Sustainability and Research into Interactions

Suman Devadula and Amaresh Chakrabarti

Abstract Sustainability is an ambitious interdisciplinary research agenda. The required knowledge, tools, methods and competencies being spread across wide-ranging areas pose challenges for researchers in sustainability who often specialize in one discipline. The efforts of researchers to understand sustainability comprehensively and contribute will be benefited if research outcomes are presented against an integrating framework for sustainability knowledge. Though general systems theory has this agenda, it targets consilience and not sustainability in particular as in sustainable development. However, systems concepts provide for a structure to imbibe aspects of sustainability. We propose a nested structure for organizing relevant research across the various scales of concerns that characterize sustainability. As understanding sustainability fundamentally requires understanding the interactions between natural and human systems, we discuss this in the context of the proposed structure and research into interactions.

Keywords Sustainability research · Nestedness · Interactions · Systems coherence

1 Introduction

Sustainability science is an ambitious agenda comparable to the Copernican revolution [1] and aspiring to integrate theory, applied science and policy, making it relevant for development globally and generating a new interdisciplinary

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synthesis across fields [2]. It emphasizes management of the human, social and ecological systems from an engineering and policy perspective at earth scale. A systemic conception of earth comprises four spheres i.e., atmosphere, biosphere, lithosphere, hydrosphere, and the interactions between them. To make a further distinction, researchers in climate change have added the *Anthroposphere* or *technosphere* as separate from biosphere in comprising anything anthropogenic i.e., the effects of human and social systems in terms of the emissions off the first-world industrial revolution [3], resource over-use [4], etc. On the other hand, skeptics opine that progress of any civilization, both cultural and economic, is afforded by the provisions of the environment, and that when environmental conditions are themselves dependent on other cycles, periods of rise and extinction of species human or otherwise, become a consequence of these cycles. The frequency, amplitude and the coupling of these cycles can lead to periods that afford life or prove detrimental to it [5], relegating questions of sustainability to happenstance.

The questioning of current development trajectories and the future that the burgeoning third-world should take, leaves little scope for chances to be taken. Hence, addressing unsustainability at the required scale and intensity requires a systemic understanding of interactions between human, social and ecological systems for making meaningful inferences and consequent action. While there are dangers of conclusive inferences out of trials to force simple reductionist models onto a diverse set of world situations [6], approaches that rely on a sub-set of potential variables of socio-environmental systems (SESs) and propose abstract cure-alls for solving complex SES problems prove detrimental too [7]. Sustainability of SESs requires us to build a coherent understanding of how systems are progressively linked to ever larger systems and how upward and downward causation linkages occur within an SES as well as across diverse sectors and scales. This is a prescription for sustainability research involving interactions across scales. The varied nature of reading material, knowledge of worthy disciplinary contributions to sustainability requires a framework for structuring disciplinary knowledge in the broader context of sustainability. In this paper, we propose a structure for supporting systemic understanding of interactions at various scales that can also be used for organizing literature on sustainability.

2 Interactions

For understanding complex systems, it is believed that a focus on interactions rather than the entities within a system opens up vistas. Interactions are ontologically equivalent to entities in *entitification*. The process of *entitification* (Fig. 1) identifies entities. The existence of a differential simultaneously provides an ontological basis for entities and interactions. Interactions are self-liquidating as the differential gradient deteriorates with interaction time. Interactions are inferred through changes in energy, material, information or entropy generically.

The dynamic of interacting entities, as real world systems, is provided by modern thermodynamics. The second law of thermodynamics gives a direction to progression of systems. Isolated systems progressively increase their disorderliness toward thermodynamic equilibrium. Contrarily, open systems, when exposed to a sufficient differential, tend to spontaneously decrease their disorderliness while increasing that of their environment. Behaving in this way, these systems evade thermodynamic equilibrium by self-organizing and increasing in complexity. Such systems are referred to as far from equilibrium self-organizing dissipative structures (FFESODS), and by nature of their behavior including information, there is much debate on such interactions to be characteristic of organisms and life. Contrasting these two types of systems, which together comprise parts and the whole of the universe, shows that while the whole tends towards disorganization and equality, parts further organization and distinction. Such systemic behavior, of the particulars as well as the whole, fundamentally describes interactions among them. This is illustrated as a juxtaposition of two cycles (Fig. 1): one, in bold arrows, represents natural cycles where sustainability is not a question as this 'is'; and two, in outlined arrows, is the anthropogenic cycle, in which, out of knowledge of natural laws, the impression of differentials onto existing entities changes the availability of opportunity (resources) to natural cycles and hence potentially, their course e.g. the construction of dams changing downstream natural cycles, accumulated GHG's changing the intensity of monsoons etc. As the services humans get out of natural systems are irreplaceable, the magnitude of change they initiate affecting natural cycles to their own detriment is the subject matter of sustainability. Note that both these cycles ever abide by natural laws, the difference being the magnitudes of action of the anthropogenic cycle resulting in magnitudes of reaction of the natural cycle. The management of consequences arising due to differences of these magnitudes is the interest of sustainability, as a praxeological prescription of what should be the case for the human use of earth. Note that the above systemic notions used to define interactions assume as entities characterized by their boundaries, when in reality it is a continuum of their properties (or attributes). This leads to the concept of boundary uncertainty influencing interactions at different scales. These scales are nested by nature. As sustainability requires a reconsideration of many prevailing ways of interaction, Fig. 2 is conceived to systemically consider interactions across nested scales of reality. Though the concept of nestedness exists in ecological, AI and social sciences, the consideration of the unifying force across scales provides a context for explicitly considering interactions. The annular areas represent scales of reality; the concentric circles demarcate scales, the crossing of which marks interactions relevant between scales from sub-atomic (part) reality to the universe (whole). The entities that comprise a scale are alone not sufficient to describe that which results in the next level. Figure 2 should be read as any annular area being a scale of reality comprising of the physicality at the scale lower to it along with the interactions relevant between these scales as indicated in the interaction column to the right, e.g. particles along with nuclear forces comprises the atom, atoms along with chemical forces comprise molecules, etc. Proceeding from the organism ring either

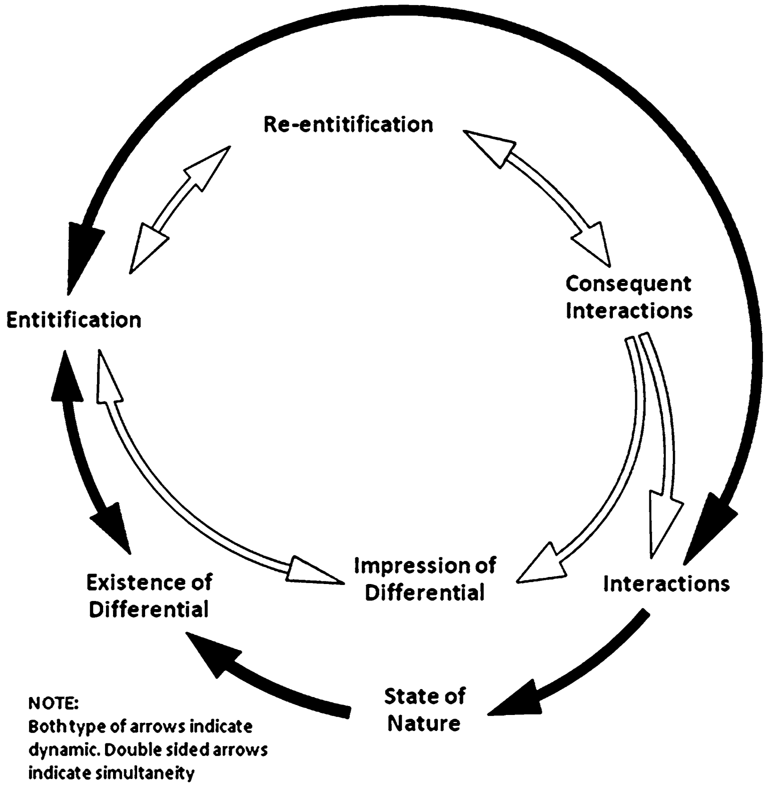

Fig. 1 Interactions in the cyclic nature of reality

ways, the dotted circles indicate the uncertainty in knowledge associated at the micro or macro scales. The organism ring is demarcated with full lines as the notion of certainty through identity, either in the form of cell wall for the cell or territory for the animal, is explicitly reinforced. However, proceeding either ways leads one to realize that identity, and in extension reality, is actually punctured. This realization of reality, the other inference of the dotted circle in Fig. 2, paradoxically leads to being nothing (represented by zero, at the centre) and everything (represented by infinity, at the outset). The implications of findings at the fundamental particle scale are applicable at the highest scale. Thus, at the scale of constituent atoms we are indisputably creatures derived from the cosmos [8]. However, the implications at the intermediary scales in terms of human-environment interactions are unclear, makes research inquiry challenging given the indeterministic, normative nature prevalent at these scales [9]. Given the fact that sustainability is characterized by requiring a transition from the self-obliterating state of affairs, the knowledge required for informing such a transition is felt at various scales culminating in a worldview which is an individual's or community's

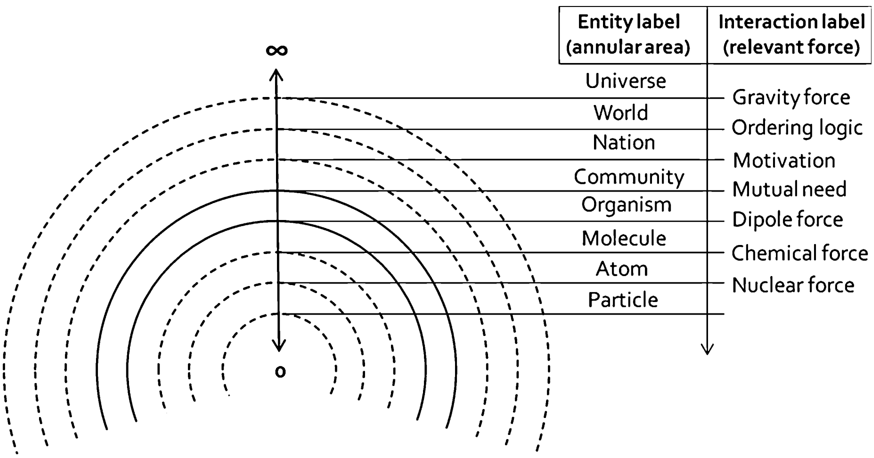

Fig. 2 A structure of reality for ordering knowledge of interactions for sustainability

conception of reality. We present issues and questions ordered according to the scales they address as relevant for a transition to making development sustainable.

2.1 Universe

The universe is so grand to our sense of time and space that we conceive it as one infinite i.e., 'uni'. Gravitational force, acting by virtue of the planetary mass and relative distance, is the unifying force of entities of the lesser scale. The grand scale of space, time and matter that the universe spans make it the bearer of evidence for answering questions of origin of matter and life within cosmic phenomena. The fact that certain life-sustaining physical constants have just come right in this earthly corner of the universe is attributed to chance [10]. We are yet to have a cosmic neighbor to share our mundane experiences of the planet and possibly learn from theirs. A view, provided by the universe beyond the earthly limits, that can establish any fact of planetary life elsewhere affords pan-earth notions of life and hence a provision for a cosmic-praxeological framework to hang our individual planetary behavior in comparison of our earthly responsibility. An example theorizing life's origin is *pan-spermia* which states that a great percentage of interstellar dust is microbial and that striking comets or meteors can be potential vehicles for these microbes to prime evolution [8] on habitable planets like earth. Another example is the notion of 'self-realization of the cosmos' [11], which, carrying forward Spinoza's idea of substance, states that the essence of universal substance is to seek plenitude. The metaphors linking this scale of reality to ours are *spaceship-earth, cosmic speck of dust, pale blue dot, cosmic sea, planetary stewardship* etc. What matters to our sustainability at this scale is the prompt knowledge of stellar events involving the earth and the ability to handle their effect e.g., a comet about to intersect the earth's revolutionary path, radiation from novae, the influence of the sun, etc. At the grandest scale the universe affords being considered as an isolated system. Consequently its ever increasing entropy makes chaos, irrespective of life's activity otherwise on earth, increasingly more probable. Though the time-scale of this fact is way beyond what can matter in a life-time, it provides an eventuality within which we may strive to achieve a goal that fits our human condition and is commonly agreed upon for its worth.

2.2 World

The world comprises nations and people in them. Nations, as protected sovereign territories by governments authorized through the consent of their people in a democratic election, come together out of common interest based on their respective foreign policy based on ordering logic [12]. The metaphors relevant at this scale of reality are mother earth, *Gaia, only home, earth democracy, earth system governance* etc. This scale and the two lower ones, nation and community, are partly or wholly human constructs, and are included as real scales in Fig. 1 as they are the sources of our highest institutions. As we have grown to be dependent upon our institutions, they serve as the instruments with which we organize effort in the economy, both for routine conduct of affairs of the state and for working out sustainable transitions required. The institutions at this scale are supranationalist e.g., the UN, ILO, IMF, WB etc. These were mostly products of first-world flagship and the necessity was/is felt particularly at times of challenges that span national borders e.g. League of Nations for stopping WW2, ILO for internationally protecting worker rights, UN for stopping WW3 and working for world peace and security, G5 nations comprising the superpowers having veto power in the UN etc. Consequently, interactions at this scale are determined by how states conduct in the international society of states based on the agreements they sign or ratify.

Sustainability is a problem irrespective of national divides and hence may be said to be situated at this scale of reality. One conception of the earth is as Gaia, indicating that the earth is a self-correcting system and that humans should consider consuming its resources within its spring-back. Though the climate crisis has proven that sustainability challenges need unqualified planetary scale efforts, nations continue to be divided on how to share responsibility for the causes of damage (CBDR argument of the Third-World), their repair, and the monetary and intellectual investment necessary for working out a global agenda. The failure of the recently held Rio+20 conference in relation to any of its preceding summits is testimonial to this fact. Leading environmentalists have observed that the call for sustainability is of earth scale, recommending 'earth democracy' from a preservation perspective. Others have called upon 'earth governance' in an effort to free individuals from the hold of their nationalist identities that offer no protection in times of natural calamity proving detrimental to humanity. Sustainability needs sincere, committed effort from the nations to invest in the required intellectual and technological capability towards helping all span the transition to a better world in which everyone realize their full potential.

2.3 Nation

The continental shelves along with geographic surface features provide for the political demarcations between countries that are otherwise explicitly erected and surveyed continuously. Beyond this the idea of a nation is constructed by two forces. One, the vesting of authority in the government by the will of the people participating in free and fair elections of representatives, and two, the patriotic feeling driven by the resourcefulness of the country necessary for sustaining its population. The metaphors in use e.g., *mother, homeland, motherland, fatherland* etc., are testimonial of the perspective of a provider of nourishment. The idea of lack of resources elsewhere accentuates the second feeling, more of which may seed fundamentalism [13]. Consequently, the matter of interest for sustainability at this scale is the preservation and distribution of national resources to its citizens through drafting effective policy [14–16] and appropriately realized and represented systems of governance and administration, the well-being indices by which national progress is measured, the human rights treaties to which nations are internationally signatory that serve to check its domestic policy against its own citizens as humans first, the transparency and independence of its judicial system to civilians, institutional provisions for recognition of civil societies etc.

2.4 Community

Environment provides necessary resources for the survival of plants and animals. Man is unique among these animals in having abilities to communicate using language [17, 18]. This enabled him to think, extend his cognition, gather groups, organize effort, enterprise and effect a change in the resources to produce tools and artifacts that in turn better equipped him for survival. Consequently his capabilities had multiplied beyond his rather frail abilities; however, this development has been non-uniform over the planet wherever people thrived into communities and civilizations. Each progressed at their own rate based on the limitations of locally available resources and their own physical and mental limitations in effecting change for their advantage. This may have led to exchange/trade across settlements and civilizations for mutual benefit driving a curiosity for and interest in exotic resources. Unlike the previous scales, the smaller size of this scale stands greater chance of suiting the physical and cognitive limitations of more of its members and hence results in more individuals knowing most about their communities. The first notions of community among simple bacteria that grow in local environs can be called ‘cultures’ while mutualism, commensalism, amensalism etc. are fitting labels for animals interacting within communities for satisfying shared needs. Ecologists, identifying the scales at which a phenomenon is applicable [19], have extensively researched establishing community structure within which they are now able to predict interactions with some certainty. Consequently, the scales at which such communities form, limited by available natural resources and mutual necessity of its members, seem to be closer to the natural cycle than higher scale constructs that are positively maintained to cater to the masses by the exploitation of resources elsewhere. This implies that communities at this scale are generally self-sustained within their knowledge-base of the surroundings and of collective action necessary for corrective measures to be taken in an event of disturbance [15]. Prevalent institutions here derive their authority either through democratically elected representatives in free and fair elections or are vested in members practicing traditional occupations that emerged in mutual necessity. Other communities that form are institutions e.g., welfare associations, manufacturing institutions, and virtual communities e.g., social networking, chat groups, etc. The role of these institutions for sustainability is commensurate with their resource use. One example is the corporate sustainability performance initiatives that have become important while emphasizing the role of the corporation in the affairs of the state and of people. Hence it is of interest to sustainability at this scale to understand how such institutions can be steered towards meeting goals of sustainability amidst tighter constraints. On another note, the community an individual is part of partly provides for the construction of his identity [20] and this is essential in framing his interactions with the other members and his contribution to the society as a whole.

2.5 Organism

From unicellular organisms to plants and humans, this level consists of all entities that are capable of self-maintenance and self-replication. This scale consists of all biota of the planet listed by the entities of the trophic levels in ecology. The fundamental unit of this scale is the ‘cell’ in its capability to maintain and replicate itself. Consequently of interest at this scale of reality are the capabilities of these organisms amidst changing contexts. The changing contexts are primarily of the environment requiring the organism to adapt to it or perish. However, contexts also change due to organismic activity, e.g., decreasing availability of resources as organismic populations increase. It is argued that the need, for formation of cell wall is necessitated by the competition for resources amidst increasing organismic populations in the *primordial soup*. This situates the problem for the organism’s sustainability amidst organisms similarly driven.

Homo Sapiens are the first to alter natural courses at planet scale and also be aware of this fact [6]. Though this generally occurs post facto, we only have instantial knowledge of doing otherwise under less severe situations like avoiding ozone depletion (Montreal Protocol). This gives rise to metaphors like *technological adolescence, earth-scale stupidity, geo-engineering, techno-fascination, earth-worthiness, megabuck science* etc. The capacity of humans residing in this scale to be aware of their bio-physical structure as well as their possible realization of entailing concepts of uncertainty and pervasiveness, make this a scale in which conceptions, however rudimentary or refined, of all the other scales become possible. One such concept is anthropocentrism that provides a basis for rights and hence sustainable development too. Objective validation of hypotheses, framed at various scales of reality through appropriate experiment and method may support the anthropocentric notion of sustainability. It is stated that to proceed "…from bacterium to people is less of a step than to go from a mixture of amino acids (molecules in Fig. 2) to that bacterium (organism in Fig. 2)" [21]. This scale of reality is also where notions of identification with oneself as an entity on the general basis of sustenance forms the pivot of all arguments in the process of evolution by natural selection. At the extremes, and exemplary in this context, are the creationist and naturalist [22] explanations to life. Consequently, the matters of concern at this scale are behavior, conduct, intentionality, responsibility, rights, duties, truth, purpose, agency etc. Correspondingly, the fields of interest are axiology and praxeology as ends, and ontology and epistemology [23] as means. In short, the worldview of humans is the fundamental concern as this [24] influences our conception of reality, including the earth and its use, in designing [25] to meet our requirements. Motivation for human action at various levels of satisfaction is otherwise provided by a hierarchy of human needs [26], though the influence of a worldview is beyond these motivations.

Worldview is a conceptual system by which we order reality, irrespective of its scale, and hence seem to find our way comfortably in it. Worldview orders interactions and the plurality of worldviews implicates sustainability of the whole. While ontological inquiry provides insight into what is and what being is, epistemological inquiry focuses on the process of acquiring this knowledge, particularly on tools and methods, and their limitations for such acquisition. Language of discourse, scientific method, deduction and inference are some examples of such tools and methods [27]. Axiology explores criteria for evaluation of reality, meaningful life worth living and what should one strive for. Sustainability, as a concept, with its notion of human centrality takes some answers for such axiological questions, granted. That human life is worth striving at the cost of anything else for by the individual himself and the community so that every individual realizes his full potential is one such answer. Even in phrases like 'environmental sustainability' or 'X sustainability', it is the human whose well-being has to be preserved, for which an environment's or x's contribution is required and hence to be ensured. However, if the epistemological basis for human centrality is ill-founded, the concept of sustainability needs to re-work its priorities as might be the case under a paradigm of 'life-centrism or ecological naturalism' [9]. Ontology and epistemology need provide the means for answering axiological and praxeological questions related to sustainability. The choices we make depend on the worldview we inherit or learn to adopt. Until we become conscious of our worldview and plan to override its influence, we may not be acting sustainably [28]. In this connection, leaders of religion and nations on different occasions have urged mankind to inculcate 'universal consciousness' that is fitting for world peace, security and sustainability.

2.6 The Lower Three Scales

These scales comprise of all a biota of the planet. Nomenclature is extensively developed in these fields, though development of integrative frameworks for organizing knowledge for interdisciplinary research has been an afterthought [29]. Implications of research findings at this level are fundamental to at all scales of reality, though within the assumed anthropocentrism, of relevance to sustainability is research that has direct implications to humans alone at whatever cost to the rest. Concepts like uncertainty encountered at these scales have far-reaching implications to our conception of reality as it could change our paradigms towards that necessary for sustainability.

3 Discussion

Sustainability science is a relatively new, inter-disciplinary, and fast developing field of inquiry, which lacks coherent reference material and textbooks [30]. Sustainability, as humanity's concern and at the scale at which it is required renders national, political and personal boundaries porous. Consequently, economies must invest in and drive the sustainability agenda domestically while co-operating to follow the sustainability roadmaps laid out by neutral, supranationalist organizations. In this regard, though the Rio Summit of 1992 was promising, the recent Rio+20 conference of the UN was a failure, described as the longest suicidal note by activist groups. Henceforth it is personal conviction in sustainability that should motivate people to commit time and effort towards influencing the short-term interests of their domestic governments towards making and leaving the planet a better place to lead life. Individuals value different scales of reality differently. These differences set up arenas for people to field opinion and discuss perspective comparatively. Sustainability, as a human ability, is predominantly a social argument, in requiring us to be able to mutually support successfully informing ourselves of realizing purposive action determined by the limits of the earth. Hence, within the natural tendency of systems to deteriorate, sustainability is a human ability to communicate action to come to grips with a deteriorating environment individually while limiting its voluntary deterioration in attending to needs alone [31]. With this basis to the argument, it is appropriate to refer to interventions as 'tackling unsustainability', in a Sisyphean sense [32], that is more real in involving more time and effort rather than a vainglorious phrase of 'achieving sustainability' which is only momentary.

The outlined inner cycle of Fig. 1 represents the design cycle of making, reflecting and modifying. From the perspective of interactions and the scales of reality across which they can occur, designers are implicated to control the amount of change that the product/process life-cycles have on the natural cycles. Philosophically this requires design to be negative rather than its conventional understanding of being positive. Negative design is about design being reactive, initiated only under circumstances where it is widely indicated that "…life has gone wrong" [33]. The stimulus for negative design is not an imagined future but a real problem in the form of a changed context similar to evolution fitting a new environmental context. Negative design intends only as much as necessary to bring the state of affairs back to being in accord with the new context. While positive design imagines a future and designs for it, negative design reacts to real world [34] problems and designs to resolve them. This contrast of design philosophy may be likened to the thermodynamic context of sustainability, i.e., as the contexts to which we need to self-organize as complex biological and social systems change naturally, personally furthering their magnitude and frequency of change is uncalled for as it may demand organization of a scale that we may not be able to match, in scale and in time. Though LCA assessments provide for point-estimates of environmental impacts, designers should be sensitive to the dynamic concern of sustainability, and assess the life-cycles of products and processes for their consequences on vital natural cycles, before going forth with product development locally or globally.

4 Conclusions

Understanding sustainability necessarily requires knowledge of aspects of multiple scales of reality and their interactions. The entailing requirements for data are so huge that sustainability research is limited to only few aspects of reality thereby falling short of making any holistic claims about sustainability. The integrative research agenda spanning scales of reality of sustainability science implicates science to coherently structure its disciplinary findings within a framework. Addressing this, a structure of reality is proposed to order knowledge of sustainability. Within the organism scale of this structure, the difficulty of addressing normative aspects within the methods of science and discussions on other approaches to conceive and understand reality is accommodated. Sustainability springs from a human rights and dignity core. As inviolable rights claiming their bearings in natural rights derived from natural law, the concept of sustainability needs to be founded naturally and thereby ground anthropocentrism, it relies on. The proposed description of interactions based on thermodynamics aids understanding the dynamics of interactions across all scales of real world systems. This, along with the description of the scales of reality proposed, indicate a probable theory of interaction that could order inquiry across disciplinary borders accommodating relevant normative aspects. Towards this, we have systemically structured exemplary sustainability literature, presenting aspects of it in context.

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