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Towards a Visual Typology of Sustainability and Sustainable Development

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Abstract: Representations of sustainability and sustainable development, as images, figures, and models have received relatively little attention in the literature, compared with textual definitions. However, there has been a concerted effort by authors to communicate complexity to specialized and wider audiences over the past fifty years. The purpose of this article is to present a taxonomy of visual representations of sustainability and sustainable development that reveal the conceptual diversity and complexity of these metanarratives of the dynamics of socio-ecological systems (SES). Using an exploratory and interpretive methodology, the principal objective is to describe and interpret the core traits of 18 different representations, which reflect the hybrid nature of sustainability and sustainable development depictions, but also allow them to be categorized into six main types. This exercise is based on the review of images used in the secondary literature on sustainability and sustainable development, and also websites that have compiled sets of images. The shared roots or common traits of the six main types are to be found in the principles of complexity, nonlinearity, holism, projection, and praxis. These roots reflect not only the dynamics of SES, but also how these system representations change according to their purposes and etiologies which are, in turn, defined by the academic, public, and private actors who design them.

Keywords: typology; sustainable development; sustainability; communication; visual representation; etiology; systems; complexity

1. Is a Picture Really Worth a Thousand Words?

Sustainable development and sustainability are concepts that can be understood from different perspectives and approaches. They are also contemporary metanarratives in that they are widely used to reflect particular worldviews. To be clear from the outset, our understanding of the concepts is as follows. Sustainability is a dynamic condition of an inhabited or uninhabited place or space, which reflects the ways in which different material and immaterial elements are interrelated. This concept is closely related to common interpretations of the homeostatic nature of socio-ecological systems (SES). All places and spaces can be understood to have a condition of sustainability, which may range from very weak, where one dimension is emphasized to the detriment of others—to very strong, where there is a balance between, rather than a substitution of, these dimensions that enable society and nature to co-exist and thrive [1–4]. Sustainability is a positive concept, as it reveals 'what is'. However, sustainable development is the process by which there is an actor-driven transformation in this condition [5]. It is a normative concept, teleological, projected, and planned, revealing 'the production of what might be'. Based on this same distinction, institutional or governance aspects are often lacking in the former, and should always be present in the latter since the agents of change have to be clearly identified. What we know from the literature, however, is that our definition or understanding of these concepts is not unique. They are hybrid concepts with multiple definitions.

Broadly speaking, there is no consensus on the definition of sustainable development, although the widespread use of the World Commission on Environment and Development definition in *Our Common Future* suggests that this is the de facto choice within this polysemic textscape [6]. What is clear, however, is that there is considerable skepticism associated with the concept, especially as it has evolved out of postwar multilateralism and alongside neoliberalism since the 1980s. Critical voices note that a leopard never changes its spots. This skepticism has also been part of the production of diverse conceptualizations of sustainable development, as competing definitions and associated narratives have been devised to challenge core values, principles, drivers, and responsibilities in transformation processes [7]. This in turn has led to considerable 'noise' in the debate, and a general perception that sustainable development is such a malleable concept that it serves each to their own.

A principal element of this 'noise' is the challenge of simplifying SES and their development (understood here as transformation), through time. The essence of communication is clarity through reduction [8] or, in mathematical education terms, a 'didactical transposition' [9] or process through which "knowledge inexorably undergoes when it is adapted from its scientific/academic character to the knowledge as it is to be taught" [10] (p. 236). However, regarding the political background and roots of sustainability and sustainable development, understandings and the portrayals of knowledge—as socio-ecological change—are neither neutral nor easily reduced [11], due to the interrelatedness of phenomena, diversity of knowledges and experiences involved, and the interlocking scales and temporal dimensions. The simplification of a universal consensus of an abstract model of sustainability and sustainable development since the 1970s is political in essence since a message is being delivered, with explicit or implicit indications of causality and responsibility, and new pathways of transition or transformation. Visual representations therefore reflect the superficial, strong, or antagonistic ideas that lie behind a concept and its communication.

These representations (images, figures, and models) are presented in diverse numeric, symbolic, causal, and artistic constructions, as they seek to communicate with different audiences. A picture may be better than a thousand words to communicate a concept, or it may fail miserably, leaving the receiver with little or nothing in terms of understanding. The word hybrid is highly appropriate in this context, both for understanding, definition, visualization, and communication. It is precisely this hybridity that is of interest in this article, in order to explore the different attributes for envisioning a concept: triggering the external memory and long-term memory; reorganization of information in the working memory; and the links between concept and tangible elements [12].

There can be little doubt that visual representations have evolved alongside definitions of sustainable development, and that they are mutually reinforcing. From the flow diagrams of the 1970s to the building blocks of the Sustainable Development Goals in 2015, via Venn and Euler diagrams, 'environmental space' [13,14], prisms [15], hexagons [16], and metaphorical visual allusions, e.g., of sustainable development as a tree [17], visualizations have all influenced how the concept has been communicated over time. Some are diagnoses (of the order, hierarchy, and relationships between variables), while others are idealized states (indicating expectations from development processes), but they are rarely compared or analyzed. The objective of this article is to construct a typology of representations by comparing and contrasting alternatives that have been circulated over the past fifty years, based on etiology and intention. This typology provides a means of classifying current and future representations, recognizing the diversity of organizing ideas and representations of SES and their transformation. The methodology is based primarily on designing a categorization of common features in these representations in order to create a typology that covers the dominant forms. It is exploratory in nature, and descriptions of the principal features of each are provided in order to support future categorizations as new representations emerge. The examples are drawn from a search of representations in academic literature and also from collections of images that have been brought together in online sites. They cover representations of both definitions of sustainability and sustainable development, and also particular applications of these concepts, for example frameworks for the development of indicators.

2. Sustainability and Sustainable Development: The Role of Visual Discourse

As a powerful metanarrative of the late twentieth and early twentieth centuries, sustainable development and its constituent quality, the sustainability of the SES, have become instruments of common discourse, both in popular media and education, as well as in policy circles. In fact, there are relatively few voices that have questioned the concept, on technical, political, or cultural grounds [18–21]. However, what sets this metanarrative apart compared with other dominant narratives of this period, such as neoliberalism or postmodernism, is the use of visual representation for its communication. If asked to communicate graphically either the concept of neoliberalism or postmodernism, most people would hesitate. However, the ways in which sustainable development and sustainability have been brought into public discourse and civic education since the 1980s in many countries, has involved visual imagery. This phenomenon has also been evident in the evolution of Corporate Social Responsibility and its reporting [22]. Visual representation is ultimately based on the semiotics of communication. Citing Wagner [23], Nuttbohm et al. [24] reduce semiotics to three key aspects, against which the images can be analyzed: intention and understanding (the structure and relationship of signs for the communicator and the recipient); the selection of symbols (the relationship of the sign to what is represents); and the complexity and pragmatism of content (the ability to express complexity and connect this with the understanding of the recipient). Whereas there are multiple media for visual representations of sustainability, with different purposes—e.g., emotive triggering of photographs of dead wildlife or degraded landscapes [25,26]—the interest of this article is in abstract representations of the concept.

The triangle of sustainability is perhaps the most notable of these representations, a figure with its triad of social, environmental, and economic dimensions, most often accompanied by different nouns, e.g., social equity, environmental quality, economic growth; the homonym of this triangle is the overlapping ring figure based on the same triad. These rings and the triangle can be dated back to the conservation work of Barbier [27] in the former, and Munasinghe [28] in the latter, and they were popularized rapidly following the widespread coverage of the Rio Conference on Environment and Development in 1992. During the 1990s, these three dimensions provided the organizational framework for the UN Commission on Sustainable Development and other UN agencies, e.g., for indicator system development [29].

What is important to highlight in both these cases is that the objective of each of these papers is to understand how economics engages with socio-ecological factors (sustainable economic development and environmental economics, respectively). They are concerned with how the discipline of economics should capture wider development impacts beyond capital and labor effects, thus questioning dominant conceptualizations of economic development. For this reason, the economic dimension is given equal relevance to the social and environmental dimensions in their representations, as they are interested in understanding the articulations involved. They do not suggest that the economic dimension per se is of equal weight to the other two for understanding sustainable development. Figure 1 provides an overview of the principal representational forms that have emerged since the work of Barbier and Munasinghe.

Lozano [5] establishes three dominant forms of visual representation that fall into the categories of Venn diagrams, concentric circles, and what he terms the 'planning hexagon'. His objective is to build on the weaknesses of each to create a more synthetic and integrated model of the triad—first tier—that could also reflect the important intergenerational (through time) dimension—second tier—of the sustainability concept (Figure 1a). His Two-tier Sustainability Equilibria (TTSE) model is visualized as a 'rolling doughnut' or in mathematical terms, as a vertical toroid. Moir and Carter [30] also provide a critique of existing models, pointing—as Lozano [5] does—to their limitations in terms of representing integration, temporal, and spatial dimensions, and also agency and justice. However, their conflated visualization of sustainability is a triptych that merely connects three 'figurative forms' by emphasizing the dimension of democracy, which they stress based on the Seghezzo´s five-dimensional model (organized through axes of places, people, and permanence) [31]. As a representation that seeks

to separate out one complex image into three phases, there is a contribution, however, the suggestion of phases or directionality—with the use of arrows—should lead to a more complex final form. Instead, the final image is Lozano´s 'rolling doughnut' (Figure 1b).

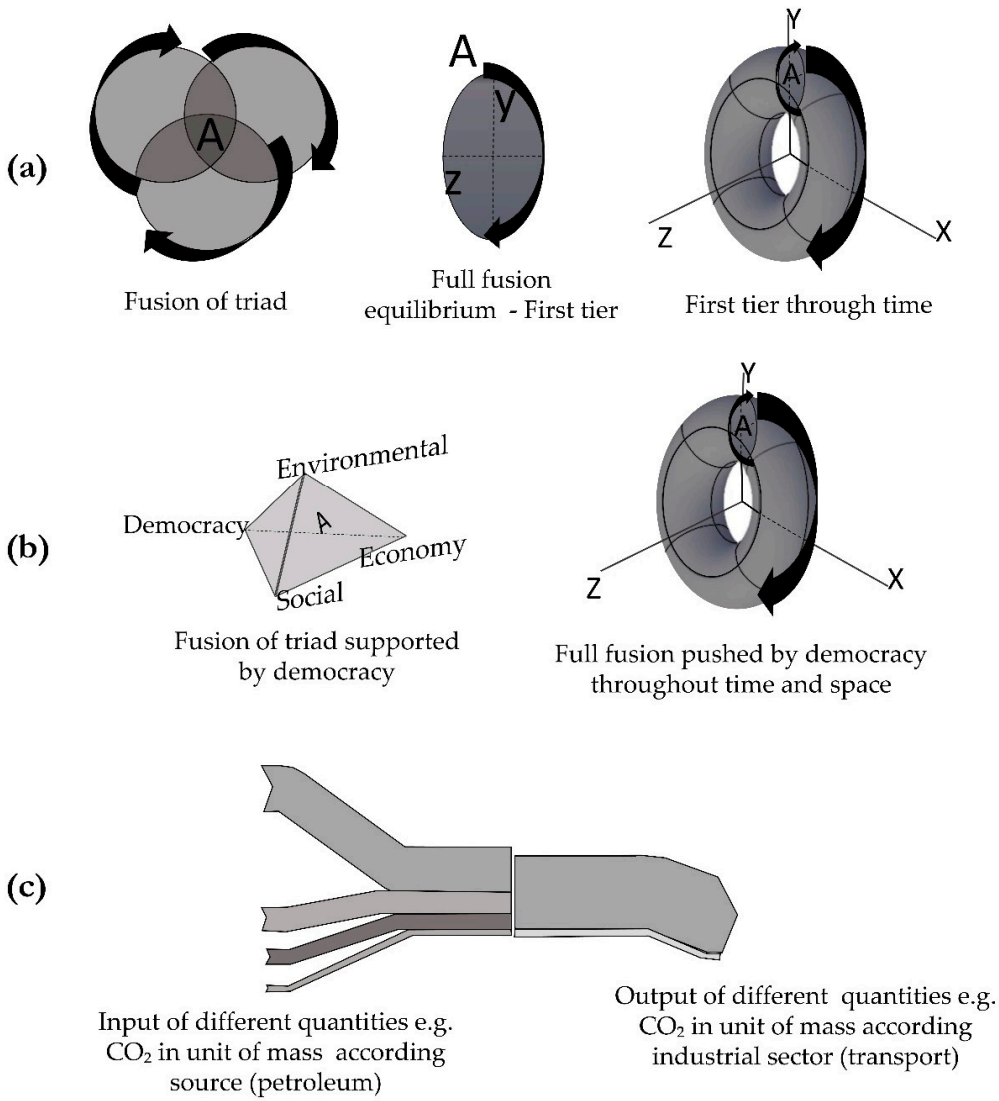

Figure 1. Reflections on the alternatives of visual representation. (**a**) Lozano's [5] proposal, (**b**) Moir and Carter' proposal [30], (**c**) Sankey diagrams [24]. Source: Authors´ modifications of originals.

A different approach to sustainability communication is offered by Nuttbohm et al. [24], who reflect on the value of Sankey diagrams that show energy and material flows through the width of arrows associated with each; it is a representation of a balanced equation (see Figure 1c). While they emphasize the need for communication and its visualization to be attuned to target groups rather than universal, they also recognize the potential limitations of the quantification of all the dimensions of sustainability, in particular the more intangible components of society. For this reason, most sustainability visualizations that seek more universal acceptance avoid the representation of data. Nevertheless, this engineering process approach to visualization, with its roots in industrial ecology, including the well-known case of the Danish city of Kalundborg [32], is clearly evident in SES approaches to representation where not only the concept is presented, but also its operationalization in situ (with an emphasis on the specificities of context).

These three articles reveal some of the inherent complexities involved in understanding visual representations and how they might be reduced to a common figure. However, the intention of

creating *the single best figure* will always be a process rather than an outcome. A visual equivalent of the Brundtland definition may be found, but it will not close down the options for other images, figures, and models to be devised and communicated; textual and visual diversity will continue to co-exist, and this may be a strength of sustainability and sustainable development discourse, or criticized as a weakness. For these same reasons, and for further analytical research, it is useful to organize these representations in categories that share common roots and intentions.

3. Data and Methods: The Construction of a Typology

3.1. Previous Taxonomies for Envisioning Sustainability and Sustainable Development

Categorizing definitions that circulate in the public arena, and which therefore shape the notions and subjective perceptions of sustainability and sustainable development more generally, is useful for understanding how knowledge is created and communicated. The categorization of a definition begins with a previous understanding of a concept, onto which a new meaning is constructed. A further step is the visualization of this idea for purposes of facilitating communication and revealing a "perceptual hypothesis" [12] (p. 462).

The classification of sustainable development and sustainability can be accommodated within taxonomies [33,34]. Broadly speaking, the work of Leiserowitz et al. [33] manages to differentiate what it is to be sustainable and what it is to be developed in order to achieve this sustainability. In terms of what it means to be sustainable, they classify nature (planet earth, biodiversity, and ecosystems), life support (ecosystem services, resources, and environment) and community (culture, groups, and places). In terms of what it means to be developed, they add people (infant survival, life expectancy, education, equity, equal opportunities), economy (wealth, productive sectors, and consumption) and finally society (institution, social capital, states, and regions). Sartori et al. [34] provide an alternative taxonomic type, by offering a chronological review of authors that identifies types of studies (empirical and theoretical), types of dimensions (environmental, social, and economic), and finally, scale (of a specific order, such as global, national, and regional). Both of these examples reveal that taxonomies can express complexity through a process of systematization. This article follows along these same lines, by creating a taxonomy based on visual representations.

Lozano [5] in his analysis and proposals of images of sustainability, constitutes a starting point in the classification of visual representations. He distinguishes five perspectives on sustainability, from the least to the most convincing, according to the author: conventional economic; nonenvironmental degradation; integrational; intergenerational; and holistic. A general criticism that the author provides is that the images respond to disciplinary, spatial, and nontemporal criteria or to the integration of different disciplines. For this reason, he arrives at a model that includes three main dimensions of sustainability, based on synergies and movement in time and space.

Lozano's classification of categories does not provide examples of visual representations with respect to conventional economics. Implicitly, it might be said that these can be addressed through a Venn diagram, where each of the domains represented by spheres do not touch each other, or in a Euler diagram, where the economy is the core for the development of the social and environmental dimensions. On the other hand, the perspective of the 'environmental nondegradation', is strongly influenced by the environmental, in which exponents "do not consider the importance of social aspects, such as the interrelation between the environment and human rights, corruption, poverty, illiteracy, child mortality, and epidemics, amongst many others" [5] (p. 1839). He does not take into consideration the work of Costanza and Daly [35], or Daly and Cobb Jr. [3], which draws on these socio-economic factors. There is a considerable body of work in ecological economics that points to the biophysical contradictions of the conventional economy and raises the need for an alternative economy based on consumption thresholds to maintain environmental spaces [13,14]. Unlike these two categories, the three remaining ones manage to classify particular figures, recognizing that the main driver should

be the fusion between integrational and intergenerational categories that, in turn, can be reduced to a fifth main category: the holistic perspective that is presented as a vertical toroid (see Figure 1b).

Moir and Carter [30] followed up on Lozano's [5] work by looking at the limitations and uses of each of these categories. Beginning with the Venn diagram, they point to the 'nonintegration' of the associated dimensions and the difficulty in establishing relationships between dimensions and making these more explicit. Based on authors such as Mebratu [36] and Lozano [5], they note that the Venn type of representation may be too reductionist and epistemologically trapped in terms of the interaction between the parts and the whole. In addition, they reveal that in this type of diagram there is a tendency that can potentially lead to a concern for the environment at the expense of social development, likewise obviating elements such as dynamism and scale. With regard to the nest diagram, technically known as Euler's diagram, the limitations point to the economy being at the center, as a nuclear concept, thus complicating the connections to social and environmental impacts and nullifying the visualization of the relationships involved [5,30].

Despite the deconstruction of various representations, Moir and Carter [30] do not take Lozano's [5] work much further in terms of understanding representations that reveal the interrelations between dimensions, complexity, scale, or governance. Unlike Lozano [5], Moir and Carter [30] provide a typological analysis of different visualizations of sustainability and sustainable development. The difficulties of mobilizing the concepts of governance and agency through visual representations are common to most of their representations. For instance, how is participation and interest group representation to be portrayed, or the role of democracy in the formation of more sustainable societies? [2,13,37]. For this reason, the question arises as to whether the concept of democracy—for example as universal suffrage [38]—could guide the necessary transformations in sustainable development, and therefore should be a *sine qua non* of a visual representation of this process.

Due to the large number of representations that have been developed over fifty years, the taxonomies employed by Lozano [5] and Moir and Carter [30] provide important insights into how to organize and understand them. Not only do they reveal ways in which different classifications of representations can convey performance or transformations, but they also point to the concepts and ideas that underpin how sustainability and sustainable development are constructed, understood, and communicated.

3.2. A Visual Taxonomy of Sustainability and Sustainability Development

Although the use of visual representations has served different theories and conceptualizations, it was during the 1990s that a particular, dominant representation of sustainability started to emerge. This was based on the environmental economics work of Munasinghe and Shearer [39], and it portrays sustainability as a hybrid concept based on a triad of connecting dimensions. Furthermore, there was recognition not only of complexity but also of learning and the capacity to act in order to transform processes and situations: "The triangle directs attention to the capacity to adapt and take advantage of new kinds of opportunities such as come with the inevitable change in environmental conditions. It is because of such changes that analytical tools need to be developed that try to reconcile the conceptual tensions" [39] (p. xxi). Another pioneering image, associated with the condition environment-economy-society was provided by Barbier [27], with the difference being the use of the Venn diagram to connect the dimensions that lead to sustainable economic development. This representation was proposed as a way of questioning conventional liberal economic approaches as well as the limitations of Marxist economics. Although both Barbier [27] and Munasinghe [28] developed visual representations that focused on the limitations of dominant *economic* approaches, they became absorbed as the forms for representing sustainability and sustainable development that were widely circulated in the 1990s and persist in contemporary sustainability imaginaries.

Both representations provide the elements and concepts that underpin sustainable development, for not only diagnostics—the operational nature of the SES—but also for pointing towards a more Platonic, desirable, utopian, or balanced future: the projection, evolution, movement, or development

of the SES, whether circular, linear, or panarchic [40]. However, it is difficult for one representation to reveal all the relevant dimensions, e.g., dimensions of a theoretical nature (social, environmental, and economic), relations (causality), and/or existing elements (ecosystem, material flows). Consequently, the visual representation of sustainability usually emphasizes one particular set of dimensions, whether a diagnosis of a system, or a desirable goal, hence, they fulfill the communication of a particular focus or concern. Bauer [41], summarizes these as: How are we? (Diagnostic), Where are we going? (Idealized state).

Another consideration is the causation that leads to the choice of the representational form. Venn diagrams have a different purpose than figures that project a relationship only by means of arrows, or a visual order of a geometric type. The ways in which figures, symbols, and words are organized within the figure respond to different purposes. However, the ways in which the key elements of a concept are organized visually respond to a specific communicational context. For example, it is possible to communicate causalities, interrelations between dimensions, fusion between (sub)concepts, correlations, gradation of a variable, and projections of concepts in tangible forms derived from nature or the built environment, or merely to transmit a simple organizational form that establishes an order for the constituent parts, as in the UN Sustainable Development Goals.

In this article, the term etiology is employed—in Greek, the study of causation or origins—in order to reveal the causes that support the choice of organization reflected in the representation. By establishing the etiology of the organization of the elements in the figure, one can try and understand the authors' intentions and, thus, reveal whether figures can be grouped together or whether they fall into another category of the typology.

Based on a review of numerous representations of SES designed and communicated since the 1970s, in published literature and available on institutional and personal websites, six categories were considered according to common etiologies (see Figure 2). These classifications have no priority or ranking order since they seek to separate visual representations into groups according to shared dominant characteristics rather than establish *the single best figure*. The first of these, *Venn and Euler*, denotes a visual distinction of independent elements, dimensions, areas, or concepts, including their fusion or merging. *Venn* highlights the outcome of fusions while *Euler* notes the concentric relations that reflect a particular order, such as in ecological economics and the categorization of capitals or assets. A second category is *Flows*, which refers to elements, dimensions, areas, or concepts that are linked by causal order, for example, input–output. They usually refer to systems that account for a process of a certain phenomenon, derived from systems theory and most often focused on systems diagnostics; see, for example, representations of the relationship between ecosystem, economy, and stocks in Daly [42]. Third, there is the *Euclidean and Cartesian*, which refers to the relationship between variables in one, two, or three-dimensional planes, each of which representing a quantitative or qualitative decrease or increase. It should be noted that the *Euclidean* denotation only corresponds to the geometric plane or space while the *Cartesian* refers to the mathematical notation of that representation. Fourth is *Geometrical organization*, which uses a geometric figure to provide visual order, without necessarily showing a direct relationship between the variables. The fifth category of the typology involves the incorporation of *Tangible forms* that reflect beings, subjects, and objects drawn from society, nature or the built environment, and that can be easily understood by most observers. Finally, there are *Hybrid* representations that bring together etiologies, dimensions, and forms that draw on the other categories. These six categories or types will be discussed in more detail in the following section.

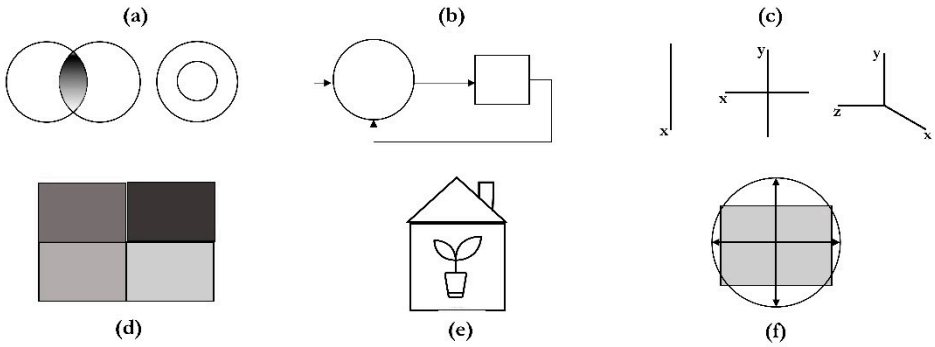

Figure 2. A visual typology of sustainability and sustainable development: (**a**) Venn and Euler, (**b**) Flows, (**c**) Euclidean and Cartesian, (**d**) Geometrical organization, (**e**) Tangible forms, (**f**) Hybrid. Source: Authors.

4. Results: Traits and Depictions of Sustainability and Sustainable Development

The representations in Figure 2 are abstractions that are derived from specific examples that emerged from a review of fifty years of images of sustainability and sustainable development available in the specialized literature, the grey literature, and the websites of organizations and individuals (see for instance Mann [43]). Each categorization is presented with three examples in order to reveal the general features, advantages, and drawbacks of each. It should be noted that the selection of examples was made on the basis of the aforementioned categories according to their etiology, and with a view to covering different time periods and definitions of the key concepts (see Figure 3).

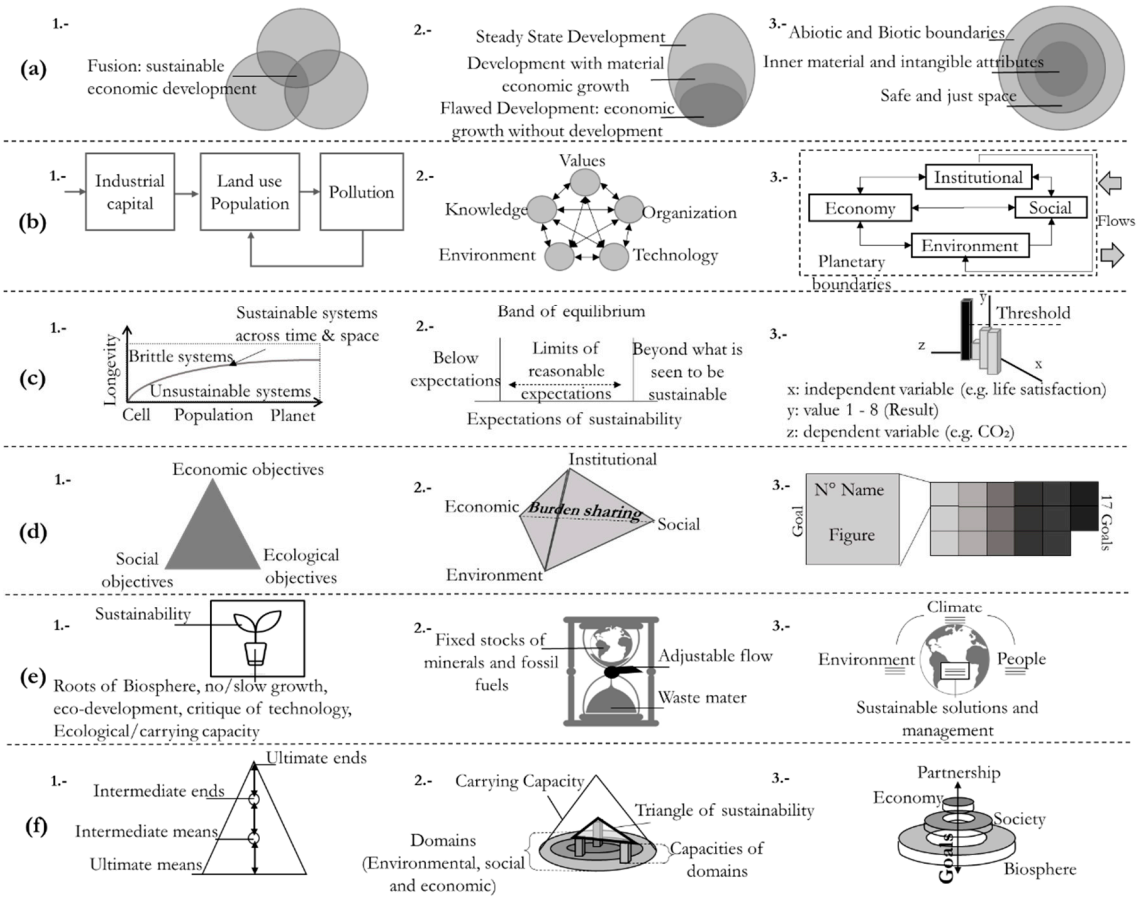

Figure 3. Examples of the visual typology. (**a**) Venn and Euler, 1 [27], 2 [44], 3 [45]; (**b**) Flows, 1 [46], 2 [47], 3 [48]; (**c**) Euclidean and Cartesian, 1 [49], 2 [50], 3 [51]; (**d**) Geometrical organization, 1 [52], 2 [53], 3 [54]; (**e**) Tangible forms, 1 [55], 2 [56], 3 [57]; (**f**) Hybrid, 1 [4], 2 [58] and 3 [59]. Source: Authors.

4.1. Venn and Euler

In the first category, we can see that the structural elements of sustainability jump to the eye. Barbier [27], in his use of *Venn*, reveals that sustainability is a fusion between social, environmental, and economic dimensions (see Figure 3(a1)). This diagram provides a hypothetical situation at a time *t* and another idealized situation at a time *t*+*n* in which there is a complete fusion of the dimensions. Similar versions of this *Venn* model, the most common of all, show different gradations of fusion of the concentric circles, but all suggest a directionality in that the goal is for these three dimensions to be considered in unison, fully overlapping, as a representation of the holism of experience rather than the abstraction of fields or disciplines.

Although Barbier [27] does not show the ideal situation in which the dimensions are completely fused—as proffered by Lozano [5]—it helps us to differentiate and contrast the fusion between dimensions (economic-social, social-environmental, and/or economic-environmental) and the degrees of sustainability that this fusion could generate, by observing the degrees of separability between dimensions. Adams [60] (p. 2) calls the different degrees of fusion "the theory", "the now", and "the change that is needed", basing his observations on the work of the International Union for Conservation of Nature (IUCN) and their use of this representation. The figure is therefore suggestive, not only of the elements themselves, but also agency and transdisciplinarity: the social dimension may be understood as the actors that initiate change, environment as the sphere in which change is undertaken, and economy as the process by which needs are satisfied. However, other terms are also used for these converging rings and may suggest other logics and attributes. For example, Dréo [61] defines the spaces of convergence as equitable (social-economic), bearable (social-environment), and viable (economic-environment). Beyond the common acceptance that there are three rings in motion, the terminology used for each varies: social, social equity, society, people, social capital; economic, profits, finance, management; environment, ecology, planet, nature, natural capital.

A different case is provided by Gallopin [44] in Figure 3(a2). Gallopin contributes from a developmental perspective to suggest how countries can achieve strong sustainable development. Although the author specifies that his model is a *Venn* diagram, it is worth noting that there is no fusion between the different dimensions, but rather a theoretical proposal that differentiates between types of development. Consequently, this type of diagram is best described as *Euler*. It roughly denotes three types of development: flawed development; economic growth; and steady-state development. What this *Euler* diagram lacks is the suggestion of how these three types engage with one another, or how one might evolve from another.

A more dynamic model, that is more suggestive, is provided by Raworth [45]. This representation contributes to an understanding of the interdependence of the different dimensions (see Figure 3(a3)). Indeed, the most effective *Euler* diagrams reveal how one dimension supports another: the social depends on the environment, while economic change and cultural values depend on social dynamics (see for instance Costanza et al. [62]). The 'doughnut' model offered by Raworth [45] is related to a tradition in sustainability representation that is best defined by the term 'environmental space' (see Opschoor and Waterings [14]; Spangenberg [13]; Larrain [63]). However, the inclusion of more detail in terms of specific elements, effectively deconstructing the three principal dimensions, narrows down on the more intangible attributes and basic needs in society: social equity, income, resilience, voice (participation), education, water, jobs, energy, gender equity, health, food, and resilience. By integrating an idea of environmental space, there is a suggestion that there are absolute but flexible limits, as the Brundtland Report [64] defines these system boundaries. This is best captured by the later term 'safe operating space for humanity' [65]. Raworth [45] therefore links a diagnostic spatial representation (environment-social) and connects this with more detail on cultural-economic values and attributes at the center, as well as consideration of some outputs from human activity (land use change, biodiversity loss, ozone depletion, ocean acidification, chemical pollution, freshwater use, ocean acidification, climate change, and atmospheric aerosol loading) and homeostatic cycles typical of the natural balance (nitrogen and phosphorus cycles).

The effectiveness of the recent promotion of Raworth's doughnut model is precisely in the same vein as Barbier's [27] rings, in that—as a visual representation—they are both highly effective in communicating key messages: operating limits and welfare in the former, and the need for fusion rather than centrifugal fragmentation in the latter. Both *Venn* and *Euler* forms have made the most important contributions to the dissemination of the sustainability and sustainable development concepts since the 1980s. As representations that are easily assimilated due to their low abstraction, they are able to link, contrast, and fuse the principal domains that are used as shorthand for understanding the main dimensions of the development process of SES: types of development [44]; types of domains or dimensions [27]; and an explicit environmental dependence [45]. In terms of their differences, Raworth [45] presents a more rigid, spatial structure, while Barbier [27] and Gallopin [44] provide more potential scenarios for the dimensions that are presented, which is in itself one of the advantages of the *Venn* figure.

4.2. Flows

In the second category, we have *Flows*. These reflect the systems theory tradition and have been prevalent during the twentieth century in a wide variety of fields, principally at atomic or cellular scales, as well as in industrial systems and geographical movements. One of the greatest advantages of *Flows* is that, for larger scales, they have facilitated the connection between the principal dimensions via a form of explicit reductionism. One of the most important examples (Figure 3(b1)) in the field of environment and development is that by Meadows et al. [46]. Although it does not present a graphic definition of sustainability or sustainable development per se, it is interesting to note how human activities end up triggering problems due to the interdependence between variables, i.e., industry, food, deforestation, natural resources, population, and pollution. What this *Flows* model provided was both an opportunity to reveal knock-on effects and trade-offs, and also the presentation of an alphanumeric view of planetary carrying capacity or global thresholds for sustainability. The ambition was to use this *Flows* model as a basis for predictive simulations and scenarios.

The work of Norgaard [47] and Gallopin [48] are also shown here in terms of *Flows*, as they conceive of sustainability as a relationship between different domains with contrasting characteristics (see Figure 3(b2,b3)). Whereas there is a quantitative emphasis in Meadows at al. (1972), Norgaard (1994) emphasizes more intangible and far-reaching attributes, such as values and knowledge, which bring more philosophical considerations into the *Flows* representation, thus highlighting the importance of ethics and culture to potential sustainability transitions or transformations. Consequently, Norgaard [47] transcends the limitation that *Flows* diagrams should only reveal cause–effect relationships. In this case, each of the five dimensions is recognized but, at the same time, they are revealed to be wholly interdependent. There may be overlaps here with the premise of Barbier's [27] overlapping rings, in that these five dimensions are a unitary whole that have been separated out in the representation to reveal the principal components of this development 'whole'. Other attributes that Norgaard [47] adds are organization, environment, and technology. These point to the links between more ethical and cultural considerations and more physical and institutional arenas, leading to definitions of sustainability that connect with more recent notions of adaptation and resilience. Gallopin [48] also stresses the institutional dimension in his *Flows* diagram, highlighting the planetary limits which are affected by the flows among human activities, both of appropriation and excretion (see Toledo [66,67]). Unlike Norgaard [47] who represents his concepts as a balanced connection between different concepts, Gallopin [48] provides more of a diagnostic that connects the political dimension to the 'classic' triad that was the preferred representation of the 1980s and 1990s.

The *Flows* category represents an opportunity to maintain the dependence or independence of the selected dimensions. The common theme to the *Flows* shown here is that they are part of the ecological economics tradition that was set in motion by Daly [68], in order to unveil the interaction of physical flows in the economic process. The three authors selected here reveal the complexity involved in representing development processes as a single 'machine'. They provide summarized

visual representations of this complexity, but with the opportunity to enter into each dimension in detail and also to understand the connections. Gallopin [48], in his Evaluation of the Sustainability of Latin America and the Caribbean (ESALC) project, provided three levels of sophistication of a development model, and was particularly creative in emphasizing the connections as much as the dimensions and subdimensions involved. *Flows* diagrams, as with other visual representations, are consistently confronted by the challenge or choice between simplicity for public communication, against detail for understanding. Clearly the audiences are different in each case, but the decision that has to be made in terms of creating a visually attractive representation or a scientifically precise representation, is similar to the differences in language used in different forms or modes of scientific communication to engage with different publics.

4.3. Euclidean and Cartesian

The third category highlights the etiology of variables' correlation and their qualitative, or generally quantitative variations. Three subtypes were identified: one-dimensional to three-dimensional (see Figure 3c). In their quantitative correlation, Costanza and Patten [49] note a scale versus time relation, from the cell to the planet and against longevity (see Figure 3(c1)). What the figure projects is a purely physical relationship that suggests that the definition of sustainability can be seen through the lens of the biophysical capacities of each species, and in relation to others at different scales. In the authors' own words [49] (p. 195): "A sustainable system in this context is thus one that attains its full expected life span within the nested hierarchy of systems within which it is embedded". This correlation facilitates the identification of 'brittle systems', in which a period of existence extends without necessarily constituting a system (organism to planet), or 'unsustainable systems', in which a system is constituted but has a short duration.

A different approach is adopted by Bell and Morse [50] where, instead of two variables, one is used—'expectations of sustainability'—in order to draw out sustainability theory and practice (see Figure 3(c2)). For Bell and Morse [50], this is key to defining qualitative potential thresholds in the development of indicators. The 'band of equilibrium' would be the agreement between different actors according to the local sustainability indicator, e.g., population's response to healthcare. As with the correlation of Costanza and Patten [49], limits of sustainability are established and these should be taken into account as diverse actors seek to meet specific goals, for example, as measured via indicators. A further step in the same direction is provided in the case of the representation of 'a good life for all within planetary boundaries' by O'Neill et al. [51]. Figure 2(c3) provides more detail in terms of the different variables involved. However, it maintains the importance of the relational elements between these variables, and incorporates an evaluation based on these variables. The independent variable is constituted by those attributes that form the quality of life spectrum (Life Satisfaction, Healthy Life Expectancy, Nutrition, Sanitation, Income, Access to Energy, Education, Social Support, Democracy Quality, and Equality). The qualitative dependent variable is that which is derived from the increase or decrease in the standard of living for people (in relation to CO_2 emissions, phosphorus, nitrogen, 'bluewater', and the ecological and material footprints). The other dependent variable refers firstly to the quantitative values of the quality of life standards, but it also displays this value (originally in red or green), in which it is possible to distinguish whether these values exceed the ecological threshold (see also "Explore scenarios" in https://goodlife.leeds.ac.uk/). Consequently, this representation enables a relational, cause-effect view on sustainability, while simultaneously including numerical thresholds on planetary capacity.

These three *Cartesian* and *Euclidean* forms are particularly strong in representing the relevance of limits in sustainability thinking. While the first focuses on the sustainability of physical entities over time, the role of human systems can be understood as another point along this horizontal axis. The inferences of limits in the terms 'brittle' and 'unsustainable' are extended further in the second figure, where the role of actors and agency, via perceptions for example, build on the notion of thresholds. As in the case of *Flows*, the aesthetics of the figures are framed by a physical-mathematical

reading of development, employing bi- and tri-dimensional forms. Although Bell and Morse [50] highlight agency, as Norgaard [47] does in his figure, the challenge of representing subjective and cultural dimensions—relating to values, knowledge, and collaboration—alongside physical parameters, remains difficult to represent, although O'Neill et al. [51] reveal that progress is being made.

4.4. Geometrical Organization

The *Geometric* type provides an aesthetic that has a strong visual-ordinal etiology. The first of the examples, from Claude [52], is typical of the use of a triangle, which has become perhaps the most popular form, alongside the intersecting rings (see Figure 3(d1)). While the rings showed the importance of the overlapping spaces, where these dimensions were considered together rather than separately as sectors, the triangle offers all of the internal space as interaction between dimensions, thus reducing the emphasis on their uniqueness in the first place. Claude [52] was particularly interested in the inclusion of a subtle difference through the word 'objective', leading the conceptualization of sustainability towards something institutional, relating to action.

The second example (Figure 3(d2)), provided by Valentin and Spangenberg [53], adds the additional dimension of institutions, as Gallopin [48] also did in his *Flow* diagram. The ways in which different authors have sought to integrate agency, rather than solely the impacted realms or objectivized dimensions, has been an important characteristic of many visualizations. Rather than showing the effects of development, the incorporation of an institutional dimension has highlighted the ways in which organized agents—in civil society, firms, and public-sector organizations—have responsibility for, and can influence these impacts and reduce trade-offs between the other dimensions of the SES. A further consideration is how an institutional dimension relates to the others, and whether it is of a different order, thus surrounding the others or central to them, as an articulating or pivotal element or driver.

A further derivative of the use of *Geometrical organization* is in its use in the communication of the Millennium (MDGs, 2000–2015), then Sustainable (SDGs, 2015–2030) Development Goals (see Figure 3(d3)). Vivid colored building blocks provide this most widely communicated visual representation of sustainable development to date. Despite having a description inside each block, there is no relation of each of them to one another; it is a list, presented as blocks, with an implicit suggestion that Goal 1 (an absolute end to poverty) is the headline indicator, as it was in the MDGs (MDG 1: a relative reduction in absolute poverty), with institutional goals at the end (Goal 17, as partnerships were for MDG 8). However, the numbering has no explicit logic. The blocks are arranged as neatly fitting units as part of a larger, whole block: the sum of its parts (with the title of the SDG graphic constituting one of these blocks). Each of the 17 thematic SDG blocks is disaggregated into its own objectives and (231) indicators. While there are 12 indicators that are repeated in different blocks, and reveal that there are overlaps, the use of blocks is certainly weaker than the other two figures in terms of projecting the interrelations that exist, e.g., within the triangle or the prism.

The option of the building blocks as a *Geometrical organization* is clearly a design choice for communications purposes, focused on showing themes rather than interdependency and interrelations. However, by presenting a form that does not stress holism and trade-offs, it may promote 'silo' thinking and improvements in the 231 indicators without sufficient recognition of the fact that actions to change one indicator trend will have repercussions on other situations and potential actions, and therefore on other indicator trends. The UN building blocks provide a good example of a visual representation whereby abstraction may impede understanding of the processes and agency involved. While the text and narrative that accompanies the SDGs emphasizes interconnectedness, holism is not communicated well in this figure.

The use of *Geometrical* forms provides an alternative to *Venn* and *Euler* diagrams, by representing sustainability and sustainable development concepts in terms of dimensions and goals that are linked in some way, via an axis or the wall of a building block. They are weaker in establishing what type of connections occur, whether fusion, causal or correlational, in relation to other representational types.

However, their strength lies in the use of forms that are most commonly used and assimilated in daily life and in formal and informal education. This familiarity suggests that their communicational element largely outweighs the intention of revealing complexity to further understanding. The propagation of the triangle in different circles is testament to this point but the triangle itself may limit the conceptualization of sustainability and sustainable development, for example the role of agency. By following in the tradition of the overlapping rings and suggesting that there are three principal axes that define SES and the development processes that shape them, it has constrained the emergence of other multidimensional conceptualizations and forms, or has at least dominated among the representations that have emerged. Perhaps the most serious limitation of this triad is how 'economy' is considered to be a dimension that equates to 'society' and 'nature' [69]. When Barbier [27] developed his model, he used the 'economy' alongside the other two to make a point about linking economy and environment more explicitly. The proliferation of the triad maintains this emphasis, but with little consideration of why this dimension has been constructed as an equal, rather than a mechanism or process that links society and nature in positive and negative ways.

4.5. Tangible Forms

By *Tangible forms*, we refer to the antithesis of rigid, mathematical figures, such as representations that have a closer connection to everyday life. As with the triangles and building blocks noted above, they are likely to have a stronger communicational impact. The first example, from Kidd [55], uses the flora analogy through which the strata (roots) indicate different concepts which ground sustainability (see Figure 3(e1)), and provide insights into planetary carrying capacity by focusing on the analogy of the single plant. To communicate the equally complex concept revealed in the second law, of entropy, Daly [56] uses an hourglass to show the importance of containing human activities and associated flows by slowing energy dissipation (see Figure 3(e2)). While the first has a strong ecological foundation, Daly's [56] is based on ecological economics. The third, revealing the importance of communication, is an example from the corporate world. Figure 2(e3) used by Neste Oil [57] focuses on the solutions that are required to improve sustainability conditions, classified under society (people), natural capital shelter (environment), and adaptation and resilience (climate); there is a strong emphasis on efficiency gains and on business engagement with human rights, although these issues are not transmitted directly through the figure.

In this category, the figures are metaphorical, at least in the cases of Kidd [55] and Daly [56]. However, the disadvantage is that there may be multiple interpretations of each. As with *Geometrical organization*, these figures are conditioned by the preconceptions of the *Tangible forms* that are selected. For instance, which attributes would represent the land and water in Kidd's [55] sustainability and sustainable development? Consequently, while these figures are aesthetically striking, the message that they convey may be less explicit, or may have to rely more fully on the accompanying text. The three figures offer contrasting proposals of how sustainability should be conceptualized. Kidd [55] for example, does not include social aspects in his definition but stresses the technological, biophysical, and economic dimensions, while Daly [56] highlights the biophysical lens and not necessarily what this means for sustainability per se (although, implicitly, the loss of energy may well be interpreted as a slow systemic demise). Finally, the Neste Oil [57] example shows how sustainability has been incorporated into the corporate sector with a focus on efficiency and Elkington's 'triple bottom line' [70]. Rather than attempting to represent a socio-ecological system and its development processes, it merely highlights how the firm projects its interests and responsibilities, in terms of solutions to specific challenges and problems, which are most often driven by regulation and consumer pressures.

4.6. Hybrid

The diversity of visual representations of sustainability and sustainable development reflect the complexity of the SES and processes that are being communicated. For this same reason, many representations capture different aspects of the other types noted above. Since there has been fifty

years of adaptation and evolution of these representations, from the systems diagrams of ecological economics in the 1970s onwards, emerging from different disciplines and with different emphases, the principal conclusion is that there is considerable hybridity. An example of the ways in which different conceptualizations have been fused can be seen in Donatella Meadows' modification of 'Daly's Triangle' [4] (Figure 3(f1)). Meadows [4] frames sustainability in order to develop indicator systems (which has been a common purpose of many figures, see Liu et al. [71]), and adapts elements of Daly's [68] *Flows* type, combined with elements of *Geometrical Organization*. An orientation to the triangle is provided by the aim of 'ultimate ends' (welfare, or similar constructions such as happiness, harmony, or community). Whereas the base of the triangle is founded on the biophysical properties of nature, the aim requires an engagement with ethical, moral, or spiritual considerations, exceeding merely physical or material basic needs. Between the 'ends' one finds the intermediate stages of 'intermediate means' (built and human capital) and 'intermediate ends' (human and social capital), highlighting science and technology in the former, and political economy in the latter. The addition of hierarchical order to the *Flows* and *Geometrical organization* types communicates purpose as much as equilibrium, with a strong anthropocentric dimension to the figure. However, this anthropocentrism is always tempered by the fact that the edifice, without its base, will crumble.

The second example fuses *Euler* and *Cartesian* 2-3D and *Geometrical organization* types (see Figure 3(f2)). One of the most flamboyant aspects of Mauerhofer's [58] example is that it places sustainability (as a two-dimensional triangle) within planetary limits, stressing an equitable development of each of the dimensions, that can be appreciated by parallelepipeds on a *Euler* form. With the purpose both of diagnosis (planetary limits) and the projection of an ideal state (triangle of sustainability), the figure offers a fine balance between the environmental dimension and biophysical limits, with the first understood as an institutional ethos, while the second is an imperative condition given by the natural order to which the human system must adapt. The last of the three figures, by Rockström and Sukhdev [59], constitutes a re-interpretation of the goals of sustainable development based on *Euler 3D* plus *Flows* of a hierarchical, bidirectional type, similar to that provided by Meadows [4]. The base layer corresponds to the protection of nature, moving upwards through the economy, and finally to Goal 17, which translates into coordination and alliances between countries and institutions in order to generate the goals. This last element highlights the importance of the institutional basis of agency in sustainability transitions, which is clearly more apparent over the past decade when compared with the 1980s and 1990s. This example is linked clearly to the geometry of the building blocks of the SDGs, but is represented in terms of Daly's Triangle and with elements of safe spaces, which was also taken up later by Raworth [45]. It has a clearly institutional origin, which suggests an idea of sustainability aligned with institutional objectives, as in the building blocks.

These figures all share the basic principal of representing complexity through simple forms, particularly Meadows [4], and Rockström and Sukhdev [59]. It is also relevant to note that they emerge from different etiologies, and have different purposes. On the one hand, Meadows [4] develops a modified triangle, with its origins in Daly's 'Steady State Economy' in order to organize elements for an indicator system, while Rockström and Sukhdev [59] aim to provide theoretical coherence to the goals of sustainable development. Mauerhofer [58] offers something quite distinctive in this regard, establishing a definition of sustainability that is also located in the space we inhabit. In all three cases, traces of other types are present, and they share the strengths and weaknesses of these choices.

One could argue that all visual representations of sustainability and sustainable development are *Hybrid* since they mimic certain tropes of previous figures, attempt to project different conflations of ideas and purposes, and offer a visual summary of this SES complexity. However, there are commonalities, and it is these commonalities that constitute the five previous types. While it may be possible to situate the three examples in this *Hybrid* type in other categories, the provision of a more flexible category to accommodate more diverse or plural forms supports the basic premise of the article, that these categories are relatively fluid given the diversity of the figures and the complexity of the ideas and concepts that they represent.

5. Conclusions: The Shared Roots of Complexity, Nonlinearity, and Holism

In the context of contemporary digital social networking, in which concise sentences and images have the potential to alter perceptions and shape ideas and opinions in brief moments, representations of frameworks and concepts have become increasingly important. They not only trigger, and accelerate, processes of reflection and cognitive understanding, but also the critical analysis of complex phenomena. This is clearly the case for sustainable development, and has been part of the incorporation of the concept since the 1980s when the term was first popularized in *Our Common Future* [64]. Since that time, many authors and organizations have tried to encapsulate their visions of sustainable development and sustainability in a figure, drawing on historical traditions in their disciplines, and systems theory and thinking in particular, such as ecology, industrial ecology, and ecological economics. This article is not a systematization of these hundreds of images of figures and models. Rather, it attempts to establish a typology of forms to which these representations can be assigned, in order to organize and summarize this diversity and reveal the differences in the etiologies that underpin them.

Undeniably, there are differences in how sustainability and sustainable development are visually defined, albeit many of the figures are not antagonistic but complementary as they view similar phenomena from different perspectives. We can see this, for example, with Gallopin [48] whose figure points to the creation of a system of indicators, while in Daly [56], the figure points to the conditions and physical limitations in which the economy moves. In other words, the images trigger different cognitive levels in which we can identify the hybrid nature of sustainability and sustainable development, but without necessarily classifying all representations as having the shared feature of hybridity (which we have reserved for type f). For example, representations in a *Tangible form* are a starting point for children, to grasp the concept while *Euclidean* and *Cartesian* representations associate these concepts with scientific traditions of relational representations. These representations show how variables relate to one another, revealing limitations or restrictions, and the ways in which they impact on one another. The commonly discussed type in this sense is the *Venn* representation. The challenge in visual representations of complexity is both to reveal the processes by which sustainability transitions are generated, while also revealing the supporting dimensions of this transformation and how they overlap. In most cases, the dimensions are reduced to environmental, social, and economic spheres of action or policy, which in turn offer a tangible route to praxis, as in Mauerhofer's model [58].

While some images deal with cognitive levels where physical elements predominate, others place more emphasis on interrelationships or agency. The key feature of these visual representations is the issue of complexity, considering interrelationships and interdependency. In comparison with other dominant metanarratives of the late twentieth century, such as capitalism, communism, modernity, developmentalism, or neoliberalism, and the comparative lack of imagery, sustainability and sustainable development have been visualized in multiple ways. This is due to the intention of revealing complexity and holism based on diverse etiologies that emerge from different disciplines and ideologies. They all, however, contrast with the linearity that dominates in terms of the argumentation and the process of the other metanarratives; W.W. Rostow's [72,73] modernization theory best encapsulates this reductionist, linear approach. Complexity and nonlinearity are shared by all six types of representation.

While the complementarity of the figures with their respective dimensions is evident, each of the figures constitutes a particular context: purpose and etiology. However, a typology that represents sustainability and sustainable development should reflect the diversity of elements and the richness of these holistic concepts, and their roots in values and agency. These representations support formulations for decision-making and for establishing priorities.

For example, Meadows and Daly are key to understanding that the economy is a process and that priorities, although of an anthropogenic nature, must establish the roles and thresholds of both biotic and abiotic matter, and the consequences of economic growth on the carrying capacity of different SES. Understanding that the conditions of sustainability in each local context are varied and particular, a representation of an idealized figure of different dimensions (most often a triad) provides a road

map for decision-making for different actors to work with and to frame their planning processes, and potentially to define indicators for monitoring them.

The six types of visual representation summarized in this article provide a means of organizing ideas and information, and almost all are rooted in systems thinking, hence SES. The same exercise could be undertaken for the thousands of definitions that co-exist, in order to establish core traits and genealogies. The commonalities of the types are evident: the focus on the triad, with the later addition of governance and agency; manifestations of complexity and holism; and orientation and projection. However, they all have contrasting etiologies and seek to emphasize different qualities of forms and processes, and communicate with different audiences. In this sense, the typology points to the challenges that are faced by praxis in sustainable development, in which simultaneous transformations must take place in science, in public policy, in private practice, and in wider society. Each of these challenges is likely to need its own visual road map of transformation that summarizes many thousands of words, and a world of complexity, in a picture. Rather than these pictures being better or worse than each other, it is important to value their relative etiologies and communicational functions for transmitting the complexity of socio-ecological dynamics and transformations.

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