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Climate and Energy Crises from the Perspective of the Intergovernmental Panel on Climate Change: Trade-Offs between Systemic Transition and Societal Collapse?

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Abstract: AR6 IPCC reports give divergent messages about the different socio-economic transition approaches to deal with the current climate emergency. The dangers of not giving a clear message to policymakers and to society on the need of changing the current socio-economic paradigm are considerable: to fall in the SSP3-7.0 scenario, which is conducive to the collapse of our current civilization. In this work, key variables to assess the main functionalities of global socio-economy are analyzed under a system dynamics approach. This allows for understanding what the evolution is of our current socio-economy in a framework of climate change and resource depletion. The aim of this work is to provide a different perspective on socio-economic evolution by identifying similar characteristics in the worst-case IPCC scenarios with historical behavior in complex societies. From such a historical perspective and the current system evolution, a conceptual model is proposed to explain our globalized complex system near to a phase transition. Then, phase transition correspondences from the model to the current socio-economic system are proposed and a series of corresponding preventive measures (in terms of social actions, economic measures, and their linked policies) are suggested to avoid collapse scenarios.

Keywords: AR6 IPCC reports; energy transition; societal transition; inequality; history dynamics; collapse

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1. Introduction

Tackling the climate crisis requires an urgent, united global effort to achieve adaptation and mitigation. The last Assessment Report (AR6) of the United Nations Intergovernmental Panel on Climate Change (IPCC) was issued in three main parts between 2021 and 2022, each part corresponding to one of its working groups (WGs). WGI is responsible for conducting physical analyses of the climate system and future evolution regarding different greenhouse gas emissions (both anthropogenic and natural); WGII focuses on the impacts of climate change on socio-economic and natural systems and the options for adaptation; WGIII reports strategies for climate change adaptation and mitigation through, for instance, reducing greenhouse gas emissions (Figure 1). The AR6 presents five scenarios that are graded according to future emission projections and their related warming potential [1], which implies an increase in average global temperature over pre-industrial levels. The acronym for the scenarios refers to policies, population, technological development, geopolitical trends, and the consequences of these for global emissions (shared socio-economic pathways, SSP [2]), and also links these SSPs to the corresponding warming potential or radiative forcing potential (from 1.9 to 8.5 watts per square meter). In short, the IPCC scenarios (Figure 1) range from SSP1-1.9, which adheres to the Paris agreements, to the worst-case scenario, SSP5-8.5, where the temperature change rises above 4.4 °C by 2100. In this context, the WGII report warns of the risk of maintaining current 'business-as-usual' policies and, thus, triggering the projected worst-case scenarios, and advocates profound social and economic transformation, discussing degrowth and post-growth as possible

solutions [3]. Despite these indications, in its Summary for Policymakers, the WGIII [4] report does not propose policies for socio-economic transformation; rather, the recommendations focus more on modifying policies on current trends and enhancing energy transition, continuing to place emphasis on achieving net-negative CO_2 emissions and carbon dioxide removal (CDR, section C3) and stating that current economic instruments have been deployed successfully (section E4). However, whether or not these instruments have been successfully deployed, emissions have not fallen as the report itself asserts (section E6). While the WGIII report notes the urgent need for action, it gives no clear message on how this could realistically be attempted. Furthermore, adherence to WGII recommendations in terms of post-growth actions would imply a systemic change that goes far beyond what is proposed in the WGIII report (for details please see Appendix A). Such contradictory advice (differences between WGII and WGIII regarding policies) entails the considerable danger that we jettison the goal of remaining below 1.5 °C (Paris Agreement) and accept the 2 °C target as being more 'realistic'. If this were to happen, there would be a high risk of continuing in line with current trends and, unavoidably, moving toward SSP2-4.5. It should be emphasized that after the first two scenarios (SSP1-1.9 and SSP1-2.6), SSP2-4.5 and SSP3-7.0 lead to changes in the global temperature of more than 2 °C by 2100 (2.7 °C and 3.6 °C respectively, see Figure 1), which is far beyond the safe limit for avoiding severe impacts of climate change on the planetary system. In addition, accepting the SSP2-4.5 pathway would increase the risk of eventually ending up on the SSP3-7.0 pathway if something went wrong. The scenarios that go beyond 2 °C imply serious environmental impacts which would entail severe societal challenges and adaptation [3]. The current trend is extremely worrying, with evident signs that we are passing too many planetary tipping points [5]. It should be noted that the narrative according to the SSP3 'regional rivalry' scenario describes a situation with high levels of poverty and ecosystem degradation and low population growth, which has historically led to societal collapse. In the SSP3 scenario, political instability or lack of agreement between nations can give rise to policies that place more emphasis on preserving the current status quo in the geopolitical arena than on caring for the environment [2].

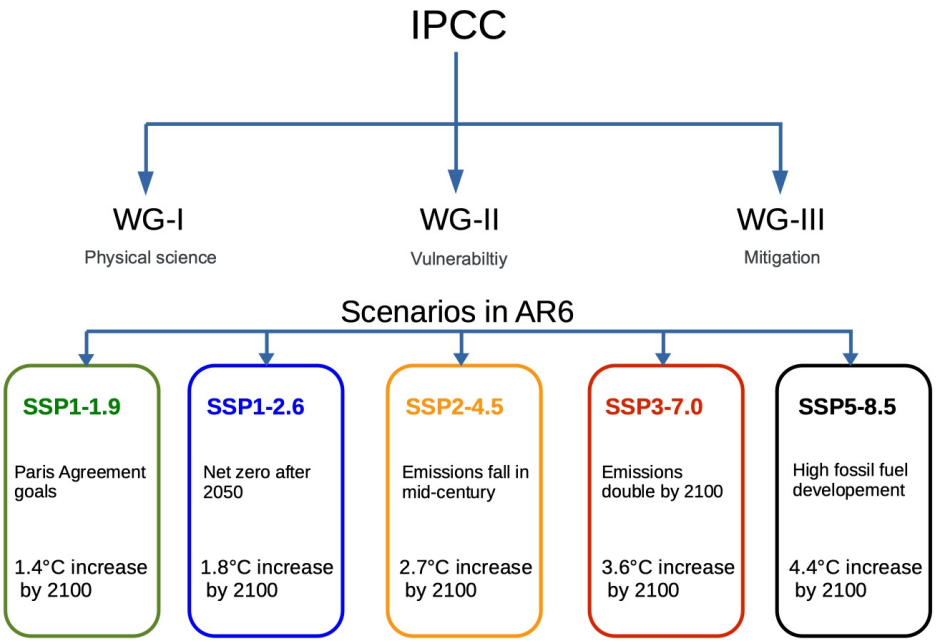

Figure 1. IPCC working groups, AR6 scenarios and their main characteristics.

The AR6 report highlights the urgent need to put change in place by 2025 and to speed up such change before 2030 ([3], section B6, page 15). There is not much time left and it will be a major challenge to avoid collapse. Thus, the safest way to proceed is through

societal transition, which includes—but goes beyond—energy transition. Aiming solely at energy transition is risky because, although technological advances might accelerate the transition to renewable energy sources, they do not always help to improve equity [6–8] or social stability, which are both crucial for long-term sustainable transition [9]. Moreover, depending on how we scale up this energy transition within the current socio-economic paradigm, there is a high danger of causing severe impacts in key ecosystems that are already damaged [10].

Within this framework of the climate action advocated in the AR6, coupled with recent increased tensions between the most powerful military countries, there is a risk of returning to a similar situation as that experienced in the 2008 global crisis. At that time, the implicit message was 'first we need to fix the economy, then we will fix the climate', although the OECD was already sounding a warning about the dangers of adopting such a strategy [11]. More than a decade later, the need for urgent action is more compelling, because there is ever more evidence showing that climate change will damage the economy in ways that have never been seen before [12]. Such changes need to be profound at a level that is unprecedented. For instance, even during COVID-19, we did not achieve the necessary emission reductions [13], and in 2021, emissions continued to grow at an annual rate comparable to the pre-pandemic one [14].

Given the possibility of serious damage to the economy that would entail severe impacts on societal functioning, it is worth looking at past situations where sudden, profound changes in resource availability occurred. The main idea is to conduct an analysis that differs from traditional historical discourse, being more aligned with the work of Turchin [15,16], in order to identify similarities regarding sudden change and societal collapse in history and determine common characteristics in rapid, uncontrolled systemic change. Such past experiences can be used to track current societal behavior from a complex systems perspective, and to propose measures to adapt to/avoid the worst situations. In line with this idea, the Section 2 describes the correspondence between patterns in ancient Rome and the current globalized socio-economy. Based on the common characteristics identified, a conceptual model is proposed for sudden change toward different end states in a system (Section 3). Next, the phase transition correspondences from the model to the current socio-economic system are proposed (Section 4). Having modeled the behavior of the main characteristics near a phase transition, a series of preventative measures (in terms of social actions, economic measures, and their linked policies) are suggested in the last section, 'Options/strategies'.

The general aim of this work is to provide a different perspective on socio-economic evolution by identifying similar characteristics in the worst-case IPCC scenarios and in past historical behavior in complex societies. Based on these characteristics, theoretical models can shed light on key functionalities of socio-economic evolution in order to identify measures to counteract the main leverage points that could drive the system to collapse or to uncontrolled behavior.

2. History as a Guide

In this section, we aim to analyze the patterns and behavior characteristic of a complex society in a situation of resources decline or environmental damage. The interest is to tackle similarities in actions, policies, and social behavior in past situations that we are reproducing in what is perceived as a situation that can compromise the regular social functioning. Historically, a society does not perceive collapse. On the contrary, it is only perceived as a general continued degradation and lack of functionalities, which, in the past, were normally functional. Thus, collapse can be analyzed as rapid, uncontrolled transition, change, and adaptation to a new situation or environment by the society affected [17]. Tainter [17] linked collapse to the concept of diminishing returns on the energy and materials that a society needs to function correctly. More complexity requires more energy/materials, and their diminishing availability obliges a reduction in complexity. The problem arises when a complex society with diminishing returns attempts to maintain the previous behavior and

social structure, regardless of the available resources. In this case, sooner or later, a sudden reduction in complexity will occur. To illustrate collapse, Tainter took the ancient Roman Empire as an example. Here, following previous works [18,19], we examine what happened then to determine whether we are repeating patterns and behaviors in the current situation of environmental degradation and limited resources. Table 1 compares six biophysical and socio-economic areas in Rome and in the current globalized socio-economy. The indicators chosen are key/driving variables in the system evolution that become particularly important near a transition. Six general areas for comparison have been selected (Table 1): economy, society, resources, politics, technology, and culture. The main indicators are: for economy, monetary evolution and debt; for society, the role of cities and the attitude of citizens; for resources, the evolution of key commodities; for politics, military and social unrest; for technology, improvements and efficiency in processes; for culture, the view of citizens on themselves and their values. The six areas can be grouped in two general levels: the first/basic one is the physical-technological capabilities of the society (resources and technology). The second one is how society deals with such a physical-technological level in terms of organization and temporal evolution. In this second level lay the other four areas. Note that two societies so distant in time and so different on many levels (technological, extension, understanding of the world, and social organization) have responded in almost the same way to manage the storms associated with the risk of collapse.

Table 1. Correspondence table for Rome-globalization in four key areas. The collapse characteristics for the Roman Empire are deduced from [17] ideas. Columns for technology and culture are inferred from [17,20,21] concepts.

	Economy	**Society**	**Resources**	**Politics**	**Technology**	**Culture**
Rome	-Retreat of trade due to the excessive taxes that traders and craftsmen had to pay. -Progressive devaluation of the currency (reduction in the amount of precious metal in each coin). -Progressive lack of revenue for the state. -Increase in public debt.	-Corruption of high-ranking officials. -Citizen passivity in the face of problems and obligations. -Middle-class crisis, overwhelmed by fiscal pressures. -Deterioration of cities, abandoned by the upper classes, who retreated to their countryside villas. -Decrease in recruitment for legions among the peasantry.	-Decrease in agricultural production. -Decrease in mining and metal production. -Pests. -Decrease in surpluses.	-Increase in the number of legions (military spending). -Increase in administration. -More insecurity (increased piracy and crime). -More social instability: riots. -Impossibility of maintaining the expansionist policy of colonization. -Difficulty managing crises in an economy based on agriculture (90%) that had reduced production.	-Stagnation of improvements in engineering. -Technology proves unable to increase surpluses (material returns) or military superiority in potential conflicts.	-Elites devoted to amusement and distraction (increase in expenditure on public buildings and sports). -Cultured elites care less about philosophy and knowledge. -Moral and ethical decline. -Belief of having a superior culture.

Table 1. *Cont.*

	Economy	Society	Resources	Politics	Technology	Culture
Globalization	-Devaluation of the international currency (dollar) through quantitative easing. -Increased fiscal pressure. -Increase in state debt.	-The crisis of the first-world middle class. -Growing fiscal pressure on the middle class. -Deterioration of cities. -Citizen passivity in the face of the most serious problems (climate and resource depletion).	-Stagnation of oil production. -Stagnation of production of other necessary minerals and metals. -Pandemic. -Risks to global food security.	-Increase in military spending. -Impossibility of maintaining a colonizing policy because of reaching planetary limits and degradation of the global periphery (third world) -Difficulty managing crises due to the need for the economy to expand.	-Reduction in the capability of technology to save energy in a growth paradigm. -Technology improvements shift from fundamental applications to information and communi-cations. -Progressive decrease in EROI (energy return on energy investment)	-Growth of advertising to stimulate over-consumption. -Degradation of education systems. -Increased belief that technology can solve everything. -Diminishing sensitivity to humanitarian issues. -Consumerism and materialism as the sole mainstream values.

Taking one indicator from each column in Table 1 as an example for our globalized socio-economy:

(1) Increase in state debt. Public debt is now around 40% of the total global debt, the highest share since the 1960s. In advanced economies, public debt is even higher, accounting for 70% of GDP in 2007 and 124% of GDP in 2020. Moreover, global debt has increased to 250% of GDP, while in 1970, it was around 100% of GDP [22].

(2) Fiscal pressure on the middle class. The OECD [23] has warned of the danger of squeezing the middle class, noting that the cost of some goods and services, such as housing, has risen faster than earnings and inflation. This is critical now, when inflation is growing faster than in previous years.

(3) Stagnation in fossil fuel production. The 2021 IEA annual report warned about the problems derived from the lack of investment in the oil industry and how this could affect supply [24]. The figures provided by IEA on the historical data show a level of stagnation in oil production of around 550 EJ in the Stated Policies scenario (page 165). This is a key point, particularly considering the current lack of capacity to grow above the diesel production maximum, which peaked around 2018 (see Figure 2). In Figure 2, we can observe how the diesel production peaked in 2018–2019, and the previous decline pattern in 2009 can be linked to economic recession. However, what we observe now seems more linked to a structural incapacity to increase the production above 2018 levels despite the high prices of diesel. Thus, this could lead to serious supply issues in the near future.

(4) Increase in military spending. Military expenditure is rising, which increases the probability of greater regionalization of the economy and escalating global tensions between opposing blocks/regions. Furthermore, the rise in military spending in some countries in response to the war in Ukraine may jeopardize climate policies. For instance, the USA and Europe advocate for international agreement on climate and the environment, but are investing ever more in the military. Thus, it seems that 'practical' policy has taken the opposite direction, using as many resources as possible to tackle the problem, and thus leaving others outside these regions behind. This situation reinforces the impression that there is a high risk of entering undesirable climate scenarios. The Ukraine war has highlighted the need for a global discussion about whether we can afford to fight climate change and undertake the necessary energy transition while, at the same time, maintaining

(or increasing) the budget on arms and associated business. This is a key question if we accept that we have limited fossil resources to fuel renewable transition and also limited time to waste them on violence and destruction. As can be seen in Figure 3, global military expenditure has been rising since the 2000s and, by 2020, had reached USD 2 trillion (see Figure 3, which is not considering the Ukraine war; time series stops at 2021).

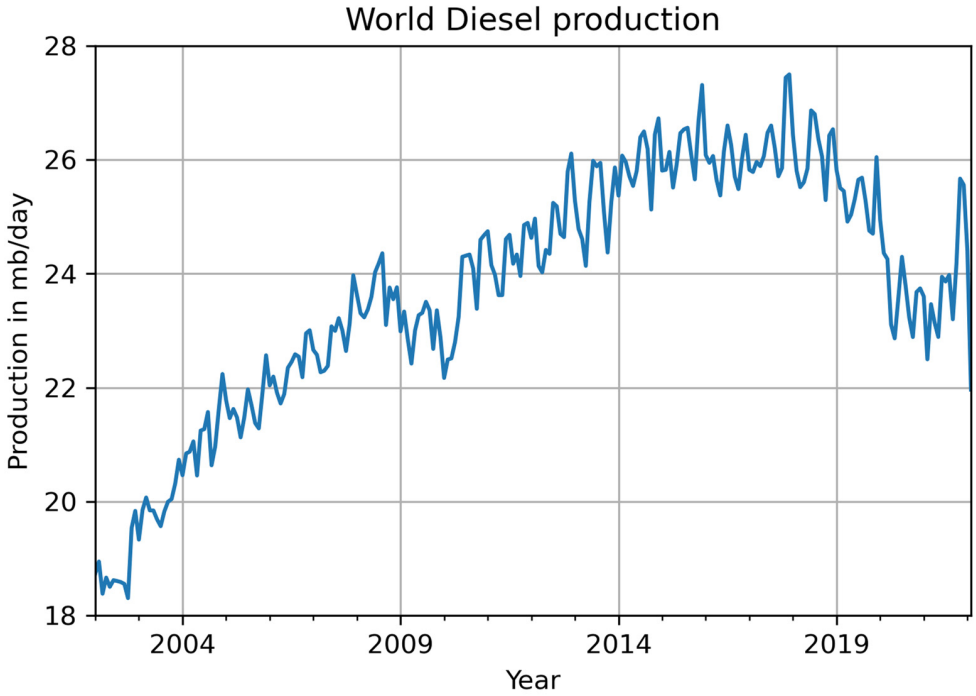

Figure 2. Time series of world diesel production (refinery output) by year in million barrels per day (mb/day) (source: JODI database http://www.jodidb.org/TableViewer/tableView.aspx (accessed on 16 May 2022)).

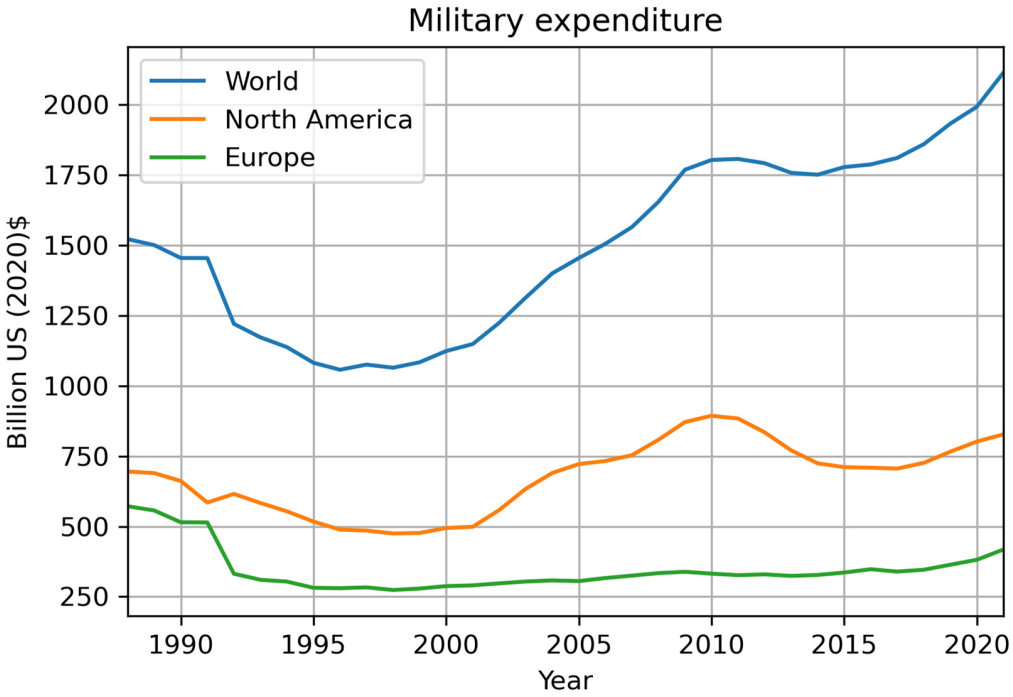

Figure 3. Military expenditure (USD billion) over time for the world, North America, and Europe. Data from SIPRI (https://www.sipri.org (accessed on 16 May 2022)).

(5) Steady decrease in EROI (energy return on investment) [20], leading to a reduction in net (or useful) energy for society. This is a general characteristic of all societies that reach the material and energy limits of the resources they are based on. In our current societal paradigm, these are fossil fuels. The reduction in the EROI of fossil fuels means there is less energy surplus available for socio-economic activities [20].

(6) Consumerism and materialism as the sole mainstream values. As in ancient Roman times, there is a general conception that the way in which we are organized represents the culmination of human evolution [25], which poses the practical problem of the impossibility of changing to a different form of social organization. The narrative on how to tackle the systemic crises we are facing is crucial when solutions are proposed. Thus, current cultural barriers anchored in individualism and competitiveness prevent our society from seeing the value of non-materialistic relationships and cooperation as keystones for global change [26,27].

This comparison shows that our management of the socio-economy in the face of a generalized crisis seems to be the same as that of ancient Rome near collapse. Nevertheless, we have a major advantage over earlier times: We have more knowledge compared to the Romans. However, the Romans 'only' had to manage the resource crisis, whereas in our era, we must adapt to a future with dwindling resources and an increasingly hostile environment and climate.

3. A conceptual Model: Collapse as a Phase Transition Phenomenon

To design strategies and create options in today's climate, ecological, and resource crisis, we need a vision of what has caused the problem and why. According to some authors [15,17,19], collapse occurs when the expansion triangle formed by the level of accessible energy, social organization, and energy flow ceases to be functional and begins to deteriorate. If we compare the socio-economic and biophysical system with a metabolism [28], we see that in the early stages of collapse (the stages at which we are now), some key socio-economic functionalities are lost simultaneously with a reduction in geographical scope [15,17]. Thus, the current system, which is centralized both geographically and in its distribution of resources (elites vs. population) [18], will jettison peripheral parts that do not affect the functioning of the central nodes of the network, namely the elites and wealthy geographical areas. This geographical deterioration not only leaves behind the poorest countries on the planet but also happens within countries, exacerbating social differences [29].

The main question is how our current socio-economy could evolve. Taking a physical phase transition system as a model sheds light on how such a collapse might behave in the future and provides insights on how to prevent it. There are different examples of transitions in physical-chemical processes such as a system near a saturation point that can be also understood as a critical point. Another example of a rapid systemic shift is when a physical system changes from one state to the other, for example, when water changes from a liquid to a gas when heated (see Figure 4). In such a system, the flow of energy from the hot to the cold source increases (from the bottom to the surface of the heating recipient), which is measured as a rise in temperature over time and also a rise in the temperature gradient (the change in temperature in space from the warm focus to the cold focus). When the system is near a transition (close to boiling point), perturbations (bubbles of air) appear in the liquid phase of the water, and the energy flow from the hottest part of the volume to the coldest is disturbed. Such perturbations tend to increase as the energy flow increases until the convection process of the fluid becomes ubiquitous throughout the volume and a disordered flow appears (boiling state). In this example, the phase transition depends not only on the flux of energy (driving variable) through the system but also on the pressure (boundary variable) at which the volume of water is exposed: Water boils at different temperatures at different pressures. As Figure 4 shows, changing pressure will lead to a phase transition but maintaining the same temperature. Using this analogy, we can identify temperature as a prognostic variable in how the socio-economy deals with

energy and resources (as driving variables) and pressure (boundary variable), where these represent environmental impacts or constraints on the globalized socio-economy.

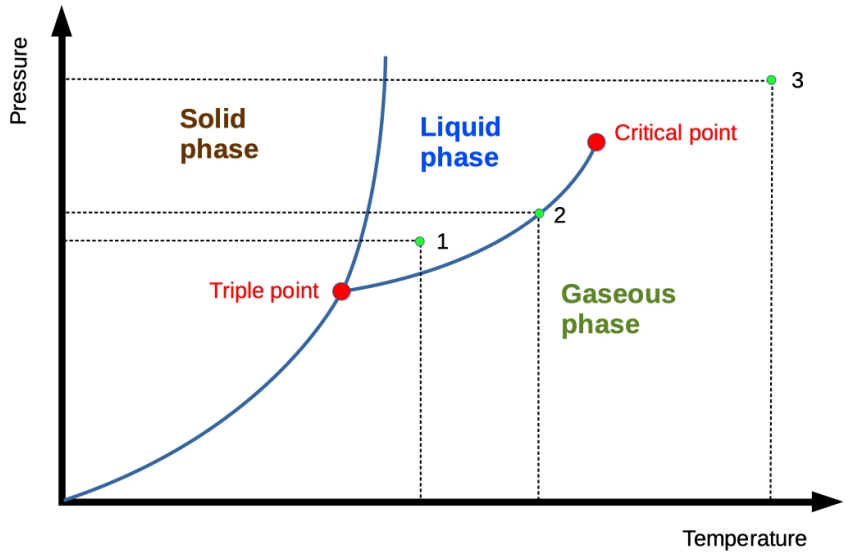

Figure 4. Water phase diagram. Point 1 is in a liquid phase (water). Increasing the temperature and pressure shifts the state to the transition point (2) where the liquid and gaseous phases co-exist; this is the boiling water phase transition. Continuing to increase the pressure and temperature, a state beyond the critical point is reached, where the fluid's physical properties change completely and the co-existence of liquid and gaseous phases is no longer possible. The analogy-model mentioned in the text refers to the shift between point 1 and point 2, when the phase transition starts and liquid and gaseous phases co-exist.

Currently, the globalized socio-economy continues to push for increasing the temperature and, therefore, exploits the available resources at a growing rate. This maintains the flow of wealth (energy and resources) from the poor majority to the rich minority of the population. In parallel, environmental degradation is also intensifying, which increases the pressure on the system, thus driving it closer to the phase transition.

The key to avoiding this phase transition is to reduce the flow of energy, materials, and environmental pressure. This will require a simultaneous reduction in temperature and pressure, which implies reducing inequalities (temperature gradient), the amount of energy/materials needed, and environmental damage (pressure).

4. From Phase Transition Modeling to Socio-Economy

In the previous section, a model was described that maps a system transition. In general terms, phase transitions can be described using 'state variables' that characterize the system and the control parameters (which drive the system's evolution from one state or phase to another) [30]. This, in turn, can describe systems out-of-equilibrium with a threshold response. Then, an analogy of the phase transition can be applied to current and past historical situations of sudden change from a centralized, stratified, and highly resource-dependent system to another requiring fewer resources and less complexity. Models for analyzing collective behavior using complex systems methodology have been constructed for social insects [31] and for socio-economic issues [32].

In a sudden phase transition, the socio-economic system will become increasingly destabilized, creating bubbles of perturbations (social instability) [16,18] that may eventually destroy the previous state, changing to another, totally different situation. In the mapping suggested here, the society's energy needs grow over time. Energy and materials (and the lack of them) are the control parameters that allow the system to function, but they also drive it to change the state. In our current globalized society, environmental

degradation acts as a boundary variable [5]. The required energy flux triggers environmental degradation, which is related to the pressure of the boundaries on the socio-economy. According to this model, in this situation, reducing the energy/resource input into the system in a controlled way is the strategy required to prevent collapse, defined as a sudden, uncontrolled lack of energy and materials for societal needs. Degrowth is the only way to avoid crossing the system's environmental phase transition lines, and this will require changing the current societal paradigm.

We are at a crossroads and must choose between managing an environmental phase transition that will cause our civilization to collapse or undertaking a social transition to avoid planetary disaster. Thus, we need to manage energy/resource consumption in a way that enables us to make the necessary socio-economy changes with sufficient speed to avert a future in which coordinated global action has become impossible due to levels of social unrest that prevent the system from functioning normally. The possible measures for the socio-economy to become more resilient to the environmental changes and resource limitation are introduced in the next section.

5. Options/Strategies

The above sections show that the socio-economy needs to avoid exceeding the limits imposed by the environment, ecosystems, and energy/material requirements, while at the same time, adapting to the constraints imposed by the changes that we have already brought about in the environment and ecosystems. Thus, from a systemic approach, it is first necessary to consider a good set of diagnostic variables and indicators that can quantify the past and current evolution of the (complex) system [33]. Second, we need to devise social transformation policies that will create a new paradigm. In short, starting from present limits, we need to design adaptive strategies/plans and implement them through a series of general global policies that can be tailored to each particular region or country. To track advances on this pathway to the new paradigm, we must go beyond the current economic indicators (i.e., GDP) and focus more on social equity and associated laws, environmental and ecosystem health, education, and information.

Strategies must be aimed at profound social reorganization that reduces society's energy/material needs [34], and we must do this quickly because we are in a state of emergency. In accordance with the phase transition model described above, the future will bring more frequent and more sustained extreme situations and more social instability, due to widespread impoverishment and the lack of a constant/growing supply of energy/materials. The strategy must include 'just transition' and 'leave no-one behind' [35], but without assuming that the resources we have now will be available in the same quantity in the future. Implicitly assuming that resources will remain the same (or in the worst case, be easily replaceable) is what Europe and the US do in their planned (public) policies under the Green Deal.

The social reorganization we need should be based on two linchpins: Decentralization (of administration, the economy, and information) [36] and democracy (of society, broadening access to knowledge and education, and increasing transparency) [37]. We must rethink all of our current tools at the social, political, and economic level to determine what will be useful and what will not, and we need to be very flexible mentally to be able to deal with the unforeseen. The environment–society complex system is approaching environmental tipping points that could endanger life as we know. However, we could take advantage of tipping points behavior, using them to enhance positive social behavior to avoid the worst scenarios [38]. This was developed by Lenton and their positive tipping points toward global sustainability [39]. Thus, strategies for the necessary transition to avoid the SSP2-4.5 and SSP3-7.0 scenarios could be based on three pillars: (1) A global agreement on legislation, (2) a global agreement on the necessary budget to deploy and the measures to apply it in time, and (3) a global awareness campaign to prepare people for the transition, in a global push for transparency. Table 2 below gives a schematized view of what this would entail.

Table 2. Measures and strategies for social transformation.

	Global Policy	Financial Measures	Communication
Measures	-Legislation on environmental crimes as crimes against humanity -Climate as a priority on the political agenda	-Reduce over-consumption -Allocate the necessary budget -Reduction in transport and internet use -Social equity -Efficiency in agriculture and water resources -Increase in protected areas and measures to ensure healthy ecosystems	-Global awareness campaign -Restriction of over-consumption and advertising

(1) Global policy and legislation:

- Legislation: Climate change and the ecological crisis must be framed as a problem that affects everyone, and we must be very rigorous in what we do and how we do it. It is necessary to provide an international legal framework that defines environmental crimes as crimes against humanity. In this respect, those who have conducted misinformation campaigns for economic gain in previous years must be brought to account. If we do not create such legislation, future generations will suffer the worst effects of the crisis and will blame us for not ensuring justice.
- Politics: In this matter, political responsibility is crucial; all political parties must make it their absolute priority. Those that do not, either have not understood the problem (in which case, pillar three should be applied) or they do understand it but do not care (in which case, the previous point should be applied).

(2) Management and financial measures:

- Consumerism: Plans must be devised to combat over-consumption and waste and raise the population's awareness of the need to reduce and reuse. It should be made clear that consumption and its consequences (increase in production of goods and expenditure), framed within an expansionist/growth model, are what have led us to the current impasse. Therefore, any effective action will involve rethinking this perceived need to increase (or maintain) consumerism, which, in turn, does not provide any long-term benefit.
- Internet adaptation: We need an awareness campaign on the energy and emissions costs [40] involved in maintaining a volume of purely leisure-oriented information accessible on the internet. Society needs to start deciding what information to keep and what to discard, establishing a maximum amount of information to be held in the cloud and its cost in terms of energy and emissions.
- Budget: Budgetary promises in the USA and the EU and their alignment with the IPCC seem ambitious, but do not fully reflect what scientists claim needs to be invested (https://www.ccma.cat/324/europe-prides-itself-on-climate-change-fight-but-does-not-pay-attention-to-science-or-give-enough-money/noticia/3014014/ (accessed on 1 November 2022)). Developed countries need to adhere to the principle of 'who has more, pays more', because they are and have been the main beneficiaries of recent decades of environmental destruction. Large corporations and multinationals must be made to pay taxes for the volume of destruction created (historical debt) and to redirect their profits toward plans to adapt to and fight climate change. Furthermore, taxes must be directed toward the structures that will otherwise disappear in the post-globalized society that awaits us. International trade and people-to-people exchanges will continue, but their volume will change.
- Social equity: Transition plans that implicitly or explicitly leave some populations behind must be penalized in line with the legal framework described above. To date, there is no international agreement on what to do or how to do it beyond the Paris agreements, which have already become obsolete and have proved unable to reduce emissions.

- Transport: Reduction in air and marine transport and transport in general. This will involve rethinking leisure and tourism: It will be necessary to redesign the current leisure system, which currently serves to create uncritical, distracted, and constantly dissatisfied people, and move toward a different system that serves to stimulate social and human values, empathy, and social cohesion. Analyses of transport [41,42] have shown that in order to have fully renewable transport fleets, some modes of transport (air and sea) must be reduced by half. Trade and economic adjustment plans must, therefore, be designed in accordance with this reduction in the volume of goods and passengers.
- Natural spaces: Preservation and expansion of nature reserves and protected areas. Non-industrialized spaces and natural spaces only weakly affected by anthropogenic activity serve as protection, facilitate adaptation to climate change, and reduce the impact on ecosystems. There is also a need for widespread education in the use and management of protected areas and rural areas.
- Agriculture and water: The uses made of land and agricultural products must change radically, moving toward farming methods that do not make intensive use of fertilizers and pesticides derived from fossil fuels and which are more closely tailored to local needs. The agricultural and livestock sector needs to be transformed to ensure local supply and reduce long-distance exports. In this respect, the current diet (focusing excessively on animal protein [43]) and the demand for luxury agricultural products (e.g., off-season fruit and vegetables) must be reassessed. It is also necessary to evaluate the impacts of climate change on agricultural and livestock production; climate change will render these activities more difficult, creating the need for medium- to long-term action plans, coordinated with land use planning. Still in relation to agriculture, we also need to consider access to and use of water resources, which, in the future, will witness a drastic reduction in availability combined with an increase in demand in order to expand renewable energy. This will be critical to manage situations such as the current heatwave in India (https://www.theguardian.com/world/2022/may/02/pakistan-india-heatwaves-water-electricity-shortages (accessed on 1 June 2022)).

(3) A global awareness campaign to prepare people for transition, in a global push for transparency:

- Global awareness: The action plans devised by governments and civil society must prioritize information on the implications of climate change. Rather than centering prices, such information should focus primarily on physical variables such as emissions and energy, indicating (and reaching consensus on) the basic level of consumption required to adapt to and manage the climate, resources, and the environmental crisis. The COVID-19 pandemic is an example of how we tackle such emergencies: Suddenly, all of the mass media was talking about pandemics at all hours in order to raise awareness, and this was justified on the grounds of the state of emergency and the health crisis. No-one complained about creating panic or alarm. Panic arises when there are no options, when people are not told how to deal with danger in an orderly, collective manner. Therefore, if we do not act sooner, not only will panic be created when the situation worsens, but the chances of management will be severely reduced. Furthermore, if we postpone tackling the current problem and do not explain all of its serious consequences, the lack of trust in those who are supposed to guide and coordinate the necessary collective actions—governments—will increase.
- Propaganda restriction: Ongoing reduction in advertising strategies and marketing of products, lifestyles, or actions that are highly polluting or involve a threat to biodiversity and/or the health of ecosystems. This will entail preventing or penalizing all misinformation strategies and greenwashing initiatives that diverge from or are opposed to adapting to and fighting climate change, ecosystem degradation, and the resource crisis. Moratoriums could be applied with legal penalties if no sufficient actions are applied in time.

All of these measures can have positive feedbacks if applied together or in a coherent sequence. For instance, taking only one measure of each pillar can support the application of the subsequent ones. This is the case, for example, of the propaganda restriction, which will help global awareness, allow better policy implementation, and also impact social equity (in the sense that current advertising is focused on enhancing over-consumption in a highly stratified society with almost no concern about poverty). Transformation of transport implies changes in consumer behavior and need to be supported by the necessary policies. Finally, changes in the agriculture and water uses need also awareness campaigns that can help preserve natural spaces and favor a global political agreement for changing legal frameworks to speed up the process. Thus, the three pillars are the basis under which we can construct the new socio-economic and cultural paradigm for avoiding an uncontrolled change toward the IPCC worst scenarios.

6. Conclusions

Not sending a clear message to policymakers about the dangers of entering undesirable scenarios (SSP2-4.5 and SSP3-7.0) [2–4] can lead to a loss of collective momentum at the international level. As a consequence, all pressure to change will be subject to each individual nation's policies and, thus, to its particular trade-off between short-term interests and mid- to long-term needs. This involves a high risk of rapid, uncontrolled transition or the collapse of our current civilization [17,19]. The model proposed here shows how this uncontrolled transition might behave, and underscores the need to reduce growth (in consumption) and mitigate inequality. We urgently need clear policies capable of mobilizing capital for the investment necessary to transform the current fossil socio-economy into a decarbonized one with low levels of inequality [7,35]. The debate required now in the political arena is how to do this. Currently, the aims are clear, but the time we have is short.

In addition to this necessary debate, more research is needed regarding the consequences of worst-case climate scenarios and how to deal with and adapt to these. First, any interpretation of the IPCC model projections should be used carefully depending on analysis needs, and a series of measures for this has been suggested by Hausfather et al. [1]. In addition to future analyses of projections, a critical view of our current cultural framework is needed. Some simplistic approaches hold fast to the belief that technological development alone has always helped humanity advance (at least in the past century), and, thus, conclude that the current climate crisis can be successfully tackled solely through technology and small social changes. However, such visions must change, along with the necessary adaptations to climate issues. Environmental and energy system scientists and social researchers need to work together to construct a new societal view with values grounded in cooperation, equality, and nature/ecosystem preservation. The challenge now is to ensure a smooth transition from the old paradigm to a new one, in a changing climate and with limited resources.

The contribution of this work lies in three main aspects. First, giving an interdisciplinary approach to find common mechanisms/patterns in different socio-economic systems, in order to show the level and the proximity of a transition toward non-desired scenarios. Second, provide an understanding on how these patterns work together and the implications of addressing the problem with partial solutions. Third, based on the two previous aspects, provide a practical framework based on three pillars that organizes and enhances the necessary process of social and cultural transformation.

The limitations of the work introduced here are related to the uncertainty that a system near a transition state shows. In such a situation, the driving variables chosen to track the system before the transition have less predictive power as the system approaches critical points. This could entail that some identified patterns or processes cannot be functional at some point, and then the suggested measures for avoiding the transition could not be applicable or will have limited effects. Thus, such limitations show that the proposed actions and transformations cannot be delayed further.

Future work should be addressed in the direction of social change and transformation under a system dynamics approach. More research is necessary on the social positive feedbacks and possible triggers to enhance different behavioral patterns that allow a fast decarbonization and also a greater ecosystem protection. Historical perspective on what are the main mechanisms that prompt social collapse is also needed. All in all, research focused on transforming our current consumerism (over-consumption model) to a new socio-economy, more compatible with social justice, environment health, and biodiversity conservation, is necessary.

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Appendix A

Sentences in the SPM WGIII mentioned in this paper.

- B6.4: In such pathways, global cumulative net-negative CO_2 emissions are −380 [−860 to −200] GtCO2 (median and very likely range [5th to 95th percentile]) in the second half of the century, and there is a rapid acceleration of other mitigation efforts across all sectors after 2030. Such overshoot pathways imply increased climate-related risk and are subject to increased feasibility concerns.
- C3. Modeled mitigation strategies to achieve these reductions include transitioning from fossil fuels without CCS to very low- or zero-carbon energy sources, such as renewables or fossil fuels with CCS, demanding side measures and improving efficiency, reducing non-CO_2 emissions, and deploying carbon dioxide removal (CDR) methods to counterbalance residual GHG emissions.
- E4. Many regulatory and economic instruments have already been deployed successfully. Instrument design can help address equity and other objectives. These instruments could support deep emissions reductions and stimulate innovation if scaled up and applied more widely (high confidence).
- E.5.2. Many regulatory and economic instruments have already been deployed successfully. Instrument design can help address equity and other objectives. These instruments could support deep emissions reductions and stimulate innovation if scaled up and applied more widely (high confidence).
- E.6. International cooperation is a critical enabler for achieving ambitious climate change mitigation goals. The UNFCCC, Kyoto Protocol, and Paris Agreement are supporting rising levels of national ambition and encouraging development and implementation of climate policies, although gaps remain. Partnerships, agreements, institutions, and initiatives operating at the sub-global and sectoral levels and engaging multiple actors are emerging, with mixed levels of effectiveness.

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