UAM, UPC and UB. De Filippo et al. (2019) they checked the different framework programmes

[65] European Union Open Data Portal available at the following link: https://data.europa.eu/euodp/es/home/.

(especially Cooperation and Capacities), and environmental protection is the one that attracted more projects (823), followed by energy savings, in which Spain participated significantly. However, HEI participation was not so remarkable (16% of participation in each area). Still, technical universities participated most intensely. The leaders were UPM, UAB, UPC, and UB. These results coincide with this study's findings. Moreover, regarding the topics, in this study, environmental protection and the social sciences and humanities appears to be the most addressed topics.

The H2020 projects and the specific call regarding societal challenges, in which there was more Spanish HEI participation, target smart green and integrated transport and secure, clean and efficient energy. The universities with more participation in this call are UPM, UPV, UPC and US.

In sum, it can be inferred that there has been a greater scientific effort by the Spanish universities dedicated to the subject of sustainability during the period studied, where the commitment of the universities has increased through their participation in projects and visibility in rankings such as GreenMetric.

5.7.2. Regarding university and governance and assessment and reporting

Beans and Driha (2015) have stated that "incorporating the concept of sustainability and energy efficiency in a university's strategic plan is crucial to obtaining the support of the university community for implementing sustainability policies and actions". According to Bieler and McKenzie (2017), strategic plans are relevant for HEIs because their offer information "on the extent to which there is a commitment towards whole institutional change". For Brusca et al. (2018), "Sustainability reports have been considered to be useful tools, both for accountability and for improving social and environmental performance; however, the literature shows that sustainability reporting by universities is still at an early stage".

In the Spanish Framework, Larrán et al. (2015a) analysed 45 strategic plans available on their institutional website.[66] In our results, 58 strategic plans have been collected, denoting an increase of the availability of this document at Spanish HEIs since 2014. Moreover, this value could be influenced by data availability and having their website updated. In addition, some strategic plans remain private (e.g., Fundación Compromiso y Transparencia) (Cavanna & Medina, 2017).

In our study, we have collected 58 strategic plans, of which 41 have mentioned sustainability. From this group, a higher percentage are public (85.37% were public and 14.63% were private). This finding coincides with that of Larrán et al. (2015a), who found 93% were public universities and 7% were

[66] In this study, only HEIs listed in IUNE Observatory has been considered.

private. In their study, they mentioned there is "scarcity of sustainability initiatives in the strategic plans of the Spanish universities analysed" (less than 40% of the strategic plans identified). In our results, we have found sustainability is mentioned (in the 70.69% of the strategic plans analysed). This fact accords with the research of Lozano et al. (2015) in a "survey answered by 84 respondents from 70 countries to review the commitment and implementation of SD in higher education". These authors have stated "that their HEIs have incorporated SD into their institutional framework", which can be interpreted as an "official commitment to SD". Overall, and following Larrán's (2015a) study, there is more commitment to this topic among public HEIs. However, the ways in which sustainability is addressed vary. Results indicate differences: Some plans remarked on environmental sustainability; and less so economic sustainability, while very few included the three pillars of sustainability. The lack of mention of the SDGs in the great majority of HEIs is also notable, although some are pioneering (e.g. UNED). Regarding the universities involved, Larrán (2015a) also found stronger engagement amongst larger institutions. However results of the present study showed different university profiles, from small universities (e.g. UDL, UJI) to large (UAB, UAH).

Bieler and McKenzie (2017) have analysed "41 strategic plans of Canadian HEIs in which sustainability was mentioned". They divide their sample by the following classification: "a) accommodative responses that include sustainability as one of many policy priorities and address only one or two sustainability domains; b) reformative responses that involve some alignment of policy priorities with sustainability values in at least a few domains; and c) progressive responses that make connections across four or five domains and offer a more detailed discussion of sustainability and sustainability-specific policies". The results indicate that accommodative responses were dominant in this study. That is, the documents in which sustainability is mentioned are presented as a political priority for the HEIs. Environmental sustainability is the most prominent.

Another important point regards sustainability reporting/assessment. That is, documents in which some aspects (or at global level) sustainability topics are addressed. "Sustainability assessment and reporting results can help HEIs to focus on coverage and performance weaknesses, thereby highlighting where actions should be taken, as well as better sustainability plans". Another aim is "to communicate the university's efforts to its stakeholders and to benchmark against other institutions and companies" (Lozano et al., 2013c). Garde, Rodríguez, and López (2013) "show that Spanish universities have little commitment to the online dissemination of information about sustainability performance". However, the findings of our analysis suggest that all universities use their webpages to include this information and disseminate SD practices, as shown in studies of Portuguese universities (Aleixo et al., 2016). The great majority of the universities analysed have shown commitment to SD with its inclusion in strategic plans or sustainability reports. Lozano et al. (2011) states that the University of Natural Resources and Applied Life Sciences (BOKU) in Vienna was the first to make such a commitment on sustainability

(2005). In the Spanish context, there is a university, the USC in 2006, which pioneered the publishing of sustainability reports in that country (Lozano, 2011a), followed by UCA and UMH, in 2007 (Zorio-Grima et al., 2018). "This increase can also be related to the performance funding system", as stated in Larrán et al. (2014).

Regarding sustainability plans collected for this study, the findings suggest that the number of actions per document by public universities is higher than that by the private ones. In this regard, 36 public HEIs have sustainability plans versus 6 private universities. Their topics can be diverse: sustainability plans or action sustainability plans; transport and mobility plans; energetic plans; declarations or best practices. This commitment is also quite recent, in line with the growing awareness of this topic. This fact was also pointed out by Lozano et al. (2013a), who stated there is a tendency towards a growing number of HEIs' sustainability reports each year. These documents are mainly related to an environmental perspective, according to similar studies (Velazquez et al., 2006). Moneva and Martin (2012) have analysed to what extent the TBL is included in the sustainability reports in the G9 countries (Spain was included). They found that these countries' institutions did not satisfy sustainability reporting principles and that there are "differences in the disclosures of universities, evidencing a limited development of the social and environmental accountability". This fact is supported by Lozano and Huisingh (2011b), who point out that "sustainability is addressed through compartmentalisation based on single dimensions of the triple-bottom line". In our case, we have determined that sustainability is more addressed by the environmental pillar.

One fact that should be mentioned is that universities that have already started their path to sustainability (they have included sustainability in their strategic plan or have sustainability plans), and they have a more active participation in the GreenMetric ranking.

Regarding networks, two important networks have been considered: CRUE and REDS. Fifty-two HEIs belongs to the first network and 36 to the second. According to Bieler and McKenzie's (2017) finding, "institutional membership to Association for the Advancement of Sustainability in Higher Education (AASHE) may be a significant factor in progressive engagements with sustainability at the strategic planning level". In this sense, all HEIs that have a sustainability plan also participated within a network, especially in CRUE.

5.7.3. Regarding campus operations

According to Leal-Filho et al. (2019), in a HEIs we can find two kinds of offices to address sustainability on campus: sustainability offices and green offices. The first is where all activities related to sustainability are coordinated (e.g. research and teaching), and the second is like a "university sustainability platform led by students or research staff". According to these authors, green offices may "support institutional efforts in pursuing and implementing sustainability".

Regarding sustainability-related units at the Spanish universities, offices (e.g., eco-campus or green or environment offices) or services can be found. Their main functions are waste management, energy efficiency or saving, mobility, and ESD activities (Alba and Blanco, 2008). Thirty-one institutions (62%) included in the present study have these offices; this number has increased from previous studies, where 23 technical units were identified (Alba and Blanco, 2008). As well, public universities outnumber private universities. Moreover, other modalities of sustainability have been identified, such as "sustainability classrooms".

5.7.4. Regarding variables influences

A chi-square test has been used to analyse the degree of association of variables between categorical data (e.g., typology, strategic plan, sustainability plan, network 1, network 2, green office and GreenMetric ranking) and numerical data (number of documents, documents with international collaboration, number of citations and 1Q documents) regarding sustainability. With the results obtained, it has been determined there are strong association between the following variables: sustainability plan versus typology; green office versus typology; and sustainability plan versus green office. That is, for instance, typology influences having a sustainability plan or a green office. This influence has been observed in the results: Public universities are more proactively aligned with the sustainable journey. Moreover, having a sustainability plan is linked with having a green office. With less association, the following relations can be found: strategic plan versus typology ($p = .04$); typology versus GreenMetric ($p = .01$); sustainability plan versus network 2 (REDS), sustainability plan versus GreenMetric ($p = .01$); and network 1 (CRUE) versus Green Office ($p = .01$).

From the whisker plots with categorical versus numerical variables, certain conclusions can be obtained. Public universities have a higher number of documents concerning sustainability identified in this study; when sustainability is mentioned in their strategic plans, when they have a sustainability plan, they are linked to a network (CRUE and REDS), have a green office or campus, or participate in GreenMetric ranking. In the number of documents with international collaboration, differences between public and private universities are more notable if they are linked with network 1, CRUE. In terms of the number of citations, a higher median in public HEIs belongs to network 1. In other words, the number of citations that public universities receive if they belong to the CRUE network is higher. This fact follows Bieler and McKenzie's (2017) findings, although not in sustainability "at the strategic planning level", but in the number of documents with international collaboration and number of citations.

5.7.5. Concluding remarks

Transformation in HEIs has emphasized the importance of the third mission, and "social and sustainability values are as important as human, relational or structural capital" (Brusca et al., 2018). However, as is highlighted in previous studies, "research on sustainability is not the first priority for many universities, and one of the main problems is the lack of interdisciplinary teams" (Velazquez et al., 2005; Larrán et al., 2014). According to León Fernández (2015), referring to other authors (Leal-Filho, 2011), "the incorporation of sustainable development in the programmes of the university must be accompanied with the structural measures, such as campus environmentalisation and other related actions, that are ccompanied by initiatives aimed at involving the university community". It is related to a new paradigm shift. The results of this section show "there has been a stronger interest in SD integration in Spanish HEIs, which accords with previous studies" (Disterheft et al., 2012). Moreover, as previous authors have pointed out, the creation of networks to work collaboratively is crucial (e.g. to centralize information, procedures, etc.).

This shows that sustainability crosses all boundaries in university activities; however, "there should be a greater commitment to SD by university leaders in order to create a holistic system". For instance, according to León Fernández (2015) by citing Benayas and Alba (2007) a strategy action for sustainability at HEIs could be as follows:

- Establish an institutional commitment and a strategic vision of the sustainability of the university.
- Develop a structure that ensures commitment and action within the university government.
- Promote and consolidate the commitment of the university community.
- Develop and maintain a technical service that ensures the development of sustainability policies.
- Institutionalize the results, having established procedures for monitoring and evaluating the sustainability of the university.

Chapter VI: Conclusions and recommendations

From the present research study, we have been able to obtain a series of conclusions described below.

6.1. General conclusions

-Regarding the scientific output of sustainability research, from 2008–2017 a total of 97,876 documents has been retrieved. The research has experienced constant growth during the period (15.92%, with a CAGR of 17.78% vs 3.57% in WoS in the same period), especially in the last period. From these documents, 81,105 documents (82.68%) are from HEIs and presented a major CAGR (19.22%).

- From the search strategy obtained, CAGR is higher in environmental research (25.06 environmental vs 7.78 social and economic research).

- A search strategy to analyse the "discourse of M&SDGs" has been conducted and identified 25,645 documents from 2000–2017. From this analysis, 21,587 documents from HEIs were detected (CAGR of 13.98%).

- There has been an increase in the number of countries and institutions involved in research, which indicates an increase in collaboration on the topic. Regarding collaboration patterns, 24.87% of the documents are with international collaboration, which is associated with a higher impact and visibility, and 27.94% with national collaboration.

- The analysis of scientific production in sustainability has shown high levels of visibility and impact over the period: 54.36% of the documents are in the 1Q and 15.51% in top 3.

6.2. Methodology

- A scientometric methodology (seed+expansion based on the CWTS WoS publication-level classification system) by considering the classic distribution of sustainability pillars has been used to delineate the sustainability output and identify the scientific output at HEIs. This methodology presents the following advantages: simplicity in its definition and aligned with sustainability science. The proposed methodology contributes to analysis of the research on SD at HEIs.

- Moreover, a similar methodology (seed+expansion based on direct citations) has been developed to delineate the discourse on M&SDGs and to determine the role of HEIs. This methodology allows one to determine papers related exclusively to this topic. In contrast, it does not capture the whole scientific output that could be linked with the topic.

- An ontology product has been created with the aim to classify the scientific output of each SDG.

- Mathematical models used in engineering have been used to predict trends with bibliometric indicators. This prediction has been proved as an additional input for estimating whether the impact is above the tendency and future trends.

6.3. Countries

- The research in sustainability research is led by the United States, China, the United Kingdom, Germany and Australia; however, in activity values, countries such as Malaysia, Cyprus or Ghana stand out. Spain is located in sixth position. The increase in the scientific output of other countries such South Korea, Iran or Malaysia during the period is also notable.

6.4. Institutions

- Regarding institutions, the Chinese Academy of Sciences and Wageningen University Research Centre lead in output of research on sustainability; the AI used in this study highlights the Swedish University of Agricultural Sciences and the University of Malaya, as the most specialized on the topic. This denotes it is not the largest institutions that present a higher specialization; in contrast, institutions with lower output could be more concentrated on it.

- The institutional sector that predominates in the generation of sustainability research is HEIs. Among the most productive institutions, the Chinese Academy of Sciences, Wageningen University Research Centre and INRA are notable. In the Spanish HEIs, UAB and technical universities (UPV and UPM) lead.

6.5. Thematic analysis

- Sustainability research has a higher representation in thematic categories such as green and sustainable science and technology, environmental sciences, energy and fuels, and environmental engineering. Some journals such as the *Journal of Cleaner Production* or *Sustainability* have published significant findings in sustainability research. In HEIs output, other journals are most notable (e.g. *International Journal of Sustainability in Higher Education*).

- Keyword analysis indicates the increase of the heterogeneity of the concepts and the emergence of concepts related to social and economic sustainability. Certain keywords presented a strong citation burst: “organization” (146.57); “ethics” (144.346), “industrial ecology” (131.58), “economics” (122.65), “CO_2 emission” (122.02), “energy consumption” (109.47) and “electricity” (103.55).

- The analysis of strong citation bursts indicated terms that have attracted attention more recently (2014–2017) (e.g. CSR), while others remain in the initial period (“ecology” or “globalization”). Moreover, certain keywords are relevant over longer times in the period analysed (e.g. “environmental management” or “politics”).

- Research output classified in each of the SDGs presents an interesting framework: goals more often addressed are SDG7, clean energy; SDG9, industry; SDG15, life on land; SDG16, peace, justice and strong institutions; and SDG8, decent work. While in the SDGs *core* dataset, the main SDGs addressed in HEIs are as follows: SDG3, health; SDG16, peace and justice; SDG11, cities; and SDG10, reduce inequalities.

6.6. Sustainability practices at Spanish HEIs

- In terms of internationalization, the participation in GreenMetric ranking has passed from 95 HEIs in 2010 to 718 in 2018 (5 vs 28 Spanish HEIs). Spanish Universities are closely associated with study of issues of waste, transportation and setting and infrastructure. Regarding projects, 1,495 projects in FP7 and 1,560 in H2020 have HEI participation (vs 292 FP7 and 336 in H2020 related to Spanish HEIs).

- In term of university governance and assessment and reporting, 41 strategic plans mentioned sustainability (85.37% were from public Spanish HEIs). Environmental sustainability is mentioned most often. Concerning sustainability plans, 36 public HEIs have them, and despite certain exceptions, the commitment to these plans is quite recent. Regarding campus operations, 31 institutions have green offices.

- In the analysis of the association between variables, a strong association has been found between the following variables: sustainability plan versus typology; green office versus typology; sustainability plan versus green office.

- Overall, a stronger interest in SD integration has been found in Spanish HEIs regarding sustainability. It would be interesting to analyse the impact of the actions of these HEIs.

6.7. Limitations

The limitations regarding the theoretical basis on which the scientometric studies are based are assumed on this study.

- One set of limitations is the biases in the international databases that have been highly relevant in several studies when collecting scientific production or the interpretation of citations, or in measuring scientific collaboration by measuring co-authors.

- Another limitation is related to scientific knowledge that is made quantifiable through published documents by the researchers. Its measurement is relevant and provides useful information about the research conducted in an area of knowledge. However, the delineation of a field does not admit of officially accepted validation measures. Still, this study has presented some approaches to it.

- The methodology used has certain limitations. Regarding the sustainability dataset, three main pillars are considered (no other pillars are identified in the literature). It has the following advantages: It captures a representative output of sustainability and identifies more documents than papers related to sustainability research.

- The ontology proposed has been created through the “key terms” of the description of SDGs, as well as the keywords identified in the M&SDG *core*. More terms could be included in the ontology.

- Another limitation is the level of analysis. The validity of the results obtained at the macro level (countries, continents or large topics) are considered with respect to those that focus on the micro level (e.g. institutions or authors). This study conducts analysis at a mixed macro and micro level, and this level should be interpreted cautiously, despite that it is more reliable than either in isolation.

- Regarding the commitment of HEIs with SD, certain limitations must be remarked upon:
    - Participation in GreenMetric is voluntary, so results have biases.
    - Regarding university and governance, and assessment and campus operations, despite that the websites relate all the procedures and activities that are relevant, it is not possible to collect complete information on the initiatives that have been carried in SD.
    - Different nomenclature in the plans was identified with different criteria.

6.8. Recommendations

After the completion of this study, and taking into account the data and results obtained, it is possible to make a series of recommendations with a special interest in future research development and practical use.

- The methodology used in this study offers a different perspective for analysing sustainability science and the role of HEIs in this research. The results obtained in this study could capture what are the main actors, features of the research (output, collaboration, impact, visibility) and thematic analysis. This material could be used to characterize (and detect research fronts) of the research on SD at HEIs and could be used for policy-makers.

- It would be important to maintain the continuity of the study of these topics and to analyse differences and potential new research fronts. Sustainability has become a topic of interest to society. In this regard, research should contribute to SD. The results obtained would offer information to policymakers to determine whether the policy is aligned with research. Moreover, research fronts analysis could be potentially used to guide publication topics or the internal policy of research centers.

- Mathematical models used in this study (state-space models) have proved to be tools that could be applied in bibliometric studies. This could be used in the research community to determine the implications of some indicators.

- The products obtained through this dissertation (*ad hoc* ontology) could be used to classify research output in other studies.

- Regarding the overview of HEIs in Spain, this information offers updated information on the situation of Spanish HEIs from different perspectives. It is important that HEIs have updated their website, not only to offer information about its performances, but also to engage the community with the problems detected and the policies and strategies developed in the framework of the university.

References

Abadal, E., Melero, R., Rodrigues, R. S., & Navas-Fernández, M. (2015). Spanish Scholarly Journals in WoS and Scopus: The Impact of Open Access. *Journal of Scholarly Publishing*, *47*(1), 77–96. doi.org/10.3138/jsp.47.1.04

Adomßent, M., Fischer, D., Godemann, J., Herzig, C., Otte, I., Rieckmann, M., & Timm, J. (2014). Emerging areas in research on higher education for sustainable development – management education, sustainable consumption and perspectives from Central and Eastern Europe. *Journal of Cleaner Production*, *62*, 1–7. doi.org/10.1016/j.jclepro.2013.09.045

Alba, D. (2007). Analysis of management and educational processes for sustainability in public Spanish universities. Research trends in Environmental Education Relating to Socio-Educational and Community Development, 197–215.

Alba, D., & Blanco, D. (2008). Indicators for sustainability at Spanish Universities. *Retrieved*, *12*(7), Art. 14. Recovered from https://www.researchgate.net/profile/David_Alba_Hidalgo/publication/228429331_Indicators_for_Sustainability_at_Spanish_Universities/links/551a98f90cf26cbb81a30621.pdf.

Albareda-Tiana, S., Vidal-Raméntol, S., Pujol-Valls, M., & Fernández-Morilla, M. (2018). Holistic approaches to develop sustainability and research competencies in pre-service teacher training. *Sustainability*, *10*(10), 3698.

Aleixandre-Benavent, R., González de Dios, J., Castelló-Cogollos, L., Navarro Molina, C., Alonso-Arroyo, A., Vidal-Infer, A., & Lucas-Domínguez, R. (2017). Bibliometría e indicadores de actividad científica (II). Indicadores de producción científica en pediatría. *Acta Pediatr Esp*, *75*(3-4), 44-50.

Aleixo, A. M., Azeiteiro, U. M., & Leal, S. (2016). Toward sustainability through higher education: sustainable development incorporation into Portuguese higher education institutions. In J. P. Davim & W. Leal Filho (Eds.), *Challenges in Higher Education for Sustainability* (pp. 159–187). Manhattan: Springer International Publishing.

Alshuwaikhat, H. M., & Abubakar, I. (2008). An integrated approach to achieving campus sustainability: Assessment of the current campus environmental management practices. *Journal of Cleaner Production*, *16*(16), 1777–1785. doi:10.1016/j.jclepro.2007.12.002.

Aleixo, A. M., Azeiteiro, U. M., & Leal, S. (2017). UN decade of education for sustainable development: perceptions of higher education institution"s stakeholders. In *Handbook of Theory and Practice of Sustainable Development in Higher Education* (pp. 417-428). Cham: Springer International Publishing.

Aleixo, A. M., Azeiteiro, U., & Leal, S. (2018). The implementation of sustainability practices in Portuguese higher education institutions. *International Journal of Sustainability in Higher Education*, *19*(1), 146–178. doi.org/10.1108/IJSHE-02-2017-0016

Alejandro-Cruz, J. S., Rio-Belver, R. M., Almanza-Arjona, Y. C., & Rodriguez-Andara, A. (2019). Towards a Science Map on Sustainability in Higher Education. *Sustainability*, *11*(13), 3521.

Allen, H., Cury, A., Gaston, T., Graf, C., Wakley, H., & Willis, M. (2019). What does better peer review look like? Underlying principles and recommendations for better practice. *Learned Publishing*, *32*(2), 163-175.

Almarshad, S. O. (2017). Adopting Sustainable Behavior in Institutions of Higher Education: A Study on Intentions of Decision Makers in the MENA Region. *European Journal of Sustainable Development*, *6*(2), 89-110.

Almind, T. C., & Ingwersen, P. (1997). Informetric analyses on the world wide web: methodological approaches to "webometrics". *Journal of documentation*, *53*(4), 404-426.

Alshuwaikhat, H. M., & Abubakar, I. (2008). An integrated approach to achieving campus sustainability: assessment of the current campus environmental management practices. *Journal of Cleaner Production*, *16*(16), 1777–1785. doi.org/10.1016/j.jclepro.2007.12.002

Álvarez-Bornstein, B., Morillo, F., & Bordons, M. (2017). Funding acknowledgments in the Web of Science: completeness and accuracy of collected data. *Scientometrics*, *112*(3), 1793-1812.

Amador, F., & Padrel Oliveira, C. (2013). Integrating Sustainability into the University: Past, Present, and Future. In S. Caeiro, W. L. Filho, C. Jabbour, & U. M. Azeiteiro (Eds.), *Sustainability Assessment Tools in Higher Education Institutions: Mapping Trends and Good Practices Around the World* (pp. 65–78). Cham: Springer International Publishing. doi.org/10.1007/978-3-319-02375-5_4

American Society for Cell Biology. (2012). *San Francisco declaration on research assessment*. Bathesda: ASCB. Recovered from https://sfdora.org/read.

Andrades Peña, F. J., Larrán Jorge, M., & Muriel de Los Reyes, M. J. (2018). Analysing the incorporation of sustainability themes into the university curricula: a case study of a Spanish public university. *International Journal of Sustainable Development & World Ecology*, *25*(7), 642–654. doi.org/10.1080/13504509.2018.1437484

Archambault, É., Campbell, D., Gingras, Y., & Larivière, V. (2009). Comparing bibliometric statistics obtained from the Web of Science and Scopus. *Journal of the American Society for Information Science*, 60, 1320–1326.

Axelsson, R., Angelstam, P., Degerman, E., Teitelbaum, S., Andersson, K., Elbakidze, M., & Drotz, M. K. (2013). Social and cultural sustainability: Criteria, indicators, verifier variables for measurement and maps for visualization to support planning. *Ambio*, *42*(2), 215–228.

Ayris, P., San Román, A. L. de., Maes, K., & Labastida, I. (2018). *Open Science and Its Role in Universities: a Roadmap for Cultural Change*. Leuven: LERU Office.

Banks, M. G. (2006). An extension of the Hirsch index: Indexing scientific topics and compounds. *Scientometrics*, *69*(1), 161–168. Retrieved from https://www.arxiv.org/abs/physics/0604216

Bautista-Puig, N., Pandiella, A., Lascurain, M. L. (2016). Dynamics and predictions with AR and ARMA models of patent applications on renewable energies in Spain from 1985 to 2014. National Congress of the Environment (Conama), Madrid, Spain. Retrieved from http://www.conama11.vsf.es/conama10/download/files/conama2016/CT%202016/1998973589.pdf

Bautista-Puig N., Carlos García-Zorita C., Mauleón E. (2019a). European Research Council: excellence and leadership over time from a gender perspective, *Research Evaluation*, *28*(4), 370–382. doi.org/10.1093/reseval/rvz023

Bautista-Puig, N., & Mauleón, E. (2019b). Unveiling the path towards sustainability: is there a research interest on sustainable goals? *International Conference on Scientometrics & Informetrics*, Rome, Italy, 17. (pp. 2770-2771).

Bautista-Puig, N., & Dudek, J. (2019c). Can Twitter hashtags be used for field delineation? The case of Sustainable Development Goals *(SDGs)*. *International Conference on Scientometrics & Informetrics*, Rome, Italy, 17. (pp. 2774-2775).

Bautista-Puig, N., Mauleón, E., & Sanz-Casado, E. (2019d). The role of universities in sustainable development (SD): the Spanish Framework. In U. M. de M. Azeiteiro., & J. P. Davim. *Higher Education and Sustainability* (pp. 91–116). Boca Raton: CRC Press. doi.org/10.1201/b22452-5

Bautista-Puig, N., Mauleón, E., & Sanz-Casado, E. (2019e). Analysis of Social, Environmental and Economic Sustainability Core: A Bibliometric Overview. *International Journal of Innovation and Sustainable Development*. In press.

Bayar, D. S. (2017). *Smart Citizens: Smart Cities from a different point of view.* Presentation at the Inspire Conference 2017. Strasbourg, France. Retrieved from https://inspire.ec.europa.eu/sites/default/files/presentations/INSPIRE_2017_Smart_Citizens_V5.pdf

Beans, C., & Driha, O. (2015). *Revision of Campus Sustainability and Energy Efficiency Policies and Pro*. Alicante: International Project Management Office (OGPI), University of Alicante, Spain.

Bergstrom, C. T., West, J. D., & Wiseman, M. A. (2008). The eigenfactor™ metrics. *Journal of Neuroscience*, *28*(45), 11433-11434.

Bettencourt, L. M., & Kaur, J. (2011). Evolution and structure of sustainability science. *Proceedings of the National Academy of Sciences*, *108*(49), 19540–19545

Bieler, A., & McKenzie, M. (2017). Strategic planning for sustainability in Canadian higher education. *Sustainability (Switzerland)*, *9*(2), 1–22. doi.org/10.3390/su9020161

Bildosola, I., Río-Bélver, R. M., Garechana, G., & Cilleruelo, E. (2017). TeknoRoadmap, an approach for depicting emerging technologies. *Technological Forecasting and Social Change*, *117*, 25-37.

Bizerril, M., Rosa, M. J., Carvalho, T., & Pedrosa, J. (2018). Sustainability in higher education: A review of contributions from Portuguese Speaking Countries. *Journal of Cleaner Production*, *171*, 600-612.

Björneborn, L. (2004). Small-world link structures across an academic web space: a library and information science approach. (PhD dissertation) Royal School of Library and Information Science. Department of Information, University of Copenhagen, Denmark. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.115.2353&rep=rep1&type=pdf

BOE (2010). *Real Decreto-ley 14/2010, de 23 de diciembre.* Por el que se establecen medidas urgentes para la corrección del déficit tarifario del sector eléctrico. Retrieved from http://www.congreso.es/constitucion/ficheros/leyes_espa/rdl_014_2010.pdf

Bolaños-Pizarro, M., Navarro-Molina, C., Alonso-Arroyo, A., González De Dios, J., & Aleixandre Benavent, R. (2011). Fuentes de información bibliográfica (IV). Bases de datos bibliográficas multidisciplinarias de interés en pediatría: Science Citation Index Journal Citations Reports (Web of Science). (Parte 2). *Acta Pediatrica Espanola*, *69*(7–8), 343–352.

Bollen, J., & Sompel, H. V. D. (2008). Usage impact factor: The effects of sample characteristics on usage-based impact metrics. *Journal of the American Society for Information Science and technology*, *59*(1), 136-149.

Bordons, M., & Gómez Caridad, I. (1997). La actividad científica española a través de indicadores bibliométricos en le período 1990-93. *Revista general de información y documentación*, *7*(2), 69-86.

Bordons, M., Felipe, A., & Gómez, I. (2002). Spanish scientific journals with impact factor in year 2000. *Revista Española de Documentación Científica*, *25*(1). doi.org/10.3989/redc.2002.v25.i1.86

Bordons, M., & Ángeles Zulueta, M. (2013). Evaluación de la actividad científica a través de indicadores bibliométricos. *Revista Española de Cardiología*, *52*(10), 790–800. doi.org/10.1016/s0300-8932(99)75008-6

Bordons, M., Morillo, F., Gómez, I., Moreno-Solano, L., Lorenzo, P., Aparicio, J., & González-Albo, B. (Coords.) (2017). *La actividad científica del CSIC a través de indicadores bibliométricos (Web of Science, 2012–2016). Technical Report*. Madrid: Consejo Superior de Investigaciones científicas (CSIC).

Bordons, M., Morillo, F., Moreno, L., Aparicio, J., & González-Albo, B. (2018). La actividad científica del CSIC a través de indicadores bibliométricos (Web of Science, 2013-2017). dx.doi.org/10.20350/digitalCSIC/8605

Borner, K. (2010). *Atlas of science: Visualizing what we know*. The MIT Press.

Bornmann, L. (2014). Validity of altmetrics data for measuring societal impact: A study using data from Altmetric and F1000Prime. *Journal of Informetrics*, *8*(4), 935-950.

Boyack, K. W., Chen, M. C., & Chacko, G. (2014). Characterization of the peer review network at the Center for Scientific Review, National Institutes of Health. *PLoS ONE*, *9*(8). doi.org/10.1371/journal.pone.0104244

Bradford, S. C. (1934). Sources of information on specific subjects. *Engineering*, *137*, 85-86.

Broadus, R. (1987). Toward a definition of "bibliometrics". *Scientometrics*, *12*(5-6), 373-379.

Brown, T. (2004). *Peer review and the acceptance of scientific ideas*. Discussion paper from a Working Party on equipping the public with an understanding of peer review. Sense about Science, London. Retrieved from http://www. senseaboutscience. org/data/files/resources/17/peerReview. pdf.

Brown, L. R. (2006). *Plan B 2.0: Rescuing a Planet Under Stress and a Civilization in Trouble*. New York: W. W. Norton & Company

Brusca, I., Labrador, M., & Larran, M. (2018). The challenge of sustainability and integrated reporting at universities: A case study. *Journal of Cleaner Production*, *188*, 347–354. doi.org/10.1016/j.jclepro.2018.03.292

Buela Casal, G. (2003). Evaluación de la calidad de los artículos y de las revistas científicas: Propuesta del factor de impacto ponderado y de un índice de calidad. *Psicothema*, *15*(1), 23-35. Retrieved from http://www.redalyc.org/articulo.oa?id=72715105

Burns, T. R. (2012). The Sustainability Revolution: A Societal Paradigm Shift. *Sustainability*, *4*(6), 1118–1134. doi.org/10.3390/su4061118

Buter, R. K., & Van Raan, A. F. J. (2013). Identification and analysis of the highly cited knowledge base of sustainability science. *Sustainability Science*, *8*(2), 253–267. doi.org/10.1007/s11625-012-0185-1

Caeiro, S., Azeiteiro, U. M., Filho, W. L., & Jabbour, C. (Eds.). (2013). *Sustainability Assessment Tools in Higher Education Institutions: Mapping Trends and Good Practices Around the World* (pp. 65–78). Cham: Springer International Publishing. doi.org/10.1007/978-3-319-02375-5_4

Caiado, R. G. G., Filho, W. L., Quelhas, O. L. G., Nascimento, D. L. d. M., & Ávila, L. V. (2018). A literature-based review on potentials and constraints in the implementation of the sustainable development goals. *Journal Clean Production, 198*, 1276-1288. doi.org/10.1016/j.jclepro.2018.07.102

Cainelli, G., Mazzanti, M., & Montresor, S. (2012). Environmental Innovations, Local Networks and Internationalization. *Industry & Innovation*, *19*(8), 697–734. doi.org/10.1080/13662716.2012.739782

Campanario, J. M. (2002). El sistema de revisión por expertos (peer review): muchos problemas y pocas soluciones. *Revista Española de Documentación Científica*, *25*(3), 267-285.

Cavanna, J. M., Medina, E. B. (2017). *Examen de transparencia Informe de transparencia voluntaria en la web de las universidades españolas 2016*. Madrid: Fundación Compromiso y Transparencia. Retrieved from https://www.compromisoytransparencia.com/informes/examen-de-transparencia-informe-de-transparencia-voluntaria-en-la-web-de-las-universidades-espanolas-2016

Chambers, D. P., & Walker, C. (2016). Sustainability as a catalyst for change in universities: New roles to meet new challenges. In J. Davim, & W. Leal Filho (Eds.), *Challenges in higher education for sustainability* (pp. 1–14). Cham: Springer International Publishing.

Chen, C. (2006). CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. *Journal of the American Society for information Science and Technology*, *57*(3), 359-377.

Chen, C. (2014) The CiteSpace Manual. Retrieved from http://cluster.ischool.drexel.edu/~cchen/citespace/CiteSpaceManual.pdf

Chinchilla-Rodríguez, Z., Corera-Álvarez, E., De Moya-Anegón F., & Sanz-Menéndez, L. (2010). *Indicadores bibliométricos de España en el mundo 2008*. Madrid: Instituto de Políticas y Bienes Públicos, Centro de Ciencias Humanos y Sociales, Consejo Superior de Investigaciones Científicas.

Chuvieco, E., Burgui-Burgui, M., Da Silva, E. V., Hussein, K., & Alkaabi, K. (2018). Factors affecting environmental sustainability habits of university students: Intercomparison analysis in three countries (Spain, Brazil and UAE). *Journal of Cleaner Production*, *198*, 1372–1380.

Cicchetti, D. V. (1991). The reliability of peer review for manuscript and grant submissions: A cross-disciplinary investigation. *Behavioral and Brain Sciences*, *14*(1), 119-135.

Ciegis, R., Ramanauskiene, J., & Martinkus, B. (2009). The concept of sustainable development and its use for sustainability scenarios. *Engineering Economics*, *62*(2).

Clarivate Analytics (2019). *Web of Science*. Retrieved from https://clarivate.com/webofsciencegroup/solutions/web-of-science/

Clark, W. C., & Dickson, N. M. (2003). Sustainability science: the emerging research program. *Proceedings of the national academy of sciences*, *100*(14), 8059-8061.

Clugston, R. M., & Calder, W. (1999). Critical dimensions of sustainability in higher education. *Sustentability and Universitylife: Environmental Education, Communication and Sustainability*, *5*(1), 1-15.

Cole, L. (2003). Assessing sustainability on Canadian University campuses: Development of a campus sustainability assessment framework. *Journal of Environment and Management*. Retrieved from http://neumann.hec.ca/humaniterre/campus_durable/campus_memoire.pdf

Cole, S., Rubin, L., & Cole, J. R. (1978). Peer Review in the National Science Foundation, , Washington, DC: National Academy of Sciences.

Corcoran, P. B., Walker*, K. E., & Wals, A. E. (2004). Case studies, make-your-case studies, and case stories: a critique of case-study methodology in sustainability in higher education. *Environmental Education Research*, *10*(1), 7-21.

Cortese, A. (2003). The critical role of higher education in creating a sustainable future: Higher education can serve as a model of sustainability by fully integrating all aspects of campus life. *Planning for Higher Education*, *31*(3), 15–22.

Costas, R. (2008). *Análisis bibliométrico de la actividad científica de los investigadores del CSIC en tres áreas, Biología y Biomedicina, Ciencia de los Materiales y Recursos*

Naturales: una aproximación metodológica a nivel micro (Web of Science, 1994-2004) (Doctoral dissertation), Universidad Carlos III de Madrid, Madrid, Spain.

Costas, R., & van Leeuwen, T. N. (2012). Approaching the "reward triangle": General analysis of the presence of funding acknowledgments and "peer interactive communication" in scientific publications. *Journal of the American Society for Information Science and Technology*, *63*(8), 1647-1661.

CRUE Conferencia de Rectores de las Universidades Españolas (2018). Diagnóstico de la sostenibilidad ambiental en las universidades españolas, Informe 2018. Madrid. Retrieved from www.crue.org/Boletin_SG/2018/2018.04.10%20Informe%20Sostenibilidad%20Universidades%20v3.4.pdf.

Dahler-Larsen, P. (2011). *The evaluation society*. Stanford: Stanford University Press.

De Bellis, N. (2014). History and evolution of (biblio) metrics. In B. Cronin., & C. R. Sugimoto. *Beyond Bibliometrics: Harnessing multidimensional indicators of scholarly impact*. (pp. 23-4). Massachusetts: The MIT Press.

De Filippo, D., Sandoval-Hamón, L. A., Casani, F., & Sanz-Casado, E. (2019). Spanish Universities" Sustainability Performance and Sustainability-Related R&D+ I. *Sustainability*, *11*(20), 5570.

De Souza, C. (2008). Impacto de las políticas brasileñas de Ciencia y Tecnología en la actividad investigadora de las universidades federales: Un estudio cienciométrico del período 2003-2015. (Tesis Doctoral), Programa de Doctorado en Documentación: Archivos y Bibliotecas en el Entorno Digital, Universidad Carlos III de Madrid, Madrid, Spain. Retrieved from https://e-archivo.uc3m.es/bitstream/handle/10016/27815/souza_tesis_2018.pdf?sequence=1&isAllowed=y

Degn, L., Mejlgaard, N., & Schneider, J. W. (2019). Using mixed methods to map vaguely defined research areas. *Research Evaluation*, *28*(4), 394-404.

Derrick, G. (2018). *The evaluators" eye: Impact assessment and academic peer review. Springer. development: Exploring possibilities for organisational change*. Londres: Palgrave Macmillan.

Disterheft, A., Caeiro, S., Azeiteiro, U. M., & Leal Filho, W. (2013). Sustainability Science and Education for Sustainable Development in Universities: A Way for Transition. In S. Caeiro, W. L. Filho, C. Jabbour, & U. M. Azeiteiro (Eds.), *Sustainability Assessment Tools in Higher Education Institutions: Mapping Trends and Good Practices Around the World* (pp. 3–27). Cham: Springer International Publishing. doi.org/10.1007/978-3-319-02375-5_1

Domínguez, S., Campoy, P., Sebastián, J. M., & Jiménez, A. (2006). *Control en el espacio de estado* (2a ed.). Madrid: Pearson Educación S. A.

Dong, B., Xu, G., Luo, X., Cai, Y., & Gao, W. (2012). A bibliometric analysis of solar power research from 1991 to 2010. *Scientometrics*, *93*(3), 1101-1117.

Du Pisani, J. A. (2006). Sustainable development – historical roots of the concept. *Environmental Sciences*, *3*(2), 83–96. doi.org/10.1080/15693430600688831

Dutz, M. A., & Sharma, S. (2012). Green growth, technology and innovation. Policy Research working paper; no. WPS 5932. Washington, DC: World Bank. Retrieved from http://documents.worldbank.org/curated/en/897251468156871535/Green-growth-technology-and-innovation

Easterly, W. (2009). How the millennium development goals are unfair to Africa. *World development*, *37*(1), 26-35.

Edwards, A. R. (2005). *The sustainability revolution: Portrait of a paradigm shift*. Gabriola Island: New Society Publishers.

Elkington, J. (1998). Partnerships from cannibals with forks: The triple bottom line of 21st-century business. *Environmental Quality Management*, *8*(1), 37–51.

European Commission (2005). **Communication from the Commission to the Council and the European Parliament - The 2005 Review of the EU Sustainable Development Strategy: Initial Stocktaking and Future Orientations. Retrieved from** https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52005DC0037

European Commission (2010). Europe 2020: a strategy for smart, sustainable and inclusive growth. Working paper {COM (2010) 2020}. Retrieved from https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:2020:FIN:EN:PDF

European Commission (2018). Environment & Climate Action. Retrieved from http://ec.europa.eu/programmes/horizon2020/en/area/environment-climate-action.

European Commission (2019). Horizon 2020 Work Programme 2018. Retrieved from https://ec.europa.eu/research/participants/data/ref/h2020/wp/2018-2020/main/h2020-wp1820-societies_en.pdf

European Patent Office – EPO (2019). Base de datos Global Patent Index (GPI). Retrieved from https://data.epo.org/expert-services/index-2-2-11.html

European Union (2018). Special Eurobarometer 479. The future of Europe. Retrieved from https://ec.europa.eu/commfrontoffice/publicopinion/index.cfm/Survey/getSurveyDetail/yearFrom/1974/yearTo/2018/surveyKy/2217

Fabrizi, A., Guarini, G., & Meliciani, V. (2018). Green patents, regulatory policies and research network policies. *Research Policy*, *47*(6), 1018–1031. doi.org/10.1016/j.respol.2018.03.005

Fay, M., Hallegatte, S., & Vogt-Schilb, A. (2013). *Green industrial policies: when and how (English)*. Policy Research working paper; no. WPS 6677. Washington, DC: World Bank.

Feng, Y., Zhu, Q., & Lai, K. H. (2017). Corporate social responsibility for supply chain management: A literature review and bibliometric analysis. *Journal of Cleaner Production*, *158*, 296-307.

Fien, J. (2002). Advancing sustainability in higher education: Issues and opportunities for research. *Higher Education Policy*, *15*(2), 143–152.

Findler, F., Schönherr, N., Lozano, R., Reider, D., & Martinuzzi, A. (2019). The impacts of higher education institutions on sustainable development: A review and conceptualization. *International Journal of Sustainability in Higher Education, 20(1), 23–38. doi.org/10.1108/IJSHE-07-2017-0114*

Fu, Y., & Zhang, X. (2017). Trajectory of urban sustainability concepts: A 35-year bibliometric analysis. *Cities*, *60*, 113-123.

Fukuda-Parr, S. (2016). From the Millennium Development Goals to the Sustainable Development Goals: shifts in purpose, concept, and politics of global goal setting for development. *Gender & Development*, *24*(1), 43-52.

Fuller, R. J. (2010). Beyond cliché–reclaiming the concept of sustainability. *Australian journal of environmental education*, *26*, 7-18.

García-Zorita, J. (2001). *La actividad científica de los economistas españoles en función del ámbito nacional o internacional de sus publicaciones: estudio comparativo basado en un análisis bibliométrico durante el periodo 1986/95* (Doctoral dissertation), Universidad Carlos III de Madrid, Madrid, Spain.

Garde Sánchez, R., Rodríguez Bolívar, M. P., & López-Hernández, A. M. (2013). Online disclosure of university social responsibility: a comparative study of public and private US universities. *Environmental Education Research*, *19*(6), 709-746.

Garde-Sánchez, R., Rodríguez Bolívar, M. P., & López Hernández, A. M. (2013). Divulgación online de información de responsabilidad social en las universidades españolas. *Revista de Educación*, (extraordinario), 177-209.

Glanzel, W. (2003). Bibliometrics as a research field a course on theory and application of bibliometric indicators. Course Handouts. Retrieved from http://nsdl.niscair.res.in/jspui/bitstream/123456789/968/1/Bib_Module_KUL.pdf

Glänzel, W., & Schubert, A. (2003). A new classification scheme of science fields and subfields designed for scientometric evaluation purposes. *Scientometrics*, *56*(3), 357-367.

Godemann, J., Bebbington, J., Herzig, C., & Moon, J. (2014). Higher education and sustainable development: Exploring possibilities for organisational change. *Accounting, Auditing & Accountability Journal*, *27*(2), 218-233.

Goldin, I., & Winters, A. (1995). Economic policies for sustainable development. In I. Goldin & A. Winters. *The Economics of Sustainable Development*. (pp. 1-15). Cambridge: Cambridge University Press.

Gómez-Caridad, I. G., & Bordons, M. (1996). Limitaciones en el uso de los indicadores bibliométricos para la evaluación científica. *Política científica*, (46), 21-26.

Gómez Caridad, I., & Bordons, M. (2009). Limitaciones en el uso de los indicadores bibliométricos para la evaluación científica.

González-Pereira, B., Guerrero-Bote, V. P., & Moya-Anegón, F. (2010). A new approach to the metric of journals" scientific prestige: The SJR indicator. *Journal of Informetrics*, *4*(3), 379-391.

Gough, G., & Longhurst, J. (2018). Monitoring progress towards implementing sustainability and representing the UN sustainable development goals (SDGs) in the curriculum at UWE Bristol. In W. Leal Filho (Eds.), *Implementing Sustainability in the Curriculum of Universities* (pp. 279-289). Cham: Springer International Publishing.

Grassano, N., Rotolo, D., Hutton, J., Lang, F., & Hopkins, M. M. (2017). Funding data from publication acknowledgments: Coverage, uses, and limitations. *Journal of the Association for Information Science and Technology*, *68*(4), 999-1017.

Gray, R. (2006). Social, environmental and sustainability reporting and organisational value creation? Whose value? Whose creation?. *Accounting, Auditing & Accountability Journal*, *19*(6), 793-819.

Greenacre, M. (2008). *La práctica del análisis de correspondencias*. Bilbao: Fundacion BBVA.

Griggs, D. J., Nilsson, M., Stevance, A., & McCollum, D. (2017). *A guide to SDG interactions: from science to implementation*. Paris: International Council for Science.

Grindsted, T. (2011). Sustainable universities–from declarations on sustainability in higher education to national law. *Environmental Economics, 2*(2). doi.org/10.2139/ssrn.2697465

Gruzd, A., Staves, K., & Wilk, A. (2012). Connected scholars: Examining the role of social media in research practices of faculty using the UTAUT model. *Computers in Human Behavior*, *28*(6), 2340-2350.

Gusenbauer, M. (2019). Google Scholar to overshadow them all? Comparing the sizes of 12 academic search engines and bibliographic databases. *Scientometrics*, *118*(1), 177-214.

Hák, T., Janoušková, S., & Moldan, B. (2016). Sustainable Development Goals: A need for relevant indicators. *Ecological Indicators*, *60*, 565-573.

Hall, B. H., & Helmers, C. (2013). Innovation and diffusion of clean/green technology: Can patent commons help?. *Journal of Environmental Economics and Management*, *66*(1), 33-51

Hallinger, P., & Chatpinyakoop, C. (2019). A bibliometric review of research on higher education for sustainable development, 1998-2018. *Sustainability (Switzerland)*, *11*(8). doi.org/10.3390/su11082401

Hassan, S. U., Haddawy, P., & Zhu, J. (2014). A bibliometric study of the world"s research activity in sustainable development and its sub-areas using scientific literature. *Scientometrics*, *99*(2), 549–579.

Haunschild, R., & Bornmann, L. (2015). F1000Prime: an analysis of discipline-specific reader data from Mendeley. *F1000Research*, *41*(may), 1–18. doi.org/10.12688/f1000research.6062.1

Haustein, S., Bowman, T. D., & Costas, R. (2015a). Interpreting “altmetrics”: viewing acts on social media through the lens of citation and social theories. In R. C. Sugimoto (Ed.), *Theories of Informetrics an Scholarly Communication*. (pp. 372-406). Berlin, Boston: De Gruyter. doi.org/10.1515/9783110308464-022

Haustein, S., Bowman, T. D., & Costas, R. (2015b). Communities of attention around journal papers: who is tweeting about scientific publications? *Social Media and Society 2015 International Conference.* Toronto, Canada. Retrieved from https://www.slideshare.net/StefanieHaustein/communities-of-attention-around-journal-papers-who-is-tweeting-about-scientific-publications

Haustein, S., Bowman, T. D., & Costas, R. (2016). Interpreting" altmetrics": viewing acts on social media through the lens of citation and social theories. In C. R. Sugimoto (Ed.), *Theories of Informetrics and Scholarly Communication*. (pp. 372–405). Berlin, Boston: De Gruyter.

Hesselbarth, C., & Schaltegger, S. (2014). Educating change agents for sustainability–learnings from the first sustainability management master of business administration. *Journal of Cleaner Production*, *62*, 24–36.

Hicks, D., Wouters, P., Waltman, L., De Rijcke, S., & Rafols, I. (2015). Bibliometrics: the Leiden Manifesto for research metrics. *Nature News*, *520*(7548), 429.

Hidalgo, D. A., Alcántara, R. B., Silva, M. T. B., del Álamo, J. B., Heras, D. B., Antúnez, X. D., … Comas, P. Y. (2012). Estrategias de sostenibilidad y responsabilidad social en las universidades españolas: Una herramienta para su evaluación. Profesorado. *Revista de Currículum y Formación de Profesorado*, *16*(2), 59–75.

Holland, J. (2000) Consensus and conflict: The socio-economic challenge facing sustainabletourism development in southern Albania. *Journal of Sustainable Tourism, 8*(6), 510–24.

Hood, W., & Wilson, C. (2001). The literature of bibliometrics, scientometrics, and informetrics. *Scientometrics*, *52*(2), 291-314.

Hook, D., Porter, S., & Herzog, C. (2018). Dimensions: Building context for search and evaluation. *Frontiers in Research Metrics and Analytics*, *3*, 23.

Hug, S. E., Ochsner, M., & Daniel, H. D. (2013). Criteria for assessing research quality in the humanities: a Delphi study among scholars of English literature, German literature and art history. *Research Evaluation*, *22*(5), 369-383.

International Council for Science (2015): Review of the Sustainable Development Goals: The Science Perspective. Paris: International Council for Science (ICSU).

International Human Rights Instruments. (2008). *Report on Indicators for Promoting and Monitoring the Implementation of Human Rights.* Geneva: United Nations.

IUNE (2019). Observatory of Spanish University System (SUE). *IUNE*, Spain. Retrieved from www.iune.es/.

Jacsó, P. (2011). The pros and cons of Microsoft Academic Search from a bibliometric perspective. *Online Information Review*, *35*(6), 983-997.

Jakaria-Rahman A. I. M., & Guns, Raf. (2017). *Determining cognitive distance between publication portfolios of evaluators and evaluees in research evaluation: a case study of Physics department – Technical Report.* Antwerp: University of Antwerp.

Jerneck, A., Olsson, L., Ness, B., Anderberg, S., Baier, M., Clark, E., ... & Persson, J. (2011). Structuring sustainability science. *Sustainability science*, *6*(1), 69-82.

Johnston, P., Everard, M., Santillo, D., & Robèrt, K. H. (2007). Reclaiming the definition of sustainability. *Environmental science and pollution research international*, *14*(1), 60-66.

Kajikawa, Y., Ohno, J., Takeda, Y., Matsushima, K., & Komiyama, H. (2007). Creating an academic landscape of sustainability science: an analysis of the citation network. *Sustainability Science*, *2*(2), 221.

Kajikawa, Y. (2008). Research core and framework of sustainability science. *Sustainability Science*, *3*(2), 215-239.

Kajikawa, Y., Tacoa, F., & Yamaguchi, K. (2014). Sustainability science: the changing landscape of sustainability research. *Sustainability Science*, *9*(4), 431–438. doi.org/10.1007/s11625-014-0244-x

Kassambara, A. (2018) *ggpubr: "ggplot2" Based Publication Ready Plots. R package version 0.2*. Retrieved from https://CRAN.R-project.org/package¼ggpubr.

Kassirer, J. P., & Campion, E. W. (1994). Peer review: crude and understudied, but indispensable. *Jama*, *272*(2), 96-97.

Kastenhofer, K., & Rammel, C. (2005). Obstacles to and potentials of the societal implementation of sustainable development: A comparative analysis of two case studies. Sustainability: Science, *Practice and Policy*, *1*(2), 5–13. doi:10.1080/15487733.2005.11907968.

Kates, R. W., Clark, W. C., Corell, R., Hall, J. M., Jaeger, C. C., Lowe, I., ... & Faucheux, S. (2001). Sustainability science. *Science*, *292*(5517), 641-642.

Katz, J. S., & Hicks, D. (1997). The changing shape of British industrial research. *STEEP special report*, 6.

King, J. (1987). A review of bibliometric and other science indicators and their role in research evaluation. *Journal of information science*, *13*(5), 261-276.

Kleinberg, J. (2003). Bursty and hierarchical structure in streams. *Data Mining and Knowledge Discovery*, *7*(4), 373-397.

Koester, R. J., Eflin, J., & Vann, J. (2006). Greening of the campus: a whole-systems approach. *Journal of cleaner production*, *14*(9-11), 769-779.

Kohn, A. (1993). Why incentive plans cannot work. *Harvard Business Revie.* Retrieved from https://hbr.org/1993/09/why-incentive-plans-cannot-work

Komiyama, H., & Takeuchi, K. (2006). Sustainability science: building a new discipline. *Sutain Sci*, 1, 1-6.

Larrán, M., De la Cuesta, M., Fernandez, A., Muñoz, M. J., López, A., Moneva, J. M., … Garde, R., (2014). Analisis del nivel de implantación de políticas de responsabilidad social en las universidades españolas. In *Conference of Spanish Public Social Councils*, Madrid.

Larrán, J. M., Herrera Madueño, J., & Javier Andrades Peña, F. (2015a). Factors influencing the presence of sustainability initiatives in the strategic planning of Spanish universities. *Environmental Education Research*, *21*(8), 1155–1187. doi.org/10.1080/13504622.2014.977231

Larrán, J. M., Madueño, J. H., Cejas, M. Y. C., & Peña, F. J. A. (2015b). An approach to the implementation of sustainability practices in Spanish universities. *Journal of Cleaner Production*, *106*, 34–44.

Larrán, M., Herrera, J., & Andrades, F. J. (2016a). Measuring the linkage between strategies on sustainability and institutional forces: An empirical study of Spanish universities. *Journal of Environmental Planning and Management*, 59(6), 967–992. doi: 10.1080/09640568.2015.1050485.

Larrán, J. M., Herrera Madueño, J., Calzado, Y., & Andrades, J. (2016b). A proposal for measuring sustainability in universities: a case study of Spain. *International Journal of Sustainability in Higher Education*, *17*(5), 671–697. doi.org/10.1108/IJSHE-03-2015-0055

Lauder, A., Sari, R. F., Suwartha, N., & Tjahjono, G. (2015). Critical review of a global campus sustainability ranking: GreenMetric. *Journal of Cleaner Production*, *108*, 852–863.

Lawrenz, F., Thao, M., & Johnson, K. (2012). Expert panel reviews of research centers: The site visit process. *Evaluation and Program Planning*, *35*(3), 390-397.

Le Blanc, D. (2015). Towards integration at last? The sustainable development goals as a network of targets. *Sustainable Development*, *23*(3), 176-187.

Leal Filho, W. (2000). Dealing with misconceptions on the concept of sustainability. *International Journal of Sustainability in Higher Education*, *1*(1), 9–19. doi.org/10.1108/1467630010307066

Leal Filho, W., Shiel, C., do Paço, A., & Brandli, L. (2015a). Putting sustainable development in practice: campus greening as a tool for institutional sustainability efforts. *Sustainability in higher education*, 1-19. doi.org/10.1016/B978-0-08-100367-1.00001-9

Leal Filho, W., Manolas, E., & Pace, P. (2015b). The future we want. *International Journal of Sustainability in Higher Education*, *16*(1), 112–129. doi.org/10.1108/IJSHE-03-2014-0036

Leal Filho, W., Wu, Y. C. J., Brandli, L. L., Avila, L. V., Azeiteiro, U. M., Caeiro, S., & Madruga, L. R. D. R. G. (2017). Identifying and overcoming obstacles to the implementation of sustainable development at universities. *Journal of Integrative Environmental Sciences*, *14*(1), 93-108.

Leal Filho, W., Pallant, E., Enete, A., Richter, B., & Brandli, L. L. (2018a). Planning and implementing sustainability in higher education institutions: an overview of the difficulties and potentials. *International Journal of Sustainable Development & World Ecology*, *25*(8), 713-721.

Leal-Filho, W., Raath, S., Lazzarini, B., Vargas, V. R., de Souza, L., Anholon, R., … & Orlovic, V. L. (2018b). The role of transformation in learning and education for sustainability. *Journal of Cleaner Production*, *199*, 286–295.

Leal Filho, W., Will, M., Salvia, A. L., Adomßent, M., Grahl, A., & Spira, F. (2019). The Role of Green and Sustainability Offices in Fostering Sustainability Efforts at Higher Education Institutions. *Journal of Cleaner Production*. doi: 10.1016/j.jclepro.2019.05.273

Leetch, A., & Hauk, M. (2017). A decade of earth in the mix: A bibliometric analysis of emergent scholarly research on sustainability education and ecopsychology in higher education. In W. Leal Filho, M. Mifsud, C. Shiel, & R. Pretorius (Eds.), *Handbook of Theory and Practice of Sustainable Development in Higher Education* (pp. 291–306). Cham: Springer International Publishing.

León Fernández, Y. M. (2015). *Universidades y sostenibilidad: análisis de actuaciones de participación en Universidades Españolas y Latinoamericanas*. Córdoba: UCO Press

Leydesdorff, L., Carley, S., & Rafols, I. (2013). Global maps of science based on the new Web-of-Science categories. *Scientometrics*, *94*(2), 589-593.

Lewison, G., Cottrell, R., & Dixon, D. (1999). Bibliometric indicators to assist the peer review process in grant decisions. *Research evaluation*, *8*(1), 47-52.

Lewison, G.; Thornicroft, G.; Szmulker, G. Y Tansella, M. (2007). Fair assessment of the merits of psychiatric research. British Journal of Psychiatry, 190: 314-318.

López-Cózar, E. D., Orduna-Malea, E., & Martín-Martín, A. (2018). Google scholar as a data source for research assessment. *ArXiv,* abs/1806.04435.

López-Piñero, J. M., & Terrada, M. L. (1992). Los indicadores bibliométricos y la evaluación de la actividad médico-científica. (III) Los indicadores de producción, circulación y dispersión, consumo de la información y repercusión. *Medicina Clínica*, (98), 142-148.

Lotka, A. J. (1926). The frequency distribution of scientific productivity. *Journal of the Washington academy of sciences*, *16*(12), 317-323.

Lozano, R. (2006a). Incorporation and institutionalization of SD into universities: breaking through barriers to change. *Journal of cleaner production*, *14*(9-11), 787-796.

Lozano, R. (2006b). A tool for a Graphical Assessment of Sustainability in Universities (GASU). *Journal of cleaner production*, *14*(9-11), 963-972.

Lozano, R. (2008). Envisioning sustainability three-dimensionally. *Journal of Cleaner Production*, *16*(17), 1838–1846. doi.org/10.1016/j.jclepro.2008.02.008

Lozano, R. (2011). The state of sustainability reporting in universities. *International Journal of Sustainability in Higher Education*, *12*(1), 67–78. doi: 10.1108/14676371111098311.

Lozano, R., & Huisingh, D. (2011). Inter-linking issues and dimensions in sustainability reporting. *Journal of cleaner production*, *19*(2-3), 99-107.

Lozano, R., Lukman, R., Lozano, F. J., Huisingh, D., & Lambrechts, W. (2013a). Declarations for sustainability in higher education: Becoming better leaders, through addressing the university system. *Journal of Cleaner Production*, 48, 10-19. doi: 10.1016/j.jclepro.2011.10.006.

Lozano, R., Lozano, F.J., Mulder, K., Huisingh, D. and Waas, T. (2013b), "Advancing Higher Education for Sustainable Development: international insights and critical reflections", *Journal of Cleaner Production, 48*, 3-9.

Lozano, R., Llobet, J., & Tideswell, G. (2013c). The process of assessing and reporting sustainability at universities: Preparing the report of the University of Leeds. *Revista Internacional de Tecnología, Sostenibilidad y Humanismo*, (8), 85-112.

Lozano, R., Ceulemans, K., Alonso-Almeida, M., Huisingh, D., Lozano, F. J., Waas, T., ... & Hugé, J. (2015). A review of commitment and implementation of sustainable development in higher education: results from a worldwide survey. *Journal of Cleaner Production*, *108*, 1-18.

Lozano-Ros, R. (2003). *Sustainable development in higher education. Incorporation, assessment and reporting of sustainable development in higher education institutions*. (MSc Thesis) Environmental Management and Policy, IIIEE, Lund University, Lund, Sweden.

Madeira, A. C., Carravilla, M. A., Oliveira, J. F., & Costa, C. A. (2011). A methodology for sustainability evaluation and reporting in higher education institutions. *Higher Education Policy*, *24*(4), 459–479

Malthus, T. R. (1872). *An Essay on the Principle of Population.* London: Electronic Scholarly Publishing Project.

Manzano, J. A., Esteve, A. E., Juan, M. I., & Cano, V. S. (2016). La universidad española: grupos estratégicos y desempeño. Bilbao: Fundación BBVA.

Marsh, H. W., Jayasinghe, U. W., & Bond, N. W. (2008). Improving the peer-review process for grant applications: reliability, validity, bias, and generalizability. *American psychologist*, *63*(3), 160.

Marshall, J. D., & Toffel, M. W. (2005). Framing the elusive concept of sustainability: A sustainability hierarchy. *Environ. Sci. Technol, (39)*3, 673-682. doi.org/10.1021/es040394k

Martens, P. (2006) Sustainability: Science or fiction? *Sustain*, *2*(1), 36–41.

Martin, B. (1996). The use of multiple indicators in the assessment of basic research. *Scientometrics*, *36*(3), 343-362.

Martin, B. R., & Irvine, J. (1983). Assessing basic research: some partial indicators of scientific progress in radio astronomy. *Research policy*, *12*(2), 61-90.

Martín-Martín, A. (2019). Generación de herramientas de evaluación bibliométrica a partir de Google Scholar. Granada: Universidad de Granada.

Maskus, E. K. (2005). The Globalisation of IPRs and Innovation in Services. *Journal of Industry Competition Trade*, *8*, 247-267.

Meadowcroft, J. (2007). Who is in charge here? Governance for sustainable development in a complex world. *Journal of Environmental Policy & Planning*, *9*(3–4), 299–314.

Meadows, D. H., Meadows, D. L., Randers, J., & Behrens, W. W. (1972). The limits to growth. *New York*, *102*, 27.

Mebratu, D. (1998). Sustainability and sustainable development: historical and conceptual review. *Environmental impact assessment review*, *18*(6), 493-520.

Miller, T. R., Wiek, A., Sarewitz, D., Robinson, J., Olsson, L., Kriebel, D., & Loorbach, D. (2014). The future of sustainability science: a solutions-oriented research agenda. *Sustainability science*, *9*(2), 239-246.

Minas, H., Tsutsumi, A., Izutsu, T., Goetzke, K., & Thornicroft, G. (2015). Comprehensive SDG goal and targets for non-communicable diseases and mental health. *International journal of mental health systems*, *9*(1), 12.

Ministerio de Ciencia y Tecnología – MCYT (1999*). Plan de fomento de las energías renovables en España*. Retrieved from http://www.idae.es/index.php/mod.documentos/mem.descarga?file=/documentos_4044_PFER2000-10_1999_1cd4b316.pdf

Ministerio de Educación (2010). *Estrategia Universidad 2015. El camino para la modernización de la Universidad*. Retrieved from https://www.uab.cat/doc/DOC_cei_estrategia2015_edicio2010

Ministerio de Industria, Turismo y Comercio – MITYC (2005). *Resumen del Plan de Energías Renovable sen España (2005-2010)*. Retrieved from http://www.idae.es/uploads/documentos/documentos_Resumen_PER_2005-2010_(8-_de_agosto-2005)sge2_DINA4_version_buena(4-08-05)_493fc9ab_c25d12d9.pdf

Mitcham, C. (1995). The concept of sustainable development: its origins and ambivalence. *Technology in society*, *17*(3), 311-326.

Mochizuki, Y. (2015). Education for sustainable development and sustainability Science: Re-purposing higher education and research. In M. Barth, G. Michelsen, M. Rieckmann, & I. G. Thomas. *Routledge Handbook of Higher Education for Sustainable Development* (pp. 35-48). Abringdon: Routledge.

Moed, H. F. (2010). The Source-Normalized Impact per Paper (SNIP) is a valid and sophisticated indicator of journal citation impact. *Journal of the American Society for Information Science and Technology*, *62*(1). doi: 10.1002/asi.21424

Moed, H. F. (2015). Altmetrics as traces of the computerization of the research process. *ArXiv,* preprint arXiv:1510.05131.

Moed, H. F. (2017). *Applied Avaluative Informetrics*. Amsterdam: Springer International Publishing.

Moneva, J. M., and E. Martín. 2012. "Universidad y desarrollo sostenible: Análisis de la rendición de cuentas de las universidades públicas desde un enfoque de responsabilidad social [University and Sustainable Development: Accountability Analysis of Public Uni- versities from a Sustainability Approach]." *Revista Iberoamericana de Contabilidad de Gestión*, *10*(19), 1–18.

Monroy, S. E., & Diaz, H. (2018). Time series-based bibliometric analysis of the dynamics of scientific production. *Scientometrics*, *115*(3), 1–21. doi.org/10.1007/s11192-018-2728-4

Moravcsik, M. J. (1989). ¿Cómo evaluar la ciencia y a los científicos? *Revista Española de Documentación Científica*, *12*(3), 313-325.

Mulder, K. F. (2017). Strategic competences for concrete action towards sustainability: An oxymoron? Engineering education for a sustainable future. *Renewable and Sustainable Energy Reviews*, *68*, 1106-1111.

Nacke, O. (1979). Informetrie: ein neuer Name für eine neue Disziplin. Begriffsbestimmung, Wissensstand und Entwicklungsprinzipien. *Nachrichten für Dokumnetation, 30*(6), 219-226.

Nakamura, M., Pendlebury, D., Schnell, J., & Szomszor, M. (2019). Navigating the Structure of Research on Sustainable Development Goals. *Policy*, 11, 12.

Nalimov, V. V., & Mulchenko, B. M. (1969). Scientometrics. *Studies of science as a process of information.* Moscow, Russia: Science.

Nederhof, A. J., & Van Raan, A. F. J. (1989). A validation study of bibliometric indicators: The comparative performance of cum laude doctorates in chemistry. *Scientometrics*, 17, 427-443.

Nilsson, M., Griggs, D., & Visbeck, M. (2016). Policy: map the interactions between Sustainable Development Goals. *Nature News*, *534*(7607), 320.

Nilsson, P. (2004). *NGO involvement in the UN Conference on the Human Environment in Stockholm 1972*. *Interrelations Between Intergovernmental Discourse Framing and Activist Influence*. Ekonomiska Institutionen, 56. Retrieved from http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A19531&dswid=3946.

Noyons, E. C. M. (1999). *Bibliometric mapping as a science policy and research management tool*. (Doctoral dissertation) Centrum voor Wetenschaps-en, Faculty of Science, Leiden University, Leiden, Paises Baixos.

Nučič, M. (2012). Is sustainability science becoming more interdisciplinary over time? *Acta Geographica Slovenica*, *52*(1), 215–236.

Ogata, K. (1995). *Discrete-time control systems* (Vol. 2, pp. 446-480). New Jersey: Prentice Hall.

Okubo, Y. (1997). Bibliometric indicators and analysis of research systems. France: OECD.

Olawumi, T. O., & Chan, D. W. (2018). A scientometric review of global research on sustainability and sustainable development. *Journal of cleaner production*, *183*, 231-250.

Olmeda-Gómez, C., Romá-Mateo, C., & Ovalle-Perandones, M. A. (2019). Overview of trends in global epigenetic research (2009–2017). *Scientometrics*, 119, 1545. doi.org/10.1007/s11192-019-03095-y

Organisation for economic co-operation and development – OECD. (2009a). *Declaration on Green Growth*. Retrieved from http://www.oecd.org/env/44077822.pdf

Organisation for economic co-operation and development – OECD). (2009b). *Manual de estadísticas de patentes de la OCDE*. Madrid: Oficina Española de Patentes y Marcas

Organisation for economic co-operation and development – OECD. (2011). *Hacía el crecimiento verde. Un resumen para los diseñadores de políticas*. Retrieved from http://www.oecd.org/greengrowth/49709364.pdf

Pandiella-Dominique, A., Bautista-Puig, N., & De Filippo, D. (2018). Mapping growth and trends in the category "Green and Sustainable Science and Technology". In *International Conference on Science and Technology Indicators,* 23., 2018, Leiden, the Netherlands. Centre for Science and Technology Studies (CWTS).

Peña, D. (2005). *Análisis de series temporales*. Madrid: Alianza.

Peñasco, C., Martínez, C. & del Río, P. (2016). *Patentes "verdes" españolas*. Madrid: Instituto de Políticas y Bienes Públicos, Consejo Superior de Investigaciones Científicas.

Pettigrew, L. M., De Maeseneer, J., Anderson, M. I. P., Essuman, A., Kidd, M. R., & Haines, A. (2015). Primary health care and the Sustainable Development Goals. The *Lancet*, *386*(10009), 2119-2121.

Priem J, Taraborelli D, Groth P, Neylon C. (2010). alt-metrics: a manifesto. *Altametrics*. Retrieved from http://altmetrics.org/manifesto/.

Priem, J., Piwowar, H. A., & Hemminger, B. M. (2012). Altmetrics in the wild: Using social media to explore scholarly impact. *ArXiv,* preprint arXiv:1203.4745.

Pritchard, A. (1969). Statistical bibliography or bibliometrics. *Journal of documentation*, *25*(4), 348-349.

Pulgarín, A., Eklund, P., Garrote, R., & Escalona-Fernández, M. I. (2015). Evolution and structure of "sustainable development": A bibliometric study. *Brazilian journal of Information Sciecne: Research Trends*, *9*(1), 24.

Quental, N., Lourenço, J. M., & da Silva, F. N. (2011). Sustainability: Characteristics and scientific roots. *Environment, Development and Sustainability*, *13*(2), 257–276. doi.org/10.1007/s10668-010-9260-x

R Core Team (2019) R: *A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing

Ràfols, I. (2018). S&T indicators in the wild: Contextualization and participation for responsible metrics. *Research Evaluation*, *28*(1), 7-22.

Ramírez Ríos, J. F., Alzate Ibáñez, A. M., & Montenegro Riaño, D. F. (2016). Los discursos de la sostenibilidad: análisis de tendencias conceptuales a partir de mediciones bibliométricas. *Questionar: Investigación Específica, 4*(1), 82-96.

Rees, W. E. (1997). Is "sustainable city"an oxymoron?. *Local environment*, *2*(3), 303-310.

Renewable Energy Policy Network for the 21st Century – Ren21 (2015). *Energías renovables 2016. Reporte de la situación mundial*. Retrieved from http://www.ren21.net/wp-content/uploads/2g016/06/GSR_2016_KeyFindings_SPANISH.pdf

Robinson, J. (2004). Squaring the circle? Some thoughts on the idea of sustainable development. *Ecological Economics*, *48*(4), 369–384. https://doi.org/10.1016/j.ecolecon.2003.10.017

Robinson-García, N., Torres-Salinas, D., Zahedi, Z., & Costas, R. (2014). Nuevos datos, nuevas posibilidades: Revelando el interior de Altmetric. com. *El Profesional de la Information*, *23*(4), 359-366.

Robinson-Garcia, N., van Leeuwen, T. N., & Rafols, I. (2018). Using altmetrics for contextualised mapping of societal impact: From hits to networks. *Science and Public Policy*, *45*(6), 815-826.

Rogers, E. M. (1962). *Diffusion of Innovations*. New York: The Free Press of Glencoe.

Rojo, J. (1999). Peer review—Experiences at national and European level. *Scientometrics*, *45*(3), 497-500.

Romero, D. M., Meeder, B., & Kleinberg, J. (2011, March). Differences in the mechanics of information diffusion across topics: idioms, political hashtags, and complex contagion on twitter. In *Proceedings of the 20th international conference on World wide web* (pp. 695-704). ACM.

Romo-Fernández, L. M., Guerrero-Bote, V. P., & Moya-Anegón, F. (2012). World scientific production on renewable energy, sustainability and the environment. *Energy for Sustainable Development*, *16*(4), 500–508.

Ross-Hellauer, T. (2017). What is open peer review? A systematic review. *F1000Research*, 6, 588-618.

Rotta, R., & Noack, A. (2011). Multilevel local search algorithms for modularity clustering. *Journal of Experimental Algorithmics (JEA)*, *16*, 2-3.

Rousseau, R., Egghe, L., & Guns, R. (2018). *Becoming metric-wise: A bibliometric guide for researchers*. Chandos Publishing.

Roy, R., Potter, S., & Yarrow, K. (2008). Designing low carbon higher education systems: Environmental impacts of campus and distance learning systems. *International Journal of Sustainability in Higher Education*, *9*(2), 116–130.

Ruhanen, L., Weiler, B., Moyle, B. D., & McLennan, C. L. J. (2015). Trends and patterns in sustainable tourism research: a 25-year bibliometric analysis. *Journal of Sustainable Tourism*, *23*(4), 517-535.

Ryan, A., Tilbury, D., Blaze Corcoran, P., Abe, O., & Nomura, K. (2010). Sustainability in higher education in the Asia-Pacific: Developments, challenges, and prospects. *International Journal of Sustainability in Higher Education*, *11*(2), 106–119.

Saadatian, O., Mat, S., Lim, C., Daneshmand, S., & Sopian, K. (2012). The birth of sustainable development. *International Journal of Energy and Environment*, *3*(6), 310-317.

Salmerón-Manzano, E., & Manzano-Agugliaro, F. (2018). The higher education sustainability through virtual laboratories: The Spanish University as case of study. *Sustainability*, *10*(11), 4040.

Salvia, A. L., Leal Filho, W., Brandli, L. L., & Griebelera, J. S. (2019). Assessing research trends related to Sustainable Development Goals: local and global issues. *Journal Clean Production, 208*, 841-849. doi.org/10.1016/j.jclepro.2018.09.242

Sam, S. (2016). The people, planet, prosperity, peace and partnership: why the sustainable development goals should matter to everyone. *Ecodate*, *30*(1), 7.

Samad, G., & Manzoor, R. (2015). Green Growth: Important Determinants. *The Singapore Economic Review*, *60*(02). doi.org/10.1142/S0217590815500149

Sánchez, M. L. L. (2012). El desarrollo de la eco-economía en España a partir del análisis de sus publicaciones y patentes. In *Congreso Nacional del Medio Ambiente*, Madrid: Fundacion CONAMA.

Sancho, R. (1990). Indicadores bibliométricos utilizados en la evaluación de la ciencia y la tecnología. Revisión bibliográfica. *Revista española de documentación científica*, *13*(3), 842.

Sanz-Casado, E. (Coord.). (2018). *Informe Iune 2018: Actividad Investigadora De Las Universidades Españolas*. Spain: IUNE. Retrieved from http://www.informes.iune.es/Informe%20IUNE%202018.pdf

Sanz-Casado E., & Moreno, C. M. (1997). Técnicas bibliométricas aplicadas a las estudios de usuarios. *Revista general de información y documentación*, *7*(2), 41.

Sanz-Casado, E. (2000). *Proyecto docente de bibliometría*. Madrid: Getafe, UC3M.

Sanz-Casado, E., Lascurain-Sánchez, M. L., Serrano-Lopez, A. E., Larsen, B., & Ingwersen, P. (2014). Production, consumption and research on solar energy: The Spanish and German case. *Renewable energy*, *68*, 733-744.

Schiermeier, Q. (2010). Green patents corralled. *Nature, 465*, *21*. doi:10.1038/465021a

Schoolman, E. D., Guest, J. S., Bush, K. F., & Bell, A. R. (2012). How interdisciplinary is sustainability research? Analyzing the structure of an emerging scientific field. *Sustainability Science*, *7*(1), 67-80.

Shapira, P., & Wang, J. (2010). Follow the money. *Nature*, *468*(7324), 627.

Shriberg, M. (2002). Institutional assessment tools for sustainability in higher education: strengths, weaknesses, and implications for practice and theory. *Higher education policy*, *15*(2), 153-167.

Sibbel, A. (2009). Pathways towards sustainability through higher education. International *Journal of Sustainability in Higher Education*, *10*(1), 68–82. doi: 10.1108/14676370910925262.

Sosik, J. J., & Jung, D. (2018). *Full range leadership development: Pathways for people, profit, and planet*. Abringdon: Routledge.

Spangenberg, J. (2011). Sustainability science: A review, an analysis and some empirical lessons. *Environmental Conservation*, 38(3), 275-287. doi: 10.1017/S0376892911000270

Spanish Government (2019). *Plan de Implementación para la Agenda 2030. Hacía una estrategia española de desarrollo sostenible*. Retrieved from http://www.exteriores.gob.es/Portal/es/SalaDePrensa/Multimedia/Publicaciones/Documents/PLAN%20DE%20ACCION%20PARA%20LA%20IMPLEMENTACION%20DE%20LA%20AGENDA%202030.pdf

Steer, A., & Wade-Gery, W. (1993). Sustainable development: Theory and practice for a sustainable future. *Sustainable development*, *1*(3), 23-35.

Stifstung & Sustainable Develoment Solutions Network – SDSN. (2019). *Sustainable development report 2019. Transformations to achieve the Sustainable Development Goals. Includes the SDG Index and Dashboards*. Retrieved from https://s3.amazonaws.com/sustainabledevelopment.report/2019/2019_sustainable_development_report.pdf

Stifstung and Sustainable Develoment Solutions Network – SDSN. (2018). *SDG Index and Dashboards Report 2018*. Bertelsmann Stiftung and Sustainable Development Solutions Network

Sugimoto, C. R., & Larivière, V. (2018). Measuring research: what everyone needs to know. Oxônia: Oxford University Press.

Suwartha, N., & Sari, R. F. (2013). Evaluating UI GreenMetric as a tool to support green universities development: Assessment of the year 2011 ranking. *Journal of Cleaner Production*, *61*, 46–53.

Tang, M., Liao, H., Wan, Z., Herrera-Viedma, E., & Rosen, M. (2018). Ten years of sustainability (2009 to 2018): A bibliometric overview. *Sustainability*, *10*(5), 1655.

Thelwall, M. (2008). Bibliometrics to webometrics. *Journal of Information Science*, *34*(4), 605–621. doi.org/10.1177/0165551507087238

Thomson Reuters (2008). Web of Science (WoS). Filadélfia. Retrieved from https://login.webofknowledge.com/error/Error?Error=IPError&PathInfo=%2F&RouterURL=https%3A%2F%2Fwww.webofknowledge.com%2F&Domain=.webofknowledge.com&Src=IP&Alias=WOK5

Todeschini, R., & Baccini, A. (2016). Handbook of bibliometric indicators: quantitative tools for studying and evaluating research. Toronto: John Wiley & Sons.

Tollefson, J. (2018). China declared world"s largest producer of scientific articles. *Nature*, *553*(7689), 390–390. https://doi.org/10.1038/d41586-018-00927-4

Tollefson, J. (2018). China declared largest source of research articles. *Nature*, *553*, 390.

United Nations Educational, Scientific and Cultural Organization. (2017). Education for *Sustainable Development Goals - Learning* Objectives. Genebra: Unesco.

United Nations (1973). Report of the United Nations Conference on the Human Environment, *Stockholm*, 5-16.

United Nations (1987). *Our common future: Report of the 1987 world commission on environment and development.* Oslo: United Nations.

United Nations (2016*). The Sustainable Development Goals Report, 2016*. Retrieved from https://unstats.un.org/sdgs/report/2016/The%20Sustainable%20Development%20Goals%20Report%202016.pdf.

United Nations Environment Programme. (2002). UNEP Annual Report for 2002. Nairóbi: UNEP.

United Nations. (2015a). *Transforming Our World: The 2030 Agenda for Sustainable Development (A/RES/70/1).* Retrieved from https://undocs.org/A/RES/70/1

United Nations- ESCAP (2015b) "Average Growth Rate: Computation Methods", *Stats Brief*, 7, 1–4. Retrieved from https://www.unescap.org/resources/stats-brief-april-2015-issue-no-07-average-growth-rate-computation-methods> accessed 13 September 2019.

United Nations (2019). *SDGs description*. Retrieved from https://www.un.org/sustainabledevelopment/

Van Eck, N., & Waltman, L. (2009). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, *84*(2), 523-538.

Van Raan, A. (1996). Advanced bibliometric methods as quantitative core of peer review based evaluation and foresight exercises. *Scientometrics*, *36*(3), 397-420.

Veiga Ávila, L., Rossato Facco, A. L., Bento, M. H. dos S., Arigony, M. M., Obregon, S. L., & Trevisan, M. (2018). Sustainability and education for sustainability: An analysis of publications from the last decade. *Environmental Quality Management*, *27*(3), 107–118. doi.org/10.1002/tqem.21537

Velazquez, L., Munguia, N., & Sanchez, M. (2005). Deterring sustainability in higher education institutions: An appraisal of the factors which influence sustainability in higher education institutions. *International Journal of Sustainability in Higher Education*, *6*(4), 383–391.

Velazquez, L., Munguia, N., Platt, A., & Taddei, J. (2006). Sustainable university: what can be the matter? *Journal of Cleaner Production*, *14*(9–11), 810–819. doi.org/10.1016/j.jclepro.2005.12.008

Vinkler, P. (1988). An attempt of surveying and classifying bibliometric indicators for scientometric purposes. *Scientometrics*, *13*(5-6), 239-259.

Vinkler, P. (2001). An attempt for defining some basic categories of scientometrics and classifying the indicators of evaluative scientometrics. *Scientometrics*, *50*(3), 539-544.

Waas, T., Verbruggen, A., & Wright, T. (2010). University research for sustainable development: Definition and characteristics explored. *Journal of Cleaner Production*, *18*(7), 629–636.

Wals, A. E. (2014). Sustainability in higher education in the context of the UN DESD: A review of learning and institutionalization processes. *Journal of Cleaner Production*, *62*, 8–15.

Waltman, L., & Van Eck, N. J. (2012). A new methodology for constructing a publication-level classification system of science. *Journal of the American Society for Information Science and Technology*, *63*(12), 2378-2392.

Wickham, H. (2016). ggplot2: Elegant Graphics for Data Analysis. New York: Springer-Verlag.

Wiek, A., Farioli, F., Fukushi, K., & Yarime, M. (2012). Sustainability science: bridging the gap between science and society. *Sustainability Science*, *7*(1), 1-4.

Wilsdon, J., Allen, L., Belfiore, E., Campbell, P., Curry, S., Hill, S., et al. (2015). *The metric tide: report of the independent review of the role of metrics in research assessment and management*. doi:10.13140/RG.2.1.4929.1363.

Wilsdon, J. R., Allen, L., Belfiore, E., Campbell, P., Curry, S., Hill, S., ... & Tinkler, J. (2015). The metric tide: Report of the independent review of the role of metrics in research assessment and management. doi: 10.13140/RG.2.1.4929.1363

Wilson, C. S. (1995). The formation of subject literature collection for bibliometric analysis: the case of the topic of Bradford"s Law of Scattering (Doctoral dissertation), University of New South Wales, Sydney, Australia.

Wilson, C. S. (2001), Informetrics. In: M. E. Williams (Ed.), *Annual Review of Information Science and Technology*, (Vol.34, pp. 3-143), Medford, NJ: Information Today, Inc. for the American Society for Information Science.

World Health Organization. (2016). *World health statistics 2016: monitoring health for the SDGs sustainable development goals*. Genebra: World Health Organization.

World Intellectual Property Organization – WIPO. (2016). "*IPC Green Inventory*". Retrieved from http://www.wipo.int/classifications/ipc/en/est/index.html

Wouters, P., Zahedi, Z., & Costas, R. (2019). Social media metrics for new research evaluation. In W. Glänzel, H. F. Moed, U. Schmoch, & M. Thelwall (Eds.), Springer Handbook of Science and Technology Indicators. Springer (pp. 687–713). Springer Handbooks. Retrieved from http://arxiv.org/abs/1806.10541

Wright, T. S. A. (2002). Definitions and frameworks for environmental sustainability in higher education. *International Journal of Sustainability in Higher Education*, *3*(3), 203–220. doi.org/10.1108/14676370210434679

Wuelser, G., & Pohl, C. (2016). How researchers frame scientific contributions to sustainable development: A typology based on grounded theory. *Sustainability science*, *11*(5), 789-800.

Yan, E., Wu, C., & Song, M. (2018). The funding factor: a cross-disciplinary examination of the association between research funding and citation impact. *Scientometrics*, *115*(1), 369-384.

Yarime, M., Takeda, Y., & Kajikawa, Y. (2010). Towards institutional analysis of sustainability science: a quantitative examination of the patterns of research collaboration. *Sustainability Science*, *5*(1), 115.

Young, H., Belanger, T., Corbin J. B., Magrill, R. M., Peterson, F. M., Thomas, D., Torok, A., & Wools, B. (1983). The ALA glossary of library and information science. Atlanda: Ediciones Diaz de Santos.

Zahedi, Z. (2018). *Understanding the value of social media metrics for research evaluation* (Doctoral dissertation). Universiteit Leiden, Leiden.

Zhao, D. (2010). Characteristics and impact of grant-funded research: A case study of the library and information science field. Scientometrics, 84(2), 293–306. doi: 10.1007/s11192-010-0191-y.

Zhou, W., Kou, A., Chen, J., & Ding, B. (2018). A retrospective analysis with bibliometric of energy security in 2000–2017. *Energy Reports*, *4*, 724–732. doi.org/10.1016/j.egyr.2018.10.012

Zhu, J., & Hua, W. (2016). Visualizing the knowledge domain of sustainable development research between 1987 and 2015: a bibliometric analysis. *Scientometrics*, *110*(2), 1–22. https://doi.org/10.1007/s11192-016-2187-8

Ziman, J (1968). *Public knowledge: The social dimension of science*. Cambridge, UK: Cambridge University Press.

Zimmerman, J. B. (2005). EPA"s P3 - People, Prosperity, and Planet - Award. *Sustainability: Science, Practice and Policy*, *1*(2), 32–33. doi.org/10.1080/15487733.2005.11907971

Zipf George, K. (1936). The psycho-biology of language: An introduction to dynamic philology. *American Anthropologist,* *38*(3), 505-506. doi.org/10.1525/aa.1936.38.3.02a00270

Zipp, L. S. (2011). Core serial titles in an interdisciplinary field: the case of environmental geology. *Library Resources & Technical Services*, *43*(1), 28-36.

Zitt, M., & Bassecoulard, E. (2006). Delineating complex scientific fields by an hybrid lexical-citation method: An application to nanosciences. *Information processing & management*, *42*(6), 1513-1531.

Zorio-Grima, A., Sierra-García, L., & Garcia-Benau, M. A. (2018). Sustainability reporting experience by universities: A causal configuration approach. *International Journal of Sustainability in Higher Education*, *19*(2), 337–352.

Appendix

- SDGs Glossary (Available at the following repository).
  Bautista, Nuria (2019): SDG ontology. figshare. Dataset.
  https://doi.org/10.6084/m9.figshare.11106113.v1