UNIVERSITY OF GÄVLE

FACULTY OF ENGINEERING AND SUSTAINABLE DEVELOPMENT
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Of Chaos And Clockworks

A Formal Criticism Of The Modern Sustainability Paradigm

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2023

Student thesis, Advanced level (Master degree, two years), 30 HE
Sustainability Science
Master in Sustainability Science - Environment and Decision Making

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Preface

As its title suggests, this thesis owes a huge debt to the works of Karl Popper and David Deutsch. If it achieves nothing else, I hope that it at least introduces some readers to the worldview advanced by these brilliant men. I would also like to thank my sister Maja for her support, and my supervisor Stephan for his many helpful suggestions and criticisms.

Sebastian Arnström, Uppsala, 2023-06-12

Abstract

This thesis is a critical review of two central theories in the modern sustainability paradigm – namely… (1) the theory that the Earth's geosphere, hydrosphere, biosphere and atmosphere form a complex adaptive system – the Earth system, and (2) the theory that all human activities are intrinsically dependent on, and constrained by, non-anthropogenic states and processes in the Earth system. The thesis explains the origins and the logic of these theories, and subjects them to formal, semi-formal and comparative criticism. Ultimately, it refutes both on formal and comparative grounds. Most importantly, it shows that theories 1 and 2 are in conflict with the theory of evolution by natural selection, and with the hypothetico-deductive model of scientific research. It also shows that they are in conflict – both directly and indirectly – with the known laws of physics. While it is true that all human activities rely on biospheric resources today, there are no physical, or natural laws that make it impossible for us to break those dependencies over time. In fact, the thesis shows that it is possible in principle to satisfy any human need by strictly artificial means, and abiotic resources that exist in abundance both inside and outside of the Earth system. An important corollary to this finding is that social and economic progress is not inextricably tied – as the modern sustainability literature suggests – to the exploitation of finite and rapidly diminishing resources here on Earth. Theories 1 and 2 both contribute to this confusion, and hence, to the bleak and irrational Malthusianism that still permeates so much of the sustainability domain. In addition, they appear to blind many researchers to the ecological benefits of technological development. That humanity can break its dependence on the biosphere is a very good thing for its non-human inhabitants. As we become more technologically advanced, we will find it easier and easier to sustain ourselves without destabilizing the world's ecosystems. The Earth's biosphere is an oasis of beauty, complexity and connection in a Universe that is overwhelmingly empty and boring. As the only animals capable of appreciating this fact, we have a clear moral duty to protect and preserve it. And we can protect and preserve it. If we just let go of the religious ideas that have dominated our field since its inception, we will find that our potential to do good in the world is far greater than we previously imagined.

Keywords: sustainability, sustainability science, complexity, complex adaptive systems, Earth system, Earth system science, resilience theory, the adaptive cycle, chaos theory, eco-theology

Table of Contents

1 Background

Out of the diverse theories and concepts that make up the modern sustainability paradigm, the most important is arguably the 'Earth System Science Approach' (ESSA) to the study of social, ecological and social-ecological phenomena. The ESSA is a theoretical framework built around the idea that the Earth's geosphere, hydrosphere, biosphere and atmosphere form a 'complex adaptive system' – the Earth system (Steffen et al., 2020). According to this model, humanity's social and economic institutions are nested components of the biosphere, inextricably tied to their parent system. All human activities are made possible, and ultimately constrained by, life-supporting states and processes in the Earth system at large. Among these are the greenhouse effect, the carbon cycle, the nitrogen cycle, and the hydrological cycle, as well as the biogeochemical absorption of waste products exiting the anthroposphere. The planet's life-supporting functions emerge from stable networks of interaction between its biotic and abiotic components, which are so ineffably complex that they are beyond our power to control, or even fully understand (Clayton & Radcliffe, 1997; Walker & Salt, 2006; Rockström, 2009; Steffen et al., 2015; Grin, Rotman & Schot, 2010; Steffen et al., 2020).

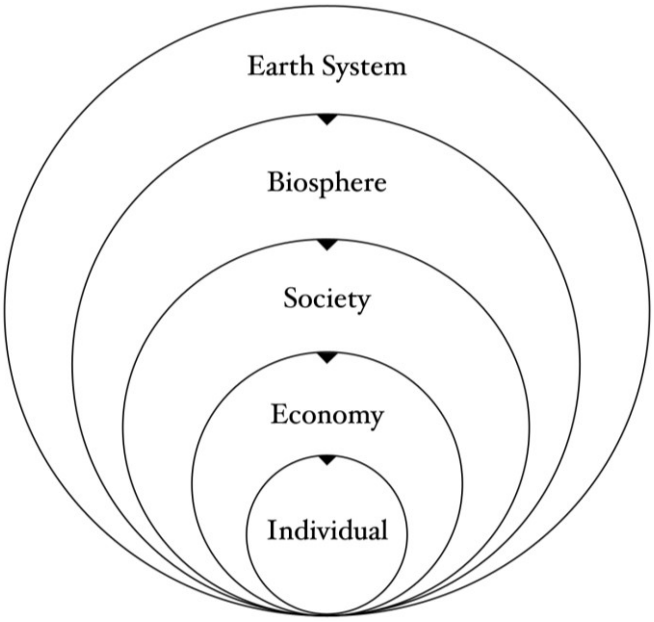

Figure 1.1 The Earth system.

So, what do the concepts of sustainability and sustainable development refer to within this paradigm? In general terms, a sustainable human activity is one that we can perform continuously without destabilizing the Earth-system processes that allow us to execute it in the first place. Just the same, sustainable development is taken to mean plans and actions that allow us to maintain and improve our social institutions, without threatening the long-term stability of their biospheric parent system (Clayton & Radcliffe, 1997). The ESSA emerged at the height of the 'first wave of environmentalism' in the United States and Europe during the 1960's and 70's, and was shaped by pioneering works in the fields of anthropology, ecology and systems theory – most notably, by Ehrlich (1968), Odum (1971), Lovelock (1972), Meadows (1972), Shepard (1973), Naess (1973) and Daly (1974). In the first iterations of the framework, it was assumed that the biotic components of the Earth system tend spontaneously towards balanced, or harmonious configurations, so as to increase their mutual likelihood of replication (see Odum, 1971; Lovelock, 1972). When the human species appeared in Africa, some 200,000 years ago, it was a well-integrated cog in this homeostatic machinery. With no ambitions of social or technological progress, our ancestors took from nature only what they needed to survive. What little they had, they shared, and when the common good demanded it, they sacrificed their personal welfare for the welfare of the group. This way, they managed to secure a life of peace and relative abundance, without straining the social fabric of the tribe, or the carrying capacity of their environment. They were a predictable, slow-growing component in the clockwork of nature, too small to challenge the integrity of its life-supporting functions. However, when humanity transitioned from hunter-gatherer to agricultural societies, this situation changed. As more and more people banded together in permanent settlements, stricter and more hierarchical modes of social organization evolved. Similarly, as their technical-practical knowledge of the biosphere grew, so did their desire to dominate and control it. Rather than adapting to their environment, they began adapting their environment to them. No longer parts of a cohesive social body, or the organic unity of the biosphere, our ancestors turned into selfish, aggressive and short-sighted beings, increasingly obsessed with individual wealth and power (see Sahlins, 1972; Shepard, 1973). These developments gained momentum – especially in the Global North – until reaching a climax in the advent of the Industrial Revolution. Since then, the anthroposphere has grown at such an explosive rate that it now threatens to subsume its biospheric parent system, and thereby eliminate the conditions for its own survival (Boulding, 1966; Ehrlich, 1968; Sahlins, 1972; Lovelock, 1972; Meadows et al., 1972; Shepard, 1973; Naess, 1973; Daly, 1974).

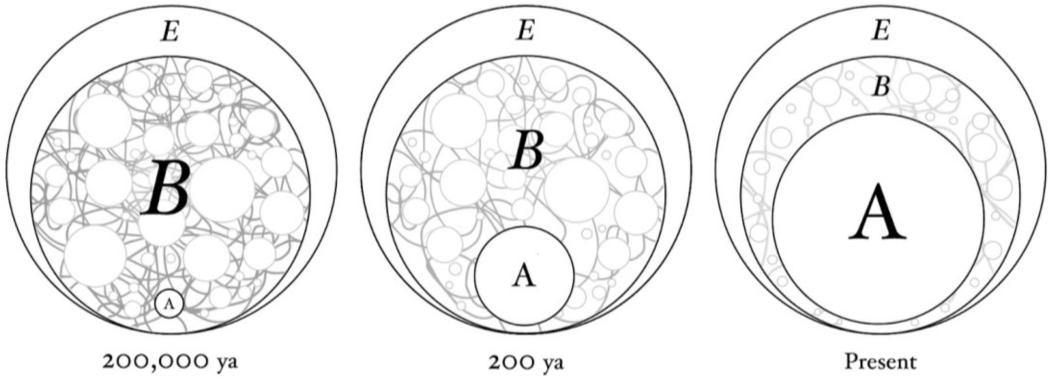

Figure 1.2 Humanity's influence (A) in the biosphere (B) and the Earth System (E).

For reasons that will be discussed in the coming chapters, the idea that the biosphere exhibits a universal, homeostatic tendency has been largely abandoned in the contemporary ESS literature, and replaced with the idea that it is 'resilient' – meaning, that it has the capacity to absorb or deflect perturbing influences, through evolution-driven processes of renewal and reorganization among its components (Chapter 1.3). Apart from this, the grand narrative of the ESSA has remained more or less unchanged (see Clayton & Radcliffe, 1997; Steffen et al., 2020; Chapin, 2022). When I first heard this story, I thought that it was very convincing. After all, it is undeniable that humanity's exploitation of the natural world has created some difficult ecological problems, including climate change, ocean acidification, toxic pollution, biodiversity loss, and the destruction of unique ecosystems all over the world (Middleton, 2018). At the same time, I had a nagging sensation that I had heard this story before somewhere. And indeed, I had. The philosophical roots of the ESSA can be traced back to a tradition of thought called Catholic physico-theology, or eco-theology. This tradition evolved from the scholastic philosophy that dominated in Europe before the Scientific Revolution, and was built around four ethico-ontological dogmas, largely derived from the Old Testament doctrine of creation (see Grober, 2007, 2012, 2018). These were…

1. The idea that the natural world was created by a great and benevolent Spirit, whose will is expressed in its architecture and its essential dynamics. (God)
2. The idea that at the beginning of time, the Earth was perfect. Because every component of the natural world moved in accordance with the will of the Spirit, they formed an integrated and harmonious whole. (Paradise)
3. The idea that the first human beings were serene and selfless creatures, who lived in accordance with the will of the Spirit, and therefore, in perfect harmony with one another, and with the rest of nature. (Adam and Eve)
4. The idea that the unity of the original world was corrupted when mankind gained the ability to think, judge and act for themselves – meaning, independent of the supreme moral will that organizes the natural world. (The fall of man)

As is obvious, all we need to do here is to replace the idea of 'God's will' with an emergent 'homeostatic tendency in nature', and 'Adam and Eve' with our Stone Age ancestors, and we have recreated the early ESS narrative almost in its entirety (see Appendix A). Again, this is no coincidence. In Appendix A, you will find the results of a deep literature review that explains the historical relationship between eco-theology and sustainability science. For the reader who is not already familiar with this subject, I suggest that you read this Appendix before continuing through the rest of the thesis. It will give you a better understanding of the problems that we will address in the coming chapters, and why it is important that we address them to begin with. You will also get a better understanding of some profoundly irrational memes that have long infected the sustainability discourse, including the idea that 'the natural world is balanced, or harmonious', and that 'our prehistoric ancestors lived peaceful and comfortable lives'. These ideas are really only intelligible as expressions of Catholic dogma. Just the same, you will learn about the origins of the notion that 'humanity is a disease on our planet', that 'ecological sustainability demands authoritarian governance', and that 'there are absolute biospheric limits to social and economic growth' (see Appendix A). These ideas – intuitively appealing as they may be – are utterly false, and as such, unsustainable components of a rational sustainability paradigm. They are also integrally related to two central theories in the modern ESS framework – the theory that the Earth is a complex adaptive system, and that humanity's social and economic institutions are nested components of the biosphere.

1.1 Purpose

The purpose of this study is to evaluate two leading theories in the modern sustainability paradigm, and by extension, all explanations and/or definitions of sustainability that derive from, or depend on, their basic tenets. These theories are… (1) the theory that the Earth is a complex adaptive system, and (2) the theory that all human activities are intrinsically dependent on, and constrained by, non-anthropogenic states and processes in the Earth system. Its intended audience consists of scientists and researchers working in the sustainability domain, and anyone else with an interest in the subject matter.

1.2 The Homeostatic Earth System

In the last chapter, we briefly discussed the dogmas of eco-theology, and their influence on the ESS framework. In this chapter, we will take a closer look at the concept of the 'Earth system' itself, and its indebtedness to the first two of these dogmas – the idea that there is a great and benevolent Spirit in nature, whose will shapes it into a harmonious and elegant, self-sustaining machinery (Chapter 1). In the early ESS framework, this doctrine was mirrored by 'the Gaia hypothesis' – the theory that there is an emergent goal directedness in nature, which organizes the biosphere as if it was a single living organism, and steers it towards producing the optimal conditions for all life to flourish (Lovelock, 1974, 1979, 1988). The seeds of this idea can be found in the work of geologist Vladimir Vernadsky (1926), and the ecosystem ecology of Howard Odum (1971). However, its definitive formulation was given in 1972 by the British inventor James Lovelock (1979). According to Lovelock, the Earth system, or 'Gaia', "[is] a complex entity involving the Earth's biosphere, atmosphere, oceans, and soil; the totality constituting a feedback or cybernetic system, which seeks an optimal physical and chemical environment for life on this planet" (Lovelock, 1979). Hence, if we just leave nature alone, it will tend spontaneously towards harmony and order, and the preservation of life. Although broadly accepted in the environmental sciences, this theory was met with considerable skepticism in the wider scientific community (Kirschner, 1989, 2002, 2003). Matters did not improve when Lovelock's critics asked him to clarify how a Gaian entity would come into being, and he responded with nothing but hand-wavy appeals to 'emergence' and 'spontaneous organization'. "Life does more than adapt to the Earth", he explained, "it changes it, and evolution is a tight-coupled dance with life and the material environment as partners, and from the dance emerges the [...] Gaia" (Lovelock, 2000). Clearly, this answer raises more problems than it solves. Biological evolution, as commonly understood, is driven by the differential survival of genes in gene pools. Generally speaking, a successful gene is one whose phenotypic effects help its host to survive and to reproduce in a specific environment. The reason that the bodies of plants and animals have sophisticated homeostatic controls is that this trait increased the reproductive fitness of their ancestors, and thereby caused genes for better homeostatic controls to persist and spread in their respective gene pools (Dawkins, 2016). Now, because the Gaia involves the sum of our planet's ecosystems, its structure will be continuously defined and redefined by the interactions of their biotic and abiotic elements. Hence, any homeostatic machinery that balances this system as a whole would have to emerge from, and consist of, stable networks of such interactions. Lovelock's conjecture was that over geological time, the interplay between life and its environment has created biologically mediated feedback loops, which regulate the Earth's chemistry, and optimize it for all terrestrial beings (Lovelock, 1979). However – and here is the rub – any such mechanisms would still have had to emerge from, and be stabilized by, the phenotypic traits of individual plants and animals. This means that for Lovelock's theory to hold, it must explain the selective pressures that would convince innumerable genes in spatially and trophically distant gene pools to 'join arms', as it were, in a planet-wide network of symbiotic, or altruistic, or public-spirited adaptations. This is where the Gaia runs into trouble. A gene that promotes an altruistic, or public-spirited trait – meaning, a trait that primarily benefits an organism other than its host – will as a rule only be successful in a specific set of circumstances – when the cost ($\mathbb{C}$) suffered by the host from its altruism is lesser than the benefit (B) gained by the recipient, multiplied by their genetic relatedness (r). With this formula – $r \times B > \mathbb{C}$ – we can explain the evolution of the wonderfully cooperative behavior of ants and other social insects, as well as the less pleasant fact that many social animals, including cats, dogs and chimpanzees, sometimes kill and eat their babies shortly after they are born. The main point here is that unless an altruistic, or public spirited trait *directly benefits* the spread of the genes that induce it, these genes will tend to be outcompeted by rivals that direct their hosts energy and resources towards more selfish endeavors (Dawkins, 1999, 2016). This makes it very difficult to explain the evolution of an optimizing Gaia – that is, unless we rubbish the Neo-Darwinian Synthesis, and subscribe to an Aristotelian, or Lamarckian, or Vernadskian theory of evolution, wherein all living things evolve towards a predetermined goal state (see Appendix A). As Dawkins points out, "The fatal flaw in Lovelock's hypothesis would have instantly occurred to him if he had wondered about the level of natural selection process which would be required [...] to produce the Earth's adaptations" (Dawkins, 1999). Perhaps it would have occurred to him even faster if he had remembered that over 99% of all species that have evolved on our planet are now extinct (Jablonsky, 2004). Beneath its layers of cybernetics jargon, the Gaia hypothesis is a surprisingly straightforward reformulation of the 1st and 2nd dogmas of eco-theology. The natural world, it explains, is ruled by a good and caring spirit, and if spared from man's incessant meddling, it will revert to its essential state of balance and interspecific harmony (see Appendix A). Regardless of Lovelock's actual intentions, this looks less like scientific conjecture, and more like an attempt to sneak Father God into the natural sciences, by disguising him as Mother Earth. For all of these reasons, modern sustainability scientists typically avoid explicit appeals to the Gaia in their work. Still, its influence is evident in nearly all of the disciplines' foundational texts. Even in the famous 'Brundtland Report', which is often derided for being too anthropocentric and modernist in its outlook, its influence is clearly visible. "In the middle of the 20th century, we saw our planet from space for the first time", the Brundtland Commission wrote, "we [saw] a small and fragile ball dominated not by human activity [...] but by a pattern of clouds, oceans, greenery, and soils... [we saw] the Earth as an organism whose health depends on the health of all its parts" (WCED, 1987). Likewise, it is regularly invoked via the popular 'Spaceship Earth' metaphor – the idea that the Earth can be likened to a great big spaceship, with the biosphere acting as its 'life-support system' (e.g. Griggs et al., 2013). However, its most important legacy is that it introduced the idea that the Earth is a 'complex adaptive system' – an idea that has since become axiomatic in the sustainability domain (Steffen et al., 2020).

1.3 The Complex Adaptive Earth System

In this chapter, we will explore the nexus of the modern sustainability paradigm – the theory that the Earth is a complex adaptive system (CAS). The CAS paradigm emerged in the mid 1980's, from a widespread effort to save Lovelock's Gaia hypothesis from the criticisms outlined in the previous chapter. To that end, its proponents took the Gaian model and reformulated it in the language of complex systems theory (Clayton & Radcliffe, 1997; Steffen et al., 2020). To make it compatible with the Neo-Darwinian Synthesis, they ostensibly removed Lovelock's assumption that the natural world is homeostatic, and replaced it with the idea that it is resilient – meaning, that it has the capacity to avoid, deflect or absorb perturbing influences, through evolution-driven processes of renewal and reorganization among its components (Clayton & Radcliffe, 1997; Walker & Salt, 2006; Steffen et al., 2020). In this chapter, we will explain the central tenets of modern Earth system theory. Departing from the format of the previous chapter, we will hold off on criticizing them until we reach the results section of the thesis.

1.3.1 Complex Systems Theory

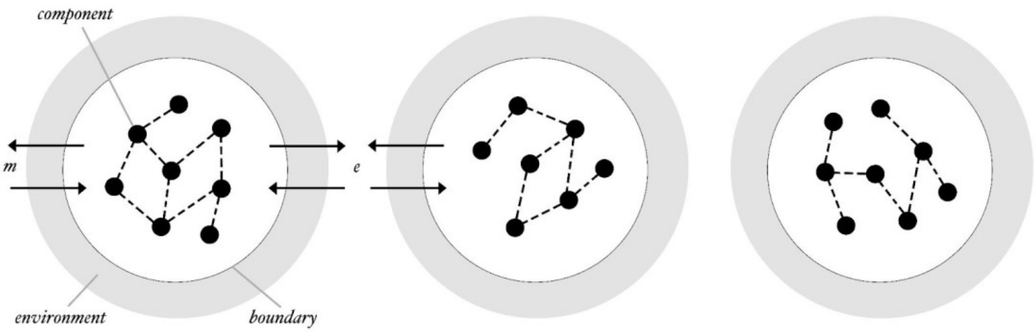

Figure 1.3. Open, closed and isolated systems.

In general systems theory, a *system* is any collection of physical or abstract entities that can be reasonably described as a unified set, or body. A physical system – which is what will primarily concern us here – consists of two or more interrelated components, and a boundary that separates them from the system's environment. An *open system* is one whose boundary allows transfers of energy and matter between the system and its environment, while a *closed system* is permeable to energy alone. An *isolated system* is one that can not communicate at all with its environment (Figure 1.10). A *complex system* (CS) consists of two or more semi-autonomous components, whose interactions give rise to *emergent*, system-wide properties and behaviors. Finally, a *complex adaptive system* (CAS) is a complex system that can absorb or deflect perturbing influences, without losing its defining characteristics. According to the CAS paradigm, everything from individual cells, plants and animals, to entire ecosystems, human societies and the Earth system as a whole are complex adaptive systems (e.g. Clayton & Radcliffe, 1997).

1.3.2 Emergence And Distributed Control

As stated above, the properties of CS arise from stable networks of interaction among their components. In CAS, these include intricate patterns of dependence and control, and feedback circuits that regulate the system's internal environment. Despite their orderliness, these networks are not shaped by a global command unit, or control system of some kind – the orderliness emerges from the interactions of their components, and the co-evolution of the rule-sets that guide their behavior. As Grin, Rotmans and Schot (2010) puts it, "[the] components in a complex system cannot "know" what is happening in the system as a whole. If they could, all the complexity would have to be present in that component. This is impossible [...] because the complexity is created by the relationships [of the] components". To illustrate how complex structures can emerge from the interactions of simple agents, CAS theorists often use the examples of... (1) the synchronous movements of flocking birds, (2) consciousness arising from the electrochemical communication of brain cells, and (3) the cooperative behavior of ants and other social insects. According to CAS theory, these are all *emergent phenomena*, arising from *spontaneous organization* in *multi-agent systems* (Clayton & Radcliffe, 1997; Chan, 2001; Walker & Salt, 2006; Carmichael, Collins & Hadžikadić, 2019).

1.3.3 Co-Evolution And Unpredictability

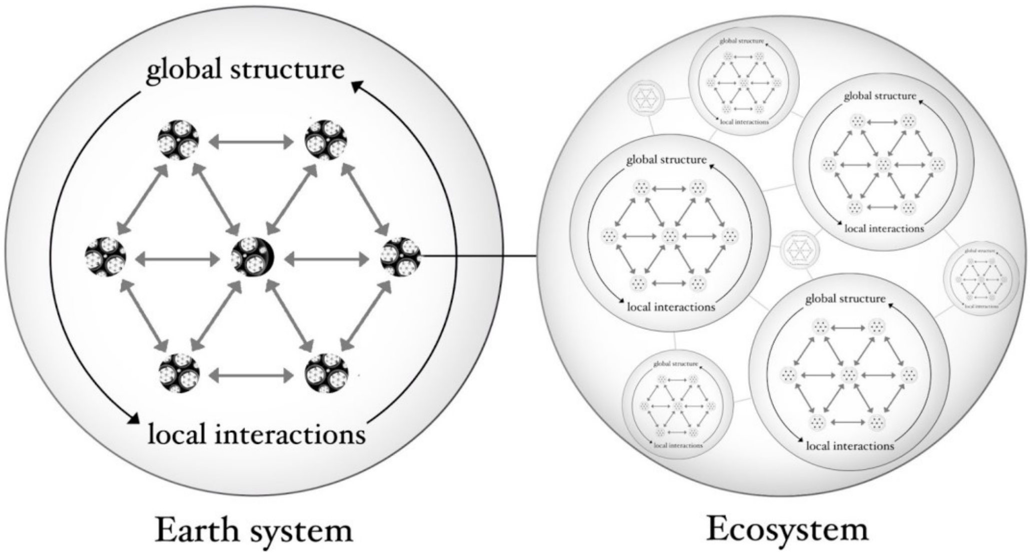

Figure 1.4. The co-evolution of the Earth system and its components.

As indicated in the last subchapter, the properties of CAS emerge from the co-evolution of its components, and the co-evolution of the system and its environment. Variation, competition and spontaneous organization at the component-level gives rise to emergent structures, which determine the system's overall behavior, and impose selective pressures on the further evolution of its constituents. As a rule, the components of CAS are complex adaptive systems themselves, and hence, they exhibit patterns of self-similarity that stretch across spatial scales. Just the same, their evolution is determined by webs of self-similar change processes occurring at different scale levels. Because of their interconnected and metamorphous nature, the attributes and operations of CAS are impossible in principle to fully understand, or control. The best we can do is to look for evidence of feedbacks and linkages that give us a clue about where they are heading, and attempt to nudge them in a favored direction (Clayton & Radcliffe, 1997; Chan, 2001; Walker & Salt, 2006; Carmichael et al., 2019).

1.3.4 Connectivity, Cascades And Tipping Points

Because of the chaotic and interconnected nature of CAS, the effects of a weak or local disturbance can sometimes snowball, or ripple quickly through the system as a whole. While a disturbance that affects a peripheral component often induces little or no change in its overall state, a disturbance that affects a central, or critical component may trigger a cascade of transitions that rapidly transform its emergent features. The same situation can arise if a gradual or cumulative disturbance pushes the system to a critical threshold, or tipping point (Clayton & Radcliffe, 1997; Walker & Salt, 2006).

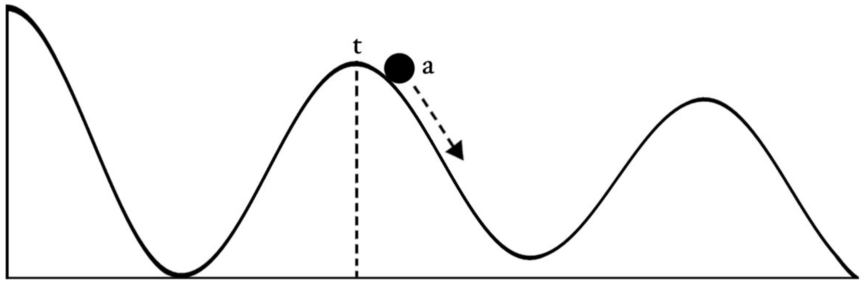

Figure 1.5. Simple illustration of a system (a) passing a tipping point (t).

For instance, if a disease attacks the brain of an organism, or a keystone species in an ecosystem, this may cause dramatic shifts in their overall dynamics. Likewise, if a disease gradually breaks down an organism's immune system, or if there is a gradual change in the climatic or trophic conditions in an ecosystem, these disturbances may reach critical levels, beyond which rapid, system-wide transitions occur. Because of their ineffable complexity, it is often impossible to determine the centrality of specific components in a CAS, or the system-wide outcomes if they should waiver or fail (Chan, 2001; Walker et al., 2004; Walker & Salt, 2006; Carmichael et al., 2019).

1.3.5 Resilience

As explained above, CAS are shaped by webs of interlinked change-processes at different scales. As such, they can exist in a range of stable configurations, or regimes, conceptualized in the CAS paradigm as competing attractors in an evolving state space, representing the sum of the life-paths that are open to them at any given time (Walker & Salt, 2006). For every regime, there is a basin of attraction that contains all possible configurations that will converge on that attractor. Whether a perturbation will push a CAS from one basin into another depends on the resilience of the system in its existing configuration – meaning, "[its] capacity [...] to absorb disturbance and reorganize while undergoing change, so as to still retain essentially the same function, structure, identity, and feedbacks" (Walker et al., 2004).

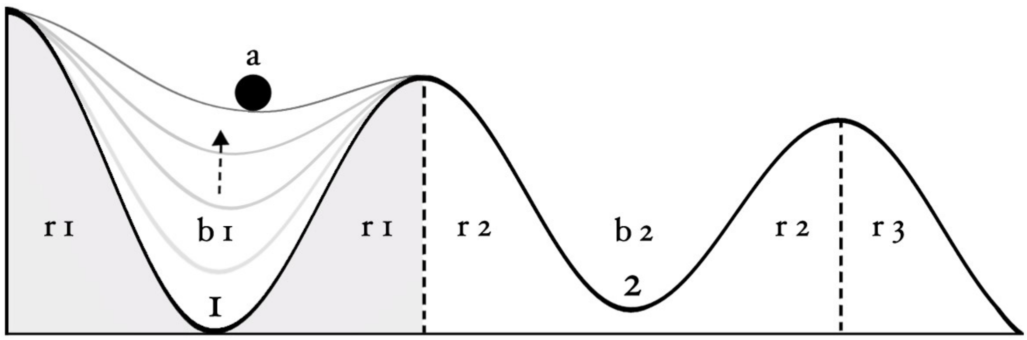

Figure 1.6. Simple illustration of a system approaching a tipping point, where (1, 2, 3) are regimes, (a) is the system state, (b) are basins of attraction and (r) is the resilience of each regime.

The resilience of a CAS, or a CAS in the basin of a particular regime, is largely determined by three factors (Folke et al., 2004; Walker et al., 2004; Walker & Salt, 2006)…

1. Its *functional diversity*, which refers to the range of different components, or component clusters that contribute in a distinct way to its emergent features.

2. Its *response diversity*, which refers to the range of response types available to its functional components, or clusters.

3. Its *modularity*, which refers to the interconnectedness and interdependence of its functional components, or clusters.

In simple terms, a diverse system will be more resilient than a less diverse one, because it has more tools to work with in an adverse situation. Put differently, it can cycle through a larger number of potential configurations before it is pushed to the edge of its current basin of attraction. A high degree of modularity is also beneficial, because it makes the system less susceptible to negative cascades. To take a simple example, an organism whose immune system is armed with a wide range of antibodies will be more resilient to disease than one with a less diverse immune system. Similarly, if a wide range of species contribute to an ecosystem function, the probability that it will survive a destabilizing change in the system's conditions is greater than if it depends on a more homogenous group (Folke et al., 2004; Walker et al., 2004; Walker & Salt, 2006).

1.3.6 The Adaptive Cycle

Despite the inherent unpredictability of complex adaptive systems, CAS theorists have nonetheless advanced a general model of their evolutionary dynamics. This model, which was first introduced by the ecologist C.S. Holling, is called 'The

Adaptive Cycle', and indicates the most probable evolutionary trajectory of a CAS, given its current stage of organizational development (Walker et al., 2004; Holling, 2004; Walker & Salt, 2006).

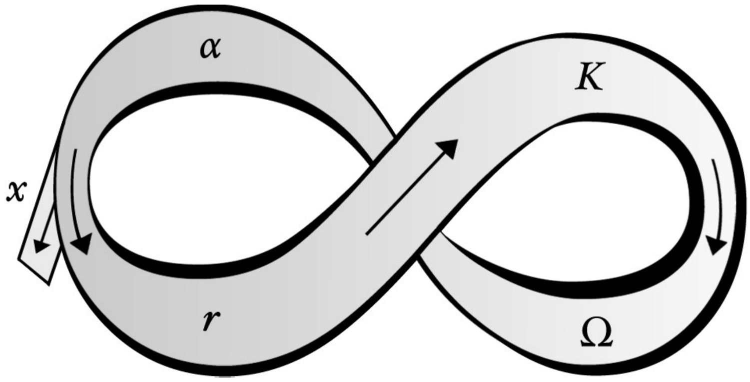

Figure 1.7. The phases of the Adaptive Cycle, where (r) is growth or exploitation, (K) is conservation, (Ω) is release, (α) is reorganization, and (x) a regime shift.

According to the Adaptive Cycle, the evolution of CAS proceeds in a dialectical cycle, or spiral, consisting of four phases…

1. The *growth*, or *exploitation* phase, where resources are available, and the components of the system explore its current niches and opportunities.
2. The *conservation* phase, where spontaneous organization among the components lead to the formation of increasingly stable and interdependent structures.
3. The *release* phase, where external shocks or internal failures lead to a chaotic loss of stability in the system, and a rapid release of resources locked up in its existing structures.
4. The *reorganization* phase, where resources are plentiful, and where new components can evolve and establish themselves in the system.

The first and second phases – the *foreloop* of the cycle – are associated with a gradual increase in the efficiency and predictability of the system, and a concomitant decrease in its overall resilience. The second and third phases – the *backloop* of the cycle – are fast and chaotic, and may lead to a regime shift, or in the worst case, a total collapse. However, the backloop also creates opportunities for innovation and novelty in the system. It is important to note that the order of the phase-transitions is not absolute – systems can sometimes jump from conservation to growth, or from growth to reorganization, or release, and so on. When applied to biological, ecological, or social-ecological systems, the adaptive cycle expands into a network of interlinked cycles at different scales, referred to as the *panarchy* of the system (Walker & Salt, 2006; Allen et al., 2014).

2 Methodology

This thesis is grounded in the modern, or hypothetico-deductive model of scientific problem-solving, originally advanced by the Austrian philosopher Karl Popper (1959, 1953), and later expanded and refined by the British physicist David Deutsch (2011, 2016). This model consists of two distinct parts – namely… (1) a universal theory of the growth of human knowledge, and (2) a normative framework for scientific reasoning, based on this theory. In this chapter, I will give a brief explanation of both. According to the hypothetico-deductive model, all knowledge grows through *variation and selection*, or *trial and error elimination*. Scientific knowledge – that is, our theories about what is out there in the world and how it works – evolves through the productive interplay of *conjectures*, *criticisms*, and *critical empirical tests*. As we move through life, we encounter epistemic problems – meaning, apparent gaps or flaws in our current knowledge. This prompts us to guess at solutions, and if possible, to subject these solutions to empirical tests. To take an example from our evolutionary past, an epistemic problem might have been – 'why do the antelopes sometimes detect our presence from far away?' – and a conjectured solution might have been – 'the antelopes detect us when we stalk them with the wind in our backs' – which might have inspired a practical test – 'let us approach them from a downwind position'. If successful, this trial would have given birth to a lineage of interesting problem-children, beginning with 'why do the antelopes detect us when we stalk them with the wind in our backs?', and so on. Here we have the basic steps of the hypothetico-deductive procedure – we… (1) encounter *problems*, (2) *guess* at solutions, and (3) *deduce*, if possible, trials of the solutions from their explanatory elements (Popper, 1963; Deutsch, 2011).

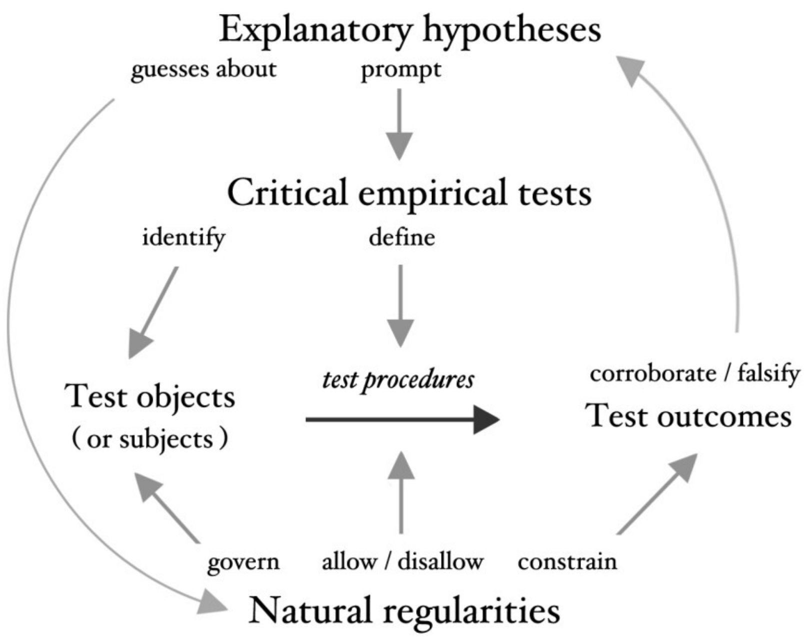

Figure 2.1. The hypothetico-deductive process.

Obviously, this is not a foolproof method for getting to the truth. Although the hunters in our example came up with a very good solution to their problem, they could just as easily have guessed that – 'the antelopes detect us when we do not pray enough before we go on a hunt' – and by a confluence of factors completely unaffected by prayer, had *that* hypothesis ostensibly confirmed. This would have been a bad outcome, since any subsequent hunting failures may have prompted a search for the infidels who did not pray enough before the hunt, or for a more effective means of appeasing the Gods, rather than an altogether different theory. As this example shows, the idea that we can verify, or justify, or prove our theories by way of observation or experiment – although a leading principle in the *inductive*, or *pre-modern sciences* – is logically untenable (Popper, 1959). Technically speaking, it is impossible to formulate a logically valid procedure whereby explanatory or predictive statements can be inferred from observation statements. This means that the latter can never be used to substantiate or validate the former. To make matters worse, there is an infinity of logically possible explanations for every possible observation statement (Popper, 1959, 1963; Deutsch, 2011). For instance, the observation sentence, 'the Sun is a bright, shining sphere that moves across the daytime sky' does not entail our current explanation that, 'the Sun is a vast, fusion-powered ball of plasma, and we live on a planet that revolves around it'. Neither does it entail the slightly more fantastical explanation that, 'the Sun is a giant torch, held above the Earth by an invisible Titan'. However, both the plasma-ball and torchlight theories are equally 'justified' by it. Lastly, because all of our experiences consist of sensory data, compiled and interpreted in accordance with our existing knowledge, we can never circumvent the fallibility of the hypothetico-deductive procedure. We are trapped, as it were, in a world of conjectures (Popper, 1959, 1963). To overcome the first of these problems, modern scientists reject all appeals to *induction* and *empirical verification*, and focus instead on *empirical falsification*. While a confirming instance of a theory can never prove it, (or justify it, or make it more probable), a genuine counter-instance of a theory would indeed *falsify* it (Popper, 1959, 1963). To overcome the second problem, they work exclusively with guesses that are both *falsifiable*, and *good explanations*. A good explanation is one that is logically sound and difficult to modify without diminishing its explanatory power, and its consistency with otherwise good explanations. Unlike the infinity of bad explanations that exist for every observation statement, the number of hypotheses that conform to these criteria will as a rule be very small (Deutsch, 2016). To overcome the third problem, they reject all claims to *epistemic authority*, and treat every theory, concept and idea – no matter how self-evident or apparently well-founded – as conjectural, tentative and open to criticism and revision. By submitting their hypotheses to intense *formal criticism*, modern scientists look for the best potential solutions to our scientific problems, and then test those against experience, with the aim of falsifying them. The hypotheses that stand up the best to their attempts at falsification are tentatively accepted as our *current best guesses* about the true nature of their explicanda (Popper, 1959, 1963; Deutsch, 2011, 2016). As Deutsch (2016) puts it, "the methodology of science is to seek out, and apparently to correct, apparent flaws, conflicts or deficiencies in our explanations (thus obtaining better explanations), in the hope that this will correct real flaws and deficiencies (thus providing truer explanations)". Incidentally, the proposition that this procedure works – meaning, that it allows us to *gradually and fallibly approach the truth* – is our best and only explanation of the immense scientific progress that occurred in the centuries during which it was formalized (Popper, 1963; Deutsch, 2011). So, to sum up – while there are as many methods in the modern sciences as there are distinct categories of scientific problems, they all, by necessity, incorporate the following steps…

1. The *formal step*, where the logical structures of new hypotheses (or existing theories) are checked to see if they contain any gaps or contradictions.

2. The *semi-formal step*, where the explanatory contents of new hypotheses (or existing theories) are checked to see if they exhibit the qualities of a good explanation.

3. The *comparative step*, where new hypotheses (or existing theories) are compared against their rivals, as well as otherwise relevant knowledge, such as observational data, the recorded outcomes of experiments, and so on.

4. The *empirical step*, where hypotheses that have survived steps 1 to 3 are tested against experience, either alone – in which case an apparent falsification will make them problematic – or together with rival theories – in which case an apparent corroboration of one theory and an apparent falsification of its rivals will lead to an empirical rejection of the falsified theories, and a tentative acceptance of the corroborated theory.

3 Method

The present thesis is a critical literature review, designed in accordance with the hypothetico-deductive model of scientific research (Popper, 1959; APA, 2010). This chapter describes the goal of the study, the literature selection, and the evaluation criteria by which the reviewed materials have been assessed.

3.1 Goal

The goal of the study is to explain the origins and the logic of two leading theories in the modern sustainability paradigm, and to critically evaluate them in accordance with the tenets of the hypothetico-deductive model. More precisely, the goal is to subject them to *formal*, *semi-formal* and *comparative criticism*, with the ultimate goal of refuting them (Chapter 2).

3.2 Literature Selection

The aim of the literature review was twofold. It sought to establish… (1) the historical origins of the modern sustainability paradigm, and (2) the historical and contemporary origins of theories 1 and 2 (Chapter 1.1). The databases employed in the literature search were Google Scholar, Science Direct, Springer, PubMed and JStor. The search words used were *history of sustainability*, *history of the sustainability concept*, *history of sustainable development* and *history of Earth system science*. The initial results were narrowed down with the help of three content-related selection criteria, (applied in the order that they are presented here)… (i) that the sources should be *well cited* in their respective domains, (ii) that they should give *cogent and precise explanations* of the historical development of the theories under review, and (iii) that they should give *cogent and precise explanations* of the theories themselves, at each stage of their historical development (Chapter 3.2). For objective (1), the top results were a set of influential books and articles by Du Pisani (2006), Grober (2007, 2012, 2018), Warde (2011) and Caradonna (2014, 2018). These sources were found to give a clear and consistent picture of the history of the sustainability paradigm. The work of Grober was in closest agreement with the selection criteria, because of its unrivaled precision in explaining the reasoning behind the theories and concepts themselves. For objective (2), the best fit was a review by Steffen et al. (2020), which is one of a few of its kind. Together, these sources were made the theoretical foundation of the literature review. Additional materials were gathered through reference and citation tracking, as is customary in reviews of complex evidence (Greenhalgh & Peacock, 2005; APA, 2010). The account of contemporary Earth system theory is based on standard textbooks in the field, and materials provided to me by my supervisor, and by doctors and professors working at Gävle University. Lastly, the comparative criticisms presented in Chapter 4 are based on apparent conflicts between Earth system theory and… (a) the hypothetico-deductive model itself, (b) the theory of evolution by natural selection, and (c) the known laws of physics. The arguments explaining these conflicts are transparent and uncontroversial, and anchored in firmly established sources in each domain, (e.g. Popper (1959, 1963) ≈ 65,000 citations, Dawkins (1999, 2016) ≈ 40,000 citations, Deutsch (1985, 1997, 2011) ≈ 10,000 citations). A further note on selection effects in critical theory papers, and how this study specifically combats this issue, can be found in Appendix B.

3.3 Evaluation Criteria

The study at hand is designed in accordance with the modern, or hypothetico-deductive model of science. Its tenets are operationalized here in three formal and comparative evaluation criteria (Chapter 2).

1. *The falsifiability criterion*
   A scientific explanation must be falsifiable – meaning, its explanans must entail factual predictions that can be tested against experience, with the aim of falsifying them.

2. *The consistency criterion*
   A good explanation must be self-consistent – meaning, it must not include any logical gaps, or other structural fallacies.

3. *The precision criterion*
   A good explanation should be hard to vary – meaning, it should be hard to modify its explanatory elements, without diminishing its coherence, its explanatory power, and its consistency with otherwise good explanations.

For obvious reasons, criterion I is not applicable to historical theories, (we can not travel back in time to test them). However, criteria II and III can be applied to any explanation in any academic discipline. Just the same, criterion I *can* and *must* be applied to any theory that purports to explain phenomena in the physical world (Popper, 1959, 1963).

4 Results

According to the ESS framework, the Earth is a complex adaptive system, and all of humanity's social and economic institutions are nested components of the biosphere. As such, they are part of an interconnected and irreducibly complex whole – a great web of dialectical change processes, constantly moving from chaos to order, and from order to chaos, reorganization and rebirth. The biosphere is an inherently metamorphous entity, exploring a landscape of possible configurations, each tending towards a transient equilibrium. This situation was well understood by our prehistoric ancestors, whose lives and practices were closely attuned to the rhythms of the biosphere (see Chapter 1). However, it has become invisible to modern man, whose reductionist worldview leads him to perceive nature as a collection of disparate entities, rather than a dynamically integrated whole. As Folke (2011) puts it, "Current perspectives and worldviews mentally disconnect human progress and economic growth from the biosphere… the life-supporting environment, if not simply ignored, has become external to society, with people and nature treated as two separate entities… People and societies are integral components of the biosphere, depending on its functioning and life-support". In the last two centuries, we have seen the rise of a culture of excess, individualism and greed, and humanity's exploitation of the natural world has increased to the point that it threatens to push the Earth from its present equilibrium, into the basin of a radically different attractor (see Chapter 1). In the words of Rockström (2009), "a new era has arisen – the Anthropocene – in which human actions have become the main driver of global environmental change. This could see [us] push the Earth system outside the stable […] state of the Holocene". As Steffen et al. (2020) points out, such a transition would likely be catastrophic for mankind, since a "Holocene-like state… [is] the only state that we know for certain can support agriculture, settlements and cities, and complex human societies". So, what then can we do about this dire situation? First, we must recognize that the Earth is a finite physical system, with finite stocks of natural resources. Hence, our current trajectories of growing production and consumption can not continue forever (see Appendix A). As Chapin (2022) explains, a "transformation toward a sustainable future requires an Earth Stewardship approach", where "[society is shifted] from its current goal of increasing material wealth to a vision of sustaining built, natural, human, and social capital – equitably distributed across society, within and among nations". In other words, "Human development and progress must be reconnected to the capacity of the biosphere, and essential ecosystem services" (Folke et al. 2011). In the previous chapters, we have outlined the theoretical origins of this narrative. Specifically, we learned that it evolved from the philosophical tradition of Catholic physico-theology, or eco-theology. We also learned that the first iterations of the Earth system narrative were straightforwardly based on the dogmas of this older tradition

(Chapter 1). In this chapter, we will show that unfortunately, this is just as true of the ideas summarized above. The main problem with the contemporary ESS framework is that it is still in conflict with the theory of evolution by natural selection. It is also in conflict with our current best theory of the growth of human knowledge – the hypothetico-deductive model – which *is* the theory of evolution, applied in the domain of epistemology (Popper, 1963, 1994). Because of this, ESS researchers inevitably misunderstand the nature of cultural change, technology, and technological development. On a deeper level, they misunderstand the unique properties of the human species, and our unrivaled potential to *do good* in the world. Most problematically, we will show that beneath its layers of complex systems jargon, the Earth system paradigm is still based on a straightforward appeal to *the supernatural*. We can illuminate all of these problems and more by asking ourselves one simple question – 'would it be possible to construct a self-sustaining human colony outside of the Earth's atmosphere?'

4.1 Sustainability, Technology And Natural Laws

As stated above, we can illuminate the problems with the modern Earth system model by asking ourselves one simple question – 'would it be possible to construct a self-sustaining human colony outside of the Earth's atmosphere?' To the best of our knowledge, the answer to this question is *yes* (e.g. O'Neill, 1974; Johnson & Holbrow, 1977; Curreri & Detweiler, 2013; Grandl, 2017; Chen, 2021). Of course, this is not to say that doing so would be easy, or cheap, or safe, and so on. On the contrary, it would be tremendously difficult, hugely expensive, and no doubt fraught with dangers, both expected and unforeseen. Equally true is that all current paths towards a colony space would require a start-up capital from Earth. Since its inhabitants would depend on basic resources such as breathable air, clean water, and renewable foods, that capital would have to contain a range of biospheric assets, including arable soils, and a variety of plants and microorganisms (see Curreri, 2007; Chen, 2021). Nevertheless, the fact that a self-sustaining colony in space *is possible* has several important implications. First, it tells us that the reason that all human societies are embedded in terrestrial ecosystems is not that they are – in some essential, or absolute sense – 'nested components of the biosphere' (Chapter 1.4). The real reason is that so far, humanity has *decided* not to colonize space. Second, the fact that we *could* build a self-sustaining colony on a space station, or an asteroid, or another planet, also tells us that we *could* maintain functioning societies here on Earth, even if the conditions on the planet were to dramatically change. Indeed, it tells us that unless it happens too quickly, we could survive a transition that leaves the Earth as barren and lifeless as the surface of an asteroid. Therefore, it can not be true that all human activities are – in some essential, or absolute sense – 'dependent on, and constrained by, the biospheric and biogeochemical processes of a Holocene-like Earth system' (Chapter 4). Finally, it also tells us that there must be potentially life-sustaining resources *outside* of the Earth's atmosphere. If this is true, and it is – the asteroid belt alone is teeming with valuable minerals, metals, and the chemical components of life – then just as terrestrial resources could be used to start a colony off-world, extraterrestrial resources could be harvested and brought back to the Earth system (e.g. Lewis, 1997, 2014). This means that what we *can* and *can not do* here on Earth is not limited in any absolute sense by the matter and energy that is present in the Earth system at any given time (Chapter 4). If we did conquer the solar system, there would be enough resources out there to sustain thousands of billions of human beings (O'Neill, 1974; Curreri & Detweiler, 2013; Lewis, 1997, 2014). These arguments illuminate some deep conceptual problems in the ESS framework. In fact, they show that unless we can refute the above claims, any model, or theory, or framework that treats 'people and societies' as intrinsically dependent on the Earth's biosphere is *false*. Having said that, I do not expect that my colleagues in the sustainability sciences will accept this assertion without further clarification. The arguments above only serve to illustrate a deeper point about the unique sustainological potential of the human species. We will now restate this point in more exact terms, beginning with an explanation of the relationship between sustainability, technology and the phenomenon of life.

4.1.1 The Technological Character Of Life

The human body – like the bodies of all plants and animals – is the product of millions of years of evolution by natural selection. As such, it is shaped to withstand a certain range of ecological conditions, and to make use of a certain range of ecological resources (Urry et al., 2016). Specifically, it is adapted to the conditions that existed in the Great Rift Valley in Africa, at the time when our species emerged (e.g. Relethford, 2010). However, as we know, our ancestors abandoned that environment a long time ago. Armed with revolutionary inventions such as clothes, carrying sacks, makeshift huts, and sticks and stones for fire-making, they spread out across the globe, and conquered habitats that would have *killed them instantly* if they had tried to settle them without these technologies. Even before we migrated out of Africa – in fact, for as long as our species has existed – the invention and application of new technologies has been *the way* that humanity has *sustained itself*. We can sharpen this point by contemplating what a technology really is. In the most basic sense, a technology is a means that allows us to transform some part of our physical environment in a way that satisfies our present wants and needs (McNeil, 2002; Deutsch, 2011, 2012). For instance, a Stone Age hut was a temporary structure made out of twigs, rocks, bones and animal hides. It allowed our ancestors to shelter themselves during bad weather, and to trap the heat from their bodies and campfires when the temperature dropped. Hence, their hut-making technology allowed them to transform a region of their physical environment, so that it corresponded more closely to their physiological needs (e.g. Relethford, 2010).

Figure 4.1. Technology.

For us living in the modern age, it is difficult to find a single element of our day-to-day activities that does not involve, or depend on, technological systems and artifacts. Most importantly, if all of those systems were to suddenly disappear, many, or perhaps even most of us would die within a matter of days. No 'essential ecosystem services' would come to our rescue – on the contrary, our local ecosystems would likely be what killed us! To differentiate between technologies that are critical to our ability to sustain ourselves, and technologies that we develop just for fun, or for pleasure, or to beautify our surroundings, we can think of the former as responses to the following question – '*how can we transform our local environment, to ensure the survival and welfare of ourselves and our offspring, and their offspring down the line?*' (compare to WCED, 1987, Ch. 2).

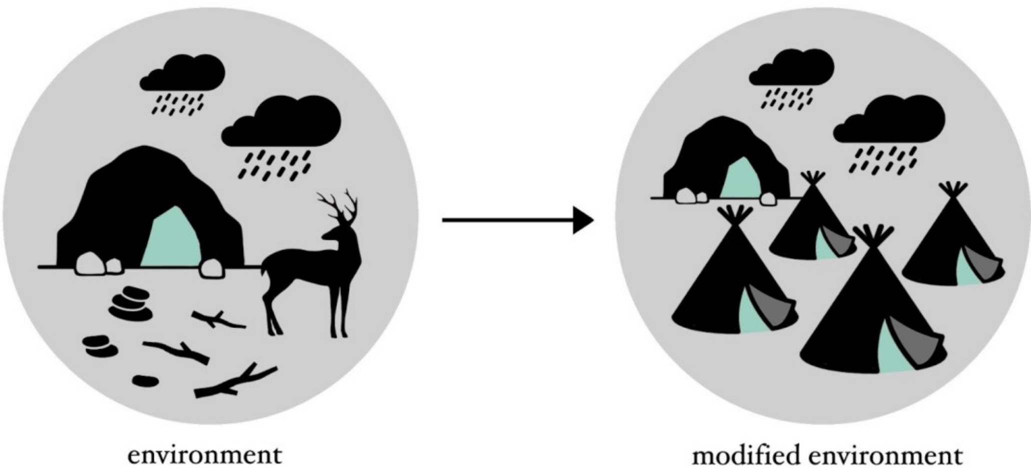

Figure 4.2. Technological development by memes.

When we put it like this, two things become evident. First, we recognize that technologies are intrinsically *knowledge-driven phenomena*. To put it in Popperian terms, they are… (1) the knowledge of how to induce purposeful transformations in the physical world, and (2) the physical effects, or expressions of that knowledge (Popper, 1963; Deutsch, 2011). Second, we recognize that there is a deep connection between technology and the phenomenon of life itself. Aside from the fact that so many animals are brilliant technologists – the ant, the spider and the weaverbird just to name a few – every organism is itself a technological system – a technological system in service of its genes. In figurative terms, they are hypothetical answers to the following question – '*how can genes transform their local environment, to increase their chances of successful replication*?' (Dawkins, 1999, 2016). Indeed, genes are precisely repositories for technological knowledge – albeit without a knowing subject – and the phenotypic traits of their hosts are the physical expressions of that knowledge (Dawkins, 1999; Popper, 1994).

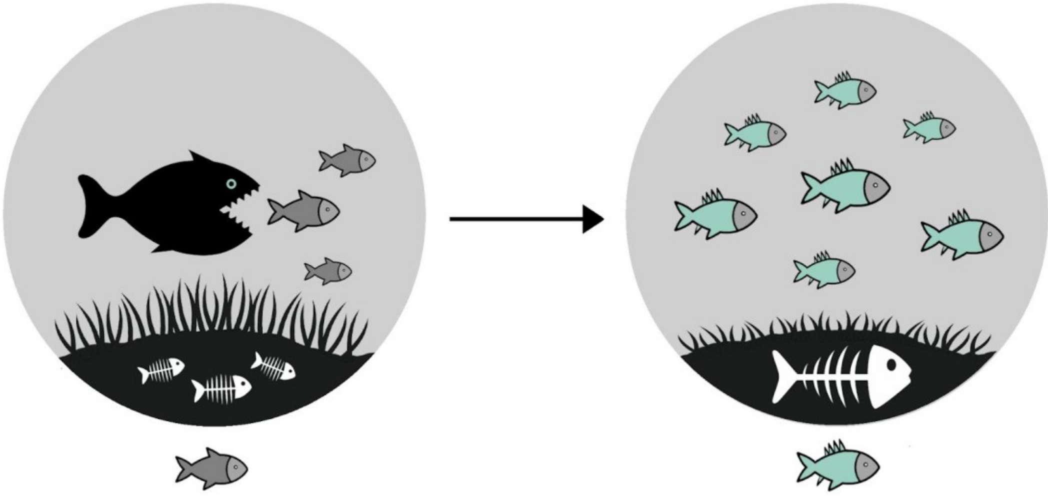

Figure 4.3. Technological development by genes.

We can thus conclude that there are two processes on Earth capable of generating technological knowledge. The first is the process of biological evolution, resulting from the differential survival of genes in gene pools (Chapter 1.2). The second is the growth of human knowledge, resulting from the productive interplay of conjectures and refutations (Chapter 2). Both of these processes can be understood as instances of 'problem-solving' by the universal method of *trial and error-elimination*, and both produce technological solutions to 'sustainological problems'. Aside from these general similarities, they are of course very different from one another. For instance, Process 1 is unconscious, slow, and brutally violent, and every failed trial results in the death of the problem-solver. In contrast, Process 2 is conscious, quick, demands no violence, and it allows the problem-solver to utilize failure as a source of *progressive self-improvement*. Lastly, because Process 1 is constrained to a narrow class of sustainological problems, its outputs are likewise parochial in their sustainological *reach*. In contrast, Process 2 may be able to solve any technological problem that falls within the laws of physics, and thus has an incomparably greater reach, both sustainologically and otherwise (Popper, 1963, 1994; Deutsch, 2011). With this in mind, let us revisit the subject of humanity's dependence on the biosphere.

4.1.2 Knowledge That Transforms The World

When we say that humanity depends on biospheric and biogeochemical processes, what we mean is that we depend on these processes to induce desirable transformations in our physical environment. As the ESS framework correctly points out, these transformations result – directly and indirectly – from the metabolic and behavioral operations of vast networks of biological organisms (Chapter 1). Hence, what we really depend on is the *knowledge* embodied in those organisms, and the *effects* of that knowledge in the material world (Chapter 4.1.1). To take an obvious example, we depend on the knowledge embodied in plants and algae of how to transform carbon dioxide and water into sugars and oxygen. Likewise, we depend on the knowledge in soil bacteria of how to transform dead organic matter into inorganic nutrients, which can fuel the growth of new plants and animals. On a higher level, we depend on the knowledge in whole communities of organisms, whose metabolic operations buffer and absorb pollutants, break down wastes, stabilize the Earth's climate, purify its air and water, and otherwise transform our environments into desirable states and configurations (e.g. Urry, 2016).

$$6CO_2 + 6H_2O + \text{sunlight} \longrightarrow 6C_6H_{12}O_6 + 6O_2$$

Figure 4.4. Photosynthesis.

The fact that we *do* rely on these processes in the first place is not itself difficult to understand. At root, it is because our own bodies are biological technologies, selected by an environment shaped by these processes (Chapter 4.1.1). Still, as discussed above, our bodies have one distinct feature that sets us apart from all other organisms – they instantiate a special type of software, capable of *creative and critical thought*. Most important for our present concerns, it can use these functionalities to generate *scientific and technological theories* – meaning, explanations of what is out there in the world, how it works, and how it can be modified in response to technological problems (Chapter 2 & 4.1.1). While all other organisms are narrowly adapted to their living environments, this software gives us a unique ability to *make environments livable*, by adapting *them* to *us*. But what are the limits of this ability? Could we really abandon the Earth altogether, and build independent societies in space? As we already know, the answer to this question is yes. The least complicated way of doing so would be to install the biospheric processes that our bodies depend on in this new environment. This problem is eminently *soluble*. All it would take is a system of space-worthy greenhouses and hydroponics facilities. The components of such a system could be constructed with resources from Earth, and then maintained and expanded with resources extracted in the asteroid belt (Curreri, 2007; Curreri & Detweiler, 2013; Chen, 2021). To avoid repeating ourselves, let us treat this matter as resolved, and focus instead on a more fundamental, and somewhat provocative question. Are there *any* biospheric technologies whose operations or effects could not, in principle, be substituted by artificial means? The easiest way to approach this question is to ask an even more fundamental one – what are the absolute limits to humanity's technological potential? Again, since we are referring here to our ability to induce *purposeful transformations in the physical world*, we can infer that there must be two inescapable limits to what we can achieve technologically at any given time. The first is *the laws of physics*, or – to include regularities at all scales and levels of emergence – *the laws of nature*. For instance, we can never develop the means to travel faster than the speed of light, or build a perpetual motion machine, or solve a mathematical problem that requires an infinite number of computational steps (Deutsch, 2011, 2012). The second is our current understanding of those laws, and of the environments that we wish to transform – in other words, the current state of our *scientific theories* (Chapter 2).

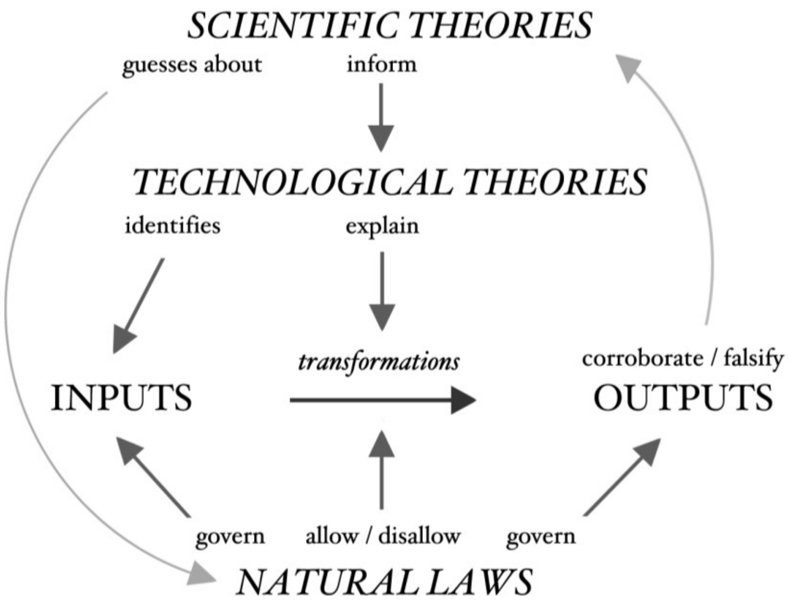

Figure 4.5. Science, technology and natural laws.

Any practical limitations will fall under these categories, since if a transformation is impossible with a given set of resources, or regardless of the available knowledge and resources, then those impossibilities will themselves be, or be the consequences of, *physical*, or *natural laws*. We can thus conclude that if we live in a comprehensible Universe – meaning, a Universe that evolves in accordance with explicable natural laws – then the only *absolute limits* to our technological potential *are those laws*. As Deutsch (2011) points out, these considerations can be summarized in one neat principle – "[any physical transformation] that is not forbidden by laws of nature is achievable, given the right knowledge". So, what does this principle tell us about the possibility of mimicking or replacing biospheric technologies with artificial ones? Since the organisms in the biosphere already exist, and since they all use but a tiny fraction of the resources in their respective environments, there can be no laws of physics that will prevent us from doing so. This argument applies equally well to their local interactions, or the ecological effects of those interactions, and so on down the line. To illustrate this point, let us consider three technologies that are possible according to the laws of physics, and which would allow us to create all of the resources that we need to survive (controlled environments, breathable air, food, clean water, clothes, medical instruments, and so on) by artificial means (adapted from Deutsch, 2011, pp. 42-78).

1. *Nuclear fusion*
   In addition to providing us with a near inexhaustible supply of clean energy, this technology could allow us to transmute light elements into heavier ones. With sufficiently advanced fusion reactors, we could convert hydrogen and helium into virtually any element in the periodic table.

2. *Nano-fabricators*
   Although far beyond our present capabilities, 3D-printers, or fabricators operating at the atomic scale are not forbidden by the laws of physics. With the right program, an atomic fabricator could produce almost any material object, from complex molecules, to raw materials, machinery, and even living beings.

3. *Autonomous robots*
   Autonomous robots, vehicles and manufacturing equipment have the potential to greatly improve the efficiency of our economic activities. They could also be used to explore and exploit hostile environments, or to make such environments livable prior to the arrival of biological beings.

On their own, these technologies could unlock incredible social and economic benefits, and working together, they could induce physical transformations that are almost too fantastical to be believed. Simply put, they would allow us to construct all of the basic resources that we need to survive out of compressed hydrogen and helium.

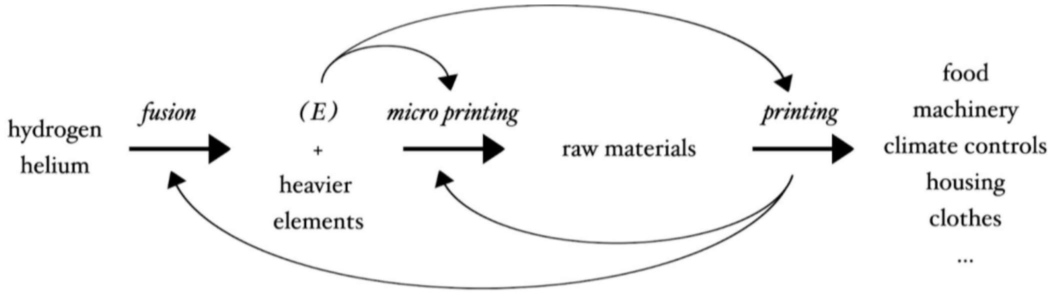

Figure 4.6. Transformations.

Since these are the most common elements in the Universe, this would drastically improve our ability to make new environments livable. Just the same, they would allow us to create a world with an average standard of living far above that of the world's richest nations today (Deutsch, 2011). They would also allow us to completely break our dependence on the Earth's biosphere, while at the same time giving us a near limitless ability to *protect*, *preserve and extend it*. If these technologies seem unrealistic, just remember that rudimentary nano-fabricators are already ubiquitous on Earth, and have been for 3.5 billion years. For instance, *cyanobacteria* are tiny, solar-powered robots, who build copies of themselves in the world's lakes and oceans (Urry et al., 2016). Of course, the point I am trying to make here is not that, 'we must develop technologies 1 to 3, so that a sustainological Utopia can emerge!' Neither is it that we need these particular technologies to break our dependence on the biosphere. The point is simply that there are no laws of physics that prevents us from substituting biospheric technologies with artificial ones. This means that the extent to which we *do* substitute them is entirely a matter of *choice*, and of whether or not we develop the *knowledge* required.

4.1.3 Through A System, Darkly

In the last subchapter, we explained that humanity's survival and welfare depends on our access to *technological knowledge*. However, whether that knowledge is instantiated in a biological or artificial substrate makes no critical difference – what matters is that it induces *physical transformations* that respond to our *sustainological needs*. Moreover, we demonstrated that if the Universe is governed by explicable natural laws, it is possible, in principle, for us to satisfy all of those needs by artificial means. Importantly, we arrived at these conclusions not by wild speculation, but by simply taking our current best explanations of ourselves and the world seriously (Chapter 4.1.2). So, where does this leave the idea that 'people and societies are integral components of the biosphere, depending on its functioning and life-support'? In order to defend it, we would have to argue either… (a) that our present understanding of the laws of physics is radically false, or (b) that for some reason, it is impossible for us to explain the transformations that are caused by the organisms in the biosphere, or (c) that despite the scientific and technological progress of the last three centuries, we do not live in a comprehensible Universe after all. None of these arguments would be easy to make. If we choose option (a), we would have to present some groundbreaking work in fundamental physics. If we choose option (b), we would have to explain why 100 years of progress in chemistry, genetics and biology is about to come to an inevitable end. Likewise, option (c) is not very attractive at all, since it would – in a much less ambiguous way than option (b) – land us right back in the domain of religious philosophy (Chapter 1). Regardless of how we phrase or formulate it, the proposition that there are physical phenomena out there that are governed by forces, or laws that are impossible in principle to investigate and explain, is logically equivalent to *a belief in the supernatural* (Deutsch, 2011). Of course, there is a deeper explanation for why the Universe is comprehensible to us. In simple terms, it is that the laws of physics consist of *computable functions*, that our brains are *universal computers*, and that our minds can utilize *conjectures*, *criticisms* and *purposeful physical transformations* (including controlled scientific experiments) to develop increasingly better approximations of these functions (Deutsch, 1985, 1997, 2011, 2016).

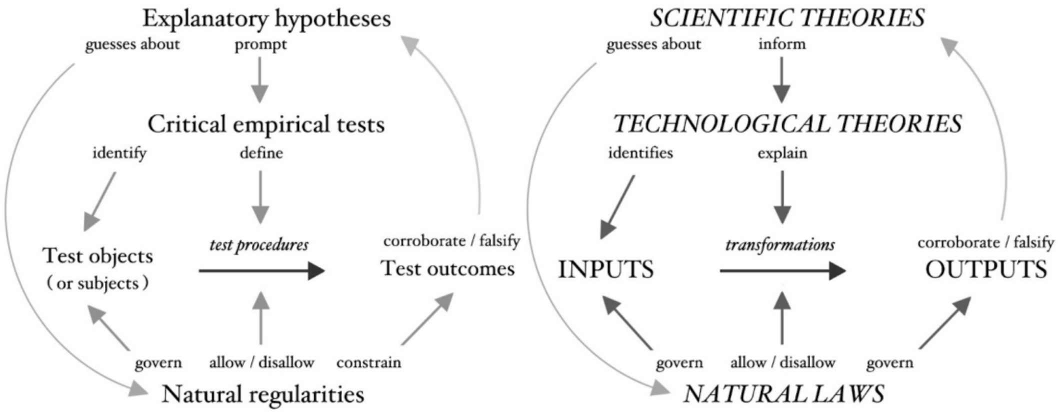

Figure 4.7. Science and technology.

This fundamental relationship between science, technology and the laws of nature explain both our ancestors' ability to successfully migrate out of the Great Rift Valley, and our present ability to leave the Earth system altogether.

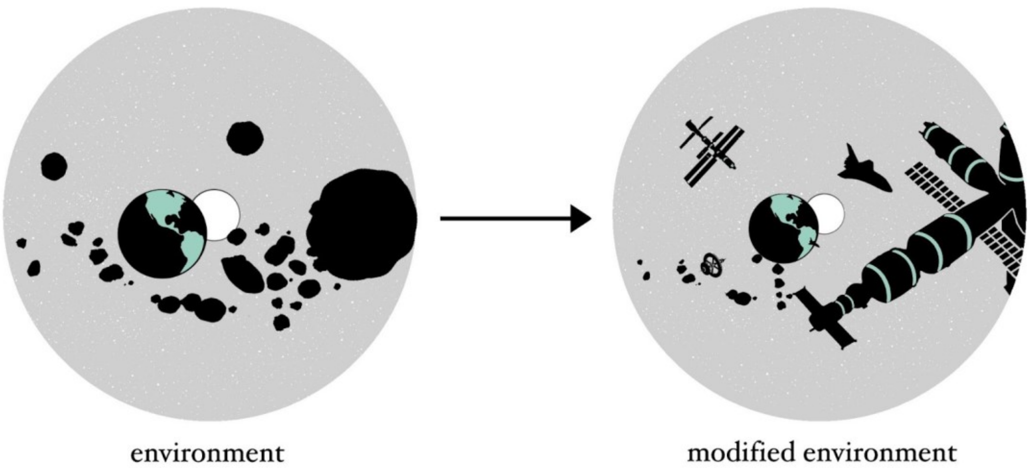

Figure 4.8. Transformations in space.

For our present purposes though, it is sufficient to note that the opposite claim – that we can *not* understand the physical world – is in direct conflict with the hypothetico-deductive model, and makes nonsense of the project of science, however we approach it (Chapter 2). Yet, if we look back at the ideas outlined in Chapter 1.4, we notice a common theme that binds them all together – namely, how the metamorphous and unpredictable nature of complex adaptive systems make it impossible for us to develop precise explanations of their attributes and operations (Chapter 1.4). As Meadows (2008) puts it, "[complex adaptive systems] are inherently unpredictable. They are not controllable. They are understandable only in the most general way… We can never fully understand our world, not in the way our reductionist science has led us to expect". Of course, in the sustainability sciences, the idea that the world is an insoluble mystery is neither new, nor controversial (see Appendix A). Regardless of how we twist and turn to avoid seeing it, the modern ESS narrative is still reducible to one simple proposition – that '*humanity was born from, is part of, and fundamentally depends on a vast and complex entity, which we are powerless to control, or even fully understand*'. And thus, the image of God endures (Chapter 1 & Appendix A).

4.2 A Formal Refutation Of The CAS Paradigm

According to Lovelock's Gaia hypothesis, the biosphere is an intrinsically balanced and orderly system. Over geological time, the co-evolution of its biotic and abiotic components has produced a network of biologically mediated feedback loops, which regulate the Earth's chemistry, and keep it comfortable for living beings. The world's plants and animals are like cells in a great body, working together for the welfare of the whole (Chapter 1.3). As we have already explained, this theory is false. While it is true that life alters the Earth's chemistry, and that feedback couplings occur between its biotic and abiotic elements, these linkages are no more likely to make ecosystems comfortable than to slowly degrade them, or to amplify disturbing influences, and so on (Kirchner, 2002). The real reason that the Earth is so well suited to its biological inhabitants is that *they* are adapted to *it* – not the other way around. Although Lovelock borrowed many concepts and terms from evolutionary biology, he forgot to consider the logic of the process to which they actually refer – the non-systematic variation, phenotypic expression and environmental selection of *technological knowledge*, instantiated in *genes*. Specifically, he forgot about the parochial reach of these entities, and their consequent blindness to opportunities for cooperation on a planet-wide scale (Chapter 1.3 & Chapter 4.1.2). This error is easier to understand if we think of it as the result of an uncritical *methodological holism* (Chapter 1.2.1). Had Lovelock spent less time thinking about life and its environment as interconnected boxes in circuit diagrams, and more about the actual physical relationships that these diagrams implied, he would surely have recognized the gaps in his theory. This brings us neatly to the 'complex adaptive systems' (CAS) paradigm. As explained in Chapter 1.3, the CAS paradigm evolved from a succession of 'conventionalist twists' to the Gaia hypothesis, intended to make it compatible with the Neo-Darwinian Synthesis (Chapter 1.3). Just like its parent theory, it builds on the fact that the orderliness of ecosystems arise from stable patterns of interaction between their biotic and abiotic components. These patterns are continuously defined and redefined by processes of variation, competition and co-evolution among these components. Unlike the Gaia hypothesis, the CAS paradigm does not state outright that ecosystems tend towards stable, or harmonious configurations. Instead, gradual change is regarded as the norm, and homeostasis is replaced with a bounded adaptive capacity (Chapter 1.3). If we stop our examination of the CAS paradigm here, it comes across as a pretty reasonable description of how ecosystems evolve. However, if we take a closer look, a host of distinctly Gaian issues nonetheless appear. The first thing we note is that the CAS model is not only meant to describe the evolution of ecosystems – it is meant to explain the attributes and operations of *every living thing on Earth*. It reduces the complexity of all known biological systems – from individual cells, to organisms, ecosystems, biomes and the entire biosphere – to one set of essential variables, functions and relationships. But that is not all – it is also a model of human beings, and of all of humanity's social and economic institutions (Chapter 1.3). It is – to put it mildly – very ambitious in its explanatory scope. Yet, if we look past their obvious differences, we notice that all of these entities *do* have one thing in common – they are all *knowledge-driven phenomena*. Specifically, they are expressions of *technological knowledge* instantiated in genes, and *technological* and *explanatory knowledge* developed by human minds. We can thus conclude that the CAS paradigm is a *theory of knowledge*, and specifically, a theory of *technological knowledge*, and its *effects*, or *expressions* in the physical world (Chapter 4.1.2). This means that in order for it to exhibit the formal qualities of a good, scientific explanation, it must either… (1) be aligned with our current best theories of knowledge – the theory of evolution and the hypothetico-deductive model – or (2) constitute a testable improvement on at least one of them. Just the same, it must either… (1) be aligned with the known laws of physics, or (2) suggest new and improved physical laws (Chapter 2). Does it satisfy these criteria? As we have already demonstrated in the previous chapters, it does not. Most egregiously, it fails to account for the critical differences between knowledge creation in human minds, and knowledge creation through biological evolution. In its insistence that 'people and societies are integral components of the biosphere', it confuses the sustainological potential of human beings with the parochial abilities of the rest of the Earth's biota (Chapter 4.1, 4.1.1 & 4.1.2). It implies that humans depend on a 'Holocene-like Earth' in the same way that all organisms depend on the environments to which their phenotypes respond. In fact, some ESS researchers go further, and argue that due to our delicate physiology and our complicated resource economies, humans are *uniquely sensitive* to environmental change (Clayton & Radcliffe, 1997, Ch. 15). This is a remarkable error, and one that we would not expect to find in a modern theory of knowledge. So, why do we nonetheless find it in the CAS literature? The answer to this question should be obvious by now – it is the result of an uncritical *methodological holism*. Imagine a cell, a society and the biosphere. If we focus entirely on their structural similarities, we can easily draw a system diagram that implies that they are near-identical phenomena. They all consist of interdependent components, whose interactions define their emergent features. They all have some kind of adaptive capacity, and all co-evolve with their environments, and so on. If we repeat this exercise enough times, and never stop to reflect about what is *different* about those systems and *why*, we may even convince ourselves that they are *a singular phenomenon*, occurring in different substrates, and at different scales (Chapter 1.3.2). From there, it is a short leap to the following argument – if an organelle is a subsystem of a cell, and the cell a subsystem of a human being, and the human a subsystem of a society, and the society a subsystem of an ecosystem, and the ecosystem a subsystem of the biosphere, *and if all of those entities are instances of the same phenomenon occurring at different scales*, then there should be a repeating pattern of interdependence between the components in each subsystem, and between the subsystems themselves (Chapter 1, 1.4 & 4). Indeed, this is how the CAS paradigm explains humanity's dependence on the natural world. We are 'integral components of the biosphere' just like the mitochondria in our cells are integral components of us. By this tortuous logic, it has transformed Lovelock's 'Cybernetic Gaia' into what might best be described as a 'Fractal Gaia' (Chapter 1.3.3). This Gaia is more dynamic and less predictable, but she is still a *global superorganism* – it just takes us a bit longer to figure that out. When we *do* figure it out, she collides just as violently with evolutionary theory as her mother did. The patterns of dependence that exist between the organelles in our cells and the cells in our bodies are *knowledge-driven*, and neither *biological*, nor *cultural evolution* could explain the existence of similar patterns in the Earth system as a whole (Chapter 1.3 & 4.1.2).

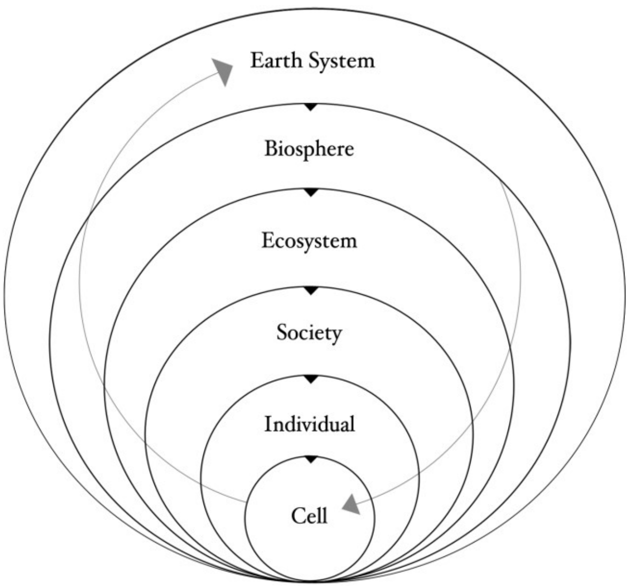

Figure 4.9. The Fractal Gaia.

But if the complex adaptive Earth is just another Gaia in disguise, how come no one has pointed this out before? Insofar as I can tell, it is because her disguise is very good. She is covered in layers upon layers of ambiguous concepts and terms, and mathematical constructs that few people seem willing to challenge (see Chapter 4.2.3). In the next subchapters, we will take a critical look at some of these concepts and terms.

4.2.1 Emergence

Instead of explaining complex adaptive systems as *knowledge-driven* – which is what they are – the CAS literature typically describes them as *emergent phenomena*, resulting from *spontaneous organization* in *multi-agent systems*. While the first part of this idea is trivially true – knowledge-driven entities are inherently emergent – the second part can be very misleading. Let us revisit the examples of spontaneous organization given in Chapter 1.3.2 – namely… (1) the synchronous movements of flocking birds, (2) consciousness arising out of the electrochemical activity in brains, and (3) the cooperative behavior of ants and other social insects. According to CAS theory, these are examples of emergent orderliness, arising spontaneously out of a more or less chaotic substrate, through the repeated interactions of behaviorally simple agents. They are 'spontaneous' and 'emergent' because there is no central command unit that directs the agents involved. No bird leads the flock, and no neuron, or neuronal cluster leads the brain, and no committee of ants organize the work on the ant hill (Chapter 1.3.2). But is this really a fair description? Not exactly. None of these phenomena emerge out of chaos, and neither are they spontaneous, or leaderless in any strict sense of the word. They are all products of the *knowledge* instantiated in the *agents' genes*. Every bird in the flock has a *shared* set of instructions for how to fly in formation – otherwise no formation flying would occur. Likewise, the neuronal structures that instantiate our first conscious thoughts are carefully arranged for this purpose – otherwise no conscious thoughts would occur. Finally, ants are born with a distributed set of instructions for how to build and maintain an ant hill – distributed because of their haplodiploid inheritance system (Dawkins, 1999, 2016). Most importantly, the genetic instructions for how to fly in formation, or boot up a human brain, or build and maintain an ant hill *are precisely that* – instructions for how to bring about emergent phenomena that increased the fitness of the agent's ancestors. This means that to explain them as products of spontaneous organization in the sense implied above, we would have to go back for thousands, or millions of years, and treat the *genes* of the agent's ancestors as the *actual agents* involved, (and not even then would the argument hold). Again, complex adaptive systems are *knowledge-driven*, and the knowledge embodied in most organisms is context-dependent and more or less fixed (Popper, 1994). This means that as a rule, spontaneous order in the sense meant above only emerges in *human systems*, because humans are the only agents capable of *spontaneously generating complex ideas* (Chapter 2 & 4.1.2). Much of the confusion around this issue seems to originate in a careless application of concepts and terms from *chaos theory* – a branch of mathematics investigating unstable and aperiodic behaviors in classical, nonlinear systems (Chan, 2001). We will expand on this problem in the next subchapter.

4.2.2 Chaos

According to CAS theory, complex adaptive systems are ineffably complex, and may undergo sudden, nonlinear state changes, even in the wake of apparently minor perturbations. Because of this, it is impossible to perfectly predict their behaviors, and therefore, to fully understand, or control them (Chapter 1.4.3, 1.4.4 & 1.4.5). A popular explanation of these features is that CAS exhibit a 'sensitivity to initial conditions', in the *chaos theoretic* sense (Chan, 2001). We will not go into full detail here about the difficulties that arise when we try to apply this framework to real-world systems, aside from making the following points…

1. The Universe does not obey classical mechanics – it is quantum mechanical – which means that 'butterfly effects' do not occur in real-world systems. In the Universe described by chaos theory, positively and negatively charged particles could not be arranged into stable configurations, and hence, solid matter could not exist (Deutsch, 1997, Ch 9).

2. That the Universe is quantum mechanical also means that 'classical chaos' does not constitute an obstacle to our ability to *explain it*. The stabilizing effects of *quantum interference*, and the fact that the world is *discrete* rather than *continuous*, are key to the computability of physical laws (Deutsch, 1985, 1997).

Of course, this is not to suggest that CAS do not exhibit nonlinear behaviors, or that they are perfectly predictable. The point is simply that, as a rule, sudden state-changes in organisms and ecosystems are preceded by causally connected events that can – in principle – be explained (Chapter 4.1.2). This view is corroborated by the fact that nearly all such state-changes that have been observed *have good explanations* (e.g. Folke et al., 2004, Figure 2). Among the various regime shifts that are described in the CAS literature, the class that is the most resistant to explanation is one that has never really been observed at all – that is, cascading regime shifts that lack a common driver, but nonetheless propagate widely across spatial and temporal scales (e.g. Rocha et al., 2018). Again, none of this is to suggest that CAS are perfectly predictable. For instance, their long-term evolution is impossible to foresee. That is because they are *knowledge-driven*, and the knowledge that will be created tomorrow can not be deduced from the knowledge that exists today

(Popper, 1963). This also means that *humans* – who can spontaneously generate complex ideas – are unpredictable at any timescale. In contrast, plants, animals and ecosystems are infinitely *more predictable*, because they are organized by knowledge that is *slow-growing*, *parochial*, and *largely fixed* (Chapter 4.1.2 & 4.2.2). These considerations once more illustrate the absurdity of the Fractal Gaia argument. They also show that the 'competing attractor' model of CAS outlined in Chapter 1.3.5 – another import from chaos theory – is very problematic, at least if we regard it as a general model of their evolutionary dynamics. Lastly, the fact that we can not predict with perfect accuracy what an animal will do next, or what an ecosystem will look like in 1000 years, does not mean that we can not develop *progressively better explanations* of their present attributes and operations (Chapter 4.1.3). Both animals and ecosystems are finite physical systems, and as such, they offer no insurmountable resistance to being explained (Chapter 4.1.2). The better we understand them, the more accurately we will be able to predict their behaviors, their sensitivity to local or global perturbations, and their resilience to destabilizing change (Chapter 4.1.3).

4.2.3 Dialectical Ecologism

In the middle of the 19th century, the German philosopher Karl Marx presented a radical new twist on the Hegelian theory of cultural development – that is, the idea that human societies evolve from a bad, or primitive initial state, towards a good, or fully developed final state, all in accordance with some divine, or social, or social-natural laws (Popper, 1945). More precisely, he conjectured that societies evolve in a dialectical cycle, or spiral, where the current socio-economic order, or 'thesis', collides with the emerging socio-economic order, or 'antithesis', until a new socio-economic paradigm, or 'synthesis' is born. Each new paradigm is defined by its technological means of production, and the power structures that emerge and solidify around these technologies. Just the same, each new paradigm has inherent weaknesses, which can be exploited through technological innovation, or 'industrial mutation'. Most importantly, every time new and better means of production are introduced, the owners of those means will use them to exploit their workers in a more brutal and efficient manner. Hence, each wave of industrial mutation will cause the suffering of the workers to grow. This increases the political tensions in society, and prepares it for the next paradigm shift. In the end, this process must result in a global proletarian revolution, where the workers of the world unite, and do away with their oppressors once and for all. When this occurs, the global sociological order will have evolved from its initial stage of *primitive communism*, through the inevitable stages of *slavery*, *feudalism,* and *capitalism*, to its logical endpoint – *a fully developed communism*. After that, the dialectical cycle will stop (Popper, 1945; Marx, 2013). Aside from its obvious indebtedness to Hegel, Marx's ideas can be understood as a teleological and equalitarian spin on Plato's theory of the 'Perfect State' (Popper, 1945). As most of you will have recognized by now, it is also the original template for *the adaptive cycle*. The first versions of this model were derived from Marx's writings by the German economist Joseph Schumpeter, and a few decades later, it was brought into ecosystem ecology by C.S. Holling (Walker & Salt, 2006). Out of all of the bad ideas that we have explored in this chapter, the adaptive cycle is by far the most dangerous. Coincidentally, it is also the most nonsensical from a scientific point of view. If we review the four phases of the adaptive cycle, and the potential connections between them, one glaring issue immediately stands out. Aside from spontaneously popping into existence from nowhere, there is no conceivable state of an organism, or ecosystem, or society that could not – with minimal effort – be interpreted as inhabiting one of those phases, or a transitional phase between them (see Chapter 1.4.6). This means that no empirical data could ever *refute* the adaptive cycle, nor meaningfully *corroborate it*. The adaptive cycle is so general and vague that it can be used to explain anything, and hence, *it explains nothing at all* (Chapter 2). Still, the worst problems appear when we try to apply it to human systems. Then it turns into precisely the oracular historicism that was peddled by Marx and his followers – complete with an implicit argument for the benefits of social conflicts and economic destruction (Holling, 2004). In the words of professor Holling (2004) himself, "the world seems to be moving towards a major transformation… In my opinion, this started […] with the fall of the Berlin Wall and the collapse of communism… Wealth itself and broadening wealth combined to lead to our present vulnerability… We are entering the back loop […] that entails the collapse of accumulated connections and the release of bound-up knowledge and capital. However, it also opens […] the opportunity for 'creative destruction'" (Holling, 2004). Of course, in the real world, humans have the ability to criticize, to reinterpret, and to creatively modify their ideas, and hence, neither we, nor our societies evolve in accordance with immutable social, or social-natural laws (Popper, 2002; Chapter 2). Any argument to the contrary is rank *biological* or *cultural essentialism*, or, as in Hollings case, a grandiose *oracular historicism*. The apparent cycles in our social and political history exist because *people create them* – often, it seems, because high-minded men convince them that they are inevitable anyway (Popper, 1945, 2002). In the first half of the 20th century, Marx's followers used the inevitability of the proletarian revolution as an excuse to embark on a 70 year long campaign of creative destruction, which ended up taking the lives of almost 100 million people (Courtois et al., 1997). So, to make a long story short, the adaptive cycle is pseudoscience of the worst kind, and for the resilience framework to make theoretical progress, it must be immediately and unequivocally rejected.

4.2.4 Planetary Boundaries?

Ironically enough, the clearest evidence that something is amiss with the modern ESS framework comes from its most popular offshoot – the 'Planetary Boundaries' hypothesis (PB). The PB is a meta-theoretical framework that appeals to all of the concepts that we have discussed in this thesis, (it even references the original Limits to Growth model and the Gaia hypothesis) (Rockström et al., 2009a). As the name implies, the PB is built around 9 hypothetical sustainability thresholds in the Earth system at large, each related to an anthropogenic disturbance factor. For every boundary (except one), there is a measurable control variable, and a critical impact level, beyond which rapid, system-wide transitions are expected to occur (Rockström et al., 2009a; Steffen et al., 2015; Persson, 2022). As Rockström et al. (2009a) explains, "Transgressing one or more […] boundaries may be […] catastrophic due to the risk […] that [it] will trigger non-linear, abrupt environmental change within continental- to planetary-scale systems". Since the PB was first introduced, 5 of its 9 boundaries have been crossed, and three of them so much so that the associated probability of 'abrupt environmental change' is at the highest level of the framework's original risk measurement scale (Rockström et al., 2009a; Persson et al., 2022). However, despite this dire situation, no planet-, or continental-, or even country-wide regime shifts have yet been observed. Why is that? Are we just having a run of amazing good luck, or is there a better explanation? There is. While the anthropogenic disturbance factors in the PB have unambiguous impacts on the local and regional levels, it is not at all clear how those impacts will cause transitions on a continental, or planetary scale. In fact, only 3 of the planetary boundaries are accompanied by *good explanations* of how this could occur – climate change, ocean acidification and ozone depletion. For the rest of the disturbance factors, the suggested mechanisms are either vague, or not explained at all (e.g. Brook, Ellis & Buettel, 2018). This is a big problem, given that the *only new information* that the PB conveys about them is that their impacts will cause, or contribute to, nonlinear state-changes in the Earth system as a whole (Rockström, 2009a; Steffen, 2015). Naturally, this has been pointed out many times before in earlier criticisms of the framework. For instance, Montoya et al. (2018) makes the following observation; "the planetary [boundaries] suggests that we can view nature […] as a type of black box – if we do not poke it too hard, we will not need to understand its details. We need not define terms, measures, processes [and] responses in operational ways. In short, ecological ignorance is bliss, if human actions remain within limits". Indeed, this is a good summary of the prevailing attitude among CAS researchers (see Chapter 4.1.3). But is it really fair to say that the PB treats nature as a black box? Not exactly. It treats it as a Fractal Gaia (Chapter 4.2). If we assume – as the theories it draws on implicitly assumes – that the components of the Earth system exhibits the same pattern of interdependence as the organelles in a cell, or the cells in an organ, or the organs in a body, it is not so far-fetched to suppose that an *untreated infection* in one part of the Earth system might eventually spread. As Rockström et al. (2009a) puts it, "There is significant uncertainty surrounding the *duration* over which boundaries can be transgressed before causing unacceptable environmental change" [emphasis added]. Without knowledge of its Gaian justification, we could not make heads or tails of this statement, because for most of the boundaries, the PB does not provide exact explanations of *what* and *where* and *why* they are, and what the *effects* of crossing them will be (Chapter 4.2). If we employ the concept in a relaxed fashion, we can view the PB as a sort of empirical trial of the modern Earth system concept. Regarded as such, it is a failed, and continually failing trial. The reason for its failure is that the PB is based on a false theory – the theory that the Earth is a complex adaptive system.

4.3 Conclusions

This thesis has examined two central theories in the modern sustainability paradigm… (1) the theory that the Earth's geosphere, hydrosphere, biosphere, anthroposphere and atmosphere form a complex adaptive system, and (2) the theory that all human activities are intrinsically dependent on, and constrained by, non-anthropogenic states and processes in the Earth system. In its introductory chapters, we explored the origins and the logic of these theories. In this chapter, we have subjected them, as well as the larger framework to which they belong, to formal, semi-formal and comparative criticism. In doing so, we have demonstrated that… (1) they still exhibit a fundamentally religious character, (they posit the existence of inexplicable physical forces, or principles, or laws), (2) they still promote an uncritical methodological holism, (the doctrine that natural systems must be understood as 'parts organized by the essence of the whole'), and (3) they still appeal to deterministic and teleological conceptions of ecosystem ecology and cultural change, (chaos theory and material dialectics). Most importantly, we have shown that they conflict with the theory of evolution by natural selection, and with the hypothetico-deductive model of scientific research. They also clash – both directly and indirectly – with the known laws of physics. Because they fail to account for the vast differences between adaptive complexity arising from the variation and selection of genes (biological evolution), and the variation and selection of memes (cultural evolution), they paint a false picture of both the workings of nature, and of humanity's relationship to it. Of course, even if we ignore these problems, neither theory is *testable*, and neither are *precise explanations* of their explicanda. Hence, we have uncovered more problems than we need to reject them on formal and comparative grounds. In brief, we have shown that… (1) the Earth does not exhibit the properties of a complex adaptive system, (as commonly defined), and (2) that humanity's social and economic activities are *not* intrinsically dependent on, or constrained by, specific non-anthropogenic states and processes in the Earth system. While it is true that all human activities rely on biospheric processes today, there are no physical, natural, or epistemological laws that make it impossible for us to break those dependencies over time. In fact, we have demonstrated that it is possible in principle to satisfy any human need by artificial means, and resources that abound both inside and outside of the Earth system. An important corollary to this finding is that social and economic progress is not inextricably tied – as the modern sustainability literature suggests – to the exploitation of finite and rapidly diminishing resources here on Earth.

4.4 Discussion And Future Directions

Humanity's capacity for creative and critical thought gives us a unique freedom that no other animals have – the freedom to extend, to modify, and to completely reject the knowledge in our genes. Likewise, it gives us a unique ability to *explain* the world around us, and to *transform* it in accordance with our conscious wants and needs. Most importantly, it gives us a unique ability to *care for one another*, and indeed, *to care for other living beings*. No other animals have the slightest interest in the fate of the biosphere, and neither do the trees, or the butterflies, or the worms in the ground. The Earth's biosphere is an oasis of beauty, complexity and connection in a Universe that is overwhelmingly empty and boring. As the only species capable of appreciating this fact, we have a clear moral duty to *protect* and *preserve* it. And we *can* protect and preserve it. With the right knowledge, we can do anything that is not forbidden by the laws of nature, and as we have seen, those laws provide us with tremendous leeway. Still, we will not get far if we refuse to accept that this is the case. If we convince ourselves that the world is an insoluble mystery, or that we depend on some unknowable power above ourselves, then mediocrity, parochialism, and violent failure will be the inevitable result. We know this because humanity has traveled down that road many times before. In this thesis, we have been harshly critical of the modern sustainability paradigm. However, none of our arguments have attacked the *central moral principle* around which the field is organized – that 'we should try to build peaceful and prosperous societies, while at the same time protecting and preserving the Earth's biosphere'. Hence, our goal has not been to overturn the sustainability domain completely. Rather, it has been to correct a number of entrenched errors in its popular theories. In other words, our goal has not been to topple the sustainability sciences, but to *advance them*. And they *can* be advanced. Even the theories that we have criticized here have many reasonable elements. However, to make progress, we must let go once and for all of the notion that the biosphere is balanced, or caring, and that 'sustainability means living in harmony with nature'. Second, we must deny every impulse towards dogmatic *holism*, or *whole-systems thinking*. Just like *methodological reductionism*, this approach is antiquated and false, and has no place in the modern sciences. We need to abandon our vague and fuzzy 'models of everything', and focus instead on developing *precise explanations* of the problems that we wish to solve, because precise explanations are far more likely to entail working solutions. Finally, it is possible to formulate an *objective*, or *universal theory of sustainability*, which integrates elements from both resilience and complex systems theory. The results of this thesis provide a rough map towards its realization, and in a series of upcoming publications, I will present it in more exact terms. These too will be unorthodox additions to the sustainability literature – most of all because they give a bright and hopeful view of our common future on this planet, and beyond.

4.5 Ethical Considerations

This thesis does not handle any sensitive data, and there are no conflicts of interest (SFS, 2003:460).

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Appendix A: The Philosophical History Of The Earth System Sciences

As with the concept of sustainability itself, the philosophical roots of the ESS framework can be traced back to the physico-theology of the early Enlightenment, and specifically, to the writings of a group of influential bureaucrats and proto-ecologists in the Holy Roman Empire (see Grober, 2007, 2012, 2018). The term sustainability was first introduced in the book 'Sylvicultura Oeconomica' – the Economics of Silviculture – published in 1713 by the Saxon accountant and mining administrator Hans von Carlowitz. Responding to the threat of a Europe-wide timber shortage, the Sylvicultura' outlined a strategy for ecologically sound forest management, aimed at promoting a 'nachhaltig', or 'sustainable' yield of this vital resource. To ensure the prosperity of current and future generations, Carlowitz argued, man must be careful when harvesting natural resources such as timber. When we exploit them too aggressively, we disturb the divine energies that organize and regenerate the biosphere, and thus threaten their future availability, both in the short and the long term. The natural world, he explained, is a mild and kind entity – Mater Natura; Mother Nature – and as long as we treat her with respect, she will continue to provide us with the things that we need. However, if we go against her wishes, or try to bend them to our will, we are committing a sin against the forces of life itself (Grober, 2007). As indicated above, Carlowitz's ideas were rooted in a tradition of thought that we might call 'Catholic physico-theology', or 'eco-theology'. Like the authors who inspired his thinking – most notably, John Evelyn and Jean-Baptiste Colbert – Carlowitz was a devoutly religious man, and throughout the Sylvicultura Oeconomica, we find him justifying his practical suggestions with appeals to the Old Testament. According to the eco-theologists, the Biblical stories, and particularly Genesis, contains an implicit argument for environmental conservation. This argument can be summarized as follows: Because the will of God is expressed in nature, nature is inherently good. Hence, man, in his now fallen state, should take care not to offend its design even further, and rather than plundering the Earth to satisfy his own selfish desires, he should return to his intended role as its protector and steward (see Grober, 2007, p. 20). To unpack this idea, and to really understand its influence on the modern sustainability paradigm, we need to familiarize ourselves briefly with the Old Testament doctrine of creation.

A.1 The Great Spirit

In the book of Genesis, it is explained that the world we inhabit was created by an all-knowing, all-powerful and perfectly good being, referred to as God. At the beginning of time, God created a perfect original world – an ecological Paradise, where every living and non-living thing coexisted in a state of exquisite harmony (see Genesis, 1 & 2; Grober, 2012). Using his own form as a template, he then constructed the first human beings – a man and a woman named Adam and Eve – and granted them dominion over the rest of his creation. To give them a home, God planted a Garden in the land of Eden, filled with every tree, bush and herb that is pleasing to the eyes and good for food. He brought the first people to the Garden, and instructed them 'to tend and to cultivate it', and thus, to be the instruments of his will, and the keepers of his design (see Genesis, 1, 2 & 3; Grober, 2012). In reward for their services, they could eat freely from the plants in the Garden, including the fruits from a magical tree that granted eternal life. However, there was one plant that they were not allowed to eat – the fruits on 'the tree of knowledge of good and evil'. This knowledge, God had decided not to instill in man, because had they received it, they would have become his *equals* (see Genesis, 2 & 3). And so, here we have the biblical ideal of 'the original people' – the stewards of an ecological paradise, living eternally off of nature's abundance, naked and content, and in perfect harmony with the rest of creation, (Grober, 2007, p. 20).

Figure A.1. The Garden of Eden (Rubens, ca. 1615).

The key to their blissful existence, as Genesis implicitly points out, was their complete lack of autonomy, both in thought and in action. They were nothing but servants of God, unburdened by material possessions, and untroubled by philosophical doubt. Like the divine will that animated them, they were spiritually pure and perfectly good (see Genesis, 1, 2 & 3). This point is emphasized in the 'story of the fall of man', which explains how *sin* came to enter God's kingdom (Genesis, 3; Romans, 5:12). This happened when after some time, the original people disobeyed his laws, and ate the fruits from the tree of knowledge. Importantly, they did not do so in an act of defiance, or due to an impulse towards exploration, or some other spark of individuality – they did it because they were told to do so by a cunning serpent. Having consumed the fruits of knowledge, Adam and Eve gained the quality of mind that God had denied them – a capacity for self-conscious, critical thought. As follows, they were transformed into intelligent, autonomous beings, aware of their own moral agency, and thus, capable of choosing their own path through life. For this crime, God banished them from the Garden of Eden, and sentenced them to live finite lives, full of suffering and hard work (see Genesis, 3).

Figure A.2. The expulsion of Adam and Eve from Paradise (Giordano, 1705).

Now, throughout history, this story has been interpreted in many different ways. Although the above reading is fairly straightforward, it is focused on the narrative elements – explicit and subtextual – that were seized upon by the eco-theological thinkers (see Grober, 2007, 2012, 2018). To summarize, these were…

1. The idea that the natural world was created by a great and benevolent Spirit, whose will is expressed in its architecture and its essential dynamics.

2. The idea that at the beginning of time, the world was perfect. Because every component of the natural world moved in accordance with the will of the Spirit, they formed an integrated and harmonious whole.

3. The idea that the first human beings were serene and selfless creatures, who lived in a state of natural grace – meaning, in accordance with the will of the Spirit, and therefore, in perfect harmony with both one another, and with the rest of nature.

4. The idea that the unity of the original world was corrupted when mankind gained the ability to think, judge and act for themselves – that is, independent from the supreme moral Will that permeates the natural world.

In these four dogmas, we see a clear influence of the scholastic philosophy that dominated in Europe before the Scientific Revolution. In particular, we see the influence of… (a) the holistic and teleological ontology of Aristotle, which holds that 'the mind of God is the substance that animates nature, and moves all things towards their true and rightful destinations', and (b) the authoritarian sociology of Plato, which holds that 'to live a virtuous life, we must abandon all individual hopes and desires, and live in complete service to the collective, or higher good' (see Popper, 1945). More to the point, we see a striking resemblance between the dogmas of eco-theology, and the tenets of the early ESS framework (Chapter 1). In fact, we see that they are almost identical to one another. To demonstrate this, simply revisit propositions 1 to 4 above, but swap out the concept of 'the Great Spirit' with that of an 'emergent, homeostatic tendency in nature', and the biblical motif of 'the original people' with our Stone Age ancestors. With this in mind, let us return to Hans von Carlowitz and the German Kameralists. Carlowitz's theories on sustainable forest management were well received by his peers, and the Sylvicultura Oeconomica quickly became a leading text in the German administrative profession. As such, it helped promote a wider revival of eco-theological thought in Germany and Europe, which, through its influence on Goethe, Herder, von Humboldt and Earnst Heackel, would culminate in the founding of the discipline of ecology (see Grober, 2007, 2012, 2018). In Carlowitz's writings, we find the first popular formulations of the doctrine that, 'to harvest biospheric resources in a sustainable manner, we must… (a) not let our rate of consumption exceed the rate at which nature replenishes them, and (b) avoid methods that destabilize the ecosystems from which they are taken' (Grober, 2007). A fine doctrine indeed. Unfortunately though, it was tangled up – as it has been in the sustainability literature ever since – with the patently absurd idea that 'the biosphere is a mild, or kind, or harmonious entity', and the associated belief that 'humanity is but one cell in the body of nature, whose welfare depends on the welfare of the whole'. These ideas – popular as they may be – are most certainly false. We will return to this problem in chapters 1.3 and 4. The remainder of this Appendix will be devoted to a discussion on the 3rd and the 4th of the eco-theological dogmas, and their impact on the historical, sociological and political dimensions of the ESSA.

A.2 The Original People

In many ways, the idea that our prehistoric ancestors lived in a Golden Age is the strangest one examined in this thesis – if nothing else for the fact that it goes so completely against the evidence in hand, (more on this later). To understand how it became part of the modern sustainability paradigm, we have to make a short detour into the field of social philosophy. For over half a millennia, a certain lineage of social theorists have been confusing our hunter-gatherer ancestors, and the traditional communities that still adhere to their way of life, with the biblical ideal of the original people. One of the earliest examples can be found in the work of Pietro Martire d'Anghiera – a historian working for the Spanish court during the Age of Discovery. Describing Columbus' encounters with the natives of Central America, he wrote; "The land belonged to all, just like the sun and water. Mine and thine, the seeds of all evils, do not exist for those people… They live in a Golden Age… in open gardens, without laws or books, without judges, and they naturally follow goodness… So in harmony with their surroundings that they all live justly and in conformity with the laws of nature" (cited in Mulder & Coppolillo, 2005). In the centuries following Columbus's exploits, this idealized vision of the tribal hunter – commonly referred to as 'the myth of the noble savage' – became a leading concept among Europe's illiberal and anti-rational thinkers. One of its most famous exponents was the Genevan eco-theologist Jean-Jacque Rousseau. In a series of essays published between 1750 and 1762, Rousseau took the idea of the noble savage and expanded it into a secularized reformulation of 'the story of the fall of man', and a fervently irrationalist critique of the European Enlightenment (see Rousseau, 2002). The first human beings, he conjectured, were simple and solitary creatures. They lived in small, close-knit family groups, who wandered the forests of prehistoric Earth, hunting and foraging to secure their subsistence. Like all animals, they were well adapted to their environment, and acted mostly on inborn impulses and expectations. Although physically formidable and more than capable of defending themselves if needed, they were calm and compassionate beings, ruled by a deep moral instinct, and a primitive, patriarchal and egalitarian social ethic. They took from nature only what they needed to survive, and had no interest whatsoever in material possessions. They just wandered the Earth, following the rhythms of the biosphere, mindful and present, and at peace with their circumstances. Theirs, Rousseau argued, was the Golden Age of humanity, which after the invention of agriculture was irrevocably lost (see Rousseau, 2002). When humanity discovered how to grow their food themselves, their flocks started to expand, both in size and complexity. Seasonal camps turned into stationary settlements, and man had to spend less and less time in the wild to maintain himself. No longer following 'the voices of nature', he became increasingly infatuated with the games of social life, and the products of his own imagination. He began to have dreams of progress – of science, art, music and technology, and of a world remade in his own image. Not to put too fine a point on it, he was tempted by the fruits of knowledge. Before long, the social and intellectual stratification of the modern world evolved, and with it, the pompous nobleman in his gold embroidered waistcoat, and the poor masses, begging him for a share of the fruits of their own labor. According to Rousseau's philosophy, the evolution of culture is the source of all human evil. Any attempt at cultural progress – no matter how small or insignificant – originates in pride and vanity and selfish ambition. As such, it removes man from his peaceful original state, and corrupts his peaceful original nature (Rousseau, 2002). Hence, nothing could be more vile than the progressivist ideals of his own time – the resurging influence of Pericles, Protagoras and Democritus, and the celebration of individualism, creativity and critical discussion, rather than the conservative virtues of discipline and obedience to authority. Like Plato before him, he spat on the soft-hearted liberalism of his contemporaries, and cried out for a return towards a simpler time – "O Sparta! you outshine forever a vain doctrine! While the fine arts ushered vice into Athens, [...] you drove from your walls the arts and artists, the sciences and scholars!" (Rousseau, 2002; Popper, 1945). But what then can we do to right the ship of society? Do we have to regress all the way back to our original state of nature in order to redeem ourselves? Not quite. To build a virtuous society, Rousseau argued, we must follow Sparta's example. We must tear down every institution of science and learning, and relieve every man woman and child of their private possessions. Then, we must erect a new social order, where every citizen is forced to abandon their individual hopes and desires, and to live in complete service to 'the general, or collective will', as embodied in the bureaucracy of the nation state. Only then will modern man be *truly free* (Rousseau, 2002) As is evident, Rousseau, much like the German philosopher Karl Marx, borrowed heavily from the sociology of Plato (see Popper, 1945; Rousseau, 2002). At the core of his political theories, we find the distinctly Platonic ideas that...

1. At the beginning of time, there was a perfect original society, and our societies are its degenerated offspring.
2. Because it inevitably moves us away from the perfect society at the beginning of time, the evolution of culture leads to nothing but corruption, injustice and evil.
3. To make our societies whole again, we must embrace a radically conservative and authoritarian political philosophy, modeled after the tribal communism of our prehistoric ancestors.

Unsurprisingly given this influence, Rousseau's ideas are replete with that dialectical sleight of hand – or doublethink as George Orwell aptly called it – which, since Plato invented it, has been the hallmark of the enemies of freedom and democracy, both on the right and left ends of the political spectrum (see Russell, 1945; Popper, 1945). For instance, we are taught that... (a) ignorance is enlightenment, (b) progress is decline, (c) wealth is poverty, and most importantly, (d) true freedom is absolute servitude (see Rousseau, 2002). More to the point, they were also an ingenious reformulation of the 3rd and 4th dogmas of eco-theology, which would inspire generations of social and environmental activists and scholars. Among his most important apostles, we find the sociologist Marshall Sahlins and the ecologist Paul Shepard. Speaking at a symposium in 1966, Sahlins advanced the theory that our Pleistocene ancestors – contrary to popular belief – lived peaceful, comfortable and spiritually fulfilling lives, in balance and harmony with their biospheric surroundings. They took from nature only what they needed to survive, and had no interest whatsoever in material possessions. What little they had, they shared, seeing to it that the tribe was fed and protected, even in periods of relative scarcity. Most of the time though, their humble wants meant that they could maintain themselves with almost no effort at all. A typical day for the hunters consisted not so much of a fight to secure their subsistence, but rather of lazing about in their campsites, dreaming up myths and stories, and enjoying one another's company. Just like Rousseau, and later Marx and Engels, Sahlins contrasted this "Zen road to affluence" with the insatiable hunger for status and wealth exhibited by modern man, concluding that, "free from market obsessions of scarcity, [the] hunters' economic propensities may [have been] more consistently predicated on abundance than our own" (Sahlins, 1972). Poverty and social injustice, he explained, are the inventions of civilization, and as such, they "increase relatively and absolutely with the evolution of culture" (Sahlins, 1972). A few years later, these ideas were echoed and expanded upon by Paul Shephard. In his book 'The Tender Carnivore and the Sacred Game', he advanced the radically primitivist thesis that, 'since the human genome was selected by a Pleistocene environment, our minds and bodies can only function properly in Pleistocene-like circumstances'. Without the cognitive challenges associated with the hunter-gatherer lifestyle, we are left in a perpetually underdeveloped state. The invention of agriculture, he explained, was humanity's greatest mistake. It promoted a new, unnatural way of life, which transformed us into stupid, aggressive and short-sighted beings, incapable of understanding the essential properties of the biosphere, expressed in the totemic-animistic myths of our tribal ancestors. It made us abandon our rightful place in nature, and set us on a path towards spiritual poverty, social injustice and ecological destruction (Shepard, 1973). Obviously, these theories were little more than sanitized reformulations of Rousseau's ideas, repackaged and resold to a modern audience. Although Sahlins' and Shepard's political views were not as openly totalitarian as Rousseau's, the fundamental problem that they each sought to address – the corrupting nature of social and technological change – is one that really only admits a totalitarian solution. Nevertheless, their ideas were widely accepted and celebrated by their peers, and set off an explosion of similar conjectures in the social and environmental sciences (see Redford, 1991; Kaplan, 2000; Nadasdy, 2005; Cahoone, 2006). They also provided the nascent ESS framework with a historical and sociological narrative, which was aligned with its technical, or physically oriented claims about humanity's relationship to nature. Of course, if we trace the origins of these technical claims, we find that Rousseau's philosophy had a determining impact on their development as well. Most importantly, it had a crucial, albeit indirect influence on the emergence of the 'limits to growth', or 'planetary boundaries' hypothesis – the idea that all human activities depend on, and are ultimately constrained by, non-anthropogenic states and processes in the Earth system.

A.3 The Limits To Growth

As stated above, Rousseau's theories of early man, and of the corrupting nature of civilization inspired generations of eco-theological thinkers. One of these thinkers – although this connection is typically not recognized – was the British cleric-turned-economist Thomas Malthus (e.g. Brooke, 2019). Malthus rose to fame in the late 1700's, with the publication of his book 'An Essay on the Principle of Population'. In it, he took the core idea in Rousseau's philosophy – that the evolution of culture leads to injustice and evil – and gave it a new, more tangible and nuanced explanation. His arguments can be summarized as follows: While social and technological innovation – like that seen at the beginning of the Industrial Revolution – had the potential to unlock great societal improvements in the short term, it would eventually lead to the collapse of civilization. In a rapidly developing society, people gain unprecedented access to affordable goods and services. Although a fine situation at first, this also removes the main barrier against unchecked population growth – namely, economic uncertainty. When people feel economically secure, he explained, they are more likely to give in to their baser urges – especially the ignorant and impulsive lower classes. Hence, any major improvement in the prospects of the underclass will be followed by an equally massive population boom, and soon, the aggregate demand for food will outrun the productive capacity of the society's agricultural systems. The reason for this, Malthus declared, is that "population, when unchecked, increases in a geometrical ratio", while "subsistence only increases in an arithmetical ratio" (Malthus, 1798). In any given region, there is only so much arable land, and when all of it has been cultivated, the progress induced by technological innovation will halt, and be replaced by famine, disease outbreaks, resource conflicts, and ultimately war (see Malthus, 1798). But what then, short of banning social and technological innovation altogether, can be done about this problem? According to Malthus, the only rational solution is for the educated elites to step in and better manage the lower classes. First, there must be a concerted effort to teach the poor abstinence and good Christian values. Second, all measures towards poverty relief must be swiftly abolished. Without a social safety net, those incorrigible wretches who are too stupid or weak to pull themselves up and improve their behavior would simply disappear, and with a little luck, drag their hopeless families into oblivion as well. This way, Malthus argued, the overall population could be reduced to a more sustainable size, without the elites having to give up the benefits of socio-technical innovation (Malthus, 1798).

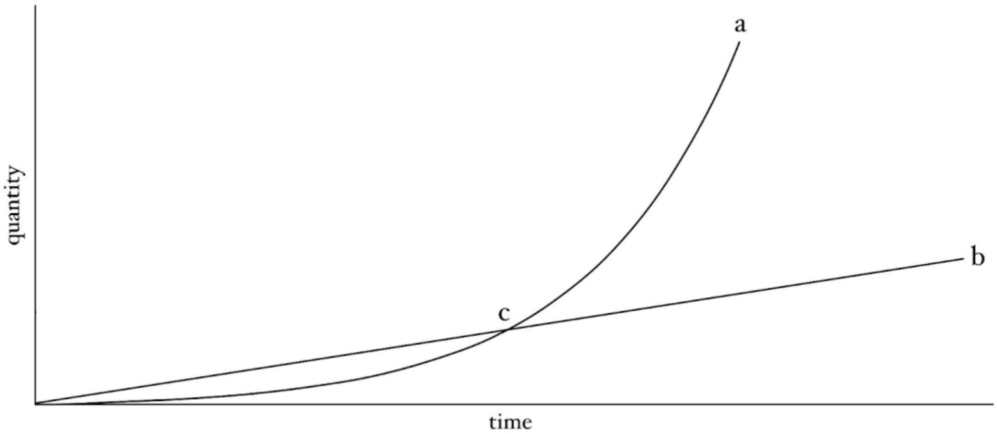

Figure A.3. Simple representation of Malthus theory, where (a) is population growth, (b) food production, and (c) the Malthusian crisis point.

In this profoundly anti-human doctrine, we find the origins of two philosophical schools, both of which became highly influential in the centuries after Malthus' death. The first is the modern school of 'eugenics' – a political philosophy built around the idea that governmental planners should 'weed out' the weak and the feeble-minded members from their communities, so as to refine and strengthen their 'collective features' (see Desrochers & Hoffbauer, 2009). Second, it was the first supposedly scientific theory to suggest that there are absolute, biospheric limits to the social and economic progress that humanity can make. Hence, Malthus was also the original author of the 'limits to growth', or 'planetary boundaries' hypothesis (see Costanza et al., 2015). In 1968, only two years after Sahlins' revived the Rousseauian myth of the noble savage, biologist Paul Ehrlich did the same with Malthus' principle of population. In his book 'The Population Bomb', he took Malthus ideas about the biospheric limits to food production and extended them – albeit in a vague and fuzzy manner – to all economic activities. High on the drugs of social and technological innovation, humanity had now overpopulated the Earth, and further birth rate explosions were just around the corner. Not only were we approaching 'peak food' – our resource withdrawals were destabilizing the life-sustaining properties of the Earth system as a whole (Ehrlich, 1968). In consequence, a catastrophic population crash would occur in the 1970's and 80's, followed by widespread economic and political turmoil, and in time, a total collapse of the liberal world order. "Nothing could be more misleading to our children than our present affluent society", he wrote, "they will inherit [...] a world in which the standards, politics, and economics of the past decade are dead" (Ehrlich, 1968). Of course, the purpose of his book was not to help stave off this catastrophe – it was too late to do anything about it. He just wanted to alert people to what was going on, and suggest a strategy whereby some fraction of the global population might be saved. Like his overall thesis, this strategy was just an inflated restatement of Malthus' original ideas. The world's leading governments – that is, 'the global elite' – would have to… (1) compel as many young men and women as possible to undergo surgical or chemical sterilization, and (2) swiftly abolish all efforts to give aid and assistance to the world's poor and war-torn regions. Without access to food, medicine and peacekeeping forces, those populations that were too weak or too damaged to pull themselves up and improve their situation would simply disappear, and thus free the rest of the world from the burden of their existence. The goal of these measures was to reduce the global community to a 'stable optimum population size' of about 1,5 to 2 billion people. For reference, this is 1 billion less people than were alive when he suggested those numbers, and 6 billion less people than are alive today. "A cancer is an uncontrolled multiplication of cells", Ehrlich explained, "[and] the population explosion is an uncontrolled multiplication of people… We must shift our efforts from treatment of the symptoms to the cutting out of the cancer. The operation will demand many apparently brutal and heartless decisions. The pain may be intense. But the disease is so far advanced that only with radical surgery does the patient have a chance of survival" (Ehrlich, 1968, 1969; Daily, Ehrlich & Ehrlich, 1994). Now, having stated these facts, I invite you, dear reader, to form your own conclusions about the moral sanity of Paul Ehrlich. Despite its monumental ethical problems, The Population Bomb became an international best-seller, and has been cited as a source of inspiration by countless environmental scientists. Two of these scientists were the biophysicist Donella Meadows and her husband, the system theorist Dennis Meadows (Meadows, 1988). In the summer of 1970, they assembled a team of 17 researchers at the Massachusetts Institute of Technology, and together, they set out to translate Ehrlich's ideas into a rigorous and testable explanatory model. The project was named 'The Limits To Growth', and its goal was to map out the maximum growth space on Earth for the human species. To that end, they developed a modeling software called 'the World 3', constructed around five variables that 'determine and limit' all of our economic activities, namely… (1) population growth, (2) food production, (3) industrial production, (4) industrial pollution, and (5) the consumption of non-renewable resources (Meadows et al., 1972). Extrapolating from data on their past developments, and copying the logic of Malthus original theory, they postulated that… (a) without a significant course correction, all of these variables would grow exponentially in the years and decades to come, and (b) that social and technological innovation could at best facilitate linear improvements in their matter-energy efficiencies (Meadows et al., 1972). Because the Earth is effectively a closed system, or so they argued, demographic and economic growth must eventually collide with one or more biogeophysical limits – for instance, the depletion of critical, non-renewable resources, or the overloading of pollution absorbing, resource generating, or otherwise life-supporting ecosystem functions. In proper Malthusian fashion, they stressed that due to assumptions (a) and (b), this was not some vague and distant concern, but a fast approaching reality (Meadows et al., 1972). According to their calculations, the economic progress that had occurred after the Industrial Revolution would come to an abrupt end at the turn of the 21th century. First, resource scarcity would diminish the outputs of the world's industrial systems. Then, with critical input goods dwindling, the world's food production and health care systems would break down as well. Due to time-lags in the responsiveness of many social and ecological functions, industrial pollution and the global population would continue to grow for a few decades, and then these variables would plummet too. At the beginning of the 22nd century, nearly half of the human population would be gone, with the remaining half facing life in an increasingly exhausted and hostile environment. This, they maintained, was the outcome of their most cheerful calculations. "We have tried in every doubtful case to make the most optimistic estimate of unknown quantities", the Meadows' explained, "and we have also ignored discontinuous events such as wars or epidemics, which might act to bring an end to growth even sooner than our model would indicate. In other words, the model is biased to allow growth to continue longer than it probably can [...] in the real world" (Meadows et al., 1972).

Figure 1.8. Earth Day protester in City Park Hall (AP, 1970).

This, of course, begs the question of what we can do to avoid this apocalyptic future? Because of the intrinsically uneven relationship between the ultimate benefits and the ultimate costs of technology, techno-fixes can not be the answer. For humanity to avoid overshoot and collapse, only a radical, cultural transformation would do (see Meadows et al., 1972). We must reject the liberal world order, and transition to what the Meadows' called 'a state of global equilibrium'. Put simply, this means that every society on Earth is reorganized in such a way that… (1) the global birth rate never exceeds the global death rate, and (2) the global rate of investment never exceeds the depreciation rate of the world's existing capital. To make this possible, most of our resources must be diverted from the production of 'non-essential material goods', such as cars, televisions, fancy clothes, and so on, to the production of 'essential', or 'higher services', such as health care, education and agriculture. Moreover, the world's rich nations must introduce radical programs for wealth redistribution, to dismantle the structural inequalities that are inherent in the liberal world system (Meadows et al., 1972; Meadows, 2013). These measures, they argued, would lead to the creation of 'dynamic equilibrium societies', existing harmoniously within the biogeophysical boundaries of the Earth. Importantly, the actualization of this new paradigm would not require that unbearable restrictions be placed on people's individual rights and freedoms. On the contrary, the transition towards global equilibrium would result in a world where the ordinary citizen is *more free* (Meadows et al., 1972). Now, at first glance, this may seem like a laudable political vision. After all, who could argue against the creation of free and fair societies, in balance and harmony with the natural world? However, if we think about it for more than a minute, we realize that this is not at all what the Meadows' were suggesting. Consider their definitional criteria for the 'state of global equilibrium' – that is, a world where births must equal deaths, global investment equal global depreciation, and where these variables are kept in "a carefully controlled balance" (Meadows et al., 1972). Obviously, *control* is the operative word here, for how could we possibly enforce this paradigm, let alone at a global level? There would have to exist a universal, regulatory framework that guides every economic decision on Earth. But how would such a framework be drafted and revised? If we let the public participate through votes and referendums, we move back to precisely the market mechanisms that we sought to abandon in the first place. On the flipside, if we do it in any other way, we inevitably move towards the formation of an international governmental entity, imbued with the power to *overrule* every economic decision on Earth. The authority of such an entity would, for all intents and purposes, be absolute, and every person alive its subject. Whether or not they fully understood this themselves, the Meadows' were arguing for the realization of the Perfect Global State – an all-knowing, all-powerful world government. When we recall the Rousseauian, Platonic and Catholic origins of their ideas, this seems less surprising. Again, any philosophical framework that begins with the idea that 'the evolution of culture is the root of all evil' must inevitably declare war against political freedom, because political freedom – that is, the freedom of individuals to think, speak and act in accordance with their own beliefs and judgements, and to peacefully challenge the established norms – is precisely what drives this evolution to begin with (see Popper, 1945; Deutsch, 2011). Now, lest I be accused of drawing speculative conclusions, it should be noted that the Meadows' – in a moment of uncharacteristic clarity – lists both Plato, Aristotle and Thomas Malthus as examples of earlier thinkers who have explored the idea of the equilibrium society (Meadows et al., 1972). They also took a page from Ehrlich's playbook, and admitted that the transition to equilibrium, albeit necessary, would be hard; "the transition [...] is likely to be painful", they declared, "and it will make extreme demands on human ingenuity and determination" – "only the conviction that there is no other avenue to survival can liberate the moral, intellectual, and creative forces required to initiate [it]" (Meadows, 1972). Indeed, before we follow Sparta's example and do away with our democratic rights to life, property and self-determination, we should at the very least demand a convincing explanation of why this is necessary. This leads us to the final point that I wish to make in this Appendix. Besides their Platonic, Aristotelian and Catholic origins, all of the theories that we have discussed above have one more thing in common – they all fall apart like a house of cards when subjected to empirical evaluation. First, the original dogmas of eco-theology appeal to the supernatural, and thus fall outside the bounds of rational discourse altogether (Deutsch, 2011). Second, the idea that our prehistoric ancestors lived in a Golden Age, however conceived, goes completely against the available evidence. More likely, their lives were characterized by constant malnutrition, rampant disease, and a culture of violence, dogmatism and inter-tribal warfare (e.g. Hill, Hurtado & Walker, 2007). In fact, genetic studies have shown that despite their supposed affluence, our Pleistocene ancestors approached *complete extinction* at least once before the Agrarian Revolution (Zhivotovsky, Rosenberg & Feldman, 2003). To underscore this point, our sister species the Neanderthals, even though they are thought to have displayed much the same cultural traits, died out in the transition to the Holocene (Apenzeller, 2013). To further underscore it, one of the oldest remains of our hominid ancestors is the fossilized skull of a three-year old girl – the Taung Child – whose eye sockets appear to have been pierced by the talons of a big bird. Most likely, she was snatched up by an eagle and carried off to its nest, where it disemboweled her and ate her brain (Berger & McGraw, 2007). This, unlike the romantic nonsense of Rousseau and his modern day followers, is a good example of what it is actually like to live as a part of the natural world. The idea that the biosphere is mild, or kind, or harmonious is one that can only be seriously entertained by people who have become so far removed from it that they can no longer recall its actual features. Third, although the Industrial Revolution was indeed followed by a period of exponential population growth, there was no consequent increase in hunger, poverty and social distress. Thanks to technological innovation in the agricultural sector, the productivity of the world's farmlands was raised more than enough to meet the growing demand (Pinker, 2018; Ritchie, Roser & Rosado, 2022). In this process, Malthus' theory was falsified, and with it, the entire justification for his bleak and misanthropic political philosophy. In the centuries that have passed since he published his essay, the human population has increased sevenfold, and the global GDP has grown by an order of magnitude. Meanwhile, the worldwide life expectancy has more than doubled, and the number of people who live in extreme poverty has fallen from 89% to 10%. Moreover, child mortality has fallen dramatically, and so has the global illiteracy rate, and more than half of the world's population now live in democratic societies, as opposed to 1% in the year 1800 (Roser, 2020). Hence, Sahlin's theories can be rubbished as well. Obviously, there was no great population crash in the 1970's and 80's, and some of the nations that Paul Ehrlich singled out as 'beyond any hope of saving' went on to experience economic and democratic revolutions on a massive scale (see Pinker, 2018). Finally, not a single one of the Meadows' predictions have been corroborated by experience, including their estimations of the reach of the world's non-renewable resource reserves (Meadows et al., 1972, pp. 56-59; USGS, 2022), the productive capacity of the world's agricultural systems (Meadows et al., 1972, p. 50; Ritchie, Roser & Rosado, 2022), and the likely trajectories of economic and demographic growth, both globally and within specific nations (Meadows et al., 1972, pp. 34-38, 43, 124; Roser, Ritchie, Ortiz-Espinosa & 2021; Roser, 2022). Most importantly, we are now more than two decades into the 21th century, and there has been no irreversible collapse of the world's industrial systems. So, perhaps we should hold off a little on the cultural revolution – at least until we can explain the discrepancies between observed reality and the theories that advocate it.

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Appendix B: A Note On Errors And Biases In Literature Reviews

This note was added in response to a methodological criticism of the thesis.

Because of the fallibility of the hypothetico-deductive procedure, all scientific theories must be treated as biased and error-laden. Indeed, the goal of all scientific methods is precisely to seek out, and apparently to correct, such errors and biases (Deutsch, 2016). Obviously, this is also the goal of critical theory papers, or critical literature reviews. As APA (2010) explains, the goal of a literature review is to "inform the reader of the state of research… [to] identify relations, contradictions, gaps, and inconsistencies in the literature", and to "suggest the next step or steps in solving the [identified] problem[s]". However, literature reviews must of course be treated as biased and error-laden too. The present study takes two steps to combat this issue. First, it gives a clear and concise explanation of the purpose of the study, its search protocols, the tools used, and the evaluation criteria according to which the reviewed materials have been assessed (APA, 2010). Second – and more importantly – *it gives an exact explanation of the epistemological and methodological assumptions on which these criteria and protocols rest* (see Chapter 2). This step – which is often neglected in mixed methods disciplines – makes every aspect of the study *unusually transparent and susceptible to criticism*, and – as explained in Chapter 2 – rational criticism is the only known antidote to scientific biases and errors. In and of themselves, stringent search protocols do nothing to strengthen the arguments, or conclusions of a critical theory paper, or a literature review. In fact, when particularly stringent search protocols, or statistical tools are needed to make sense of the literature in a field, this is a clear indication that its methodological standards are much too relaxed. In fields that pursue *falsifiable*, *cogent* and *precise explanations*, we are unlikely to find more than a few competing explanations for any given explicanda (see Deutsch, 2016; Chapter 2). Now, because it is unusually transparent, a critical reader can easily check if there is a logical relationship between the tenets of the hypothetico-deductive model and the methodological principles of this thesis, and between these principles the materials and arguments presented herein. Just the same, he or she can easily check if the formal and comparative criticisms in the results section are consistent with the study's basic evaluation criteria – meaning, that a scientific theory is bad to the extent that it is… (a) unfalsifiable, (b) logically inconsistent, (c) imprecise and easily variable, and (d) in conflict with otherwise good explanations, without improving upon them (see Chapter 2 & 3.3). Let me conclude this note with an example of how the criticisms in the results section follow from the methodological principles of the study. In Chapter 4.2.2, I indicate that while the models of chaos theory may be useful in some contexts, and while they may seem like good approximations of nonlinear behaviors in (supposedly) complex adaptive entities, they can not, in fact, explain those behaviors. The reason for this is that the models of chaos theory only apply to perfectly deterministic systems, and complex adaptive phenomena are not deterministic – they are… (a) quantum mechanical, and (b) shaped by the non-systematic creation of new knowledge, (in genes and in memes) (see Deutsch, 1997; Popper, 1994). Because quantum mechanics and evolutionary theory are far more precise explanations of the discussed explicanda, and because the models of chaos theory offer no explanatory improvement on either of them, the evaluation criteria of the study demands that we reject the latter in favor of the former (see Deutsch, 1997; Chapter 2). Again, a critical reader may challenge this assertion, but not on the basis that it appeals to 'biased', or 'cherry-picked', or 'esoteric' concepts and ideas, or unstated, or vague methodological principles. Just like this one, every argument in the thesis follows in a clear and consistent manner from the assumptions, principles and criteria stated in Chapters 2 and 3.

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