Conceptual integration for social-ecological systems

an ontological approach

Greta Adamo[0000−0001−8108−2383] and Max Willis[0000−0001−9718−4966]

ITI/LARSyS, Caminho da Penteada, 9020-105 Funchal, Madeira, Portugal
{greta.adamo,max.willis}@iti.larsys.pt

This version of the contribution has been accepted for publication, after peer review but is not the Version of Record and does not reflect post-acceptance improvements, or any corrections. The Version of Record is available online at: https://doi.org/10.1007/978-3-031-05760-1_19. Use of this Accepted Version is subject to the publisher's Accepted Manuscript terms of use https://www.springernature.com/gp/open-research/policies/accepted-manuscript-terms.

Link to the published version: https://link.springer.com/chapter/10.1007/978-3-031-05760-1_19

Conceptual integration for social-ecological systems

an ontological approach

Greta Adamo[0000−0001−8108−2383] and Max Willis[0000−0001−9718−4966]

ITI/LARSyS, Caminho da Penteada, 9020-105 Funchal, Madeira, Portugal
{greta.adamo,max.willis}@iti.larsys.pt

Abstract. Sustainability research and policy rely on complex data that couples social and ecological systems (SESs) to draw results and make decisions, therefore understanding the dynamics between human society and natural ecosystems is crucial to tackle sustainability goals. SESs frameworks are employed to establish a common vocabulary that facilitates the identification of variables and the comparison of results. A variety of SESs approaches have been proposed and explored, however integration and interoperability between frameworks is missing, which results in a loss of relevant information. In addition, SESs frameworks often lack semantic clarity which exacerbates difficulties in developing a unified perspective. In this paper we demonstrate the use of ontological analysis to unify the main elements of two prominent SESs paradigms, the social-ecological system framework (SESF) and the Ecosystem Services (ESs) approach, to build an *integrated social-ecological perspectives* framework. The proposed conceptual framework can be adopted to combine existent and future results from the two paradigms in unified databases and to develop broader explanatory and decision-making tools for SESs and sustainability research.

Keywords: Ontological analysis · Social-ecological system framework · Ecosystem Services.

1 Introduction

Analysing the relationships between the natural environment and human societies is at the core social-ecological systems (SESs) research [16]. One of the main motivation behind SESs is to build a knowledge-base useful to create a shared understanding of environmental and societal feedback and impacts [10,16]. SESs are often grounded on conceptual frameworks that support the identification of key elements and their interactions [11,34]. Two widely adopted SESs approaches are the Ecosystem Services (ESs) [6] that reflects on the natural world as support of human well-being, and the social-ecological system framework (SEFS) [39,41] that aims at specifying a common language dedicated to human-nature dynamics. Both ESs and SESF are supported by conceptual representations of the system inter-linkages, the former is often associated with the *cascade model* [33] and the latter with the framework proposed by Ostrom [41].

In the context of sustainability and sustainable development [53] SESs frameworks are crucial for planning and decision-making as they create a common vocabulary, organise knowledge, define variables, and align results. For example, climate change projections and models based on environmental data are key tools for policymakers [37] and are closely related to the understanding of SESs resilience, adaptation and robustness [3,16]. Some SESs approaches adopt maps to visualise, communicate and assess relevant ESs [15] in which the identification of indicators and the selection of datasets (i.e. environmental and social) represent important methodological steps [55]. Thus defining a clear semantics for SESs components and aligning concepts among existent theories is central to create a common ground, preserve relevant knowledge and exploit information systems to maximise the production and comparison of models and results. Despite the intense development of SESs frameworks [11] and the effort to define a shared ontology that captures social-ecological interactions and pressures [39,41], SESs are still poorly defined [16]. Inconsistencies are found within specific SESs approaches, for instance there is still a lack of a standardised vocabulary and classification in ESs, which coupled with ambiguous concept semantics can affect how practitioners use and interpret ESs notions [48]. In addition, many SESs approaches are challenging to compare and integrate due to their theoretical differences [11]; this results in a disconnect between approaches, an over proliferation of concepts and variables that might explain similar phenomena, and a lack of an unified framework that hinders clear definition of indicators in the SESs community.

In this paper we provide an integration of the main SESF and ESs notions using ontological analysis as an approach for semantic clarification.[1] Although the combination and comparison of SESF and ESs is not new in the literature, see e.g. [8,45], a comprehensive semantic analysis of SESF and ESs notions and their interlinks is still missing. We propose an *integrated social-ecological perspectives* framework, that facilitates the unification of the main SESF and ESs elements. The framework can be a tool to define and integrate concepts from both paradigms, to promote unambiguous data representation, extend the reach of SESs and sustainability analysis and potentially create tools to compare results. The paper is organised as follows: Section 2 introduces SESs, SESF and ESs states of the art. Section 3 is dedicated to the ontological clarification of SESF and ESs components and the presentation of the integrated framework. Final considerations are presented in Section 4.

2 Social-ecological systems

SESs are complex, dynamic assemblages of social (e.g., governance and norms) and ecological (e.g., ecosystem functions and species) elements. The notion of

[1] The images in this work can be found in high resolution at this link.

SESs emerged in the 1970's, but over the past 20 years SESs has became a proper interdisciplinary research field that encompasses environmental and social sciences, economics, business management, engineering, computer science and humanities with approximately 12,990 publications dated in 2019 [16].

The initial focus of SESs was on resource management to understand systems' *resilience* to impacts and disturbances [10,16]; to this end Berkes and Folke developed a SESs framework [10] that explained the links between ecological, social and economical aspects by considering *ecosystem*, *people* and *technology*, *local knowledge*, *property right* and *institution*, and their reciprocal connections and feedbacks. More recently the SESs debate has been enriched by including the notion of systems' *robustness* [3,16], defined as the capability of a system to maintain performances under pressure. The robustness of the system may be affected by several parameters, such as institutional decisions and human behaviours, and is analysed on the basis of external and internal disturbances (e.g. natural disasters and changes in demographics vs. system reconfigurations). To capture these dynamics Anderies et al. [3] propose a SESs framework that involves *resource* used by *resource users* (e.g. fisheries-fisherpeople), the collective entity of *public infrastructure providers* (e.g. public council) and *public infrastructures*, which are differentiated between physical and social capitals (e.g. canals, ports and rules). The analysis of systems' robustness encompasses all these actors and their interactions, for example understanding the dynamics between resource users and resource extraction involves several aspects from property rights to sense of collectives, participation and policy that supports the management of common-pool resources (CPR) [42], e.g. fisheries.

Over the course of its development SESs research has proposed several conceptual frameworks that allow for the capture of human-natural ecosystems relationships by adopting different perspectives, levels of analysis and granularity [11]. In the following we review two popular frameworks, SESF [39,41] and ESs [6].

2.1 Social-ecological system framework

SESF stems from the field of political science [11] and evolved from different streams of research such as collective action, CPR management, governance and community self-organisation [44]. SESF is a domain ontology that aims at creating a shared ground among scholars and experts through a vocabulary that specifies complex social-ecological interactions to organise and optimise knowledge sharing and develop a diagnostic system for SESs governance [9,39,41]. SESF includes concepts and their interactions that can be used to define variables for a wide range of case studies specific to the management of CPR, for example small-scale fisheries [9] and community-oriented systems, such as irrigation [18]. A list of SESF applications can be found in [44].

SESF has expanded over the years with refinements and extensions, however for the sake of simplicity in this paper we refer to the version proposed by McGinnis and Ostrom in [39]. The framework (see Figure 1, adapted from [39]) is organised in tiers (i.e. classes of variables) and targets a domain in which *actors* extract *resource units* that belong to a wider *resource system*. At the same time actors are also responsible for the maintenance of the resource pool based on rules defined by the *governance system*. Activities such as resource extraction and maintenance are included in *action situation* in terms of *interactions* and *outcomes* within the social-ecological system. The higher tier of the framework includes *resource systems*, *resource units*, *governance systems* and *actors*. All of these elements are involved in the *action situation* that results in reciprocal feedbacks. Finally *related ecological systems* and *social-economic-political settings* represent broader and exogenous social-ecological system settings that can pressure the system's equilibrium. The second level tiers include sub-classes of the first tier, their qualities and attributes. The full second level tiers table can be found here [39]. These variables can be adopted to assess positive and negative factors that affect self-organisation management of CPR to avoid over-exploitation [41] as well as for diagnostic processes that involve human-nature relations [9].

Despite the broad conceptual framework and range of applications, SESF presents some limitations. While data collection and analysis are becoming central to the study of SESs in conjunction with sustainable development and climate change monitoring, forecasting, environmental planning and decision-making activities, SESF remains challenging to adopt in empirical settings and in the collection of primary data. In these situations variables would need to be aligned to the data which would require a deep knowledge of the framework. This challenge is reflected also in the complexity of comparing results, data management and interoperability. Any modification of the variables list represents another issue, for although the framework is supposed to be extensible, trades-off need be considered between the introduction of new variables (e.g. bio-chemical-physical ecosystem parameters) and the maintenance of the theoretical ground of SESF. Moreover, the introduction of new domain-specific variables poses further questions, such as what precisely is a variable within SESF, how to distinguish between variables and indicators (e.g. water quality) and when to determine classification of variables and sub-variables, considering also that the definition of tier is not clearly specified [34,43,44]. These ontological challenges affect and potentially hinder the methodological setting and development of SESF and its potential applicability to sustainability studies [43,44].

Specific studies have been proposed to integrate ontological strategies and provide formal structure for SESF, manage its complexity and issues of integration and comparability [27,34]. These issues have been addressed by the Social-Ecological Systems Meta-Analysis Database (SESMAD) project [19] and the SES Library developed by the Arizona State University (ASU).[2] Despite these efforts, a clear and unified semantics for concepts and variables to facilitate comparisons among results has not been forthcoming.

[2] seslibrary.asu.edu

2.2 Ecosystem Services

Nature provides humans and societies with many essential goods and benefits, such as food, water and energy [33]. The study of human dependence on the natural environment is at the core of ESs research that focuses on the role of nature in support of human life and well-being, and the effects of human-based ecosystem pressures on health, economy, politics and more [6]. In the Millennium Ecosystem Assessment (MA) [6] ESs are grouped as *provisioning* (e.g. food, water), *regulating* (e.g. climate and disease regulation), *supporting* (e.g. soil formation) and *cultural* (e.g. educational and recreational). These ESs are linked to different aspects of human well-being, such as safety and materials for life (e.g. food, shelter). Unfortunately, research outcomes from the MA reported that 60% of ESs are over-exploited and degraded, a condition that was linked for instance to poverty, loss of biodiversity and unsustainable development [6,33].

The Economics of Ecosystems and Biodiversity (TEEB) initiative [46] focussed greater attention on the valuation of ESs as a tool for decision-making [51] that allows for quantitative assessment of the importance of nature for society and welfare, and estimation of trade-offs between the presence of human activities and the preservation of natural ecosystems in a sustainability setting [25,35]. Valuations can be performed both in monetary (e.g. market value) and non-monetary terms (e.g. measures of attitudes) [35]. The valuation of ESs is often connected to spatial characteristics, and the use of data-driven maps then becomes relevant [51] for instance to visualize the geographical spread of ESs and facilitate communication among various stakeholders. Note that ESs maps can be adopted not only for economic valuations, but also for ecological and socio-cultural assessments [15,55]. The identification, mapping, assessment and valuation of ESs represent important steps to build a more sustainable and effective environmental management. Indeed, ESs and biodiversity knowledge-bases ground decisions for environmental policies, such as the EU Biodiversity Strategy [17,55].

Despite the long tradition of studies in ESs and Ecosystem Approach [33], the development of dedicated tools (see e.g. Chapter 4.4 of [15]) and their applications at sovranational and intergovernamental levels, a unified definition of ESs and relevant associated notions is missing [47]. Without a standardised conceptual ground the unification and comparison of ESs analysis outcomes is challenging [45]. In addition there remains some confusion between core ESs concepts such as *service*, *benefit* and *value* [47,48]. However, some scholars have recognised similarities among ESs communities in terms of production and delivery of ESs; these have been summarised and represented by the cascade conceptual framework [33,47]. The cascade (see a simplified and adapted version in Figure 2 [47])[3] includes the main elements of ESs divided into two groups, the environmental and the social-economical systems, and the pressures that the latter exerts on the former. The ecological system focuses on the *structures*, *functions* and *services* of ecosystems as habitat type and composition, performed

[3] We condense the notion of ecosystem *process* with ecosystem *structure* and *function* following results reported in [48].

cycle, and ecosystem characteristics that that can be utilised for human sustenance, health and well-being. The service element plays a role of mediator in the cascade, connecting the natural ecosystem with social-economical systems. Indeed structures and functions allow the materialisation of ecosystem services that are associated to human *values*, both monetary and non-monetary, due to the *benefits* they carry and their potential affects on well-being [47]. The cascade framework serves as a conceptual foundation for the Common International Classification of Ecosystem Services (CICES) [32], a reference framework that translates several classifications systems such as MA and TEEB and related research and provides a terminological standard for the ESs community.

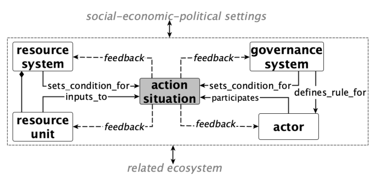

Fig. 1: SESF.

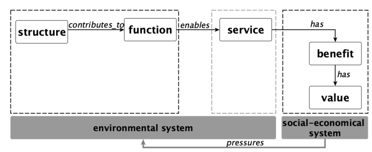

Fig. 2: ESs cascade.

3 Ontological foundations for social-ecological systems

We examine the ontological meanings of the main SESF and ESs elements and merge them into our proposed integrated framework. Some of the SESF concepts are complex, such as resource and governance systems, and first require the disambiguation of their "atomic" counterparts (e.g. resource and governance). In this writing we elucidate the following components: *resource*, *actor*, *governance*, ecosystem *structure* and *function*, ecosystem *service*, *benefit* and *value*.

The semantic clarification of the aforementioned notions follows the steps of (i) examining common-sense and literary definitions, such as consulting the Cambridge Dictionary[4] and the Lexico.com powered by Oxford[5] and field-related literature, then (ii) employing well-established foundational-, domain-, and applied ontologies research. Due to the desctiptive and conceptual nature of SESs frameworks and the purpose of this paper, in the second step we mostly reference ontological studies that are applied in the domain of information systems, such as data-, information-, and conceptual modelling. For example, we reference *Unified Foundational Ontology* (UFO) [28] and applications/extensions of *Descriptive Ontology for Linguistic and Cognitive Engineering* (DOLCE) [36] (e.g. [14,50]). UFO is widely used as a grounding for conceptual modelling and DOLCE has a natural language and cognitive approach and has been widely

[4] dictionary.cambridge.org
[5] www.lexico.com

adopted in information systems. Note that the former is based on the latter [4]. Several works that contribute to our analysis are often interrelated, e.g. the paper of Boella et al. [12] is associated with DOLCE, Bottazzi et al. [14] propose an extesion of DOLCE for organisations analysing notions such as roles and norms and Andersson at al. [4] present an ontology of value ascription useful for enterprise modelling that is based on UFO. This technique of utilising ontologies as a methodological ground for the disambiguation of concepts is described in [1].

3.1 Ontological clarification of SESs components

Resource. In the SESF literature the notion of resource traditionally refers to CPR, natural or human-made, which are subject to possible over-explotation due to the challenges involved in regulating access [42]. Examples of CPR are animals, plants and artificial constructions.

The dictionaries define resources as assets that are beneficial or valued by individuals or collectives and which contribute to their functioning.[6] This condensed definition stresses the notion of resource as a valuable entity and an asset that potentially can be used, yet the definition is still unclear due to the variety of entities considered as resources. To disambiguate the semantics of resource we start from several ontological studies in the domains of enterprise modelling, manufacturing and business process modelling that define resource as the *role* that objects plays in the context of *activities* or *plans* to achieve *goals* [2,7,24,50]. Ontologically, roles are dependent upon other objects to be existent and are often realised in contexts, for instance the mud-lined trench dug x perpendicular to a stream can play the role of an irrigation canal in the context of subsistence farming. While activities are occurents performed by actors, plans are *information objects* (e.g. a document) that describe situations or a set of activities and their organisation to achieve a certain goal [12,50]. In this way, resources can be *assigned to* activities and can be *relevant for* plans [2,50].

In SESF resources are divided into *natural* and *human-made*, the latter also referred to as *artefacts* that in contrast to natural resources are typically intentionally designed by actors to have certain characteristics on the basis of plans and goals [13]. Adopting the distinction proposed in [50], resources can be played by *physical objects*, (e.g. fishes and dams) and *amount of matters*, (e.g. sands and gold.) Physical objects and amount of matters present characteristics that determine their adoption as resources in a particular plan, for example specific benthic species may play the role of resources in certain SESF studies while in others they may not. Note that resources carry *values* associated to their characteristics whether or not that resource is actually exploited [50]. Indeed these values are dependent upon the plans and goals in which the resource is allocated and potentially utilized in the future.

Actor. SESF includes the identification of relevant actors, previously named "users" [39], who are involved in the management of resources. While some

[6] dictionary.cambridge.org/us/dictionary/english/resource; www.lexico.com/en/definition/resource

common-sense and terminological definitions of actor relate to specific staging/acting activities, a more general dictionary definition of actor is one who takes part in an activity/process.[7] We define the ontology of actor following an account of UFO dedicated to social entities called *UFO-C* [28] that we have simplified and modified for the purpose of this paper and domain. The UFO extension is based on the distinction between *agent* (e.g. persons and institutions) and *object* (e.g. rocks and norms), both of which can be physical or social. Note that in this writing we use the terms agent and actor interchangeably.

One of the main differences between actors and objects is that the former bears *intentional moments*, i.e. beliefs, desires and intentions, that have a *propositional content* and a directionality (e.g. "I intend x") related to a specific *situation*. For example, the propositional content of intentions are goals that can be satisfied by a situation (e.g. to catch fishes without over-exploiting the resource). Intentional moments may trigger activities performed by actors that are the execution of plans; these may or may not be satisfied according to the intention-goal of the actors, and can involve the presence or use of resources. An example of action-interaction is that of *communicative acts*, in which actors use language for instance to share opinions, ask questions, to commit formal acts and create *social moments* that exist due to the situation generated by the actors. Actors may also interact with each other in complex actions (e.g. two or more fisherpeople coordinate their fishing activities) and can use resources in activities, the participation of resource in such activities can take several forms: *creation* (i.e. the existence of the resource is the output of the activity), *termination* (i.e. the non existence of the resource is the result of an activity) and *change* (i.e. the resource acquires or loses one or more characteristics as the output of the activity).

Thus resources and actors can be ontologically related and this linkage can potentially influence outcomes within and between SESs. Indeed actors can decide over resource allocation, manipulation and consumption, thereby modifying socio-ecological balances.

Governance. Clarifying the notion of governance is not an easy task due to the wide variety of meanings that have been attributed to it [49]. We begin with dictionary definitions of governance as the activities/actions within administrative systems and practices for national and organisational management.[8] These definitions depict governance as a kind of action undertaken by governing-managing states and institutions. Scoping the definitions from within the field itself and extending into sustainability sciences, governance has been defined as a normative, rule-based and strategic process to guide behaviour in the context of policy ([52], p. 3, referencing [38]), as a social function that guides humans and societies to expected goals ([22], p. 6), as an intended result of strategic institutional

[7] dictionary.cambridge.org/it/dizionario/inglese/actor; www.lexico.com/en/definition/actor.

[8] dictionary.cambridge.org/dictionary/english/governance; www.lexico.com/en/definition/governance

decisions to tackle problems ([22]. Governance has also been distinguished from *government*, which is a collective entity that may perform a form of governance ([22], pp. 6-7).

Despite our efforts we were not able to find existing ontological literature on governance, however we are able to explore this through works that analyse related concepts, such as norms, organisations, roles and decisions (e.g. [12,14,20,31]). Drawing from the definitions presented above, we consider governance as a specific kind of activity performed by agents that involves norms, commitments and decisions to achieve shared goals. The activity of governance regards *policy* [52] that can be defined as an agreed plan of action formally stipulated by a group of people, e.g. organisations, institutions, governaments, or a kind of document that communicate such an agreement.[9] Thus the notion of policy encompasses both the planning and the execution of plans on the basis of a group's agreements, again based on commitments. Governance activities are typically performed by affiliated actors playing roles [14], examples are the president and the chief administrator of an organisation that share common goals described in the administration's plans. Actors involved in governance establish and recognise social objects such as *norms*, *social commitments* [28] and shared *decisions*; these three are parts of the plans and are directed towards specific governance goals. Norms are descriptions that can be satisfied, or not, [14]; social commitments and decisions (i.e. type of intention [30]) are social moments typically originating from actors' interaction and communication [20,28] that might be directed towards an activity [31]. Norms and social commitments are connected to the notions of *validity* and prescription, as such they guide actors' activities [14] and decisions within the scope of governance.

Structure and function. While ecosystem structure has been defined in terms of composition, distribution and conditions that allow species to survive [23], ecosystem function carries more elaborate semantics such as specifying the operating mechanisms of an ecosystem (e.g. energy flow, nutrient cycle, regulating systems) as well as the capability of an ecosystem to deliver services useful for humans [21,23]. In order to define the semantics of structures and functions we start by briefly scoping the intuitive semantics of the former and derive implications that are useful to understand the latter.

The Cambridge dictionary defines a structure as the configuration of the parts of a system or object,[10] stressing the role of *parts* of a *whole* and their organisation. In this work we focus on a specific kind of parthood relation called *functional parthood*, in which the whole is organised in structural and functional parts [56], such as the CPU of a computer and the gills of a fish, and allows for the definition of *functional roles* [40]. These kinds of roles, which have been also formalised for UFO [29], allows for the capture of relations between systems and their components as structural and functional unities, which is useful in clarifying their semantics within SESs.

[9] dictionary.cambridge.org/dictionary/english/policy

[10] dictionary.cambridge.org/dictionary/english/structure

Functional parthood can be explained in terms of *functional dependence* [54], in which the parts play some sort of functional role in the context of the whole and vice versa. For example, certain ecosystems are functionally dependent upon specific insects to carry pollen and propagate species and certain insects are functionally dependent upon the whole ecosystem to reproduce and continue the species. The parts and the whole can be involved in an active *functioning as* role at a certain time in addition to bearing some latent functions that might be useful in the future [40,54]. Functional roles can be *social* and/or *natural* depending on the context in which the role is played.[11] For example, the president of organisation x plays a social functional role as the administrative head, the mangrove forest plays a natural functional role as an habitat for crabs, as well as a social functional role: coastal protection for human communities. While social roles are social concepts based on descriptions [2,14], natural roles are realised within specific bio-physical and chemical conditions, for instance the mangrove forest plays the natural functional role of habitat for crabs only when crabs are co-located with the mangroves.

A functional part of a whole system can be of different kinds, however in the context of ESs and SESs, three classes are most relevant, namely *replaceable*, *persistent* and *constituent* [40]. Replaceable functional parts are those that can be changed and replaced by the same kind without compromising the whole, for example individual species exemplars can be replaced by others of the same species without changing the nature of the whole ecosystem. Persistent functional parts refers to parts that exist only if the whole exists, an example is the presence of species that are dependent upon specific ecosystem dynamics to survive. Finally constituent functional parts are those that are part of the whole whether or not they are present at a certain time, such as seasonal species that contribute to an ecosystem in a certain period of the year.

Service. The core concept of ESs is represented by *service*, which is described as a benefit/outcome that natural ecosystems provide to humans, such as health and well-being, and then is useful for humans due to its value [6,47]. Ecosystem services are delivered due to the structure and functions of nature [21,47].

Dictionary definitions[12] specify a service as a kind of activity, such as the assistance provided by an organisation, business or the public sector. Service has also been defined as the correct functioning or availability of a system. In these definitions the notion of service is associated to the one of action/activity and is more often related to an intentional act performed by humans. To examine this we first focus on the analysis of the service concept, starting from the ontological, business-oriented and web-service literature to understand the differences and similarities between more classic definitions of service (e.g. agentive and intentional) and the one adopted by ESs.

[11] The distinction between social and natural roles can be found also in [5].

[12] dictionary.cambridge.org/dictionary/english/service; https://www.lexico.com/en/definition/service

Services have been described as activities, capabilities, results, changes and values [26]. A more general definition of service encompasses the notion of commitment as grounding an understanding of what a service is [26]. In this sense a party x commits to perform an action a in favor of a party y on the basis of certain conditions c. A commitment is typically an intentional act [28] that involves constraints on actions [26]. Consider that a service commitment may exist even without a service delivery; in a business example, paramedics are committed to providing aid services to their users even when nobody is calling for emergency service (i.e. a triggering event for service invocation). Services are thus a commitment-based activity (i.e. events), which we define as *commitment-based service*, that involve participants (e.g. parties). Thus services are differentiated from *goods* that are objects, transferable and owned due to their ontological structure [26]. Finally, some technological services are provided by automated systems and artificial agents, such as web-services and data queries; however these kinds of services are designed and maintained by human actors as commitment-based services.

This simplified ontological analysis of services provides an opening insight on some differences within the notion of ecosystem services. Indeed, while a service is commonly conceived as intentionally provided by someone, typically an agentive participant, in the case of ESs the role of the provider is played by nature. However, the environment does not have the same agentive characteristics of a human actor and even indulging the idea that nature has some sort of agentivity and intentionality (e.g. by being goal-oriented), it is yet not explicit nor possible to investigate if ecosystems have the intention of committing to service delivery to humans (i.e. the consumer). For these reasons we model the notion of ecosystem services twofold, from one side commitment-based services that are intentionally extracted and provided by actors (e.g. food, water, raw materials) and ecosystem services that are unintentionally provided by ecosystem structure and the involvement of functional roles, such as regulating and maintenance. Here we can see how the concept of unintentional provision of an ecosystem service may be confused with the one of natural function, as indeed ESs are not based on commitment and the ecosystem provider does not receive anything directly in exchange for the service. However ESs differ from functions due to their association with values, valuations and benefit for humans, notions that are not always associated with ecosystem function. Indeed ecosystem services, as well as commitment-based eocystem services, are valued by actors involved in the activity of extraction or accessing and are influenced by governance decisions. Note that the notion of service in the ESs approach might be adopted beyond its classic meanings as an instrument to facilitate understanding of the value-oriented connotations of ecosystem functions and products. This consideration is not a recommendation for changing the term service from ESs, but rather an encouragement for communities of practice which employ ESs to specify the meanings of terms and adopt clear definitions to avoid ambiguity.

Benefit and value. As introduced in Section 2.2, some ESs applications include economic valuations and quantitative and qualitative analysis of ecosystem services benefits [25,35]. In the cascade model goods (i.e. products) and benefits bear values, monetary or not [47]. For example, mangroves have structural and functional characteristics that provide services, such as coastal protection, that impact human well-being and therefore provide benefits associated to values. Although both values and benefits are central to the ESs approach, the former has been the subject of critical debate due to its overloaded semantics, interpretations from different communities such as economists and ecologists, and a complex literature elaborating intrinsic and instrumental values of nature [25]. We start our analysis from the notion of value, defined in dictionaries as a monetary amount, the importance or usefulness of something, a symbolic representation and a guide for behaviours and judgments,[13] to extract the semantics of benefit. This in turn is defined as something having positive characteristics or outcomes.[14] Note that we focus in particular on human attribution of monetary and non-monetary values, this is based on the interpretation of ESs as a descriptive and normative human-made instrument to assess ecosystem outcomes.

Following a simplified interpretation of the ontological study proposed in [4], which is grounded on UFO, and extending it for SESs, we continue the analysis using the notion of *value ascription* that is a contextual relation between an actor and an entity, such as a service or a good. These *value objects* (i.e. object to which values are ascribed) present qualities that are central to the valuation activity either for their functional role, (e.g. insects that carry pollen could be valuated for their functional role in an ecosystem) as well as non-functional role based on actors' *preferences*, (e.g. the westerly seashore is preferred by the actor x for its aesthetic qualities). Similarly to value objects, activities (and their associated goals) can also be ascribed to values; these types of activities are called *value activities*, an example of which is a commitment-based service such as coast guard rescue and the ecosystem service of water quality provided by soil. Actors, individuals and collectives ascribe values to entities on the basis of intentional moments (e.g. desires and preferences) that are dependent on contexts, for instance coral reefs are valued as providers of recreational and/or provisioning services. Various contextual factors influence value ascription, these include *norms*, *conditions of the actors* (i.e. physical and mental) and the *environment* (e.g. temperature), *location* and *product availability*. The valuation relationship that involves both actor and value entity results in two kinds of outcomes, namely *cost specific valuation* and *benefit specific valuation* based on the desires and preferences of the actor. While cost specific valuations are "negative" and dependent on the use and access of value entities besides their economic prices, benefit specific valuations are "positive", linked to the qualities, capability and outcomes of value entities fitting the actors' desires and preferences. In the example of fishes delivering a food provisioning service, the cost associated with that service could reflect accessibility to the fish stock and the technology

[13] dictionary.cambridge.org/dictionary/english/value; www.lexico.com/definition/value.

[14] dictionary.cambridge.org/it/dizionario/inglese/benefit; www.lexico.com/definition/benefit

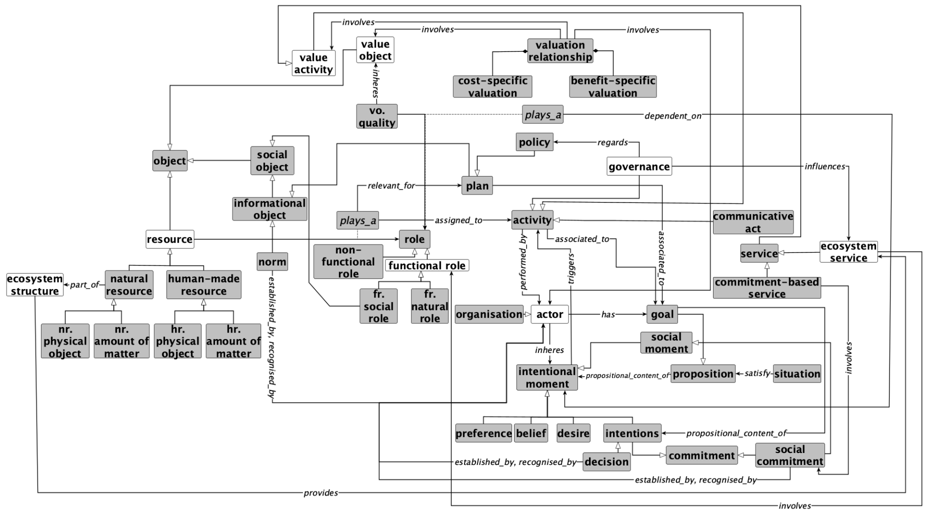

Fig. 3: Integrated framework for SESs

required for extraction, while the benefit of the same service is food availability and associated quality of life, health and well being in a certain context.

3.2 Integrated social-ecological perspectives framework

The section above presented a preliminary ontological analysis of the main notions of SESF and ESs to ground an integrated social-ecological perspectives framework, (see Figure 3[15]), that provides an unambiguous semantics and conceptual organisation of the core components of SESF and ESs. Figure 3 depicts a wide spectrum of SESs concepts and their relationships as defined in the previous section. White boxes represent elements associated to SESs, and while some of them maintain the same label, such as *ecosystem service*, others are modelled following the previous ontological clarifications, for example *functional role*. The added concepts are represented using grey boxes; some of these are extracted from the ontological literature, such as *informational object*, others from the SESs literature such as *natural resource*. One of the main challenges is the handling of the concept of ecosystem service, and this has been overcome by differentiating the element of service as intentional *commitment-based* or otherwise.

While other works have concentrated on the adoption and comparison of both SESF and ESs (e.g. [8,45]) or focus on formal analysis of one of the two approaches (e.g. [34]) such an ontological analysis and integration in an unified model of the main SESF and ESs elements and relationship is unique to the literature. As a final remark, our intentions for this work is to present an approach, i.e. ontological analysis, that provides for (i) a clearer semantics of SESs

[15] In Figure 3 "natural resource" "human resource", "value entity" and "functional role' are abbreviated respectively as "nr.", "hr.", "vr." and "fr."

components and (ii) a unified framework for SESF and ESs to address the challenges related to data comparison, vocabulary disambiguation and frameworks integration. The proposed framework does not aim to replace existing conceptualisations and become yet another approach, instead the goal of this work is to refine already adopted theories and improve upon their limitations.

4 Conclusions and future works

This paper presents an application of ontological analysis in the context of sustainability and SESs. We introduce a framework that integrates the main components of SESF and ESs approaches with the purpose of clarifying their semantics, an issue that is still open in the SESs communities, and promote integration and comparability of studies to address sustainability challenges. We believe that the proposed framework can be the starting point to address some of the inconsistencies between SESs interpretations that are also reflected in data collection and hermeneutic activities.

As a next step we envision the extension of the integrated framework to address the complex SESF's notions of resource and governance systems as well as action situation. We also foresee the inclusion in the presented conceptualisation of the roles that technology plays in SESs and how it impacts human experience, natural ecosystems and backgrounds sustainability initiatives (Adamo and Willis, *unpublished manuscript*). Another important action will be the application and evaluation of the integrated framework, for instance in real world case studies such as in the context of marine and coastal research, and to align sustainability-relevant concepts of existing tools and methodologies, such as for ESs modelling [15].

Acknowledgements This research was funded by LARSyS (Projeto - UIDB/50009/2020).

References

1. Adamo, G.: Investigating business process elements: a journey from the field of Business Process Management to ontological analysis, and back. Ph.D. thesis, DIBRIS, Università di Genova, Via Opera Pia, 13 16145 Genova, Italy (5 2020)
2. Adamo, G., Francescomarino, C.D., Ghidini, C.: Digging into business process meta-models: A first ontological analysis. In: Advanced Information Systems Engineering - 32nd International Conference, CAiSE 2020, Grenoble, France, June 8-12, 2020, Proceedings. Lect. Notes Comput. Sci., vol. 12127, pp. 384–400. Springer (2020). https://doi.org/10.1007/978-3-030-49435-3_24
3. Anderies, J.M., Janssen, M.A., Ostrom, E.: A framework to analyze the robustness of social-ecological systems from an institutional perspective. Ecology and society **9**(1) (2004)

4. Andersson, B., Guarino, N., Johannesson, P., Livieri, B.: Towards an ontology of value ascription. In: Formal Ontology in Information Systems - Proceedings of the 9th International Conference, FOIS 2016, Annecy, France, July 6-9, 2016. Front. Artif. Intell. Appl., vol. 283, pp. 331–344. IOS Press (2016). https://doi.org/10.3233/978-1-61499-660-6-331
5. Arp, R., Smith, B.: Function, role, and disposition in basic formal ontology. Nature Precedings pp. 1–1 (2008)
6. Assessment, M.E., et al.: Ecosystems and human well-being, vol. 5. Island press United States of America (2005)
7. Azevedo, C.L.B., Iacob, M., Almeida, J.P.A., van Sinderen, M., Pires, L.F., Guizzardi, G.: Modeling resources and capabilities in enterprise architecture: A well-founded ontology-based proposal for archimate. Inf. Syst. **54**, 235–262 (2015)
8. Ban, N.C., Evans, L.S., Nenadovic, M., Schoon, M.: Interplay of multiple goods, ecosystem services, and property rights in large social-ecological marine protected areas. Ecology and Society **20**(4) (2015)
9. Basurto, X., Gelcich, S., Ostrom, E.: The social–ecological system framework as a knowledge classificatory system for benthic small-scale fisheries. Global Environmental Change **23**(6), 1366–1380 (2013)
10. Berkes, F., Folke, C.: Linking social and ecological systems for resilience and sustainability. Beijer International Institute of Ecological Economics, The Royal Swedish ... (1994)
11. Binder, C.R., Hinkel, J., Bots, P.W., Pahl-Wostl, C.: Comparison of frameworks for analyzing social-ecological systems. Ecology and Society **18**(4) (2013)
12. Boella, G., Lesmo, L., Damiano, R.: On the ontological status of plans and norms. Artif. Intell. Law **12**(4), 317–357 (2004)
13. Borgo, S., Franssen, M., Garbacz, P., Kitamura, Y., Mizoguchi, R., Vermaas, P.E.: Technical artifacts: An integrated perspective. Appl. Ontology **9**(3-4), 217–235 (2014). https://doi.org/10.3233/AO-140137
14. Bottazzi, E., Ferrario, R.: Preliminaries to a DOLCE ontology of organisations. Int. J. Bus. Process. Integr. Manag. **4**(4), 225–238 (2009). https://doi.org/10.1504/IJBPIM.2009.032280
15. Burkhard, B., Maes, J.: Mapping ecosystem services. Advanced books **1**, e12837 (2017)
16. Colding, J., Barthel, S.: Exploring the social-ecological systems discourse 20 years later. Ecology and Society **24**(1) (2019)
17. Commission, E.: Eu biodiversity strategy for 2030. bringing nature back into our lives. Communication for the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the regions pp. p–25 (2020)
18. Cox, M.: Applying a social-ecological system framework to the study of the taos valley irrigation system. Human Ecology **42**(2), 311–324 (2014)
19. Cox, M.: Understanding large social-ecological systems: introducing the sesmad project. International Journal of the Commons **8**(2) (2014)
20. Dastani, M., van der Torre, L.W.N., Yorke-Smith, N.: Commitments and interaction norms in organisations. Auton. Agents Multi Agent Syst. **31**(2), 207–249 (2017). https://doi.org/10.1007/s10458-015-9321-5
21. De Groot, R.S., Wilson, M.A., Boumans, R.M.: A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological economics **41**(3), 393–408 (2002)
22. Delmas, M.A., Young, O.R.: Governance for the environment: New perspectives. Cambridge University Press (2009)

23. Eugene, P.O.: Relationships between structure and function in the ecosystem. Japanese Journal of Ecology **12**(3), 108–118 (1962)
24. Fadel, F.G., Fox, M.S., Grüninger, M.: A generic enterprise resource ontology. In: Third Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises, WET-ICE 1994, Proceedings. pp. 117–128. IEEE (1994)
25. Farber, S.C., Costanza, R., Wilson, M.A.: Economic and ecological concepts for valuing ecosystem services. Ecological economics **41**(3), 375–392 (2002)
26. Ferrario, R., Guarino, N.: Towards an ontological foundation for services science. In: Future Internet Symposium. pp. 152–169. Springer (2008)
27. Frey, U., Cox, M.: Building a diagnostic ontology of social-ecological systems. International Journal of the Commons **9**(2) (2015)
28. Guizzardi, G., de Almeida Falbo, R., Guizzardi, R.S.: Grounding software domain ontologies in the unified foundational ontology (ufo): The case of the ode software process ontology. In: CIbSE. pp. 127–140. Citeseer (2008)
29. Guizzardi, G., Botti Benevides, A., Fonseca, C.M., Porello, D., Almeida, J.P.A., Prince Sales, T.: Ufo: Unified foundational ontology. Applied Ontology **17**, 1–44 (2021)
30. Guizzardi, R.S.S., Carneiro, B.G., Porello, D., Guizzardi, G.: A core ontology on decision making. In: Proceedings of the XIII Seminar on Ontology Research in Brazil and IV Doctoral and Masters Consortium on Ontologies (ONTOBRAS 2020). CEUR Workshop Proceedings, vol. 2728, pp. 9–21. CEUR-WS.org (2020)
31. Guizzardi, R.S.S., Perini, A., Susi, A.: Aligning goal and decision modeling. In: Information Systems in the Big Data Era - CAiSE Forum 2018, Tallinn, Estonia, June 11-15, 2018, Proceedings. Lect. Notes Bus. Inf. Process, vol. 317, pp. 124–132. Springer (2018). https://doi.org/10.1007/978-3-319-92901-9_12
32. Haines-Young, Roy Potschin, M.: Common international classification of ecosystem services (cices) v5.1 guidance on the application of the revised structure. Fabis Consulting Ltd. The Paddocks, Chestnut Lane, Barton in Fabis, Nottingham (2017)
33. Haines-Young, R., Potschin, M., et al.: The links between biodiversity, ecosystem services and human well-being. Ecosystem Ecology: a new synthesis **1**, 110–139 (2010)
34. Hinkel, J., Bots, P.W., Schlüter, M.: Enhancing the ostrom social-ecological system framework through formalization. Ecology and Society **19**(3) (2014)
35. Liu, S., Costanza, R., Farber, S., Troy, A.: Valuing ecosystem services: theory, practice, and the need for a transdisciplinary synthesis. Annals of the New York Academy of Sciences **1185**(1), 54–78 (2010)
36. Masolo, C., Borgo, S., Gangemi, A., Guarino, N., Oltramari, A.: WonderWeb deliverable D18 ontology library (final). Tech. rep., IST Project 2001-33052 WonderWeb: Ontology Infrastructure for the Semantic Web (2003)
37. Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S., Péan, C., Berger, S., Caud, N., Chen, Y., L. Goldfarb, Gomis, M.I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J., Maycock, T.K., Waterfield, T., Yelekçi, O., Yu, R., Zhou, B. (eds.): Climate Change 2021: The Physical Science Basis. Cambridge University Press (2021)
38. McGinnis, M.D.: An introduction to iad and the language of the ostrom workshop: A simple guide to a complex framework. Policy Studies Journal **39**(1), 169–183 (2011). https://doi.org/https://doi.org/10.1111/j.1541-0072.2010.00401.x
39. McGinnis, M.D., Ostrom, E.: Social-ecological system framework: initial changes and continuing challenges. Ecology and society **19**(2) (2014)

40. Mizoguchi, R., Borgo, S.: A preliminary study of functional parts as roles. In: Proceedings of the Joint Ontology Workshops 2017 Episode 3: The Tyrolean Autumn of Ontology. CEUR Workshop Proceedings, vol. 2050. CEUR-WS.org (2017)
41. Ostrom, E.: A general framework for analyzing sustainability of social-ecological systems. Science **325**(5939), 419–422 (2009)
42. Ostrom, E., Burger, J., Field, C.B., Norgaard, R.B., Policansky, D.: Revisiting the commons: local lessons, global challenges. science **284**(5412), 278–282 (1999)
43. Partelow, S.: Coevolving ostrom's social–ecological systems (ses) framework and sustainability science: four key co-benefits. Sustainability Science **11**(3), 399–410 (2016)
44. Partelow, S.: A review of the social-ecological systems framework. Ecology and Society **23**(4) (2018)
45. Partelow, S., Winkler, K.J.: Interlinking ecosystem services and ostrom's framework through orientation in sustainability research. Ecology and Society **21**(3) (2016)
46. Pavan, S., Heidi, W., Christoph, S.S., Carsten, N., Joshua, B., Patrick, t.B., Haripriya, G., Pushpam, K., Ben, S.: Mainstreaming the economics of nature: A synthesis of the approach, conclusions and recommendations of teeb. Tech. rep., TEEB (2010)
47. Potschin, M., Haines-Young, R., et al.: Defining and measuring ecosystem services. Routledge handbook of ecosystem services pp. 25–44 (2016)
48. Potschin-Young, M., Haines-Young, R., Görg, C., Heink, U., Jax, K., Schleyer, C.: Understanding the role of conceptual frameworks: Reading the ecosystem service cascade. Ecosystem Services **29**, 428–440 (2018)
49. Rhodes, R.A.: Governance and public administration. Debating governance **5490** (2000)
50. Sanfilippo, E.M., Benavent, S., Borgo, S., Guarino, N., Troquard, N., Romero, F., Rosado, P., Solano, L., Belkadi, F., Bernard, A.: Modeling manufacturing resources: An ontological approach. In: IFIP International Conference on Product Lifecycle Management. pp. 304–313. Springer (2018)
51. Schägner, J.P., Brander, L., Maes, J., Hartje, V.: Mapping ecosystem services' values: Current practice and future prospects. Ecosystem Services **4**, 33–46 (2013)
52. Stephan, M., Marshall, G., McGinnis, M.: An introduction to polycentricity and governance. Governinig Complexity: Analyzing and Applying Polycentricity, Cambridge University Press, Cambridge pp. 21–44 (2019)
53. Un, U.N.: Transforming our world: the 2030 agenda for sustainable development. Working papers, eSocialSciences (2015)
54. Vieu, L.: On the transitivity of functional parthood. Appl. Ontology **1**(2), 147–155 (2006)
55. Vihervaara, P., Viinikka, A., Brander, L., Santos-Martín, F., Poikolainen, L., Nedkov, S.: Methodological interlinkages for mapping ecosystem services–from data to analysis and decision-support. One Ecosystem **4**, e26368 (2019)
56. Winston, M.E., Chaffin, R., Herrmann, D.: A taxonomy of part-whole relations. Cognitive science **11**(4), 417–444 (1987)