# The Omnipresent Role of Technology in Social-Ecological Systems

## Ontological Discussion and Updated Integrated Framework

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**Abstract.** Technology-driven development is one of the main causes of the triple planetary crises of climate change, biodiversity loss and pollution, yet it is also an important factor in the potential mitigation of and adaptation to these crises. In spite of its omnipresence, technology is often overlooked in the discourses of social and environmental sustainability, while in practice sustainability initiatives often draw criticism for favouring technical solutions or oversimplifying the relationships between society, environment and technology. This article extends our RCIS 2022 publication "Conceptual integration for social-ecological systems: an ontological approach" with an ontological examination of technology in two prominent social-ecological systems paradigms, *social-ecological system framework* (SESF) and *ecosystem services* (ESs) cascade. We ground the ontological analysis of technology on analytical and postphenomenlogical philosophical literature and effect several re-designs to the initially proposed integrated framework. The main aim of this work is to provide a clearer and theoretically founded semantics of technology within SESF and ESs to improve knowledge representation and facilitate comparability of results in support of decision-making for sustainability.

**Keywords:** Philosophy of technology · Ontological analysis · Social-ecological system framework · Ecosystem services cascade

## 1 Introduction

Technological development is a major contributor to climate change, biodiversity loss and pollution (e.g. [29]) yet technology is also an essential tool for finding solutions to these tripartite crises [10,15,47]. The fact that very few natural resources are accessible, beneficial or valuable to humans without the existence and availability of some kind of technology to extract them [15,24] reveals a fundamental human-nature relationship as decidedly technological. Technology here refers to resource extraction tools and infrastructures within social-ecological systems (SESs), but also to Information and Communication Technology (ICT), the main epistemological grounds for environmental science and knowledge production via data collection, analysis and for example, climate change predictions [44]. While a few attempts have been made to create over-arching frameworks


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[4,32], the literature on sustainability and related scientific fields often lacks in-depth analyses or assumes an overly simplified view of technology [36]. This tendency, frequently accompanied by ambiguous or unspecified semantics and a lack of theoretical foundations, is reflected in *social-ecological system framework* (SESF) [34] and *ecosystem services* (ESs) cascade [40], two widely applied SES frameworks used to capture common knowledge, define indicators, collect data, visualise results and manage resources for decision-making. The lack of a clear, explicit reification of technology limits the accuracy of those worldviews. In addition there are still challenges of comparing, aligning and integrating SESF and ESs outcomes [39] resulting in scarce information reuse and the compartmentalisation of sustainability knowledge [8].

The aforementioned issues are tackled in this paper using ontological analysis to clarify concepts and define aspects of technology within SESF and ESs cascade that without specification affect the assessments emerging from SESs analysis. Moreover this work proposes a unified conceptual and theoretical base of technology continuing the integration begun in the RCIS 2022 contribution [2]. The broader objectives that guide this extension are: (i) to establish a more explicit semantics of the main SESF and ESs components, (ii) to include technology-related concepts that can improve the quality of knowledge representation, and (iii) integrate the use of both approaches for comparisons of data and results in a unified perspective that will extend the reach of sustainability studies. This analysis of technology is performed by examining the state of the art of SESF and ESs cascade and extracting, where possible, the conceptual components related to technology. These are defined ontologically on the basis of both material and social-critical aspects (see also [18,50]) by incorporating analytical philosophy and applied ontology approaches with postphnomenology [27,49].

The paper begins with a review of some relevant interpretations of technology (Sect. 2), followed by treatments of technology found within SESF and ESs (Sect. 3). It then presents the analysis and inclusion of technology-related concepts in the integrated framework from RCIS 2022 (Sect. 4). Then the new concepts are discussed using the example of aquaculture (Sect. 5) and in conclusion future works are addressed (Sect. 6).

## 2 Perspectives on Technology

Providing a unified definition of technology is hindered by the prevalence of two contrasting perspectives in the literature, one that focuses primarily on the social dimension of technology called "humanities philosophy of technology", and another that revolves around technology as an engineered product called "engineering philosophy of technology", which is closer to the analytical philosophical heritage [19]. Regardless of their differences, these two are intertwined and both are relevant for a complete and multi-faceted interpretation of technology within sustainability contexts that require social-technological approaches [3]. In particular the "humanities philosophy of technology" discussions concerning "instrumentalism" alongside "critical theory" considerations [17] provide a continuum that enriches the social aspects of the analytical perspective of technology.

*Some Philosophical Accounts of Technology.* Technology in this work is considered to be an entity created by humans, therefore an artefact. A common way to define artifacts refers to objects created intentionally to achieve a goal [41], thus artifacts are only those that are *intended* (here meant as *prior* to the production stage) [31]. This general definition fits with a widespread interpretation of technology in climate change and sustainability research known as *instrumentalism* [17,36] which assumes that technology is designed to achieve desired results. This vision considers technology as neutral, then not loaded with *specific* social-cultural values (besides perhaps efficiency), and under the control of humans [17]. The neutrality of instrumentalism has nevertheless been challenged [19], for although technology is interpreted as goal-oriented, this does not imply that there are no values embedded in those goals, a point also discussed by Feenberg [17]. Technology emerges from the world of design and engineering and is therefore situated in a wider societal context with constituent needs and values (e.g. the safety or sustainability features of technology). Instrumentalism has been linked to an overabundance of *technology fix* approaches that do not sufficiently consider broader social-ecological systems, which is particularly problematic in the context of sustainability [19].

In contrast with instrumentalism, *critical theory*-derived interpretations regard technology as not only managed by humans but also charged with societal values. In the critical sense technology is more than a neutral tool, it is also a framework that provides for the shaping of society [17]. This idea is reflected in what Feenberg calls, somewhat confusingly, *instrumentalization theory* which encompasses two aspects of technology, its functional-technical properties, also named "primary instrumentalization", and socio-cultural contexts such as power dynamics that influence the design and the designer(s), which is called "secondary instrumentalization" [18]. Among the critical theories of technology described in [36] is *postphenomenology*, that combines (i) phenomenology, in which the object-(artifact) is not only perceived by the human subject but also mediates their experiences through mutual engagement [28], (ii) pragmatism, in which technology is considered only within use contexts [51], and (iii) empirical studies of actual technologies in which philosophical investigations revolve around technology instances [49]. At the heart of postphenomenology is an elaboration of mediating relations (embodiment, hermeneutic, alterity, and background) [27,28,48,49] through which technology mediates human experiences, visions of the world, choices and actions [49].

As discussed in [18], instrumentalization theory presents some analogies with a perspective of technology proposed within the analytical philosophical tradition, that is *the dual nature of technical artifacts* [50]. According to this duality, technical artifacts carry *functions* that cannot be explained only by their *physical characteristics* since functional specifications involve *social-intentional* aspects. Studies of technical artifacts, therefore, entail analysis of their physical properties as well as their intended functions relevant to a *use plan* [50].

In the context of applied ontology, relations between the artefact itself, including its characteristics, and the intentional agents are formalised in [11]. This defines artefact as purposely mentally created by an agent through a process of selection. Those artefacts are modelled by distinguishing their material composition (e.g. physical object and amount of matter) and the artifact itself, i.e. material + intentional aspects. Different from physical artifacts, social artifacts are those that are acknowledged within a community. Rather than grounding the concept of artifact on functions, [11] considers the more general notion of *capacities*, which are useful to describe the qualities of a certain artifact, and *attributed capacities* that are connected with the intentions of its creators. Kassel offers another in-depth formalisation [31], which aligns with ìnstrumentalism to describe artefacts as entities created with prior intentions and successfully produced. Technical artefacts for Kassel are those having properly ascribed functions, considered as the capacity of the artefact to achieve a goal in a context when the properties of the artefact are directed to its intended effects, which can include accidental functions. Those functional aspects can be ascribed privately by an individual or publicly by a social group. A dedicated analytical investigation of *social artifacts* is proposed by Thomasson [46], offering two main theses. The first considers an artifact as something with intended *features* that can range from material properties to normative characteristics and which *could* also include intended functions. Secondly, it observes a less general class of artifact, the *public artifact*, that is recognizable by a certain group or community and is dependent upon *norms*, which guide the behavior of the community's members and contexts. Public artifacts depend upon collectives and are representations of normative practices and shared semantics, an interpretation that is closer to critical theories of technology.

The literature on technology offers many other useful interpretations and definitions. However, we chose the above concepts to begin a discussion using material and social technology perspectives, which ground the analysis in the following sections.

## 3 Technology in Social-Ecological Systems

SESF is an ontology composed of social and environmental variables organised in multiple conceptual levels, called tiers, aimed at providing a shared understanding to diagnose the sustainability of SESs [34,37,39]. The main SESF tier elements are *resource unit*, *resource system*, *actor, and governance system* tailored together in the *action situation* interactive pool. Exogenous elements that might influence the system framework are *social-economic-political settings* and *related ecosystems*. A full list of the second tier variables can be found in [34] Table 1. With its origins in political science and focus on preserving common-pool resources [9], the language of SESF tends towards ideas connected with sustainable resource management. ESs takes a different approach and focuses on the services provided by nature that contribute to human well-being [7,40]. Following the *Common International Classification of Ecosystem Services* (CICES)

[23] the main classes of ecosystem services are *provisioning* (e.g. crop, water), *regulation & maintenance* (e.g. flood protection and pest control) and *cultural* (e.g. scientific and symbolic experiences derived from ESs). The cascade conceptual framework explains ESs based on ecosystem *structure*, *process* and *function* that provide ecosystem *services* that are *beneficial* for human societies and carry *values* [40]. The ESs paradigm is an amalgam of both natural science and ecological-economics [9]; its language and applications lean towards economic valuation and visualization of ecosystem services to orient policy and decision-making [39].

*Identifying Technology in SESF and ESs Cascade.* The two frameworks adopt different perspectives and scales of analyses even though both SESF and ESs represent an ecological and a social partition [9]. Divergences are also reflected in their approaches to technology, which in SESF is only partially developed and in ESs is notable for its absence. Based on our current knowledge, neither of the two frameworks expresses a direct commitment on how to interpret the role of technology.

SESF includes explicit references to technology and several second tier variables encompass technological artifacts either directly or indirectly. Technology (S7) is attributed to the *social, political and economic settings* that are external factors influencing social-ecological systems at local or global scale [34]; examples comprise relevant existent technology and ICT facilities, such as mobile phones and information systems, yet this variable is the less examined in literature [37]. Technologies available (A9) is a variable of the *actors* element describing the accessibility level of relevant technology, amount of technological artifact available and the extent of physical surface, e.g. land and ocean, in which technology is used [37]. Finally Human-constructed facilities (RS4) are included in SESF's *resource system* and facilitate the realization, maintenance and enhancement of the *resource unit* (stock) [26]. Examples are tourism and transportation infrastructures (e.g. boardwalks and harbours), human-constructed habitats (e.g. artificial reefs or aquaculture ponds) and ICT infrastructures for data processing and management [37]. Implicit references to technology and ICT can be found in several SESF concepts, for example most of the *action situation* second tier variables (e.g. Harvesting (I1), Information sharing (I2), Monitoring activities (I9) and Evaluative activities (I10)). Besides the direct inclusion of technology in SESF and related research of SESs robustness involving for example energy and public infrastructures [5,26,34], technology elements remain second-tier and are not given the same level of prominence as the social and ecological first tier components.

In the ESs cascade artificial entities are not explicitly included, even though most ecosystem services are not immediately available to meet human needs and are implicitly linked to technical artifacts used by humans for extraction or access. Technology then forms part of the *production boundary* [40] where the social and economic systems overlap with the ecological system, and where goods (with their associated benefits and values) are derived from ecosystem services. The ecosystem *services* themselves are considered as desired outputs of the ecological system (derived from ecosystem *structure* and *function*). The CICES nomenclature [23] begins for example with the provisioning (biomass) ecosystem service 1.1.1.1 "Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes" and gives the example of a wheat field before harvest, which yields goods and benefits that include "Harvested crop; Grain in farmer's store; flour, bread". Harvesting of wheat requires at the very least simple tools, yet modern agriculture typically involves mechanisation and technologies for sorting, cleaning, preparation, storage and transport. The CICES cultural biotic ecosystem services 3.1.2.1 "Intellectual and representative interactions with natural environment" and potentially also 6.1.2.1 "Natural, abiotic characteristics of nature that enable intellectual interactions" both refer to scientific investigation, and by implication the presence and use of technology. Section 4.2 and 4.3 of CICES extended version list material and energy sources that are bound to sophisticated technologies for conversion, transmission and storage.

## 4 Conceptualising Technology in the Integrated SESs Framework

In this section we provide an informal disambiguation of technology concepts, an extension and re-design of the SESs integrated framework proposed in [2]. Our previous work modelled and integrated several SESF and ESs cascade components. These included the general notion of *resource*, which provides the ground for resource unit and system, *actor* and *governance*, which set the basis to better understand the governance system, *ecosystem structure*, *function* (now *functional role*) and *service*, *value* & *benefit* represented through the *valuation relationship* based on [6]. That investigation followed a simplified ESs version that does not include ecosystem *process*. The ontological analysis of each of those elements was based on relevant applied ontology research especially in the domain of information systems, such as the *Unified Foundational Ontology* (UFO) [22] and the *Descriptive Ontology for Linguistic and Cognitive Engineering* (DOLCE) [33] and related works.

After the review of philosophical literature and the representations of technology in SESF and ESs cascade, this research follows a two-step approach: (i) ontological analysis of technology entities and relations in the SESs frameworks and (ii) re-design of the initially proposed integrated framework. Step one concerns the semantic disambiguation and definition of SESF and ESs technology components, employing "humanities philosophy of technology" and applied ontology as theoretical grounds. Consistency with our previous work is ensured by continuing to reference UFO, DOLCE, and cognate ontological literature, such as the study of resources proposed in [42]. To further analyse the social aspects of technology within SESs, in which technology affects the access to a certain resource or service and thereby shapes the worldviews of actors involved in a certain SESs context, we adopt both analytical works, such as [11,46], and postphenomenology as a critical perspective of technology. Although we recognise the different theoretical underpinnings of analytical and humanities approaches, we believe that often the challenges of creating a bridge between the two perspectives are related to linguistic and heritage discrepancies and not to absolute divergences. The methodological steps of ontological analysis are provided in [1]. The semantic clarifications are actualised in step two by either re-interpreting existing elements based on the outcomes of step one or by introducing newly defined components and relations. Note that these two steps run parallel.

### 4.1 Ontological Analysis of Technology and Its Integration

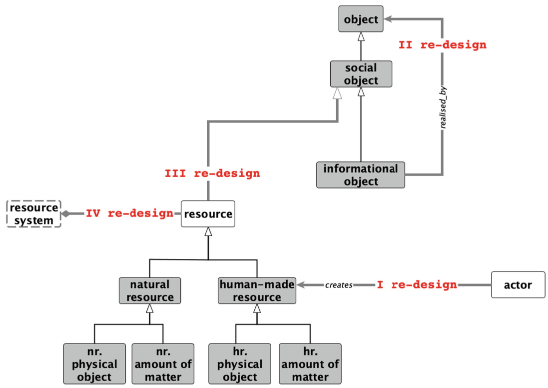
We begin this investigation by considering the general definition of artefact included in Sect. 2 as something intentionally created by agents with certain characteristics that satisfy a purpose and we use this definition as a starting point to extend the notion of *human-made resource* presented in [2]. A *human-made resource* is defined as a role played by an artificial object (*physical object* or *amount of matter*) assigned to *activities* and relevant for a *plan*. This relevance is derived from characteristics or qualities of the artifact that make it suitable to achieve a goal [42]. While the aforementioned descriptions are included in the initial integrated framework, the relation `creates` between the *actor*, which holds *intentional moments* with *propositional content* [22], and the human-made resource is newly introduced (`I re-design`) and refers to the intentional mental creation of the artefact performed by the actor [11]. As in the previous version, resources, including those made by humans, carry *values* because of their functions that are linked to their qualities. Those values were modelled through the contextual relation of value ascription [6], labelled *valuation relationship*, that is the assignment of values from an actor to an entity, more specifically objects and activities. Another update here regards the relation between *informational object* as the provider of propositional and immaterial technical content (e.g. model, code or plan) that is typically `realised by` a support [42] as also formalised in DOLCE Lite Plus (DLP) [20] (`II re-design`).

In the previous work *resources* were classified as *objects* [22], however after further analysis of the literature the concept of resource in the context of SESs has been re-defined as a social-public entity, congruent with definitions provided in [11,46]. Now a resource is classified as a *social object* that plays *social functional roles* and is recognized, formally or informally, within a certain community of people (`III re-design`). One inconsistency arises from this decision, as indeed many human-made and all natural resources also have material properties. To accommodate this we adopt the approach proposed in [42], in which resources play roles (social objects) while retaining their material character. This grounds the framework elements *nr physical object* and *nr amount of matter* together with *hr physical object* and *hr amount of matter*, where "nr" and "hr" stand for "natural resource" and "human-made resource", respectively. These are resources playing roles in a context, yet are also subclasses of the non-role/contextual entity *object*. Inspired by the formalisation of SESF proposed by Hinkel et al. [25] we also extend the "resource" side of the framework by including the concept *resource system* (`IV re-design`) that encompasses both *natural* *resource* and *human-made resource* (Fig. 1a depicts I, II, III, IV re-designs). Following on with an expansion of *governance system* we explicitly introduced from UFO the entity *social actor* [22][1] which is a kind of actor that subsumes *organisation* and can define *norms* (i.e. information objects), *social commitments* and the newly introduced *social decision*, which is a kind of social commitment (i.e. social moments) [22] `recognised and established by` a social actor. The aforementioned concepts enrich the notion of governance as an *activity* `performed by` the social actor that `regards` *policy*, i.e. a formally agreed plan [2]. Those re-designs (number `V`) are represented in Fig. 1b.

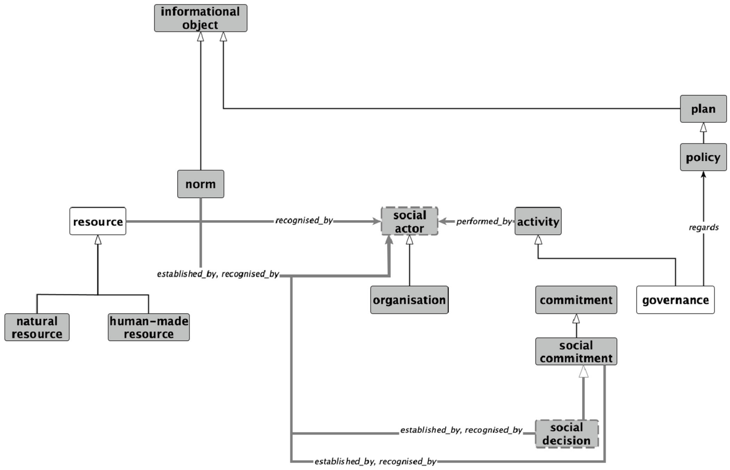
*Technological Mediation in SESs.* This phase concludes with the `VI re-design` (Fig. 1c); the resulting framework can be found in full here. The `VI re-design` involves the notion of technological mediation inspired by postphenomenology [27,28,48,49] and schematized in [3]. We include this conceptualisation of technology to extend the definition of human-made resources, as social objects recognised within a group of actors, to explicitly capture the mechanism through which technology frames and shapes human actors' *intentional moments* and potentially also their *actions*. Such mediation that the actor experiences occurs due to an engagement between the actor and the technology. Focusing on the four base mediation relations [27,48], (i) *embodiment* between actor and human-made resource occurs when the former adopts the latter to extend their capabilities. For example, the breathing apparatus for underwater exploration mediates and expands the human possibilities to reach into the marine environment. (ii) The *hermeneutic* relations involve the interpretation by the actor of symbolic representations provided by the human-made resources, in the way that a digital coastal map mediates the sailor's knowledge of the route, regulations, and hazards, and then also mediates their navigation of the environment. (iii) The third mediation, *alterity*, occurs when the actor interacts with the human-made resource as a "quasi-other", such as when a sailboat's autopilot is perceived as a member of the crew. Finally (iv) the "invisible" *background* relation occurs when the human-made resource is performing without being noticed by the actor, such as the GPS satellite system upon which mariners depend. These mediations enable human experiences, epistemologies and practices [3,49].

The inclusion of the perspective provided by technological mediation requires a conceptual shift: human-made resources are not only collectively selected and recognized to achieve goals, such as to extract provisioning ESs or use human-constructed facilities, but also ways of engaging with and interpreting situations that have consequences on the actor's worldview(s). For example without sensors and equipment that mediates our information access through hermeneutic interpretation, scientists would not be able to monitor and generate knowledge of certain environmental conditions, nor would relevant information be available for decision-making [3]. These aspects are captured in the re-designed framework through the relation `mediates` between human-made resources and intentional

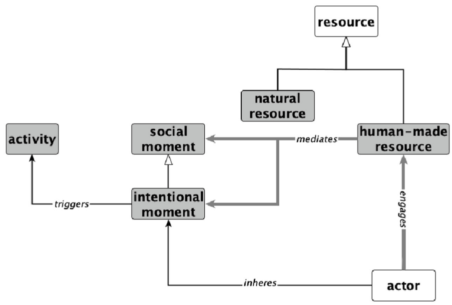
[1] The paper of Guizzardi at al. [22] refers to *agents*, for the purpose of this work we consider *actor* and *agent* as interchangeable.




(a) I, II, III, IV re-designs




(b) V re-design




(c) VI re-designs

**Fig. 1.** Framework re-design snippets.

moments (beliefs, intentions, desires, preferences and decisions) that are `inherent` to the actor, the latter derived from UFO and taking inspiration from the phenomenologist Husserl. Although we borrow the relation `mediates` from postphenomenology, it is also included in UFO to define "material relations". Those, in order to bind the ralata need another entity, called *relator*, for example "town A being connected with the dive center B" is mediated by the existence of a road (the relator) between A and B (the relata) [22]. However in the new framework we present the existential dependence as more specific, referring to certain *intentional moments* that cannot exist without the presence of technology. When representing the notion of mediation in postphenomenology we refer to [3] and require another relation, `engages`, between *actor* and *human-made resources*. This expresses the co-shaping connections between the human subject and technology. To summarise, without the mediation of the human-made resource the actor could not have certain intentional moments and then perform certain actions, and at the same time the actor needs to engage with the human-made resource in order to elicit its characteristics and allow the mediation to emerge. Note that human-made resources mediate both (private) intentional moments and social moments that are inherent to communities of actors (after Kassel). In Table 1 are listed the new entities and relations described in this section.

**Table 1.** Integrated framework extended components.

| Re-design # | Entity | Relation | |
|---|---|---|---|
| `I re-design` | - | actor *creates* hr | |
| `II re-design` | - | information object *realised by* object | |
| `III re-design` | *social object* | resource *is a* social object<br>resource *recognised by* social actor | |
| `IV re-design` | *resource system* | resource system *composed of* | nr<br>hr. |
| `V re-design` | *social decision* | norm *recognised and established by*<br>social decision *recognised and established by*<br>social commitment *recognised and established by* | social actor<br>social actor<br>social actor |
| `VI re-design` | - | hr. *mediates* intentional moments<br>actor *engages* hr | |

## 5 Discussing the Example of Aquaculture

In this section we discuss the integrated framework considering the SESs scenario of *aquaculture*, which according to the controlled vocabulary AGROVOC developed by *Food and Agricultural Organization* (FAO) [14] is the farming and management of aquatic organisms, such as fish and algae. The expansion of aquaculture worldwide is responsible for increased production and consumption per capita of seafood proteins [16], i.e. a rise in provisioning ecosystem services, but also the transformation of what were once common-pool resources (e.g. free-swimming fish and crustaceans) into private, commercialized goods

[13]. Advances in technology and engineering have fostered intensive production which can have adverse environmental consequences, such as changes in coastal water quality, degradation of coastal habitats, and spread of disease to wild fish populations [13,35], and have introduced social inequalities through loss of access to traditional fishing grounds, livelihoods and scarcity of important dietary proteins that disproportionately affect marginalized communities (see [21,45]). For these reasons aquaculture has become the focus of both SESF [30,38] and ESs [21,35] sustainability investigations, yet important technology-related aspects of this SES remain undisclosed. Although this theoretical examination is not a replacement for a real-world case study, it demonstrates how an attention to technology helps represent authentic SESs settings.

Starting from the initial definition of aquaculture and viewed through the integrated framework, aquaculture is an *activity* (kind of farming) performed by *social actors*, i.e. farm operators and workers, to achieve the planned *goals* of controlling *natural resources*, the aquatic organisms, and restricting access to provisioning *ecosystem services* within the system. This is achieved by performing a series of more specialised activities involving the management of reproduction, growth and protection from predation [13]. In many cases achievement of these goals is dependent on modification of the environment and the employment of dedicated *human-made resources*, such as cages, nets, artificial ponds, aeration equipment and specifically crafted feed. Though dependent on the same *ecosystem services* as wild harvesting, which involve *functional roles* played by *natural resources*, aquaculture systems are often artificial or semi-natural ecosystems.

The management and improvement of production efficiency, particularly in intensive aquaculture, also relies on sophisticated human-made ICT resources that provide knowledge (*informational objects*) derived from marine data [1]. The collection of such data, for example oxygen content, pH, temperature and salinity, is allowed by sensing technologies that mediate (through embodiment, hermeneutic and background relations) the understanding of the state of the aquaculture farm. This can support more efficient production as aquaculture operators monitor bio-chemical conditions affecting the life-cycles of the *natural resources* to determine optimal times for feeding and harvesting, yet can have unintended consequences as operators push the ecological carrying capacity of the *resource system* to it limits, using monitoring technology to maximize harvests. Meanwhile established regulatory frameworks (*governance* and agreed *policies*) often require that same monitoring data to ensure sustainability at local and regional scales [3]. Where *policies* are in place, producers can be required to restrict operations so that biophysical parameters remain within acceptable tolerances. In this case the mediation of technology fosters sustainable ecosystem management yet can have the unintended consequence of raising barriers to participation as prevailing socio-economic conditions particularly in developing countries hinder access to expensive monitoring technologies [43], and can diminish opportunities to exploit the *resource system*.

*Aquaculture Examples from SESF and ESs.* To complete the discussion we extract two toy examples from real-world SESs case studies, focusing on their

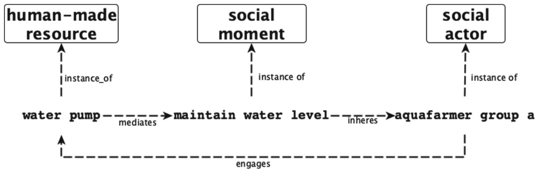



**Fig. 2.** Example of SESF instances.

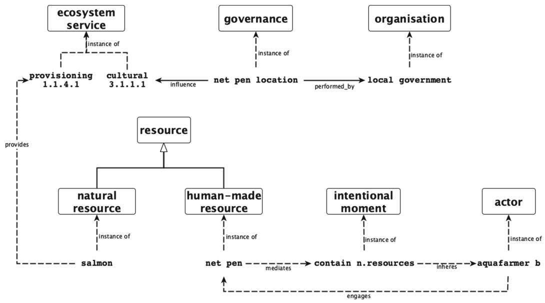



**Fig. 3.** Example of ESs instances.

technology-related components; the first SESF study regards community-based pond aquaculture in Indonesia [38]; the second examines intensive salmon farming in Chile through ESs [35]. Although the scale of analysis and the methodologies of the two are different, both consider social and ecological parameters. Note that the visual snippets are graphically inspired from examples proposed in [12]. In the SESF study, stakeholder engagement revealed the importance of water pumps for local aquafarmers to maintain pond water levels during the dry season, and a government aid program made a pump available to one group of aquafarmers. Figure 2 represents a snippet of this scenario which depicts "water pump", "aquafarmer group *a*" and "maintain water level" respectively classified as *human-made resource*, *social actor* and *social moment* following the integrated framework. The social moment of the aquafarmer group is mediated by the presence of the water pump that when it is engaged (i.e. adopted) would allow to keep the water in the pond at desired levels throughout the dry season.

The second example, based on ESs, involves an aquafarmer who requires a net pen to control the salmon. Meanwhile government regulations are not in effect to control the placement of net pens which is affecting the seascape and impacting tourism. Figure 3 captures this scenario in which the *intentional moment* "contain natural resource" of the *actor* "aquafarmer b", is mediated by the existence of the *human-made resource* "net pen" which allows for the control of the *natural resource* "salmon" and access to the provisioning *ecosystem service* for nutrition (CICES 1.1.4.1). The aquaculture farms are located in coastal areas which provide valuable cultural *ecosystems services* (e.g. ecotourism), nevertheless the lack of *governance* regulations concerning "net pen location" from the *organisation* "local government" is devaluing the environment in particularly beautiful areas that have high potential for tourism.

The previous discussion of aquaculture is intended to exemplify the use of the same theoretical ground to analise both SESF and ESs investigations. While the discussion of environmental monitoring makes visible unintended consequences of technology, the first case study excerpt shows how the existence of a technology affects group decisions. The second pinpoints trade-offs in SESs impacts and benefits that could be managed by governance activities. Together these illustrate the potential implications of such an integrated framework for sustainable policy development.

*Limitations.* The possible limitations of this work include (i) the focus only on two SESs frameworks and (ii) the adoption of specific perspectives on technology. From the multitude of SESs theories (see [9]), we focus on SESF and ESs due to their prominence in available literature, and decades of real-world applications. Concerning point two, our discussion is limited by reasons of space and we acknowledge that there are many interesting works that have not been included in the discussion. However we refined our selection to representative works from both the analytical philosophy/applied ontology and critical theory literature that include both material-technical and social-critical examinations of technology.

## 6 Conclusions and Future Works

In this follow-up to our RCIS 2022 paper we continue the ontological investigation and conceptual integration of SESF and ESs cascade paradigms by exploring technology-related notions. Our hybrid focus melds different perspectives on technology, which prompted several re-designs to the initially proposed integrated framework. This demonstrates how ontological analysis can clarify and facilitate the conceptual integration of different knowledge streams, in this case SESF and ESs cascade. The integrated SESs framework has been updated, yet much remains to be done to achieve useful comparability of data and results from diverse, often extremely localised sustainability research. Potential next steps in this work are to unpack the SESF *action situation*, explore the ESs *production boundary*, and further analyse the value dimension. To evaluate the proposed framework we foresee two interconnected tracks. The first is the development of participatory workshops with in-house domain experts and partners in local SES research to review the framework's concepts and relations, and query the appropriateness and utility of our approach for analysing actual real-world studies. Outcomes from these workshops will support a second track, which involves the implementation of the framework in the *ARtificial Intelligence for Environment & Sustainability* (ARIES) platform [8].

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