A vocabulary for sustainability
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ABSTRACT
The definitions of sustainability and sustainable development in the literature often appear contrasting and contradictory, raising the need for clarification and standardization. This manuscript introduces a formal vocabulary for sustainability to achieve word and meaning standardization for sustainability researchers and strategists. It formalizes key concepts such as processes, systems, ecosystem, sustainability, development, and adaptation by providing an English description and a mathematical formalization. These support a high degree of consistency and applicability for science and explicit the approximations needed to deal with the complexity of the specific context they inquire about. The clarifications also allow the author to conclude distinguishing sustainability, its necessary conditions and related strategies. He shows that sustainability may need exploitation, adaptation, parasitism, or mutualism, which these must not be confused with sustainability itself, and that mutualism entails the most extended longevity.

1. Introduction
The definitions divergence
The importance of sustainability and sustainable development reached the root of global policies and debate, as shown, for instance, by agenda 2030 (United Nations, 2015), the European Green Deal and Cop26. However, academicians are still debating the meaning of the words sustainability and sustainable development providing many definitions and consequently generating a certain degree of confusion. A clear example of such confusion is the utilization of PRISMA or similar mechanisms to find a definition (Mensah & Ricart Casadevall, 2019). The other is Moore’s attempt, employing text-based analysis algorithms, to condensate 209 studies into a definition (Moore et al., 2017). The very same adoption of such a method seems to suggest that sustainability is not a well-defined concept but a probabilistic expression of a latent idea. However, this supposed latent idea is not necessarily reached by aggregating its multiple applications. A probabilistic and text-based approach reveals the most frequent use of sustainability, but if its latent concept is correlated with others, if it is not unique, or if the real meaning is misused, then such an approach may reinforce the errors and confusion. Moreover, both definitions as those of Moore (Moore et al., 2017) and Morelli (Morelli, 2011), the first based on algorithms and the latter on experience, reach a high complexity that an intuitive concept as sustainability perhaps has not. Instead, it seems that such complexity arises by aggregating heterogeneous concepts into a unique definition, falling far from the latent idea of sustainability, while we would benefit from disaggregating them to analyze how they concur and when they are necessary for sustainability.

The structure
This work aims to provide a vocabulary by disaggregating and defining the terms related to sustainability from sustainability itself. In order to perform such a task, it follows a brief debate about sustainability and its main related concepts, and then a sequential set of definitions and examples concerning basic concepts, such as processes, system, development and sustainability. Eventually, the vocabulary focuses on the (later defined) conditional necessary conditions, such as adaptation and mutualism, that are important ways to reach sustainability, although not always necessary nor substitutive of the very same sustainability definition. The appendix includes a table with the list of symbols adopted and the related variables used to help the reader.

Preliminary notes: Vocabulary
A vocabulary is a set of customs, the words, that contain meanings allowing interlocutors to understand each
other. As such, generally, to make a vocabulary means to seek and group such customs. From this standpoint, it is not much more than a literature review and, although very useful, is not innovative. Our standpoint is different because, as already explained, we deal with words used with different and sometimes irreconcilable meanings. A discourse based on words with multiple and discordant meanings will be ambiguous and discordant. It follows that our effort is the selection, reinterpretation, or proposition of meanings and customs to obtain a harmonic discourse. Likewise, some words such as ‘system’ have a general meaning that the vocabulary proposed does not want to substitute but specifies in the sustainability discourse. As such, we are proposing customs that cannot be accused of being inconsistent with others’ customs; possibly, they may be accused of being useless for the sustainability discourse. The author sustains that the vocabulary proposed is useful for at least three reasons. First, it guarantees standards useful to avoid confusion and misunderstanding; to quote this vocabulary entails the adoption of precise customs and meanings. Second, the words introduced are supported by a light English description and its accurate mathematical formalization allowing a direct scientific utility and unicovity. Finally, the words proposed, on the one hand, compose a functional system helpful for acquiring knowledge on sustainability, on the other, they have an abstractness that allows for specific problem applications. Such a consonance with the sustainability discourse determines the difference between an arbitrary customs choice and fruitful knowledge that, ultimately, is the added value of this vocabulary.

2. Prelude to the vocabulary

Human history: Sustainability and sustainability needs

Human sustainability is not a new issue (Gomis et al., 2011), it emerged over our history continuously. At its beginning, humans depended entirely on their capacity to exploit the nature supply and to adapt to it. We were harvesting or hunting to survive, and our impact on the environmental equilibria was neglectable. Then, humans learned to cultivate and breed, and our life sustainability depended more and more on the survival of these plants, animals and processes and vice versa in a mutualistic relationship generating mutual benefits. However, other resources, such as wood and minerals, appeared to still be coming from an infinite natural supply. The larger the human size, the smaller the world became, the more clear nature supply limits appeared, pushing human survival strategy progressively from a cowboy economy in an apparently infinite world to spaceship maintenance (Jackson, 2011; Meadows et al., 1972).

We changed human sustainability strategies but not sustainability itself: we were struggling to adapt to an undominated and unpredictable nature, we were building mutual relationships with her to have mutual benefits, and we were exploiting her for our survival or thriving. These and other strategies coexisted in different proportions over time, and none of them always guarantees sustainability: adaptation, mutualism, parasitism and others (see III.v) are neither synonymous with sustainability nor always necessary to be sustainable.

(keywords to refer to in the vocabulary: conditionally necessary conditions, adaptation, mutualism, parasitism, exploitation)

From linear to systemic

Contemporary human impact size treats the equilibria of the planet’s ecosystem functioning, demanding us to plan our actions carefully, but what should we care about exactly? Human and other beings’ life are, first of all, processes. The resources organization in the space entails these processes activation or inhibition that, in turn, interact affecting the very same resources. Such a cycle involves a continuum of generations on a past-dependent path that is often not reversible. Consequently, with our actions, we are responsible for both our and the future generations survival and quality of life, and if we take our responsibility, then sustainable development becomes ‘The ability of humanity to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs’ (World Commission on Environment and Development, 1987).

The challenge is primarily to individualize the relevant processes and define them properly (III.i). In turn, we need to understand how they interact in complex systems that may emerge or hide them (III.ii). Classically, the literature recognized three main systems, spheres, or pillars, whose interactions determine their reciprocal sustainability: economy, society and environment (Adams, 2006; Goodland & Daly, 1996; Holmberg, 1992; Sarkis et al., 2006). This triple aggregation is progressively decomposed as sustainability science grows (Pater & Cristea, 2016) to achieve higher knowledge and, consequently, the capacity to define our development to sustainability (III.iii, III.iv).

(keywords to refer to in the vocabulary: process, system, sustainability, development)
Goal

The farther we are from defining all the processes and systems involved, the higher the degree of arbitrariness we face. This arbitrariness is especially evident when researchers define the needs differently, sometimes delegating it to utility (Dietz et al., 2009; Knight & Rosa, 2011; Pearce et al., 1989; Pezzev, 1989; Prescott-Allen, 2001), sometimes oriented to human dignity and sometimes to other principles (Bova, 2021; Daly, 2013; Lovelock, 1979; Holy Father Francis, 2015). Because in all these cases, the definition of needs is delegated to ethics, and because it is mostly a matter of ethics deciding what is worth or not to sustain (human life, human welfare, nature maintenance, or other), then ethics plays a vital role in sustainability. This increases the complexity because there is not a shared consensus about which ethics should be adopted (Bova, 2020; Bowels, 2016; Ruse & Wilson, 1986; Sandel, 2010, 2012; Sedlacek, 2011; Sherman, 1990; United Nations, 2015; Williams, 1983). Since each ethic potentially leads to different targets for sustainability that, in turn, lead to definitions divergences, to meet this underdetermination in the vocabulary, the author refers to a generic goal (III.iv). Such an underdetermination reveals the power of a clear vocabulary: for each goal, it provides tools to determine the goal sustainability; hence, the words acquire a precise meaning even if applied to different targets, and there will not be confusion if such a target is explicit.

(keywords to refer to in the vocabulary: goal, chain goal)

3. Vocabulary

3.1 Resources, stocks, context, laws and processes

We argued that sustainability needs to individualize the processes, which stocks of resources activate them, and how these processes shape these resources and their stock back. In the first part of the vocabulary, we will formalize these elements considering a generic space composed of a context, the set of resources and the way they are organized, and a constitution, the set of processes active if the context has the required stock.

The aim is to propose a generalized base for sustainability independently of its specific application (environment, welfare, finance, biology, etc.), although it is meant primarily to help design sustainable development strategies. Accordingly, the vocabularies need a certain degree of abstractness, which must be filled according to the desired application. Hence, we will consider a generic and unspecified space, its points (resources), set of points (stock) and the set of all the points (context). The terminology adopted will be proven to help to deal with such abstractness. The resources are either the results of the process or what this process needs to be activated such as it may be wood for the process of generating furnitures. More specifically, the resources are the process domain or codomain because whenever a resource interacts with nothing (i.e. no process has it as domain or codomain), then it is not measurable, has no impact and, as such, can be neglected without perceptible effects. A stock is a set of resources, and the context is the set of all the space resources.

The following parts formalize blocks of the vocabulary, and each block is followed by an interpretation and an example to clarify its words meaning.

Resources, stock and context

Definition 1.1 Let \( \chi \) be a space. A point of \( \chi \) is said resource, a set of resources is said stock, and the union of all the resources of \( \chi \) is said context (\( \Theta \)) of \( \chi \).

Constitution and processes

A constitution is the set of all the perceptible functions in a space. A perceptible function or, equivalently, a perceptible law is an observable law where observable means that their domain and codomain differ, and both are not empty.

Definition 1.2 A constitution (\( \mathcal{U} \)) is the set of all the functions (\( f \)) of \( \chi \) that have a domain (\( f \)) different from the codomain (\( \tilde{f} \)) and both domain and codomain are not empty. Formally: \( \mathcal{U} = \{all \ f \in X : f \neq \tilde{f} \wedge f, \tilde{f} \neq \emptyset\} \)

The functions belonging to a constitution are said perceptible functions or laws.

A process is a perceptible law which effects are observed.

Definition 1.3 Let \( f \) be the law of the constitution \( \mathcal{U} \) of a space \( \chi \), \( f \) is said process if its domain belongs to the context \( \Theta \) of \( \chi \). Hence, \( f \) is a process of \( \chi \) \( \iff \) \( f \subseteq \Theta \wedge f \subseteq \mathcal{U} \)

A process is also said to be an observed law because it is a law in action, perceptible since its domain is satisfied and (therefore) has an observable impact on the context.

The process \( f \) will be represented by a letter that has as subscript the domain and the codomain in this order and separated by a vertical bar as follows: \( f_{\mathcal{U}} \).
**Interpretation**

This symbolism has the following interpretation. The constitution is all the laws that apply in the part of the world studied (the space). The laws that are potentially observed in χ are perceptible and perceived (observed) laws are processes. These processes are observed every time their domains (needs) are satisfied by the context resources. In turn, the processes have a codomain, the set of resources they generate and that flow into the context.

**Example:** Consider photosynthesis here simplified for convenience as a law having the sun and CO₂ in the domain, and O₂ in the codomain; formally, it would be defined as (sun, CO₂ | O₂). Since the domain is different from the codomain it is a perceptible law, and if in the context there is the necessary sun and CO₂, it is an observed law affecting the same context by removing sun and CO₂ and adding O₂. The O₂ produced cumulates in the context, and it is not a perceptible law since its domain (O₂) is equal to its codomain (O₂), it is a resource and the overall amount of O₂ with their spatial coordinates the O₂ stock.

### 3.2 Aggregations

Determining how to maintain specific processes is a critical issue for sustainability, and in order to do so, we need to understand how these processes interact and aggregate into systems. In the following lines, we will first distinguish systems from objects. The first is an aggregation of interacting processes where the interactions lead to an external (from the system) domain and codomain different from the mere union of these processes domain and codomain.

**Object**

An object is a set of non-interdependent processes

**Definition 2.1** Let P be a set of processes $P = \left\{ P_{(p_i|\bar{p}_i)}, \ldots, P_{(p_n|\bar{p}_n)} \right\}$, P is said object if $\forall i, j \in [1, n] : i \neq j, (p_i \cap \bar{p}_i) \cup (\bar{p}_i \cap p_i) = \emptyset$.

**System**

A system is a set of interdependent processes

**Definition 2.2** Let P be a set of processes $P = \left\{ P_{(p_i|\bar{p}_i)}, \ldots, P_{(p_n|\bar{p}_n)} \right\}$, P is said system if $\forall i \in [1, n], \exists j \in [1, n] : i \neq j, (p_i \cap \bar{p}_j) \cup (\bar{p}_j \cap p_i) \neq \emptyset$.

An Object or System P is represented as a capital letter having (i) as subscript the domain and the codomain in this order and divided by a vertical bar (ii) as high script the list of the processes belonging to them:

$$ P_{(p_i|\bar{p}_i)}^{P \cap p_i} $$

When there is no risk of confusion, the high script will be neglected such that representation is equal to the process but with capital letters: $P_{(p_i|\bar{p}_i)}$.

Let us highlight that (i) if P is an object, then the domain (codomain) of an object is the union of the domains (codomains) of its processes, (ii) the domain (codomain) of a system is the union of the domains (codomains) of its processes minus the union of the domain-codomain interceptions. Formally, let S be a system, $\overline{D}$ be the union of the domains of the processes of $S$, and $\overline{C}$ the union of the codomains of the processes of $S$, then the domain and codomain of $S$, respectively $S$ and $S$, are $S = D - (D \cap \overline{C})$ and $S = C - (D \cap \overline{C})$.

**Subject**

A subject is a set composed of at least one system and one object

**Perfect cycle**

A system where the embodied processes are such that the system domain is empty because its inner processes domains are already satisfied by its same inner processes codomain ($S = D - (D \cap \overline{C}) = \emptyset \iff D \cap \overline{C} = D$), is said to be a perfect cycle. Since its domain is always satisfied and its internal process continuously holds, it is an intuitive ideal sustainable system. Moreover, a perfect cycle that satisfies as well $S = C - (D \cap \overline{C}) = \emptyset$ is remarkable since it does not change the context, losing de facto its perceptibility and, as such, can be neglected to reduce the analysis complexity.

**Ecosystem**

The ecosystem ES of a system or object $S$ is the most extensive possible system in the space embodying $S$; it includes all the net of relationships directly or indirectly linked with $S$ domain or codomain.
The ecosystem of a system or an object A is the largest system observable embodying S.

Definition 2.3 Let \( e^{(x)}_{(S)} \) be a system or an object, let \( x \) be its space and \( U \) the space's constitution, and let \( ES^{(x)}_{(S)} \) be a system such that \( S^{(x)}_{(S)} \subseteq ES^{(x)}_{(S)} \subseteq U \); \( ES^{(x)}_{(S)} \) is said ecosystem of S if \( \exists \ A^{(a)}_{(\Delta \lambda)} \subseteq U : (A^{(a)}_{(\Delta \lambda)} \notin ES^{(x)}_{(S)} \cup \exists \{ A^{(a)}_{(\Delta \lambda)} \} \text{ is a system} \).

Interpretation

If correctly aggregated, a system or object reduces the number of relevant information to elaborate by synthesizing a set of processes to a mere domain and codomain. For instance, to individualize an ecosystem of an animal A, means to synthesize the processes concurring to A life by seeking the ecosystem domain satisfaction.

Example: Let us consider a forest and define it as a set of trees. If the latter is defined as an object made by the only process of photosynthesis (sun, CO₂ \( \mid \) O₂), then a forest is an object because the trees do not interact with each other (i.e. their domain codomain interception is empty). Let us further say that the three is an object also composed of the processes 'flourishing'. The latter is defined as the transformation of sun, water and ground minerals into fruit (sun, water, ground minerals \( \mid \) fruit). A tree is again an object because these processes do not interact, and their aggregation would result in (sun, CO₂, water, ground minerals \( \mid \) fruit). Let us further consider an object and a process: humans and gathering. Human is an object having a unique process (O₂, water, food \( \mid \) labor), and gathering is a process made of (labor, trees \( \mid \) food). The set human and gathering is a system (call it 'fruit picker') because the codomain labor of humans is the domain of gathering. Such a system would result in (O₂, water, food, fruit \( \mid \) food) eliminating labor because it is produced and consumed internally. Hence, if properly described, a system can reduce the pieces of information needed. Moreover, tree and 'fruit pickers' are a system (water, sun, ground minerals, CO₂ \( \mid \)) since the fruit is used by gathering to produce food consumed by the same fruit pickers. It is not a perfect cycle because its domain is not fully satisfied by its codomain. In such a scenario, the ecosystem of a human would include forest and the set of all the fruit pickers becoming (water, sun, ground minerals, CO₂ \( \mid \)).

3.3 Misspecification and miss inclusion: Plato's shadow set

Some have argued that the meaning of sustainability varies according to context, forcing us to be as explicit as possible when defining our terms. An argument is offered that disputes this conclusion by maintaining that it is not the meaning of sustainability that changes with respect to context, but rather our understanding of the context itself (Sherman, 1990).

Due to its complexity, we must reduce the space we study into a representation. Such a reduction can be costly and lead to two sources of confusion: misspecification and miss inclusion. The first concerns the over-reductionism that approximating an element's features leads to potentially wrong results and differences in the models and definitions. The second concerns the inclusion of non-relevant elements, increasing the possibility of mistakes. These mistakes are not nowadays fully eliminable (Maggino & Alaimo, 2021), but their reduction is the final aim of sustainability science.

To formalize these sources of mistakes, the author uses Plato’s cave allegory. The set of laws adopted by the researcher (\( U_R \)) are the shadows of the constitution that the researcher can see. Similarly, the shadow context (\( \theta_R \)) is the shadow of the context as it appears to the researcher.

Plato’s shadows set = (\( \theta_R, U_R \))

Let the researcher Plato’s shadow set be (\( \theta_R, U_R \)) and its space-time instant be (\( \theta, U_1 \)), then

- Plato’s shadows set is said to suffer context miss inclusion if \( \theta_R - \theta_1 \neq \emptyset \) and is said to suffer constitution miss inclusion if \( U_R - U_1 \neq \emptyset \).
- Plato’s shadows set is said to suffer context miss specification if \( \theta_1 - \theta_R \neq \emptyset \) and is said to suffer constitution miss specification if \( U_1 - U_R \neq \emptyset \).

3.4 Goal, sustainability and development

Goal and time

The effort of sustainability researchers is to individualize the processes composing the systems and objects and their interaction over time to understand both the evolution of the context and their goal achievability and sustainability. These goals must be intended as processes, objects, and systems that the analyst must or wants to achieve in a specified time and, accordingly, must be existing (i.e. perceptible) and, as explained later, sustainable at that time.
Definition 3.1 Goal is the set of objects and systems the researcher enquires about sustainability.

Definition 3.2 A time instant \( t = (\theta, \mathcal{U}) \) is a set composed of one context (\( \Theta \)) and one constitution (\( \mathcal{U} \)).

When there is no risk of confusion, we will refer to a time instant as time.

Development
A development describes the evolutionary sequence of the context and the constitution. When the constitution does not change, that is when the development is consistent, it describes the context change over time instants due to the constitution effects on the same context and due to the previous. Hence, a consistent development merely describes a sequence of post-dependent contexts, it has no qualitative connotation.

Development is the time sequence of a space context and constitution.

Definition 3.3 A development \( T_{t=i+i+n} \) is a set of \( n \)-ordered time instants \( T_{t=i+i+n} = [t_i, t_{i+1}, \ldots, t_{i+n}] \) such that \( \forall i \in [1, n-1] \) \( t_i = (\theta_i = \mathcal{U}_{i-1}(\theta_{i-1}), \mathcal{U}_i) \)

Consistent development is the time sequence of a space context and constitution where the latter includes immutable laws.

Definition 3.4 A consistent development \( T_{t=i+i+n} \) is a development where all its time instants have the same constitution. \( T_{t=i+i+n} = [t_i, t_{i+1}, \ldots, t_{i+n}]: \forall i \in [1, n-1] \) \( t_i = (\theta_i = \mathcal{U}_{i-1}(\theta_{i-1}), \mathcal{U}_i = \mathcal{U}_{i-1}) \)

Sustainability
Once the goal is defined, we can check if it is sustained in its space development. It is sustained if that development provides the resources the goal domain needs over time and if the goal processes belong to the development constitution (that is a coherency condition). The goal sustainability is past dependent: it results from the past interactions of systems, objects and the context. Hence, sustainability science studies whether the processes, objects, and systems coevolution within their context entails the sustainability of the goal.

A goal is said sustainable in a space and over a time period if it exists over that space development in that time period.

Definition 3.4 Let \( T_{t=1,n} \) be a development, an object, or system \( O^{f(\Theta)}_{\Theta} \) is said sustainable in \( T_{1-n} \) if \( \forall i \in [1,n], T_i = (\theta_i, \mathcal{U}_i), \mathcal{Q} \subseteq \theta_i \land f \subseteq \mathcal{U}_i \)

Let us consider as goal humans beings; if we intend domain as needs, then sustainability means meeting the needs of present and future generations similarly to the famous Brundtland commission definition (World Commission on Environment and Development, 1987). Need is a blurred word, and we already debated the enormous difficulties of reducing approximations; nevertheless, needs are often substituted with an even blurrier word: utility. The latter focuses on the perception of needs satisfaction and, as such, it is not necessarily consistent with reality (Bova & Ślesyński, 2020) and human life survival (Daly, 2013). Many intended sustainable development as non-declining utility (Pearce et al., 1989; Pezzev, 1989) where the initial utility, and not human life, is the goal. The non-declining condition is necessary because utility is always an existing (sustainable) function (process) if there are no other conditions. If what matters is utility, then the ecosystem must be approximated as a system of capital valued according to their capacity to provide utility and which interaction and substitutability become the central issue to understand if the development entails the utility maintenance (Markandya & Pearce, 1988; Pearce et al., 1988; United Nations Statistical Office, 1992).

If we consider as goals living beings, a living being is said sustainable in space and over a time period if it survives over that space development in that time period. Hence, sustainability means survival if and only if we restrict the goal to be a living being or a set of living beings. Moreover, survival would anticipate and explain sustainability strategies (Gökçekus et al., 2007; Hosomi, 2007). The understanding of sustainability as survival when we enquire about living beings (or other similar ‘creature’ as firms (Chavas, 1993)) will allow us in the following sections to better understand the sustainability strategies: survival may be achieved by cooperation and synergism or by conflict, exploitation and parasitism. We will explain that cooperation and mutualism are the most promiscuous for long-term sustainability, but we will also stress that we should not believe it is always achievable.

Example: Let us assume that our goal is the human ecosystem described from our previous example (water, sun, ground minerals, CO2 |) and that we are interested in enquiring about its sustainability over x years. Humans’ ecosystem is sustainable if its domain is satisfied for x years in the world (space) development. This is equivalent to saying that it is sustainable if there is enough water, sun, ground minerals and CO2 in the context for x years. Only in this context because no other processes are providing these resources as far as we know. Moreover, the development context will change each year by losing the resources needed from the human ecosystem and receiving nothing. Finally, we implicitly assume that these processes are true, which means that they belong to the constitution and are not
changing, which is equivalent to saying that the constitution is constant over development.

III.v Conditionally necessary conditions

This section introduces a further vocabulary expansion involving concepts such as adaptation and mutualism crucial for sustainability. These will be defined as conditionally necessary conditions (CNC) because they are necessary for the sustainability of a goal conditionally to specific conditions.

Conditional necessary conditions

Definition 4.1 A conditionally necessary condition is a condition that becomes necessary only under a set of assumptions or circumstances.

Such a definition distinguishes what is always necessary for a goal to be sustainable and what is necessary only in a given (conditioned to a) development. The first includes the goal domain satisfaction, and the latter includes the necessary interactions with specific objects or systems necessary to satisfy the goal domain in specific circumstances. To the extent that we are free to modify our goal or ecosystem, any change is a strategy that may entail different CNC applying to our goal. As such, their understanding helps to identify which are the effects of different modifications and strategies on the goal sustainability. Applied to living beings, these can extend or abbreviate the survival of the goal.

The rest of the section formalizes the following conditionally necessary conditions: adaptedness, exploitation, mutualism and parasitism.

Adaptedness

Adaptation is the set of actions leading to becoming adaptable. Adaptedness is the final result of a successful adaptation; in this sense, it is a posteriori result (Mayr, 1992). Adaptedness is important when it is a conditional necessary condition, when the goal has no other possibilities to be sustainable than to adapt. We need to define what it means to adapt precisely. Let A and B be systems or objects, A adapts to B if the domain of A is satisfied only the codomain of B. If A domain can be satisfied only by B, then A depends on B and B existence becomes a necessary condition for A sustainability. If there are alternatives, to be adapted to B ceases to be necessary and we say that A partially adapts to B. However, if we aggregate the set of objects and systems satisfying the domain of A (and if such an aggregation exists), we can conclude that A adapts to such an aggregation. In particular, if such a system exists, it is included in A’s ecosystem by the same definition of ecosystem.

A system or object is said to adapt to another system or object if it depends on the latter.

Definition 4.1 Let \( A, B \) be systems or objects of the same space, \( A \) adapted to \( B \) if \( A \cap B \neq \emptyset \)

Conditionally adaptable.

Definition 4.2 Let \( A, B \) be systems or objects of the same space, and let \( ES(B) \) be the ecosystem of \( A \) is said to adapt to \( B \) if \( (A \cap B = A) \Lambda \left( \exists C \subseteq \overline{B} \right) \subseteq \left( \exists S(B) \right) \Lambda \left( A \cap C \neq \emptyset \right) \)

Adaptation, intended as the change of a system or object to adapt to something, can now be revealed as a strategy not necessarily guaranteeing sustainability: its effectiveness depends on the systems or objects to which the goal adapts. If the adaptation leads to depending on a system or object sustainable for a short time, then this adaptation leads to short sustainability of the goal and vice versa.

Example: Let us consider our previous examples and focus on the human-trees relationship. Humans need food and oxygen. The trees provide both of them, the first indirectly by the picking fruit process and the latter directly. Hence, in this example ~5 human adapts to trees. Suppose now, the space is also composed of other objects able to provide food and oxygen. In that case, humans partially adapt to trees. Moreover, if we aggregate trees and the other systems providing food and oxygen in a new system, humans adapt to the latter.

Exploitation

To adapt means to find a source for the domain satisfaction in an object or system. As such, adaptation allows the goal sustainability until the latter is sustainable. If no objects or systems provide all the necessary resources, the goal needs to seek them in the context. Exploitation is the absorption of these context resources that are not regenerated (if they were regenerated, we would have adaptedness to the source providing them). Exploitation guarantees sustainability over a period of time as long as is big the amount of necessary resources in the context. Hence, sooner or later, exploitation stops guaranteeing sustainability. However, if there are no alternatives, exploitation becomes a conditional necessary condition for the goal sustainability.
A system or object is said to exploit the context if it depends on context resources that are not (re)generated by any other system or object.

**Definition 5.1** Let \( A_{(A,X)} \) be a system or object in a space \( X \) having a context \( \theta, A_{(A,X)} \) is said to exploit \( \theta \) if \( (A \cap \theta \neq \emptyset) \)

\[
\Lambda \left( \exists \ B \left( (B,B) \subseteq X : A \cap \theta \neq \emptyset \right) \right)
\]

**Example:** Let us consider two macro systems, Humans and Nature, where the latter provides the resources needed by the first. Nature codomain consists in a certain amount of resources fitting Humans domain. If Humans’ domain is satisfied by that amount, Humans adapt to Nature. If it exceeds Nature codomain, Humans exploit the environment (context) for the exceeding part, compromising their long-term sustainability.

**Parasitism**
Parasitism means adapting to another object or system without contributing to the latter sustainability. Hence, it means subtracting resources from the host without providing any directly or indirectly valuable resource for the host or its ecosystem. A parasite adapts to its host without contributing in any way to the host’s survival. As such, if there are no alternatives, it becomes a conditional necessary condition.

A system or object \( A \) is said to be a parasite of a system or object \( B \) if \( A \) depends on \( B \) and \( B \) does not depend on \( A \).

**Definition 6.1** Let \( G \) be the goal, \( ES_{(ES,ES)} \) its ecosystem, and \( A_{(A,X)} \) an object or a system such that \( G \neq A_{(A,X)} \), \( A_{(A,X)} \) is said a parasite of \( G \) if

\[
(A \cap (ES - A) \neq \emptyset) \land A \cap (ES - A) = \emptyset
\]

It is self-evident that eliminating parasites is a way to seek longer goal sustainability; however, parasitism must be treated carefully. It may be the case that taking two goals \( A \) and \( B \) for \( A \) \& \( B \) is a parasite and vice versa. If we define the goals differently, we will have different necessary conditions. However, using the correct vocabulary, we can deal with different goals by changing neither the meaning of the words nor the definition of sustainability.

**Efficient ecosystem and chain goal**
The efficient ecosystem is the ecosystem without subparts that reduce the resources available and demanded directly or indirectly by the ecosystem without providing any useful codomain. It is an ecosystem without its parasites.

**Definition 7.1** The efficient ecosystem of a goal \( G \) is the ecosystem of \( G \) without parasites.

**Chain goal**
A chain goal is an object or a system that must be sustained to sustain the (main) goal. It is individualised by the efficient ecosystem because each system and object belonging to it needs to be sustained to directly or indirectly sustain the goal. Hence, given a goal, for instance, the life of a human being, the chain goals are these systems or objects that must be satisfied to maintain human being life, such as these objects or systems providing humans with water and food.

**Definition 8.1** The chain goals of a goal \( G \) is the set of systems and objects composing the efficient ecosystem of \( G \).

**Mutualism**
In ecology, Mutualism describes the ecological interaction between two or more species where each species has a net benefit (Judith, 2015). In general, mutualism among two systems or objects means mutual dependence: they need each other to be sustainable. It is a special type of symbiosis. In our vocabulary, it simply means they adapt to each other. Consistently, it is a necessary conditional condition if there are no other alternatives available than a mutual adaptation for both parts, and it is a partial (or more often called optional or facultative) mutualism if these alternatives exist.

A system or object \( A \) is said to be in a mutualistic relationship with a system or object \( B \) if \( A \) depends on \( B \) and \( B \) depends on \( A \).

**Definition 9.1** A system or object \( A \) is in partial mutualism with a system or object \( B \) if \( A \) partially adapts to \( B \) and \( B \) partially adapts to \( A \).

**Definition 9.2** A system \( A \) or object is in mutualism with a system or object \( B \) if \( A \) adapts to \( B \) and \( B \) adapts to \( A \).

Mutualism is an improvement compared to mere parasitism because a part contributes to other needs by reducing or eliminating the need for exploitation and consequently allowing for longer sustainability. Mutualism can be interpreted through a proper aggregation, for instance, a chain of systems where each system adapts to the next (\( A \) adapts to \( B \), \( B \) to \( C \), \( C \) to \( D \), \( D \) to \( A \)) is adaptation in its subparts and mutualism if properly aggregated (\( A \) to \( B \), \( B \) to \( C \)), \( C \) to \( D \), \( D \) to \( A \)).
This entails that we can consider a circular economy as a chain of processes that, properly aggregated, create mutualistic systems or, ideally, a perfect cycle. A perfect cycle is the maximum expression of mutualism because it entails the perpetual sustainability of the mutualistic systems.

4 Discussion

4.1 Clarifying the general meaning of the definitions

Sustainability needs a goal, what to sustain, and in most cases, it should be pacific to consider human life as a goal; nevertheless, this is not necessarily true, and sustainability researchers may focus on other species, inanimate things, or abstract concepts as utility. To sustain humans (i.e. humans are the goal) means guaranteeing their survival. Humans can be defined through processes, and the maintenance of these processes entails the maintenance of their life. These processes interact and depend on each other forming the human system; in most cases, it is convenient to isolate the human system domain by identifying the inputs and other conditions necessary for its functioning (i.e. its life). By including the other objects and systems providing what the human domain demands, we are obliged to extend our focus on the human ecosystem, intended exactly as the net of interdependent processes (i.e. systems) that, if exist, then entail human existence. The human ecosystem’s existence depends on how its sub-systems and processes interact and how the ecosystem interacts with the context and its resources. If ecosystem sustainability depends on non-renewable resources, it must exploit the context to survive. To the extent that subparts of the ecosystem adapt each other becoming mutualistic, the ecosystem can reduce exploitation. The sustainability of humans and their ecosystem may adopt different strategies according to the length of time that strategy guarantees their sustainability; accordingly, each evolution to be a parasite, exploit, adapt, or mutualism is potentially valid. The following section will explain why we should aim toward mutualism, but while mutualism may represent the end of the fight for survival, the pathway to reach it may include other strategies.

4.2 Insights on the best strategy

We argued that each strategy is valid to guarantee sustainability and that one or the other may be necessary according to the circumstances. To sort these strategies in terms of goal sustainability longevity, we need to introduce further considerations. Let us consider (i) the fundamental law of energy conservation, the total energy of an isolated system remains constant, and (ii) the second thermodynamic law, that entropy over time is never decreasing in a closed system. Let us call our resources energy such that the overall amount of resources of the space is constant, it can only transform, and any transformation generates a positive or null entropy. Entropy must be intended as the amount of energy that became useless (Ayres et al., 1998), equivalently, as waste intended as these resources not satisfying the ecosystem domain. Finally, let us notice that any process generates a non-negative amount of waste.

Due to the finite amount of useful energy and the goal perceptibility, independently of its codomain (i.e. independently of the entropy generated and therefore the second thermodynamic law implications), exploitation consumes the context useful energy progressively until it is no more available to sustain the goal. Implicitly, it also entails that the codomain of the goal does not, directly or indirectly, concur with the sustainability of these systems or objects providing its domain resources because these do not exist. Hence, the goal codomain is a pure generation of waste.

If A adapts to B, then A sustainability endures until B is sustainable. In turn, if B exploits the context, then the previous considerations hold. Moreover, if B does not even partially adapt to A, then A is a parasite of B. If B partially adapts to A there is partial mutuality, and the waste is only the part they do not reciprocally adapt for; they generate less entropy together than by being separately obliged to exploit or to be parasites.

Switching from parasitism to mutualism increases the longevity of both the parasite and host (Wilson, 2014) by reducing the residual need to adapt to others or exploit the context. If partial mutuality becomes mutuality, there is no waste generation at all; it is a perfect cycle and entails perpetual sustainability. Figure 1 summarizes the previous lines of reasoning. The second law entails that a perfect cycle is an unreachable ideal aim (Śleszyński, 2018), but even without entropy, we showed that exploitation is destined to fail and the closer we go to mutuality, the lower the exploitation and entropy generated. Hence, to prolong the goal sustainability, our strategic aim can be generally said to be to reduce the entropy its ecosystem generates. Not surprisingly, life is an entropy-generating process found in low entropic systems (Lovelock, 1979; Smolin, 1997).
4.3 Sustainability rejects immutability and needs courage

Ideally, we aim to promote human life and its longevity by studying its sustainability conditions and those of its ecosystem. Such a study progressively aims to reduce the degree of approximation (that remains necessary) and may lead us to conclude that our goal is not sustainable. Consider the previous example of two human groups whose sustainability is conditioned to adaptation to a certain system (let us say a cultivable field) which codomain cannot sustain both groups (i.e., each group is a parasite to the other). In this case, we are obliged to choose which group to save or to save none. Once the goal group is selected, if the other group refuses to extinguish, only power and conflict may guarantee the sustainability of at least one group. War, which can be intended as the impendiment to the opponent’s domain satisfaction leading to its unsustainability (i.e., death), becomes a sustainability strategy or the failure of any sustainability possibility (Cairns, 2003). In this sense, and awareness of the enormous problems of population, human impact, climate migration and others (United Nations, 2021; United Nations Population Fund, 2021), sustainability scientists cannot be timid in their prescriptions and must be ready to accept that their role is less pleasant and comfortable than defining an ideal ethical development or nature protection.

By adopting a proper vocabulary, we are forced to avoid determining a contradictory, blurred, or unsustainable goal, and we must see that sustainability may entail unpleasant choices such as exploitation and parasitism. Sustainability definitions embodying any strategies such as ‘sustainability is adaptation’, ‘sustainability is mutualism’, and so on, must be regarded with scepticism. Sustainability is the maintenance of the goal over a certain time and in a specific space, it may be achieved with different strategies, and these must be continuously individualised; there is no catch-all tactic. In the same view, sustainability cannot be the natural capital maintenance, first because capital entails a monetary subjective-based evaluation, and second because immutability is precisely the opposite of life; sustainability may entail reshaping the environment, as humans always did, and its shape must be oriented to life or human life sustainability. In other words, sustainability is an easy concept, and any rigid word juxtaposed with it fails to recognize the complexity and the mutability of the systems, objects, laws and resources concurring to the sustainability achievement.

4.4 Final remarks

The vocabulary introduced does not exhaust all the definitions needed; more should be included, such as predation, stability (Volker & Wissel, 1997), resistance and resilience. Nevertheless, this extension would go beyond the targets of this work that have been successfully achieved: to provide a common and clear vocabulary for the essential elements concerning sustainability.

The nomenclature introduced makes sustainability a concept adaptable in different fields and disciplines without losing its meaning: it can be employed in system analysis and then specified in economics, ethics, ecology and other sciences. As such, it can be the base for an interdisciplinary discourse aiming at completing instead of differentiating the sustainability science. This is not only a possibility; such an integration is a necessity. Indeed, a goal sustainability is directly related to evolution and natural selection, as the nomenclature
suggested. Evolution is described by the development that, in turn, is governed by the interactions of objects and systems according to the laws of nature. The determination of the goal involves ethics. The study of the laws of nature is mostly a matter of natural sciences. The design of organizations and systems refers mainly to engineering and social sciences. Only the cooperation between these disciplines can reduce confusion and make sustainability a growing science.

5. Conclusion

Aggregating all the concepts related to sustainability and sustainable development in the latter definitions is confusing at best. Something is sustainable over a specific time if it exists in that time and exists in that time if its existing conditions are satisfied. Mutualism, adaptation, parasitism and exploitation are all potentially valid strategies to satisfy the existing conditions, and we may be forced to employ one or the other according to the circumstances. Clearly, mutualism guarantees longer sustainability and must consequently be preferred – if possible – to exploitation, but these considerations must be distinguished from the definitions of sustainability and sustainable development. Hence, sustainability is not adaptation, mutualism, parasitism, or exploitation, it is a clear concept whose winning strategies change over time according to the context.

It is complex to determine the existing conditions and the best strategy to hold due to many heterogeneous and concurring processes. In this regard, a proper vocabulary plays a vital role. The accurate definitions of processes and how they emerge once aggregated into systems and objects and their direct link to the resources change allows step by step to determine both the process sustainability, the development of the space considered and the threats of the (necessary) approximations employed. To control such a complexity, the mathematical formalization of these elements is a fundamental way to have consistent reasoning and individualize the piece of the reality to inquire further. Consequently, a vocabulary with these characteristics serves as a pillar on which to reconduct the diaspora of definitions to a set of questions to solve.

The main questions to enquire about sustainability are as follows: (i) what do we want to sustain (goal), (ii) which are the existing conditions for the goal, (iii) which systems and objects satisfy them and (iv) which are their existing conditions. Such an investigation endures until we define the goal ecosystem. The first question, what to sustain, needs a deep ethical investigation. Should we sustain human lives, human welfare, natural capital, or something else? Adopting different goals entails considerable differences because the chain goals and the ecosystems we derive from may differ enormously; a little difference in the goal is enough to determine a very different ecosystem. The second question concerns the individualization of the necessary conditions for the adopted goal to be sustainable over a defined lap of time. Such a step requires understanding other systems and objects composing the ecosystem and the parasites that threaten its longevity. Each system and object may have different relationships with the other elements of the space and the context. Does its sustainability depend on exploiting the context, being a parasite, adapting to another system, or maintaining mutualistic relationships? These strategies must be recognised and adopted; they exist as such. However, to the extent that there is space for changes and assuming that we prefer the strategy with the most extended longevity, we should aim to achieve mutualism. Mutualism entails that the codomain of a mutualistic system or object satisfies the domain of another object or system in the ecosystem and vice versa, increasing their longevity by reducing the waste and entropy generated. Finally, those steps require the cooperation of different disciplines, from ethics to biology, and each partial view increases the approximation with potential harm to the strategy’s success.

Notes

1. ‘After a defined period of time, the program, clinical intervention, and/or implementation strategies continue to be delivered and/or individual behaviour change (i.e. clinician, patient) is maintained; the program and individual behaviour change may evolve or adapt while continuing to produce benefits for individuals/systems’ (Moore et al., 2017).

2. ‘This paper defines environmental sustainability as meeting the resource and services needs of current and future generations without compromising the health of the ecosystems that provide them . . . and more specifically . . . as a condition of balance, resilience, and interconnectedness that allows human society to satisfy its needs while neither exceeding the capacity of its supporting ecosystems to continue to regenerate the services necessary to meet those needs nor by our actions diminishing biological diversity’ (Morel, 2011).

3. ‘From Rio to Kyoto, Bali, and Copenhagen, one of the defining concepts of our contemporary global culture is “sustainability”. But what is sustainability and how is it justified? What are we trying to sustain? Obviously, not everything that is sustainable is worth sustaining. So what makes some things worth sustaining and others not? Different answers have been given by different groups that reflect their own interests. How are we to judge among competing interests? To answer these questions, we will argue that sustainability is at its heart a matter of
ethics. To some this view may seem obvious. However, it is often overlooked or assumed without question. The problem with this situation is that when ethical views are left unspoken and assumed, the door is opened for counterproductive disputes. The goal of this paper is to explore the ethical foundation of sustainability, and highlight its essential importance’ (Gomis et al., 2011).

4. The reader should note that an object can be composed by a unique process such that from now on we will refer exclusively to objects to identify both a unique and a set of processes (whenever this set is not a system).

5. The reductionism applied by these examples to explain the terminology stresses how a discourse based on acceptable approximations may either lead to make huge mistakes or re-understand better our world.

6. Any goal is composed by processes, whenever aggregated, and any process must be perceptible, that as we saw means that the domain differs from the codomain and that both domain and codomain are not empty set.

Acknowledgements

The author is grateful for the precious conversations with Niccolò Cioli that enriched this paper.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The author received no direct funding for this research.

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Public interest statement

There is no unique and shared definition of sustainability; hence, we need clarification and standardization. This paper introduces a formal vocabulary for sustainability that uses both an English description and a deep mathematical formulation to help generate a consistent discourse for sustainability analytically and strategically. The vocabulary proposed highlights that sustainability is not necessarily adaptation, exploitation, parasitism, or mutualism; each is a potentially necessary condition for being sustainable, but they are not sustainability itself. The paper concludes by showing that mutualism guarantees the most longevity and that, whenever possible, it should be the favourite strategy.

Data availability statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

I confirm that all the research meets ethical guidelines and adheres to the legal requirements of the study country.

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Appendix: Nomenclature and symbols

Table 1. Symbols and names used.

| Symbol | Name                | Symbol       | Name                        |
|--------|---------------------|--------------|-----------------------------|
| $\chi$ | Space               | $f_{(\Omega \| \Omega)}$ | Process                     |
| $\Theta$ | Context             | $P_{(\Omega \| \Omega)}$ | Object or system            |
| $\Omega$ | Constitution       | $(\Omega \| \Omega)$ | System or object domain (left) and codomain (right) |
| $f$    | Function            | $T_{(t_1 \rightarrow t_n)}$ | Development or consistent development |
| $\xi$  | Domain              | $t_n$        | Time instant                |
| $\xi_n$ | Codomain            | $G$          | Goal                        |