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The Six Critical Determinants That May Act as Human Sustainability Boundaries on Climate Change Action

Filipe Duarte Santos [1,*], Tim O'Riordan [2], Miguel Rocha de Sousa [3,4,5] and Jiesper Strandsbjerg Tristan Pedersen [1,6]

1. cE3c—Centre for Ecology, Evolution and Environmental Changes, CHANGE—Global Change and Sustainability Institute, Department of Physics, Faculty of Sciences, University of Lisbon, 1749-016 Lisbon, Portugal; japedersen@fc.ul.pt
2. School of Environmental Sciences Member, Centre for Social and Economic Research on the Global Environment (CSERGE), University of East Anglia, Norwich, Norfolk NR4 7TJ, UK; t.oriordan@uea.ac.uk
3. Department of Economics, University of Évora, 7004-516 Évora, Portugal; mrsousa@uevora.pt
4. CICP Research Center in Political Science, University of Évora, 7004-516 Évora, Portugal
5. CEFAGE-UE—Center for Advanced Studies in Management and Economics, University of Évora, 7004-516 Évora, Portugal
6. Geosciences, Copernicus Institute of Sustainable Development, Environmental Sciences, Utrecht University, 3508 TC Utrecht, The Netherlands

* Correspondence: fdsantos@fc.ul.pt

Abstract: Significant advances have been achieved in multilateral negotiations regarding human development and environmental safeguarding since the 1972 UN Stockholm Conference. There is much greater global awareness and action towards sustainability. However, sustainability has persistently been sidelined, leading to the identification and definition of a transgressed "safe and just space for humanity". Here we develop a new evolutionary approach and methodology to explain the reasons why sustainability continues to be a difficult challenge for contemporary societies to adopt. We argue that these originate in six major biological, social, psychological, political, and cultural critical determinants that resulted from human biologic and cultural evolution. Although they are essential for human prosperity and wellbeing, these characteristics may also act as human sustainability boundaries. It is possible to reduce the inhibiting power of each critical determinant in the pathways to sustainability, a vital process that we term softening. Identifying, knowing, and softening these impediments is a necessary first step to achieving sustainability through greater self-knowledge and transformational processes. The application of the present methodology is restricted here to the climate change challenge. We examine the ways in which each human sustainability boundary is capable of obstructing climate action and offer possible ways to soften its hardness.

Keywords: sustainability; environment and development; evolutionary approach; critical determinants for sustainability; sustainability boundaries; climate change action

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1. Introduction

The Great Acceleration [1] was a period in human history within the anthropocene that started after the Second World War. It is characterized by two democratic waves [2], improved socioeconomic conditions in many world regions, high global population growth, and huge increases and diversification in the production and consumption of goods and services. There was also a remarkable enlargement of the world's Gross Domestic Product (GDP), of direct foreign investment, of energy generation and consumption, mobility, telecommunications, digitalization, urbanization, globalization, and the use of natural resources. Some of these changes are reflected in the altered functioning of the Earth's system, which encompasses our planet's interacting physical, chemical, biological, and human processes [3].

The need to protect the environment and guarantee continued access to natural resources motivated the Global North to convene the 1972 United Nations Conference on the Human Environment in Stockholm. That was also the year when "Limits to Growth" was published [4], which modeled for the first time the likely undesirable long-term consequences of indefinite economic growth. Its controversial predictions remain relevant to this day [5].

The Stockholm Conference initiated a multilateral process on environmental diplomacy and action. In its initial phase, the World Commission on Environment and Development produced the 1987 Brundtland report "Our Common Future" [6]. The report introduced the concept of sustainable development, defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The initial focus on environment and human development evolved into three dimensions of sustainability—environmental; social; and economic sustainability—in the 2030 Agenda for Sustainable Development; with its 17 Sustainable Development Goals (SDGs), adopted by the United Nations in 2015. In spite of the relative increases in prosperity over the last 50 years and much greater global awareness about sustainability, water scarcity, food crises, and extreme poverty tighten their hold in some of the least developed and fragile countries; social and economic inequalities increase within and between countries; and humanity is challenged by climate change, overexploitation of natural resources, pollution, waste, and biodiversity loss in an international setting experiencing considerable geopolitical strife.

There is criticism that sustainable development does not have an agreed-upon definition [7,8]. It is too vague and wide-ranging to provide guidance, and it is not sufficiently attractive to mobilize the human resources necessary to meet the socioeconomic and environmental challenges of today [9]. "Pluriverse" alternatives to the dominant "one-world sustainable development" view have also been proposed [10]. There is a growing preference, including in government and private sector publications, for the broader and more inclusive concept of sustainability [8].

Rarely has a conceptual idea penetrated so deeply into a broad range of human activities and acquired more rapid and powerful visibility, with the capacity to influence governments, business, law, education, non-governmental organizations, and public opinion worldwide [11–13]. Nowadays, there is a broad "in principle" consensus about the need to achieve, as soon as possible, some form of global and inclusive sustainability. This is because some form of creative redistribution of well-being, based on ecological principles and human rights, is deemed necessary for persistent prosperity to evolve across the world. But many challenges remain. World leaders at the UN SDG Summit in September 2019 called for a decade of action [14] for sustainable development. They pledged to mobilize financing, enhance national implementation, and strengthen institutions to achieve the SDGs by the target date of 2030. In a follow-up meeting at the UN General Assembly of 2023, they bemoaned the lack of progress to reach some of the SDG targets. Here, we examine why this might be the case. Our approach is based on the assumption that human self-knowledge develops and strengthens the inner resources needed to address sustainability challenges. Solving them requires transformations that are not only technological and political but also operate at the inner personal level [15].

2. Methodology

We address the current quest for sustainability with a new evolutionary approach to explain the human origins of the social, economic, environmental, and cultural sustainability crises that continue to afflict contemporary societies. Ripoll [16] and Bohler [17] argue that there are unchangeable neural, anthropological, psychological, and sociological human traits that prevent humans from reaching sustainability. We do not follow the argument that humans are prevented from reaching forms of sustainability. In turn, we propose that it is possible to identify and systematize the critical evolutionary determinants that may establish boundaries along sustainability pathways and that these boundaries can be softened. Social communities with the characteristics of the "exemplary ethical communities" proposed by [18], dating back centuries or even millennia, constitute an example where the sustainability boundaries were softened.

The proposed research question is: What are the basic human evolutionary "backstory" reasons that are hindering sustainability, and how can we overcome them? In answering the first part of the question, we are delving into the space-time where human biological, social, psychological, and cultural determinants evolved.

Is it possible to construct a scientific methodology to identify the human inner determinants acquired in the human biologic and cultural evolution that, while very important for survival, well-being, and economic prosperity, may also currently act as impediments in the pursuit of sustainability? Although there is no accepted scientific methodology to this end, we note that science has successfully unraveled significant facets of the biological and social evolution of the *Homo genus* over the past 2.6 million years, leading to modern humans. Anthropology has comprehensively investigated aspects of *Homo sapiens*, encompassing biology, evolutionary history, societal features, and cultural dynamics from ancient times to the present day.

Arguments are presented supporting the feasibility and utility of identifying human critical determinants (HCDs) that may act as contemporary human sustainability boundaries (HSBs). Critical because they are decisive for reaching sustainability. "May act" because we believe that the HSBs can be softened by personal commitments capable of spurring institutional and governance transformations, rendering sustainability more accessible. The methodology used follows an inductive evolutionary approach based on in-depth analysis through biological, anthropological, sociological, psychological, economic, and political data sources and seeks to identify the smallest set of interacting and interdependent HCDs. This parsimony is defined by the condition that the HCD set is the minimum set capable of providing a complete and coherent explanation of why sustainability is currently proving to be an elusive objective. The HCD set comprises two distinct sub-sets, each delineating the influence of different evolutionary features. The first sub-set, consisting of two determinants, is characterized by intrinsic biological attributes, predominantly observed at the individual level. The second sub-set, comprising four determinants, is characterized by social and cultural attributes present at both individual and collective levels. The HCDs have been essential for human development and wellbeing. However, they may also act as HSBs when functioning as impediments to progress towards sustainability. In such an operating mode, we designate them as boundaries and not as barriers because they are not imposed externally upon us. They have a human origin, although we may not be fully conscious of their role.

The present methodology is based on the recognition that humans are a deeply social biological species, relying strongly on cooperation [19]. The appearance of Homo sapiens resulted from a biological evolution followed by a cultural evolution that likely started with the emergence of early symbolic behavior [20–23]. This double process created identifiable biological, social, psychological, political, and cultural traits that framed six major HCDs. They have been present for a very long time, some for many millions of years, others for hundreds to thousands of years, and still others only in the last three centuries. They are common to all of us, although they manifest themselves in different forms and with different intensities. We are not addressing here the reasons for this differentiation at the individual level, but their global friction in the quest for sustainability.

The urgency of controlling our interference in the Earth system has been highlighted by the concept of planetary boundaries. Rockström et al. [24] identified nine boundaries that define the "safe space for humankind" concerning the Earth system and its biophysical subsystems and processes. According to the authors, the boundaries in three systems—the rate of biodiversity loss; climate change; and human interference with the nitrogen cycle—were exceeded around 2009, placing humanity in a region of high risk outside the zone of uncertainty [24]. An update of this work finds that six of the nine boundaries have now been transgressed, suggesting that the Earth system is now well outside of the safe operating space for humanity [25].

Kate Raworth [26] went a step further and introduced a visual framework shaped like a doughnut where one finds a "safe and just" space between the planetary boundaries of survival and the social boundaries of reliable livelihoods. These are defined through statistical indicators that describe a safe social foundation for various determinants, such as food security, income, water and sanitation, health care, education, gender equality, social equity, and so on [26,27]. More recently, safe and just Earth system boundaries for climate, the biosphere, water and nutrient cycles, and aerosols at global and subglobal scales have been defined [28]. These frameworks serve to monitor humanity's deviation from sustainability, to characterize the resulting risks, and to help indicate the best courses of action.

In the present approach, we are not delving into the "safe and just" space for humanity. We remain in human space-time, where the HCDs play the leading roles in staying within the "safe and just" space for humanity or in leading towards the crossing of planetary boundaries of survival and social boundaries of livelihoods.

It is possible to reduce the inhibiting power of each critical determinant in narrowing the pathways of human societies toward sustainability. This is a vital process, which we term softening. Each HSB acts on the three sustainability components, and each has a certain degree of hardness when we attempt to soften their action on each component. The hardness (softness) of the HSB has a global spatial dependence that is continually evolving with time. HSB softening can be achieved through appropriate transformative pathways [29]. Incremental changes to "business as usual" are currently far from successful, so transformative human processes are necessary to safeguard humanity's sustainable future [30]. The most promising, consensual, comprehensible, and universal current pathway is to reach the 169 UN SDG-quantified targets by 2030. This goal is unlikely to be fully achieved in time. It will probably require more robust human transformational processes.

Each HSB acts on the social, economic, and environmental sustainability components with a certain degree of hardness. Based on the analysis developed in the next section, we make a qualitative assessment of the relative hardness that each HSB imposes on fulfilling each of the three sustainability components using a three-point scale—strong; moderate; and weak (Table 1). The evaluation was made using the methodology developed in this paper. It assumes that the HCDs act as an HSB in the foreseeable medium and long term, not only in the short term.

Table 1. Current relative hardness of each sustainability boundary to the advancement in each of the three components of sustainability (social, economic, and environmental), graded on a 3-point scale. The last line indicates the current hardness of each sustainability boundary to climate action, also graded on a 3-point scale.

	Hardness of Human Sustainability Boundaries					
	DRS [1]	**TD [2]**	**HNI [3]**	**SIU [4]**	**CFR [5]**	**IGGR [6]**
Social sustainability	moderate	moderate	weak	strong	strong	strong
Economic sustainability	strong	strong	weak	moderate	moderate	strong
Environmental sustainability	strong	strong	strong	moderate	weak	strong
Climate Action	moderate	strong	weak	strong	moderate	strong

[1] Dopaminergic Reward System; [2] Time Discounting in Intertemporal Decisions; [3] Human-Nature Interconnectedness; [4] Self-Interest and Utility; [5] Cooperation and Free-Riding; [6] International Geopolitical and Geo-strategic Relations.

Using a three-point scale, a qualitative analysis of the current relative hardness of each HSB to implement social, economic, and environmental sustainability was performed. The other way of weighting this scale is to use a Delphi approach involving a survey, which is outside the scope of this work. The dimensions of justice, human rights, and equity were included in the analysis of the social sustainability component. The dimensions of prosperity, well-being, and long-term sustainable economic development were included in the economic sustainability component. Finally, the dimensions of natural resource sustainability and conservation of biodiversity integrity, genetic and functional, to support the well-being of current and future generations were included in the environmental sustainability component. The results are shown in Table 1. The holistic hardness of each HSB, defined as the arithmetic average of the hardness ratings for the three components of sustainability, is shown in Figure 1.

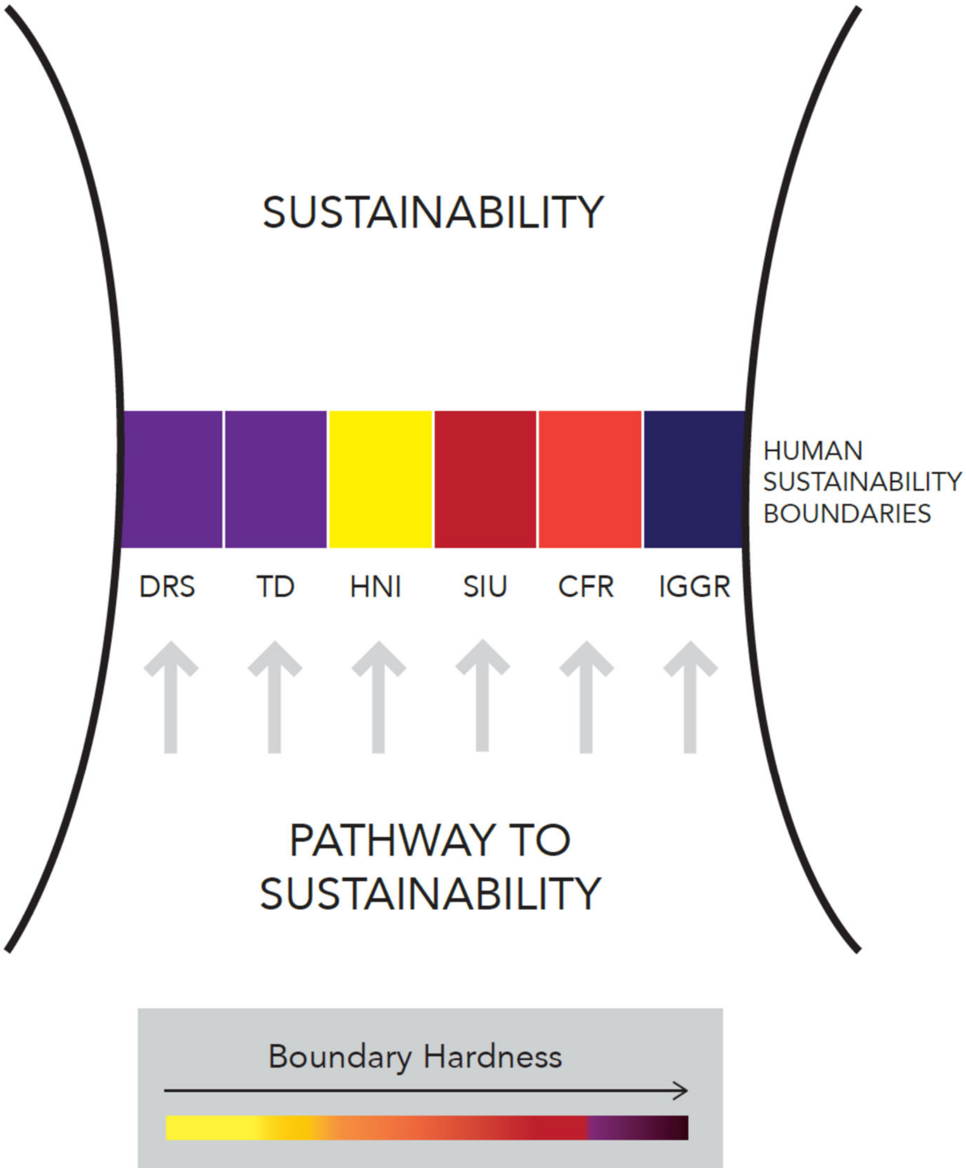

Figure 1. Holistic sustainability boundary (calculated using Table 1) of the six human sustainability boundaries: Dopaminergic Reward System (DRS), Time Discounting in Intertemporal Decisions (TD), HNI: Human-Nature Interconnectedness, Self-Interest and Utility (SIU), Cooperation and Free-Riding (CFR) and International Geopolitical and Geo-strategic Relations (IGGR). The arrows indicate the movement towards sustainability.

In this paper, we focus our attention on anthropogenic climate change, which has a prominent role in the 2030 Agenda. SDG 13 calls for urgent action to combat climate change and its impacts to reach five targets characterized by eight indicators. This SDG is linked to all the other 16 SDGs of the 2030 Agenda, and in particular SDG 7 on affordable and clean energy. More specifically, the present methodology provides insights into why climate change has often been described as a "wicked" problem because of its complexity, interconnected nature, and difficulty in finding a solution, in contrast with "tame" problems, which have a clear optimum solution [31,32]. The application of the HSB methodology to climate change helps to understand its full complexity and find solutions to the problem.

Using a three-point scale, the relative hardness of each HSBs ability to implement effective climate action was analyzed. This analysis is presented and discussed in the section that follows, and the results are included in Table 1. The application of this methodology to other sustainability challenges, such as the depletion of natural resources, the circular economy, and biodiversity conservation, is not presented here.

3. Human Critical Determinants That May Act as Human Sustainability Boundaries

3.1. The Dopaminergic Reward System

The first critical determinant is the dopaminergic reward system (DRS). This is the most important reward pathway in the brain. The brain responds to a rewarding stimulus by releasing dopamine, the main neurotransmitter associated with pleasure. The DRS is located in the mammalian part of our brain and is responsible for basic human motivation for specific actions. These actions are driven by survival necessities (e.g., eating, reproducing, avoiding pain, and providing pleasure) and the requirements of cultural endurance (e.g., acquiring social status, minimizing effort, and gleaning information). They play a central role in ensuring the reproductive success of our species and human survival and wellbeing.

More than 200 million years ago, mammals developed a six-layer neocortex and a compartmentalization of the striatum that enhanced cortico-striatal connectivity [33]. This biological evolution improved behavioral flexibility [33]. The striatum is part of the basal ganglia in all present-day mammals and performs a critical function in action selection. The DSR has been located in the basal ganglia since much before the period of rapid encephalization in the Homo genus. Their function is not reasoning, a capacity in humans and other mammals that is assured by more recent cortical structures, mostly the frontal and prefrontal cortex [33]. However, the DRS has the essential function of rewarding the basic motivations for specific actions such as eating [34,35], reproducing [36], and avoiding pain by providing pleasure. It is also involved in acquiring social status [37], minimizing effort [38], and gleaning information [17]. During the evolution of the Homo genus up to Homo sapiens, the complexity of the connectivity of the basic ganglia with the neocortex increased. This stronger connectivity means that the neocortex can have some control over the response to stimuli potentially rewarded by the DRS.

The DRS is common to all humans, but stimuli are very diverse in the human population. Repeating the stimulus is the way to provide more pleasure because the nerve cells release more dopamine. The DRS by itself has no mechanism for establishing limits on its contribution to the reproductive success of our species. It is compatible with unlimited global population growth, which is not a desirable outcome. The DRS functions as a neurochemical motor for growth in the brain. During most of the Holocene, human reason and endeavor have been able to project this unrestricted principle of growth into our social, agricultural, economic, financial, and technological society's models [17]. If limits to growth exist [4,5], they represent a concept that is unrelated to the DRS mode of functioning but can be easily grasped by the brain. DRS by itself is also compatible with indefinite economic growth because it rewards the consumption of goods and services to the extent that they provide satisfaction or pleasure, a process that is optimized through utility maximization.

In the pre-historic past, survival/reproduction/pleasure-connected growth in populations and natural resource use could be satisfied by the environment at the local and regional levels. The pace of sourcing of current growth at the global level tends to become restrictive. This seems to have been the case at least since the beginning of the Great Acceleration in the middle of the 20th century, including the "age of sustainable development", [39]. This first critical determinant has a biological origin and is common to all individuals. It contributes to both individual and collective behavior.

Because of its nature and presence in all aspects of life, it is one of the more challenging to soften when functioning as an HSB. Softening this first HSB requires a greater awareness of the relationships between decisions rewarded by the DRS and reaching a given SDG. This awareness paves the way for an increased involvement of the neocortex in such decisions. The increased involvement may be able to decouple the brain's neurochemical motor for growth from unsustainable growth models.

Its relationship with climate change stems from the interdependent connection between the current human activities that contribute to anthropogenic greenhouse gas emissions (GHG) and some of the much-diversified DRS stimuli in contemporaneous societies across the world. There are many examples of that connection. The most significant results from the high global dependence on fossil fuels for the provision of abundant and affordable global primary energy, an indispensable way to maximize utility, in particular through DRS stimuli. This dependence has been of the order of 80% in the last 50 years and was 82% in 2021 [40] and 81.8% in 2022 [41]. Steadily, the costs of renewable energy are falling, so here is a viable substitute that is receiving large investments. If the future dominant primary energy sources are decarbonized and the DRS drive is still satisfied, then there is a basis for a softening.

Energy is not a direct stimulus to the DRS; it has an indirect effect. It is essential to produce globally the growing amount and diversity of goods and services that are consumed, some of which are stimuli for the DRS. Meat consumption involves the DRS and has a significant impact on sustainability, particularly on climate change [42]. Softening the DRS impact on climate change could be achieved, for instance, by voluntarily restraint in ruminant meat consumption, thereby reducing methane emissions. There is also a case for prolonged awareness-raising of the personal health benefits of lower meat consumption, coupled with cultural shifts in moral coordination. In the case of energy, providing reliable employment in clean energy-related jobs may well support a softening in this difficult arena. In view of the indirect relation with energy, DRS hardness for climate change action, in particular mitigation, is estimated to be moderate.

3.2. Time Discounting in Intertemporal Decisions

The second critical determinant stems from time-discounting in intertemporal decisions. These are decisions made now that have consequences over multiple time periods. It is abbreviated as time-discounting (TD). Time discounting measures the greater value assigned to an immediate reward over the value assigned to the same reward postponed [43–45]. This devaluation caused by the postponement time is called time discounting. The way the value of the reward lessens over the time of postponement is called the psychological time discount function. In the context of economics, it is assumed that the human discount function is exponential, which implies a fixed-time discount rate. The higher the rate, the stronger the discounting of the future. Here, more reward is sought at the outset.

How to deal with time discounting is critical for achieving sustainability. The main reason is that movement in the safe and just space for humankind towards the Earth system or planetary boundaries is generally relatively slow, taking place in time intervals that encompass multiple generations. Sustainability issues that involve such large time intervals become almost irrelevant due to the relatively high values of human time discounting rates [43,46,47]. Unless we develop the capacity to consider them relevant in the present, human TD acts as a HSB that tends to increase risk and amplifies uncertainty about the future.

Climate change provides a good example of TD acting as a HSB because the choice of the social time discount rate to make the cost-benefit analysis of investing in mitigation is critical to preventing dangerous human interference in the climate system [48]. The Stern review [49] attributes a relatively low value to the social time discount rate. This choice is an incentive for a rapid energy transition, which is a good outcome for present and future social generations. Stern's choice contrasts with the higher values proposed by Nordhaus, which give greater priority to more robust economic growth in the short term [50,51]. However, the Stern review showed that this short-term strategy fails in the medium and long term because it implies much larger damage costs that result from the impacts of future unabated climate change.

Climate change offers another example where TD acts as an HSB. Human TD has difficulty grappling with the consequences of large and increasing carbon dioxide (CO_2) anthropogenic emissions to the atmosphere. The reason is that these consequences persist for thousands of years—intervals of time that are too large to influence our present decisions and actions. When an additional tonne of CO_2 is emitted into the atmosphere, only about 50% is taken up by the land biosphere and the ocean. The remaining component, called the airborne fraction, stays in the atmosphere and is removed by several processes on multiple timescales. It takes decades for the CO_2 to be captured by the biosphere, and by the surface and upper layers of the ocean, centuries to be captured in the deep ocean, thousands of years to be incorporated into sediments formed from shell-building organisms, and tens to hundreds of thousands of years to be captured from the atmosphere by the silicate weathering slow process [52]. About 15–40% of the CO_2 emitted remains in the atmosphere for more than 1000 years [53]. This means that for the human rate of TD, the additional CO_2 emitted to the atmosphere behaves as if it stays there "forever". The CO_2 that contemporaneous social generations are currently emitting is likely to affect the Earth's climate and cause harmful impacts on human generations over thousands of years. In view of the two powerful impediments that TD imposes on climate action, its hardness is evaluated as strong.

This second HSB has its origin in our biological and psychological characteristics, which are common to all humans and manifest mostly at the individual level. It is also one of the HSBs that is more difficult to soften because humans are disposed to bias value in favor of immediate or short-term gratification but not of long-term gratification.

Softening the second HSB depends on the capacity to project the future using science-based scenarios and to build the ability to make intertemporal decisions that are able to prevent the more severe scenarios, as also proposed by "longtermism" [54]. Softening depends on an increased awareness of long-term problems and on the involvement of the neocortex in intertemporal decisions that have implications for the sustainability of human endeavor. Making clearer the significant and unavoidable consequences of failure to soften for future generations who currently have no say in their prospective plight may also add to the improved softening process. Coupling this with the emerging benefits of clean technology and new forms of living in a sustainable world will also help the softening process.

3.3. Human-Nature Interconnectedness

The third critical determinant reflects the cultural evolution of human-nature interconnectedness (HNI) and how it affects the quest to stay within the safe and just space for humankind. HNI manifests itself mostly at the collective level. It probably started to change with the human cultural evolution that accelerated around 40,000 years BP. This process was stimulated by the agricultural and industrial revolutions and by rapid industrial urbanization [55]. Currently, most of the world's population no longer depends directly on the natural environment and its resources to survive and thrive. A large part of the human population has degraded the HNI because nature, biodiversity, and ecosystem services have become abstract concepts. The conquest of nature and the overexploitation of some natural resources advanced the idea of the sacredness of nature. This powerful idea contributed to the need to conserve refuges of pristine land in protected areas [56]. These are isolated, unintegrated, vulnerable, and endangered.

HNI manifests itself both at the individual and collective levels, but it has a stronger expression at the latter. It can act as the third HSB because devaluing HNI induces the erroneous perception that conservation of biodiversity and ecosystem services are mostly deemed to be superfluous and that natural capital can always substitute human-made capital [57]. On the other hand, since promoting the value of HNI is a pathway to sustainability [58], it softens the HSB potential.

Unabated climate change is a potential threat to life on Earth. Its impacts are recognized as an increasingly major driver of biodiversity loss [59]. Furthermore, biodiversity in food and agriculture is in decline, posing a risk to global food security [60]. Climate change has negative impacts on agriculture and food security by lowering crop yields due to more frequent droughts, heat waves, and flooding, as well as increases in pests and plant diseases.

Enhancing HNI reveals the critical value of biodiversity for human development and well-being, and therefore it is also a pathway to address the climate change challenge. On the other hand, devaluing HNI tends to reinforce emissions and hence aggravate climate change. Currently, there is a growing empathy for the values of enhanced nature in our everyday lives [61]. Although HNI has a strong hardness regarding biodiversity conservation, its hardness for climate action is estimated to be weak when compared with the other more powerful HSBs (Table 1).

3.4. Self-Interest and Utility

The fourth critical determinant for sustainability regards the evolving concepts of self-interest and utility (SIU) and manifests itself both at the individual and collective levels. Homo sapiens surpasses other species in the complexity of its cooperation and defection [43]. This achievement was made possible through the interdependent processes of genetic and cultural evolution. During historical civilizations, concepts related to cooperation, such as altruism, self-interest, selfishness, and egoism, had a remarkable evolution. Before the concept of altruism was introduced by Auguste Comte, the moral principles of beneficence and benevolence were developed and practiced by Christianity and other religions [62].

The word selfishness was first used in the English language in the 17th century. Selfishness was considered by Presbyterians to be morally objectionable behavior before God and society [63]. Currently, altruism is recognized as having positive effects on society, but hurtful aspects have also been identified [64]. On the other hand, selfishness is not considered necessarily bad [65]. Egoism can be either descriptive or normative. The concept of descriptive egoism, or psychological egoism, was first introduced by Thomas Hobbes, who suggested that all human behaviors are motivated by self-interest. He proposed that "of all voluntary acts, the object of every man is his own pleasure" [66].

The Hobbesian apology of self-interest opened the way for the development of utilitarianism and the economic theory of Adam Smith [67], spearheading the success of mainstream economics. Ethical egoism and rational egoism are two forms of normative egoism [68]. The critical question that separates the utilitarian morality of Jeremy Bentham and John Stuart Mill [69,70] from normative egoism is the extent to which maximizing an agent's self-interest maximizes the self-interest of other agents. Adam Smith's economic theory thesis, namely that humans' natural tendency for self-interest can be directed to result in economic prosperity for all, has partially solved that question [67]. He explains the mechanism with the well-known metaphor of the "invisible hand." Market failures caused by the negative externalities of mainstream economics can be fixed by correcting the origins of those failures. However, the negative impacts of market failures tend to increase with economic scale and, therefore, with global GDP growth [71–73]. This tendency increases the challenge of correcting them. Until now, market corrections have been unable to achieve environmental sustainability and allocate the resources that provide higher levels of wellbeing in a way that distributes wealth more equitably [71–73].

Utility maximization, which forms the core of neoclassical economics, is considered by Simon [74] as the best-developed formal theory of rationality. The consumer´s level of satisfaction increases with the level of total utility. This relationship justifies the inclusion of self-interest and utility in the fourth HCD. Utility maximization "tends to produce benefit, advantage, pleasure, good, or happiness" [69], largely through material possession. Being partly rewarded by the DRS mechanism, it creates a positive feedback loop that may risk favoring consumerism.

The current mainstream economic model has been highly successful in utility maximization, in part by exploring and offering all the possibilities of stimulating the DRS mechanism. Consumerism becomes more unsustainable in a linear economy that transforms a large part of natural resources into throughput waste rather than deploying material reincorporation through establishing a circular economy. The achievements of mainstream economics in providing strong economic growth, economic prosperity, well-being, and a good life and in liberating hundreds of millions of people from extreme and severe poverty, especially during the Great Acceleration, are strongly related to the role played by SIU as a critical determinant since that time. Such success has turned SIU potentially into an HSB since there is increasing evidence that it is difficult to make the dominant economic paradigm compatible with sustainability [75]. For instance, as regards natural resource use, it has been shown that no country meets the basic needs of its citizens at a sustainable global level [76].

Softening the fourth HSB requires transformational changes at the personal, collective, institutional, and governance levels, with a stronger focus on fairness of treatment, equity, and sufficiency instead of self-interest and utility. Economic models based on the 'wellbeing economy', an economy that intends to pursue human and ecological wellbeing instead of material growth [77,78], constitute efforts along that pathway.

SIU is strongly related to the use of fossil fuels because of their historical role as humankind's main primary energy source [48]. Fossil fuels have provided great utility to mankind by improving the average economic prosperity globally, especially in the last two centuries [79]. The intense use of energy contributed to a 7.8-fold increase in the global population from 1800 to 2019. Furthermore, fossil fuels were the major primary energy source that boosted the past three industrial revolutions. They were able to sustain exponential global economic growth, leading to a 33-fold increase in global GDP per capita between 1800 and 2006 [80]. Global primary energy consumption increased from 20 EJ in 1800 to 584 EJ in 2019 [81,82], a 3.7-fold increase in primary energy consumption per capita [48].

Energy has a more direct relationship with SIU than with DRS because it enables the production of goods and services that can potentially maximize utility. The energy transition away from fossil fuels to control climate change is a difficult process on a global scale because it does not necessarily maximize the utility provided by the abundant fossil fuel resources, especially in the countries that benefit from extracting and exploring their resources. In other words, GDP growth loses its absolute primacy in a rapid energy transition. This difficulty implies that SIU acts as a strong HSB as regards solving the global challenge of climate change.

There is a second connection between climate change and the fourth critical determinant for sustainability, which involves the issue of socio-economic inequalities. Individual GHG emissions rise with the total utility enjoyed, or, in other words, with the value of increasing the quantity, quality, and variety of goods and services consumed. Wealth drives changes in lifestyle choices, diets, housing requirements, cars, boats, and travel. The satisfaction of the self-interest of people belonging to high-income brackets or with high socioeconomic status (high-SES) [83] through increased utility raises the amount of GHGs that they emit.

The disproportionate share of fossil fuel use by high-SES people has been researched since at least 2015 and is now well established [83–87]. Chancel [87] uses new income and wealth data from the World Inequality Database [88], combined with individual footprints of GHG emissions from input-output models, for the 1990–2019 period. In this study, per-capita emissions include emissions from domestic consumption, public and private investments, and imports and exports of carbon embedded in goods and services traded with the rest of the world [87]. It concludes that half of all GHG emissions are released by one-tenth of the global population, and just one-hundredth of the world population (77 million individuals) emits about 50% more than the entire bottom half of the population (3.8 billion individuals) [87]. The widest gap in GHG emissions per person and per year is between the top 10% in North America, which emits 68.8 tCO2e, and the bottom 50% in Sub-Saharan Africa, which emits 0.5 tCO2e [87]. As regards global emissions growth during the 1990–2019 period, the top 1% was responsible for 23% of emissions growth, while the bottom 50% was responsible for 16% of emissions growth. Contrary to the situation in 1990, in 2019, 63% of global inequality in individual emissions is now due to a gap between low and high emitters within countries rather than between countries. This result suggests that high emitters' lifestyles follow a common globalized model across international boundaries, unrelated to the country they call home.

SIU is the critical determinant that makes high-SES people disproportionately responsible for the present situation regarding global climate change. In this way, SIU acts as an HSB. To mitigate climate change, it will be necessary to soften the SIU-HSB. The question is how to do it. It is very likely that self-interest and utility will always be present, but it is possible to control their influence so that the strong correlation between high-SES and GHG per capita emitters decreases. Individual GHG emission levels have critical implications for achieving the national mitigation targets under the Paris agreement but have not been explicitly included in the design of climate change and sustainability national policies. The introduction of regulations, tax instruments, and other national climate policies [87] would be a way to soften SIU as regards climate change. Up until now, national climate change policies have targeted primarily the majority of the population, which is made up of low-income and low-emitter groups. The associated carbon price signal is felt and affects the bulk of the population, but has been insufficient to seriously affect and induce changes in consumption and investment patterns of the high emitter groups [89,90]. Current national climate policies have been unable to address the specific issue of the high-emitter SES groups that are driven by the fourth HSB.

To soften this HSB, Chancel [87] proposes a regulatory approach with progressive tax instruments centered on consumption as well as capital assets such as asset portfolios and investments. Nielsen et al. [83] propose various types of regulations, but with a stronger focus on psychology [91]. They defend that high-SES people have a disproportionate influence on climate change as investors, as role models, as participants in organizations relevant to the mitigation effort, and as citizens that can influence public policies or corporate behavior. It is suggested that this influence can be channeled to increase the mitigation effort, but the question remains if this process is able to change people's own lifestyles in order to reduce the resulting high emissions. They conclude that "further research and discussion of strategies for changing their (our) actions are certainly warranted" [83].

The reason why SIU functions as an HSB as regards climate change mitigation is rooted in our individual and collective behavior at the global scale, which gives a preferential value to utility maximization, although with different levels of intensity across the world. This tendency has been particularly notorious since the beginning of the great acceleration and affects other environmental aspects of sustainability besides climate change. A similar point of view is taken by Wiedmann et al. [86] when they argue that the most affluent citizens globally have greater responsibility for the negative impacts on the environment and are bound to play a critical role in the effort to bring about safer environmental conditions. In view of the direct relationship that SIU exhibits both with energy and high GHG emitters, its hardness towards climate action is estimated to be strong (Table 1).

3.5. Cooperation or Free Riding

The fifth critical determinant is termed cooperation or free riding (CFR). This applies to the question of how important human cooperation is for sustainability. The question involves the concepts of voluntary cooperation, conditional cooperation, and free riding for the common good. Contributing to the common good is driven by providing greater social inclusiveness and greater equity in the provision of public goods, including the safeguarding of natural resources and the environment. It is typically a collective type of critical determinant. CFR is related to SIU since the marginal personal benefits of contributing to sustainability are often likely to be close to zero, while the costs may be quite high. In such a situation, the standard model of rational and selfish behavior predicts that cooperation will be very unlikely. However, contrary to this prediction, we observe voluntary and costly contributions to global public goods [92–94]. These voluntary contributions can take diverse forms of altruistic behavior, such as the "warm glow" of giving, image motivation, and supporting moral norms.

The benefits that result from the action of co-operators toward the common good are shared by voluntary co-operators, conditional co-operators, free riders, defectors, or rational egoists [95]. Many people worldwide contribute voluntarily with their initiatives, actions, and resources to reduce the risks of unsustainability. Others that have the capacity to be co-operators for the common good are not so involved or stand aside the multidimensional effort to reach sustainability. They may be tempted to free-ride because they devalue the personal cost of unsustainability.

In this function, CFR becomes an HSB. The first experiments on free riding were performed by Bohm [96] and later by many other researchers [97,98]. These experiments indicate that about half the people are conditional co-operators, who tend to match the contributions of their groupmates. About 30 percent are free riders, while the remaining have other, more complex behaviors [99,100]. Free riders for the common good are an impediment to sustainability, while increasing the percentage of voluntary and conditional co-operators contributes to sustainability.

In the case of climate change, the impact of CFR-HSB can be softened by increasing the percentage of voluntary and conditional co-operators for climate change action. This goal can be achieved through processes that improve awareness and knowledge about the collective advantages of controlling climate change and by promoting altruistic forms of cooperation to reach that goal. Voluntary cooperation in climate change mitigation is recognized as an important driver of mitigation [101]. Individual and community voluntary efforts to promote climate mitigation in local interventions encourage shifts in norms and behaviors that can be replicated on a larger scale [102].

Conditional cooperation for climate mitigation was studied in an experiment in Beijing, China. The results indicate that "the probability of contributing to CO_2 emissions reduction is higher if the subjects considering contributing to CO_2 emissions reduction can assume that a two-thirds majority of all the other subjects are also willing to do so, compared to a situation where only up to one-third of all the other participants decide to contribute to this scheme" [92]. This form of conditional cooperation shows the importance of economic and social interactions in everyday life to enhance contributions to the common good and to climate change mitigation [103].

Finally, we note that TD-HSB is very likely to reinforce the hardness of the CFR-HSB because the "forever" effect of all additional CO_2 emitted to the atmosphere disheartens cooperation for immediate seemingly sacrificial mitigation [104]. CFR hardness for climate action is evaluated as moderate in view of the difficulty observed in past decades, especially in the high-GHG-emitter countries, to mobilize society to deliver effective mitigation and adaptation measures through cooperation. There is a pressing need to move beyond the frame of mind of appearing to be concerned to find the willingness to cooperate in climate action for the common good. It is likely that policies encouraging more local and neighborly actions to mitigate and adapt may further soften the CFR boundary.

3.6. International Geopolitical and Geostrategic Relations

The sixth critical determinant for sustainability is the international order resulting from the international geopolitical and geostrategic relations (IGGR) between countries at the global scale, especially between the major powers and their allies. This is proving a more complex critical determinant for sustainability at the collective level. Although fundamentally related to human cooperation and defection, it includes all dimensions of social bonding resulting from the defense by each sovereign state of its religious, cultural, historical, political, and economic national identity, its security, and its strategic interests. The way governments engage in international cooperation depends, to a large extent, on domestic politics and the demands of societal groups across countries [105]. Nationalism, by promoting the identity and the interests of one's own nation, tends to exclude or impair the interests of other nations. Thus, the emergence and strengthening of various forms of nationalism is likely to hinder the international cooperation required for sustainability [106]. These factors increase the complexity of the critical IGGR determinant. The world is fragmented by a hierarchy defined mostly by military and economic power that includes all countries, with a small number playing leading roles. State interests define their geopolitics and, in particular, their geostrategy, which involves military, economic, ideological, political, historic, and religious interests. Geopolitics is also moved by interests related to energy [107,108], water, and all other natural resources with strategic value, including the minerals critical for the net zero energy transition [109,110]. The strong dependence that sustainability has on geopolitics, especially on the major powers' geopolitics, increases the importance of IGGRs role in reaching sustainability.

There is generally a high level of cooperation on sustainability issues in IGGR, but non-cooperation is increasingly a possibility. IGGR may become non-cooperative, degenerate into economic and technological conflicts due to geopolitical and security concerns, or descend into an international armed conflict. In cases of non-cooperation, IGGR becomes an HSB that can be powerful in extreme situations. The Brundtland Commission's report, and in particular the definition of sustainable development, reflects primarily the concern for the sustainability of human civilization on a planet with finite natural resources. Nevertheless, global implementation of the 17 SDGs depends critically on policies and measures that are developed at national and local levels. It also relies on cooperation between sovereign states to help optimize the transition to sustainability in all countries. Global progress towards sustainability, measured by the SDG targets, in areas such as peace, justice, poverty eradication, food security, decent work and sustainable economic growth, conservation of terrestrial and marine biodiversity, water resource availability, mitigation and adaptation to climate change, and other areas, depends largely on international cooperation between states. This cooperation should be supported by or at least be compatible with the geopolitical interests of the countries involved.

Sustainability is not confined to national or local scales. It is often a global challenge that depends on what is happening in all countries and, above all, on whether there is peace and cooperation, especially between the major powers. A current example of degenerating IGGR is provided by the US and China, the world's two leading economies. The bilateral policy initiated some 40 years ago between the two countries was changed by a trade conflict that started to develop in 2017 [111,112]. This led to protectionism and growing geostrategic tensions that include ideological, political, military, economic, and technological aspects [113]. The present less cooperative bilateral relationship has global impacts on social, economic, and environmental sustainability, particularly by hampering world economic integration and fostering fragmentation. China and the US, being the first and second largest GHG emitters [114], have a special responsibility to cooperate in climate action to decarbonize the global economy.

Cooperation between the US and China stalled in August 2022. The war that resulted from Russia's invasion of Ukraine in February 2022 is an extreme example of an IGGR breakdown that acts as an HSB. It constitutes a breach of SDG 16 that caused significant disruptions in financial, food, and energy flows across the globe. The conjugation of this crisis and other ongoing and emerging conflicts, with the 2020 COVID-19 pandemic and the increasing harmful impacts of climate change, have led to an economic slowdown and cost-of-living increases in various countries, high national and global debts, and the hunger crisis in the most vulnerable countries.

On the brighter side, we note that there is currently a political, economic, and environmental interdependence between the major powers and their allies that is acknowledged, which makes decoupling unlikely in those three domains. Increasingly, geopolitical and geostrategic interests tend to converge when dealing with outstanding transnational problems such as pandemic threats and climate change.

Softening the sixth HSB is constrained by political realism, the principle that world politics is a field of conflict among actors pursuing primarily wealth and power [115]. Frequently, this "realism" implies that a state only agrees to and abides by international sustainability norms if such norms do not in any possible way imply or even give the impression that they leave the state at a relative disadvantage vis à vis its competitors as regards its geopolitical and geostrategic interests. According to this principle, colliding sovereign geostrategic interests tend to prevail over all other individual or collective interests. However, that is not likely to happen due to the increasingly higher degree of interdependence between advanced economies and emerging and developing economies that has been created by a more populous, complex, and globalized world.

Softening IGGR can be achieved by progressively converting sustainability into an essential element of interdependence in international relations. This approach would decrease the risk of non-cooperation, in particular by promoting the knowledge, consciousness, and action needed to defend "Our Common Future", as suggested by the universal concept of sustainability.

In the domain of the environment and natural resources, there is a vast and complex assemblage of international agreements and protocols based on legally binding documents. Such agreements are primarily produced by the United Nations and include policies covering the global climate, atmosphere, ocean, freshwater resources, biodiversity and nature conservation, desertification, pollution, hazardous waste, the use of outer space, and nuclear safety. In some cases, the effectiveness of these agreements and protocols is limited, partly because geopolitical and geostrategic national interests prevail over the need to reach agreed-upon objectives. The failure of the UNFCCC and associated agreements and protocols to decrease systematically the global emissions of GHG in the last 39 years (since the UNFCCC entered into force) is an example. The accords that were reached have been poorly implemented due to a lack of adequate oversight mechanisms and penalties in cases of noncompliance. Geopolitics and nationalism have been leading most countries with large fossil fuel resources to satisfy economic self-interests in the short term from their exploration instead of contributing to the global energy transition [116]. Moreover, fossil fuels are still an important geostrategic economic commodity. This chain of interconnections suggests that the hardness of TD, SIU, and IGGR for climate action should be evaluated as strong.

Barrett and Dannenberg [117] find in a lab experiment that the pledge and review mechanisms in the Paris Agreement are largely disconnected from the actual contributions towards emission reduction targets. A review process affects targets and pledges more than actual contributions. Cooperation between countries is more likely to be improved through strategies of intrinsic within-issue reciprocity, where cooperation is conditional on the past cooperation of other countries on the same issue [118,119]. In the context of climate change, using surveys from 26 countries, it was found that most people have unconditional policy preferences and insist that their national policies should not depend on the climate policies of other countries [120]. The authors conclude that "cooperation is unlikely to arise from the kinds of intrinsic trigger strategies that have received so much attention in the international relations literature".

The role of IGGR becomes critical as regards the controversial deployment of solar radiation management (SRM) geoengineering, and particularly its more affordable form of stratospheric aerosol injection (SAI). Many authors defend that SRM, being an intervention on a planetary scale, involves technical, political, and ethical risks that require a fair and effective system of global governance that is impossible to implement with the current system of IGGR [121–124]. SRM would impact all countries in ways that can only be assessed by modeling procedures at the planetary scale, involving considerable uncertainty at the regional level [125]. Such uncertainty enhances the likelihood that some countries will be winners and others will be losers as a result of the SRM implementation process. This situation requires a fair and just governance system at the global level that effectively includes all countries [126]. A proposed UNEP resolution in 2019 to undertake an assessment of geoengineering options, including SRM, failed to reach consensus [127].

An opposing current of thought considers that it is possible to develop, within the current international system of IGGR, a governance model for SRM deployment at the global scale [128–130]. It is argued that the implementation of SRM has the potential to reduce the climate injustice associated with the differentiated impacts of anthropogenic GHG emissions on a global scale [131]. Some of those who advocate the deployment of solar geoengineering also argue, implicitly or explicitly, that international climate governance has been largely ineffective, which risks being an incoherent position. They point out that the Paris Agreement's temperature goal is unlikely to be met, given current trends in governance and policies, a situation that enhances the possibility of SRM deployment [131,132].

4. Conclusions

HCDs in the human evolutionary "backstory" with biological, social, and economic underpinnings were identified. Understanding their nature, characteristics, functionality, and development throughout human biological and cultural evolution is an exercise in self-knowledge/awareness of our current difficulties in attaining sustainability. The dominant viewpoint is that full priority should be given to implementing actions to create new technologies, social structures, and governance systems that effectively promote social, economic, and environmental sustainability. A complementary but different perspective is presented here. We defend that human self-knowledge develops and strengthens the inner resources needed to address sustainability challenges. Solving them requires transformations that are not only technological and political but also operate at the inner personal level. This attitude is especially important because sustainability is a very recent concept, with less than 40 years of attention, to which we are still adapting. We argue that it is possible to reduce the inhibiting power or hardness of each HCD when acting as a HSB in the sustainability pathways of human societies. This is a human development process, which we term softening. The present group of six HCDs is viewed as minimal, and others with less critical determinants may be further identified.

In the analysis of the relative holistic hardness shown in Figure 1, we find that IGGR has the highest value of holistic hardness, followed by DRS and TD with the same value, then SIU, CFR, and finally HNI with the lowest values. The dominant HSBs are IGGR, DRS, and TD. The first is distinctively the more complex collective HSB, and the latter two have a remote biological origin that makes them more difficult to overcome. Nevertheless, softening these further is far from impossible, as many examples across the world actively practicing sustainability have shown. In these settings, the hardness/softening measures would undoubtedly vary.

The application of the present methodology was restricted here to anthropogenic climate change, which is likely to be the most pervasive and challenging threat to human societies and their gifted natural environment the world has ever experienced. The way each HSB is capable of obstructing climate action and the possible ways to soften its boundary hardness were discussed. As summarized above, the analysis shows that TD, SIU, and IGGR impose the strongest hardness, while DRS and CFR are moderate and HNI is weak (Table 1). We argue that the same type of analysis can be extended to other sustainability challenges, such as biodiversity conservation, sustainable use of natural resources, or the SDGs of the UN 2030 agenda. We are aware that softening the HSBs is likely to be a difficult process because the causes of resistance have been long in gestation and enduring in the human condition. Yet, we consider that the human capacity for adaptation and evolution based on accumulated knowledge can overcome and adjust to the sustainability challenge. This may well be advanced by recognition of the causes, consequences, and conciliations connected to HSBs.

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