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What do we talk about when we talk about Social-Ecological Systems? A literature review

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1. Abstract

In the last decade, probably in response to global changes and environmental crisis, the use of the term "social-ecological system" (SES) in the scientific literature has been growing. This is certainly a sign of the recognition of the need and importance of transdisciplinary research. Here, we explore whether the use of the term is a buzzword, or it actually represents a key concept toward the integration of social and ecological research. We compiled a data base of publications (N=1289) that mentioned SES in title, keywords and abstract. Subsequently, we analyzed: authors affiliations, type of work (conceptual, empirical, review), study site, prevailing human use, temporal and spatial scales of analysis, kind of variables analyzed (socioeconomic, biophysical), and the method/s used to integrate them. We detected four time spans in the use of the term (1975-1997, 1998-2006, 2007-2012, 2013-2016). Our results suggest that SES is a widely invoked concept to study the interface between social and ecological systems. Most works show some common elements such as the analysis of resilience, ecosystem services, sustainability, governance and adaptive management. However, the majority of studies does not study SES as a whole, integrating both social and ecological variables and their feedback loops. We consider that SES is still a concept in construction in order to build a necessary framework to integrate social and ecological sciences. For a robust evolution we recommend to focus on 1. a conscious, discussed

and agreed effort of scientists to conduct transdisciplinary research needed to study SES; 2. developing methodological tools for the true integration of social and ecological data.

Keywords

Adaptation, Complex Adaptative Systems, Ecosystem Services, Governance, Resilience, Sustainability, Transdisciplinary

2. Introduction

The widespread and profound, wanted or not, changes observed around the Earth have prompted the recognition that there is an urgent need to understand the ways in which humans affect and are affected by nature. It has become essential to work in the complex interface of ecological and social systems, which is where policies of land uses are developed [1, 2]. However, the fact that the proportion of pristine ecosystems is minor and most of our ecological understanding derive from conservation areas - national parks and other- is a constraint for truly appreciate the complexity of our living ground [3]. There is indeed an increasing consensus that many of the complex issues worldwide regarding environmental crisis require management under the framework of sustainable development, as has been expressed into the Sustainable Development Goals [4]. In turn, this involves integrating the social and natural sciences and there is a growing agreement about transdisciplinary research as a key tool to face environmental challenges. Hence, there is a need to expand the boundaries of the land –related resource systems and the focus of study. These modifications mean changing the study object towards social-ecological systems.

The terms “socio-ecological system”, “socio-ecosystem” or “social-ecological system”, from now on SES, are used as synonyms and have emerged to address this complexity and integrate the social and ecological sciences. It is an anthropocentric concept appeared in the Anthropocene context of global change. The theoretical formalization of the concept has triggered the research and literature around SES [4, 5, 6, 7, 8, 9, 10, 11, among others]. Nowadays those terms are widely used in environmental sciences. However, as with many other complex concepts associated to terms that have become fashionable buzzwords in the history of environmental sciences (e.g. biodiversity, resilience, governance, sustainability), there is a risk of these important concepts falling

into confusion or banalization [12, 13, 14], by emptying them of a clear significance. Although the concept is not rigid [10] and there are different approaches and perspectives to understand it [15, 16], it can also be used as a commonplace term just because it is on trend. In fact, several authors do not believe that there is the need of coining this new concept, as by considering humans as part of nature, ecosystems already include social systems [17].

SES, as complex adaptive systems, possess emergent properties [18, 19], being resilience, or the system's ability to continue to function when intrinsic and extrinsic disturbances occur, one of the most important [4, 19]. SES constitute co-evolving systems in which territorial and socioeconomic structures maintain constant and reciprocal interactions [4, 20]. The biophysical-cultural coevolution in which agriculture has risen is a clear example of this. The emergent properties that are susceptible to identification and analysis depend on the social and ecological nature of the variables considered, their scale and the study methods used. However, cultural and ecological processes operate at different spatial and temporal scales, thus being difficult to find appropriate methodologies to measure and combine both types of variables at a meaningful appropriate scale [21, 22].

The aim of this systematic literature review is to analyze what has been considered and published under the term of SES since it first appeared. Specifically, the type of work where SES are considered, where and by whom, under which kind of management, the type of variables analyzed, the temporal and spatial scales and the methodology used. Drawing on the results we address the main landmarks on the history of SES and discuss some major points derived from the analysis of the data specially related to the asymmetries that might be identified. These potential unbalances refer to issues such as: theory vs. empirical evidence, biophysical vs. socioeconomic and cultural variables, agricultural intensification vs. urban expansion, and SES in developing countries vs. SES in developed countries. Based on the results we elaborate some recommendations for the use of the term and promotion of the concept. We believe the results of this review will be useful to define the state of the art, identify gaps of knowledge and address future research lines.

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3. Methods

In December 2017 we conducted a review in Scopus searching in title, keywords and abstract for the terms “socio-ecosystem”, “social-ecological system”, “socio-ecological system” and their Spanish translations, excluding those related to the areas of biomedicine, business, mathematics and physics. We used Scopus as the main database but also explored the trajectories of researchers and research groups using Google scholar.

The search threw 1,289 studies corresponding to a period of 43 years. Based on differences in the number of published articles and their fit to regression equations (R^2>0.7), we detected time spans in the use of the term. We analyzed 990 studies selected through a stratified sampling design, according to the different time spans detected (approximately 70% in each period). We deleted studies of year 2017 because of the time-lagged response of publication process.

From each study we looked for information related to the characteristics of the publication, the importance given to the term, the management system studied, the scale of analysis, the variables analyzed and the analytical procedures (Table 1). We assessed the importance given to the term by looking into each study whether the authors defined the term and/or cited previous definitions. We built a data matrix that was analysed by means of descriptive statistics, mainly measures of frequency, using R 3.4.2 [23].

We characterized each country by its Gross National Income per capita (GNI, reported in US$; https://data.worldbank.org/indicator), and used Social network analysis (SNA) to analyze the relationships between the funding country of the research (nodes; units of the network) and the country where the study area was located (edges, links or interactions between nodes). The intensity of this relationship (thickness of the links) is represented by the by the number of papers that share the same link. These concepts are displayed in a social network diagram, where nodes are the points and edges are the lines. We used package networkD3 from R [24].

4. Results

Based on the change in the slope of the linear fitting equations and the results of the mean comparison test, it was possible to differentiate four different time spans in the use of the term: 1975-1997, 1998-2006, 2007-2012, 2013-2016, with an increasing rate

of published papers per year (Fig. 1). The number of papers published in each period was significantly different from the number of papers published in the other periods identified (F-test, $p<0.05$).

Throughout these periods, a total of 1,059 organizations were represented, although only a few of them could be considered as SES-specialist, having led as first institution at least five papers on this topic. For example, the Stockholm Resilience Center led as first institution with 32 papers, followed by the Natural Resource Institute of Manitoba and the Arizona State University with 13 and 10 papers, respectively (Fig. 2a).

The great majority of SES studies corresponded to research articles in the domain of environmental sciences (60%), followed by social sciences (25%) and agricultural and biological sciences (15%) (Fig. 2b). 62% of these studies were conducted by researchers whose origin was in the natural sciences, while 30% had its origin in the social sciences.

The ten most frequently used keywords, associated with SES, were resilience, ecosystem services, sustainability, governance, adaptation, vulnerability, adaptive management, climate change, adaptive capacity and institutions (Fig. 2c). Only 4% of publications mentioned SES in the keywords without studying it explicitly. With regard to defining the term, 16% of papers analyzed included a general definition of SES, whereas 29% cited someone as a reference for it.

Empirical studies represented a majority (42%). These studies generated and analyzed data of concrete study systems and were followed by conceptual papers (34%) and reviews or meta-analysis (21%) of different topics related to SES. From the conceptual papers, 20% described some kind of model to analyze SES behavior in space and/or time (Fig. 2d). The main spatial scale of analysis at which SES were studied was local (53%), followed by regional (38%) and global (9%). Most temporal scales were in the range of 1-3 years, although there were several studies in the range of 30-100 years.

In empirical studies, the “type of management” mostly analyzed related to productive activities, mainly fishery and agriculture (Fig. 3a). The variables most frequently recorded in empirical studies were of the socioeconomic type (91%), almost doubling in importance studies that reported on biophysical variables (52%). In each type, variables coming from interviews at local scale (32%, Fig. 3 b) and mapping and remote sensing analysis at regional scale (36%, Fig. 3 c), were the most frequently reported. Only 43%

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of empirical studies gathered field data of both biophysical and socioeconomic variables, and half of these used some quantitative method to integrate both types of variables. The most frequent combining methods were mainly related to geographic information techniques, quantitative models, and multivariate analyses. The average inter-annual increase in the use of socioeconomic variables was 1.26 times higher than the increase in the use of biophysical ones, and 2.58 times higher than the increase in methods integrating both types of variables (Fig. 4).

A majority (53%) of the studies reporting on "place of study" were located in countries of the Global North. However, 60% of studies that were conducted in countries of the Global South, were leaded by organizations of the Global North (Fig. 5).

5. Discussion

5.1. Evolution of the term

The temporal dynamics of the publication rate at four different consecutive and overlapping phases (Fig. 1), can be explained by some key works and actions. The term "social-ecological system" was first published by Crook *et al.* (1976) and Emory and Harris (1981) in the context of animal behavior, and followed by Goldberg (1985), who studied some of the coping strategies of "human-centered socioecological systems" [25, 26, 27]. In this period, there was not a common understanding of what SES meant, but researchers used the term to refer to social-ecological relationships, when they understood that what they intended to study was not embraced by the concept of ecosystem. Berkes and Folke (1998) started to use the concept of SES as an integrated approach of "humans-in-nature", linking it to the concept of resilience and emphasizing the biophysical limits of nature [5]. Concurrently, Simon Levin (1998) used Holland's concept of complex adaptive systems to describe SES as non-hierarchical and dynamic systems [6]. The concept was further developed when Berkes and collaborators (2003) schematized its multi-scalar and nested properties [7]. This formalization of the term and the foundation of the Resilience Alliance (RA) in 1999, probably triggered the "second phase" of SES history, from 1999-2006, where the number of publications using SES started to grow, linked to the concept of complex adaptive systems (mean rate = 4.06).

In 2007 the Stockholm Resilience Centre (SRC) was funded, embracing the concepts of resilience and SES jointly [28]. Since then, the number of publications grew at a faster rate (mean rate =18.23), and used the term more consistently. In this phase, SES were usually related to socio-ecological resilience, understood as "the capacity to adapt or transform in the face of change in social-ecological systems, particularly unexpected change, in ways that continue to support human well-being" [28]. Associated to the recently created SRC, Ostrom and collaborators proposed a general framework to analyze SES, where they defined the variables that were to be measured in each SES subsystem in order to study it [9]. Concurrently, Glaser and collaborators proposed a working definition of the concept of SES, that included governance systems: "a social-ecological system consists of a bio-geo-physical unit and its associated social actors and institutions" [29]. In 2013, the SRC incorporated the term SES to the program of Sustainable Development Goals (SDG), and this probably prompted the "fourth phase" (mean rate = 20.60) in the use of SES, from 2012 onwards, where the number of publications significantly increased. In this fourth phase, the term was linked to governance systems and noteworthy, the socioeconomic variables recorded were relatively more abundant than the biophysical ones (Figs. 1 and 4). This is probably related to the fact that the majority of these publications focused on land management and decision making.

5.2. The matter of SES: what, who, how and where?

Half of all publications referred to empirical studies that generated and analyzed, either primary data obtained in the field, or secondary data. The rest of publications were conceptual studies that may or not propose a model, or were based on reviews and descriptions. Empirical studies mostly incorporated socioeconomic variables through semi-structured interviews, particularly in the fourth phase (from 2012 onwards, Fig. 4). This is probably related to the fact that the incorporation of SES to SDGs implied decision making and management issues that were mostly accomplished with socioeconomic information. However, it is remarkable that these efforts, mostly published in journals of environmental sciences, were typically made by researchers from institutions linked since its origin to the natural sciences. This suggests a greater research motivation of natural scientists towards studies on SES, that is not mirrored by institutions rooted in social sciences. However, there is an implicit risk of simplifying the social complexity of SES by incorporating just a few socioeconomic variables by

researchers with insufficient background on social sciences. Anyhow, this reflects an answer to the urgent need to change the working system, from natural ecosystems to the interface of ecological and social systems [3, 30] accompanying the emergence of the new science of sustainability [4].

But ironically, parallel to this turn of natural scientists to work with socioeconomic data, there were comparatively few studies that analyzed biophysical variables and the ones that did so, mostly based them on landscape and remote sensing analysis at regional scales. The study of SES is typically related to the study of Ecosystem Services, however, evidence suggests that the biophysical functions of Ecosystem Services are progressively being neglected. This result supports the need of incorporating biophysical information in the study of SES [31, 32] and reflects the challenge of acquiring datasets measured at fine resolution. Indeed, the spatial scale at which studies were conducted was mostly local, probably oriented to analyze any specific kind of management, and secondly, regional, mainly oriented to governance studies. These evidences suggest that there is a gap between theoretical developments and empirical information able to provide effective integration between social and biophysical data.

The different spatial and temporal scales at which sociological and ecological processes operate make it difficult to find appropriate methodologies to combine both types of variables at their meaningful scale and study SES, aiming to extract their emerging properties [21, 33, 34, 35]. To avoid scale-driven mismatches between these different sources of data and to generate sound inferences, data must be assembled into a single and comparable scale [36], [37] (pp: 23-40), which is not a trivial challenge. In fact, although around 40% of empirical studies reported both biophysical and sociological variables, only the half tried to develop tools to integrate both sets of variables. These efforts were mainly accomplished using Geographic Information Systems, multivariate analysis, and mathematical models, such as multiple regression analysis [20, 38-40] or Bayesian networks [41-43]. Thus, there is room for developing SES studies by using analyses that combine both sets of variables at different spatial and temporal scale. Social-ecological network approaches are a promising tool for social-ecological analysis [44]. Some applications include the role of social networks in natural resource management [45], the spatial organization of biological populations in fragmented landscapes [46], scale mismatches and the value of social networks [47] and networks which consider ecological sites that are interconnected by a mobile livelihood strategy

such as transhumant pastoralism [48]. Canonical correspondence analyses are also a promising tool to jointly analyze social and ecological structures [49, 50]. In a complementary fashion it is important to develop a conceptual discussion among disciplines involved in SES study. Social research must engage in biophysical analysis as well as the reverse, but embracing all profoundness and theoretical background of both social and natural sciences.

Regarding the management system studied, as expected most of studies referred to productive activities, mainly fishery and agriculture. While agriculture is the human activity that occupies most land surface of the Earth, together with rangelands [3], fishery is the only productive activity based on a wild resource, which implies such a volume of market and population. Additionally, fisheries tend to suffer from the tragedy of the commons at the country level [51]. Alerting on over-fishing may be a geopolitical strategy to control fisheries in non-territorial waters as risking such a resource would produce enormous impact on societies and economy at a world level. Therefore, it could have been this imminent risk and catastrophic consequences on societies, the reason to trigger the joint study of societies and ecosystems under the term of social-ecological systems. In fact, it is in the coastal areas where the experiences and theory of "integrated management", that imply considering variables of different disciplines, have had more development. Something similar has happened with the "integrated watershed management" [52]. In contrast, despite the recognized importance of urban ecology and "novel ecosystems" [53, 54], comparatively few studies on SES analyzed management activities typically related to urban or suburban areas, such as urbanization, tourism or waste production (but see [55-60]). Analysis of rural-urban gradients under a SES perspective is also an understudied but promising field [49]. Also, whereas warfare affects a large portion of ecosystems often with profound changes [61], very few studies implicitly considered this factor in their analysis (but see [62]).

Finally, studies on SES are equally represented in countries with high and low GNI, contrary to what Martin *et al.* (2012) found when mapping where ecologist worked (Fig. 5) [3]. This can reveal a hidden perception of a linkage of SES to rurality, traditional practices, conflictive socioeconomic scenarios and other issues related to developing countries. However, the fact that most of studies conducted in the Global South come from organizations affiliated to the Global North dilutes the possibility that they can affect policies. With this aim research practice must incorporate a clear awareness on

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the fact that theory and practice come from systems that are placed within some specific cultural context.

5.3. A concept in transition

Results from this study suggest that on the whole, the term SES is not a buzzword empty of significance. On the contrary, the concept is being shaped progressively using inputs from different key works on the matter, and nowadays the majority of publications using this term, study the SES system explicitly as explained in section 5.2. Indeed, the fourth phase reflects what Folke (2016) describes as SES towards sustainability for human well-being [28].

However, the lack of a common use of the term also reflects that the term "social-ecological system" is not yet a clearly defined concept, accepted by all scholars. Instead, it is still a concept under construction that is integrating many currents of thought originated from different disciplines. Despite of the lack of a general definition, results of this study show some common elements in most works dealing with SES. Such common elements that are evidenced through shared keywords are among others, resilience, ecosystem services, sustainability, governance, adaptation, vulnerability, adaptive management and climate change. These standard elements can help building a shared definition of SES. They mostly refer to system' emergent properties and conceptualizations of key features aimed at fostering sustainability pathways. However, the frequency of keywords referring to social problems such as poverty, inequality, land grabbing, resource access conflicts, corruption and even warfare, is comparatively smaller [63]. This situation may be driven by the registered less participation of social scientists or by the dominant research interests highlighting resilience and adaptation as core properties for the future, rather than a critique position on current complementary social problems structuring social-ecological challenges.

Finally, the articulation of well documented frameworks, can build bridges in terms of communication and language among scientific disciplines [64]. For example, frameworks that have originated from different research arenas such as the State-and-Transition Model, rooted in resilience approach and natural sciences [65], and the sustainable livelihoods approach, rooted in vulnerability approach and social sciences [66], can provide a conceptual basis for theory and operative integration [67]. Similar examples are the search for a more integrated use of sustainability and resilience

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317 concepts in an environmental management context [68, 69], as well as resilience and
318 vulnerability [70].

319 *5.4. Recommendations for the future*

320 The SES oriented research has inspired advances in sustainability science and practice
321 [10]. Based on results from this study we identify six issues that we think need to be
322 addressed in order to consolidate the study of SES throughout the world and foster
323 progress towards sustainable development. They complement those priorities
324 highlighted by Fischer *et al.* (2015) and insist in some observations made previously by
325 other authors [31, 32].

326 1. A shared definition of social-ecological system would be desirable to
327 consolidate the concept in the context of the emerging science of sustainability.

328 2. Social scientists should collaborate with biophysical scientists as well as the
329 reverse, to achieve a true transdisciplinary approach to study SES.

330 3. Biophysical data based on field sampling at meaningful scales must not be
331 forgotten in the study of SES to provide scientific foundations for Ecosystem
332 Services.

333 4. Methods to integrate social and biophysical data at a sufficiently fine resolution
334 and prone to be comparable to different scales must be developed.

335 5. More emphasis should be made in the study of SES in management activities
336 typical of urban and suburban areas, as well as considering the study of SES
337 under warfare and social conflict scenarios

338 6. Care must be taken so that research practice in developing countries is
339 participative and incorporates a clear awareness on the fact that theory and
340 practice come from systems that are placed within some specific cultural
341 context.

342 **6. References**

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Table 1. List of variables considered in each study and the corresponding attributes

Variables	Attributes	Objectives
Publication characteristics		Description
Type of publication	Empirical, Theoretical, Modeling, Review	
Year of publication		
Organization of the first author	Origin in natural or social sciences	
Country's Gross National Income (2018)		
Subject area of publication	Environmental, biological or social sciences	
Importance given to the term		Assessing the importance given to the SES term
Location of the term	Title, abstract, keywords	
Definition of the term	Yes, no	
Characteristics of the system studied		
Location of the study area	Countries, places of study inside countries	
Country's Gross National Income (2018)		Social Network Analysis showing relationships between origin and site of study of publications
Main management/ focus of publication	Fishery, agriculture, conservation, cattle ranching, urbanization, forestry, tourism, agro-silvo-pastoral, hunting, restoration, mining	Description of the management system studied
Scale of analysis		Temporal and spatial scales at which the studies are conducted
Temporal scale	Days, months, years, centuries	
Spatial scale	Local, regional, global	
Variables analyzed		Type of variables mostly analysed
Biophysical	Climate variables, landscape, abiotic factors, census, samples/lab analyses	
Socioeconomic	Socioeconomic indicators, workshops, participant observation, interviews, previous surveys	
Analytical procedures		Methods used to combine different type of variables
Analysis of both biophysical and socioeconomic variables	Yes, no	
Methods used to combine both variables	Models, Multivariate analysis, GIS	

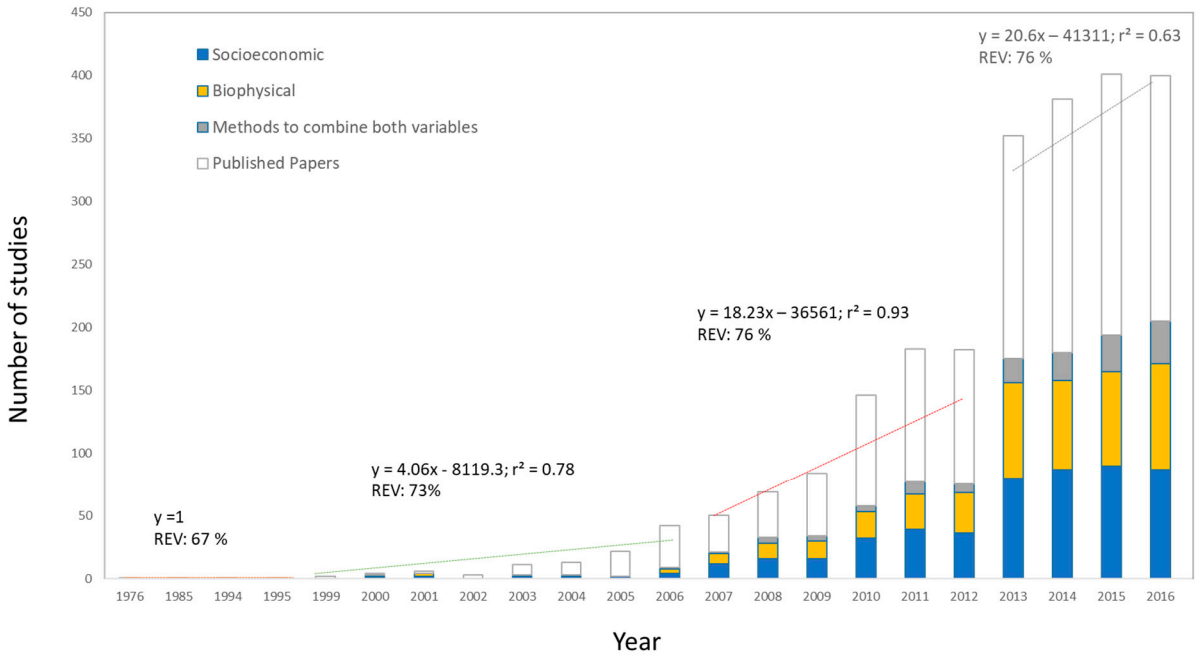

Figure 1. Evolution of publications containing the term SES in title, abstract or keywords. White bars represent the total number of publications and colored bars, the number of publications analyzed. Dashed lines adjust the different periods detected. It is shown the regression equation, the coefficient of determination (r^2) and the percentage of publications analyzed in each period (REV). Different colors refer to the number of publications using biophysical (blue) or socioeconomic (yellow) variables and some method used to combine both type of variables (grey).

a) Organizations leading at least 5 SES publications

b) Subject area of publication

c) The first 10 mostly used keywords

d) Type of study

Figure 2. Percentage of studies belonging to different publication characteristic's categories.

a) Management system

b) Socioeconomic variables

c) Biophysical variables

Figure 3. Characteristics of empirical studies addressing SES

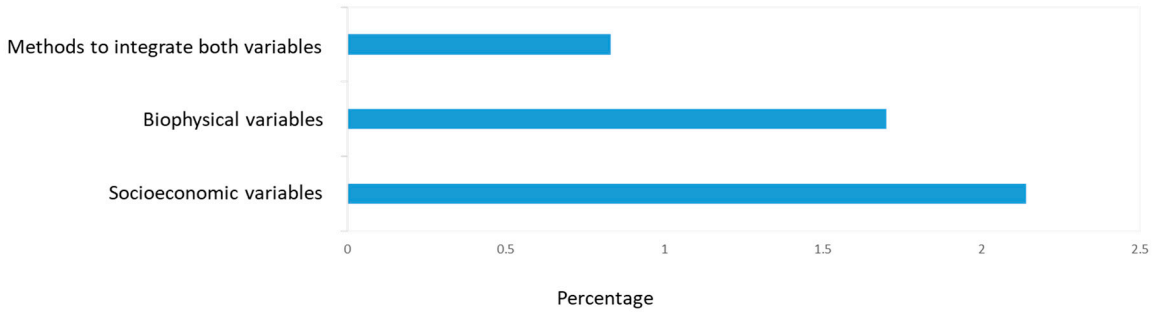

Figure 4. Average interannual variation of studies analyzing socioeconomic or biophysical variables, or integrating both types of variables in relation to the total number of papers reviewed each year between 1976 and 2016

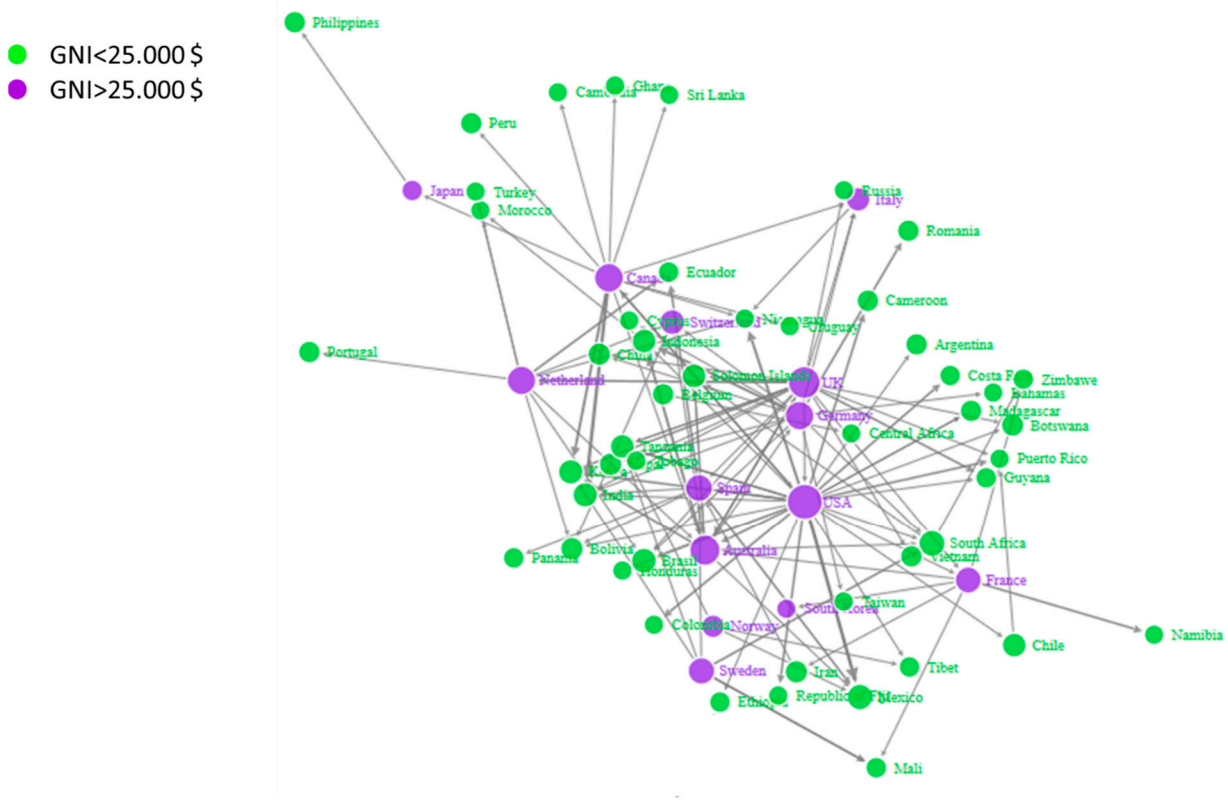

Figure 5. Social Network Analysis showing the relationship between the funding country of the research (nodes) and the country where the study area is located (edges). The number of papers that share the same relationship is represented by the thickness of the links. Countries of the Global South (Gross National Income <25000 US$) are represented in green and countries of the Global North (GNI > 25000 US$), in blue