Navigating Overlapping Climate and Economic Uncertainties in the Transition from Fossil Fuels to Solar Energy

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Abstract: ***This paper explores the intricate interdependence between climate change dynamics and global economic uncertainties, particularly in the ongoing transition from fossil fuels to solar energy. Drawing on theories of complexity and entropy, the author underscores how overlapping uncertainties contribute to systemic instability and demand interdisciplinary adaptation strategies. Emphasis is placed on climate tipping points, nonlinear economic behaviors, and the limitations of conventional models in forecasting. By advocating for data-informed, AI-augmented simulations and rapid innovation, the study proposes that climate adaptation must be reframed as both a scientific and economic imperative. Overlapping is also adding new ways of understanding the underlying physical mechanisms determining the critical dynamics of both climate and economy. Climate scientists believe that Earth's climate is approaching various irreversible tipping points. It is even possible to reach a global tipping point as several tipping points may eventually converge in a single assembly process. Thus, it became imperative to find out just how close they might be. The exact level of warming required to trigger any specific tipping point is not clear. The danger is to have global warming on its road and world energy production on another. That is, to continue the unsustainable trajectory of the global economy. The resolving of the problem lies in the markets and the development of future technologies. Transition from fossil fuels to solar energy is necessarily about business confronting uncertainty in our time.***

Keywords: climate tipping points, economic uncertainty, entropy economics, fossil fuel transition, complexity theory

1. Introduction

It became common to say "we live in an age of increasing complexity" because we live in an instantly present global interconnection where every day we hear about climate extreme events or about accelerating technology and their effects on the global economy. This article seeks to examine how the overlapping uncertainties in climate science and economic systems challenge traditional models of development, and to propose integrative pathways toward adaptation in the context of transitioning to solar energy. While fossil fuels facilitated economic growth, they simultaneously intensified climate warming and forced us to accelerate the use of green energies. The sources of complexity are many and increasing and in general simple to explain using the knowledge accumulated already in science. One such example is revealed by the fact that eliminating sources of air pollution was also hiding another uncertainty of climate change. The strong actions of removing the sulphur dioxide aerosols have saved millions of lives, improved public health and curbed environmental problems like acid rain. Encouraged by early success, policymakers overlooked the atmospheric cooling function of SO_2 aerosols, reflecting sunlight back into space and helping to make clouds denser and whiter, and so more reflective. Recent data show an extra warming generating extreme responses to the removal of aerosol pollution in certain regions *"which have experienced increases in tropical cyclones, the emergence of warm patches of ocean water or more intense heatwaves"* [1]. These changes can only be explained when aerosol pollution trends are added to climate simulations. There is still a great deal of uncertainty about the magnitude of the overall cooling from SO_2. We think firmly that the uncertainties of climate change are certainly reduced if less CO_2 is emitted. But, if aerosol cooling is documented as a strong overall factor in the atmosphere, there will be more warming because fossil fuels tend to be phased out and, as a result, aerosol pollution falls. In fact, this phenomenon as almost all other studies in climate science underscore the importance of multiple consequences induced by anthropogenic activity.

The new problems stemming from this increasing complexity are eventually rooted in the economy. And maybe this complexity is too big to be solved with the existing economic models. That constitutes a strong reason to study the overlapping of the uncertainties in climate and economy and investigate the correlations between the parameters describing the dynamics of natural phenomena and the indicators of economic behavior. In many cases we are confronted with the mingling of chance and change seen from outside of our intentions. In climate science, *"The investigating process is often an iterative cycle of modelling and experimentation, where we face the lack of sufficiently detailed data on dynamic processes and also lack of complete theoretical models to interpret and understand the data available for analysis"* [2].

Can we systematically resolve all the complications, subtleties, and alarming signals occurring in the system? In both cases we have to engage in resolving the immediacy to the consequences of global warming.

A better understanding of the interconnectedness and coexistence could be achieved in the overlapping of the uncertainties which inform that coexistence. Indeed, fundamental problems of global development remain unsolved and the combined efforts of climatologists and physicists, economists and mathematicians and also computational scientists, both theorists and experimentalists, could be of great utility. This investigative complex is better suited to uncover hidden layers of reality because the way nature works seems to be a boundless space of active and dormant interactions. Overlapping is also adding new ways of understanding the underlying physical mechanisms determining the critical dynamics of both climate and economy.

If we consider both the climate change and the economic processes as a whole, as we should in our present world, and analyze them from the viewpoint of physics, both are material and informational. For a long time this was not the case. And even when scientists informed us about this intrinsically powerful correlation, or better say coexistence, the necessity of taking into account and caring for the conviviality between them was ignored. Already in 1970, Nicholas Georgescu Roegen introduced the entropy law into economic science [3]. The available or free energy, which enters the economic process in a state of low entropy, i.e. a higher ordered structure, is under our complete command, while the unavailable or bound energy is in a state of high entropy, i.e. chaotically dissipated in disorder. Economic processes exist only because we bring and use some free energy (low entropy) into a system from outside. The free energy is irrevocably degraded into bound energy. Valuable natural resources (energy and material) are used in the economy and valueless waste is thrown out. And why didn't human society acknowledge that striving through economic growth is necessarily and increasingly tapping the environmental low entropy? I think that Georgescu Roegen gives a clear explanation: *"The true economic output of the economic process is not a material flow of waste*, *but an immaterial flux: the enjoyment of life (*joie de vivre - in french). *If we do not recognize the existence of this flux, we are not in the economic world"* [4]. The prosperity of the abundance economy masked the environmental costs until pollution accumulation revealed its unsustainability. The remedy was conceptually simple, as indicated in 1976 for example, but very complex socially: *"It's then obvious that the future of humanity resides in the possibility of directly using the energy of the sun".* [5]. Here we are, unfortunately 50 years later, in the transition from fossil fuels (energy and pollution) to sun (unlimited energy and no pollution). So late because for a long time conventional economics expressed overwhelmingly the race of economic development, that is, approved and developed the concept of continuous unbounded economy growth while disregarding climate science results. A powerful example of this narrow economic philosophy is that it ignored the scientific results obtained by Syukuro Manabe and Klaus Hasselmann who discovered already in 1967 the CO2 greenhouse effect in the atmosphere. They received the Nobel Prize (for physics) fifty four years later. This illustrates quite clearly the association of immediacy (always existing in the economic decisions) and the sense and direction related to uncertainty, because in this case the uncertainty was actually created and superposed inevitably on the intrinsic natural background of it. It triggered the intensifying dynamics of climate change. We could have created growth and improved the conditions of life in the world for less than the cost of creating the uncertainty of climate change of our time. But, for so many years prudence has been dramatically ignored. Politics, globally, forgot that prudence creates a reservoir for action and lacking it is narrowing the action space. The hardest uncertainty now is the well documented possibility of climate tipping points appearence, defined as ''abrupt climate change'' occurring *''when the climate system is forced to cross some threshold, triggering a transition to a new state at a rate determined by the climate system itself and faster than the cause''* [6].

However, human art is very much alive to adapt our economy and way of life to the present condition of uncertainty. At the very minimum, shaping the disorder it's better than being shaped by it. The effects of climate change are making our world even more unpredictable than ever before. We do need to apply rigor to study unpredictable phenomena. I refer directly to the intimate and complex connectivity between nature, economy and politics. Indeed, fundamental problems of global development remain unsolved and the combined efforts of climatologists and physicists, economists and mathematicians and also computational scientists, both theorists and experimentalists, could be of great utility. In a similar context of unresolved complexity, Roman suggested that *"when the overlapping is realised, the investigation of random ...events has a clearer direction, with a higher degree of confidence (including acceptable, low level of errors). We may reach the assembly phase of the scientific story"* [2].

Climate change, entering a phase of acute and complex emergency, could be also a turning point for the economy science seen from the foundations of thought and of psychology perspective (laid down by Keynes in his tribute after the death of Frank Ramsey) *"in which theory and fact, intuitive imagination and practical judgment, are blended in a manner comfortable to the human intellect "*. Today we advanced more in this psychological perspective: *"Commitments, relationships, values, and convictions, even "the self" as a persisting entity, are a matter not just of how one has acted or is acting but of how one thinks about the future and how one will or would act in various futures"* [7].

Challenged by uncertainties we build theoretical models, both in describing the physics of phenomena as well as the statistical treatment of data and reduce substantially the space of randomness. The significance of this study lies in its attempt to synthesize complex climate and economic uncertainties into a cohesive analytical framework, offering a novel perspective on adaptive strategies for sustainability in the face of unpredictable system behavior.

2. Approach and Framework

Between the zone of certainty beyond all doubt and the zone of incomprehensible uncertainty, the sources of which are nothing but chance, we need to use solid results from a vast interdisciplinarity in our present quest to a predictable road to a global sustainability, both in economy and society. We seek a strategy that aims at more objective knowledge of natural phenomena and also to comprehend better economic behavior, yet it doesn't necessarily provide one more coherent point of view. Climate science and economics use very different approaches except that both need to analyze the largest possible amount of data. But, under the consequences of climate change, there is an objective need to materialize the advances in climate science in both the economic way of thinking and the economics of markets. As mentioned already [2], In climate science, the investigating process is often an iterative cycle of modelling and experimentation, where we face the lack of sufficiently detailed data on dynamic processes and also lack of complete theoretical models to interpret and understand the data available for analysis. The complexity of the climate change - economy global coexistence is primarily reflected in the closely interconnected uncertainties. On one hand we have a theoretical and practical knowledge of the uncertainties manifested in the climate change dynamics, i.e. understanding the physics in the intimacy of real phenomena and developing mathematical models that can predict global warming dynamics as well as the occurrence of extreme climate events. On the other hand, there are new patterns of the global and regional developments of the economy. Similar to an extreme climate event, a critical convergence of initial conditions and interactions may disrupt financial or economic networks.

In climate science itself the overlapping of theoretical modelling of turbulence, which is the main feature and a physical support of fluid flows, and the statistical analyses of extreme climate events is weak and rarely conclusive for practical use [2].

Studying the results obtained in climate science and those in the economics of unpredictable behavior of financial and economic markets show that information about low-likelihood of high-impact events through gathering vast amounts of data related to such events is not enough in order to achieve a credible and useful probability or estimation of the possible consequences. The phenomena studied in the social and behavioral sciences are inherently unpredictable and indeterminate. They display the traits of complex systems. Thus, it is necessary to study the dynamics of the system by simulating its behavior under very small perturbations combined with the theoretical models for improving the knowledge of the inner mechanisms. There are compelling reasons to believe that it is impossible to make accurate, nontrivial predictions concerning human behavior as much as we don't have them in the analysis of extreme climate events. In the interconnection and interaction between them it might be that extreme events or crises could either become more frequent or announce a tipping point. Since we are compelled to study the emergency of the present complexity, this paper aims to enlarge the framework of this study by an attempt to bring together pieces of knowledge accumulated in climate and economy.

3. Climate uncertainties, statistical phenomena and the complexity of economics

Many say today, in economy and politics, "the uncertainty is here to stay". A majority of them don't properly acknowledge that in fact uncertainty is a non-ephemeral reality. Uncertainty is a constituent in the intimacy of nature and society. Uncertainty is also created by human (political or economic) decisions, generally a non-intended result but mostly from arbitrary ones. I advance the idea that probably today the most important central theme in the way of life, and in particular in the economy, is uncertainty. In the reasoned great board of the Universe never forget the uncertainty if you want to fight successfully the imprecision. As Epictetus said : *"Don't put your purpose in one place and expect to see progress made somewhere else"* [8]. The causes of random events in nature are physically determined, but so numerous and complex that they only have provisional truths. One example of global importance is the Atlantic Meridional Overturning Circulation (AMOC) which is part of a system of currents which move heat (a power of more than 1000 Terawatts) around the oceans of the world, which is paradoxically a very delicate element of Earth. As we register a continuous trend of increasing ocean-surface temperature and salinity caused by global warming, simulations of the agency making AMOC current show that it could be stalled. The consequences are so bad - for Europe that could mean a sudden, severe cooling, even as the rest of the world keeps warming - that AMOC could be the most dangerous tipping point within the several others under scientific investigation right now. And since the system is unpredictable we don't know the level of uncertainty about how far away the threshold actually is. Stories like this one offer a good example of how climate science often works at the cutting edge of knowledge advancement. Many assumptions about the nature of the uncertainties may work for a number of case studies but could be significantly wrong in other cases. Disregarding the uncertainties comes eventually to treat the symptoms not the causes. Unpredictability, essentially expressed through risk, uncertainty and complexity, forces us to simulate actively, including through virtual slight modifications of the registered real situations of extreme events, and find practical, imperative tools of the adaptation to climate change. Indeed, we are confronted with a new human landscape. It's that some anomalies become the new normal. Let's keep in mind that uncertainty is the great enemy of action. Many issues in logic today are no longer about central notions like truth or proof, but rather about processes of verification, argumentation, communication or general interaction and interdisciplinarity. Human knowledge itself is not certain. We can have only provisional truths. Therefore, we must manage to reach a state of accommodation with uncertainty and unpredictability: *"We have, on the one hand, life experience taken over and assimilated in society and, on the other hand, experience gained from daily real life. That is also why our action is meant to build resilience to deal better with unpredictable events"* [9].

The global economy, like the climate, is less stable than we expect – and that should be also a source of opportunity. Part of the problem is that we've thought about policy on climate change using old economic ideas, such as equilibrium. This means that the economy is balanced because supply and demand in the market are equal to each other. But this is at best a sufficient approximation of reality in very simple cases. They are useful for certain purposes but cannot solve many other real problems. Acknowledging the complexity of our world, more evident due to our present capacity to detect larger and more deep rooted interconnections, we should treat the economy as a complex system. Making accurate predictions is extremely difficult with standard economic approaches that fail too often to be trusted as purely mathematical results. New approaches are necessary because the existing ones, applied indiscriminately to all kinds of situations, are a waste if not a cause of grave wrong decisions. In situations of high complexity it is, in fact, hard to decide what is known and what is not and it is harder to decide what is significant and what could be considered as negligible while preserving the basic characteristics of the system. The concept of "complexity economics" seems to be promising since it "*recognizes that economies have quite a lot in common with other complex systems, such as ecosystems, biological evolution or even Earth's atmosphere"* [10]. The complexity of today's economy should and could be better apprehended by adopting the concept of complex adaptive systems that are fundamentally open to their environments, exchanging information with external sources and allowing for the entrance of new agents and the construction of new relationships. In complex systems we observe that the high density of inter-connections between their parts make possible self-organizing and self-reproducing structures, generating emergent properties that are more than the sum of their parts. In the traditional social-scientific linear models predictions are useful but reflect poorly the real dynamics. The behavior of physical as well as social reality display features of complex non-linear systems and in this case the long-term predictions are impossible.

Efforts have been made in quantum physics to establish a generalized uncertainty theory, a mathematical theory of incompleteness or lack of information, or lack of specificity, or imprecision devoted to handling incomplete information. I mention it here because a close analogy between the theory of turbulence in fluid flows - the main feature of extreme climate events- and the quantum theory of fields seems very attractive [2].

Time, memory and data, perception and expectation, are subject to the imprecision implied by the action of random factors. We are finding solutions every day using powerful algorithms to treat random sequences provided that these sequences are chaotic and also *typical* (i.e. having the property of the stability of frequencies), meaning that they *"belong to any reasonable majority. In choosing some object at random, we have confidence in the fact that this object will fall precisely in such a majority"* [11]. There's a need for very timely information and everybody wants it to be as accurate as possible, but the more timely it is, the less certainty we have on the estimates. Obtaining a reliable result or estimate in physical sciences is expensive, while in economics it is much cheaper (although the statistical collection of data is not cheap) but less reliable. And to have a reasonable idea about how much uncertainty we have around the estimated values and to track changes in the longer run remain of paramount importance. The great global goal of net-zero carbon has to include a major project on this data collection (new and old) in spite of the inevitable statistical noise around it. Essentially, economics and finance are not branches of pure mathematics - meaning the phenomena are described with mathematical equations which become solvable if the system is in equilibrium - but practical fields of knowledge. In the economy, we never have a stable equilibrium. As a result, providing reliable predictions is quasi impossible. We can and have to perform *"detailed examination of the data, and of the methods of collection, to determine what information they are fit to give, and how they should be improved to give more or other information"* [12] and acknowledge Gosset's suggestion that *" the only valid reason for rejecting a statistical hypothesis is that some alternative explains the observed events with a greater degree of probability"* [ibidem [12], pag.19]. But few econometrics textbooks make the distinction between statistical and economic significance. *"A significant finding is by itself "nearly valueless": obviously the important thing is to have a low real error, not to have a "significant" result at a particular station. Experiments at a single station [that is, tests of statistical significance on a single set of data] are almost valueless. . .. What you really want is a low real error."* [13]. Of course, the underlying statistical model used in economics should describe the data reasonably well. On the theoretical approach side, from the explanatory point of view , Doyne Farmer (author of *"Making Sense of Chaos"*) stated that: *"the psychological explanation of the divergence between economic prediction and reality has to be considered strongly"* [10]. We have to ensure that all relevant explanatory variables have been properly accounted for. In particular, we should be well aware that in complex systems, either in economy or in natural climate, the behavior is non-linear, prone to bifurcations and eventually chaos. The real world is indeed very complicated and disordered and our search is for a pattern that eliminates some of the chaos. Eliminating some factors as non-significant for the statistical sample should in itself be based on specific analysis in each case. Basically, the process of collection and use of data is to decide when an estimated model is adequate on statistical grounds. Kolmogorov, founder of the theory of probability, did not think that every event has a probability: *"Certainly not every event whose occurrence is not uniquely determined under given conditions has a definite probability under these conditions. The assumption that a definite probability (i.e. a completely defined fraction of the number of occurrences of an event if the conditions are repeated a large number of times} in fact exists for a given event under given conditions is a* hypothesis *which must be verified in each individual case"* [14].

High probability predictions cannot be considered as practically certain in all cases and also, very small probability doesn't automatically mean that the event will not happen in the statistical phenomena (which are a source of probability). Kolmogorov replaced the equally likely cases concept with frequency which is a fundamental tool in climate predictions, keeping the essential link with reality. The article on *Probability* published by Kolmogorov in the *Encyclopedia* [14], is all the more instructive since its content was meant to be read by lay people with no special mathematical education. People will never stop to want to know that there is some meaning and purpose in the world around us. As stated by Noson Yanofsky, a student of Kolmogorov, *"We abhor randomness and love patterns"* [15].

To get rid of the noise in the economy we use the smoothing out of available data and make an estimate of the average. In climate science predictions are made with similar statistical analysis but they say too little about the extreme events, the turning or tipping points. The risk is also that we may predict many more turning points than we actually have. And that is closely related in complex systems to the compelling factor of the sensitivity to the initial conditions. In order to not overreact during the average times that we tend erroneously to consider normal, we have to assiduously work around the tipping points. Climate changes are pushing us to reconsider more and more if the old extremes are not the new normal. In the end, of course, the first decisive matter is if the amount of available data is large enough for the reality and the predictive simulation of it to be in fair agreement. Which means also to take advantage of the new sources of digitized information, like accurate or quality virtual simulation of extreme events. The quantitative predictions of hazards, by far the most difficult to make, necessarily are not enough. Indeed, it is crucially important to achieve a high degree of confidence in our conclusions, if we consider them as conclusions; otherwise, we risk a lot to hand over the cause (of a phenomenon) to processes we don't understand or control. In nature, the occurrence of extreme events, like floods, heat waves, hurricanes or tornadoes, could be the result of an unrepeatable chain of events and cascade of contingencies. The true essence of the language of nature is that nature never stops speaking to us through the changes, small or big, slow or rapid, that we observe and register with our sophisticated devices or simply with our senses. What we get from facts and data is hugely important yet rarely enough. The solving of them, like solving a puzzle, is the real problem, which imply multifaceted cases. Allow me to call it a "polynomial puzzle". Such a puzzle could be resolved by overlapping the causes, or even better, the methods used to simulate the causes. The adaptation to climate change in economy and business is such a puzzle. Moreover, we don't know if the adopted solution in such a complex system is the best one. Noson Yanofsky (professor of Computer Science), explained that *"Kolmogorov's complexity theory teaches us that, at the deepest level, there is no sure way to determine the best pattern. We will simply never know if the pattern that we have found is the best one"* [15].

4. Climate tipping points and the related change in economic expectations

The nature of the climate threat inevitably includes critical thresholds (tipping points in the American terminology). Climate optimists believe that nature's resilience is (almost) unbreakable and, as a consequence, the damages inflicted to the natural environment by human activities are very limited. Their optimism is based on their impression that the damages are gradual and very often are also invisible. But, the moment of truth, unpredictable, can appear in the form of a drastic change, when a critical threshold is reached. My experience in this field [16] has shown the dynamics leading to a critical threshold in the case of the water quality of the Danube River in a period of ten years (1975-1985): *"The Danube has resisted "heroically" the assaults of the massive pollution inflicted by the big European cities (Vienna, Bratislava, Budapest, Belgrade) until its capacity of self-purification was doomed".*

Today climate scientists believe that Earth's climate is approaching various irreversible tipping points. I would add that it is even possible to reach a global tipping point as several tipping points may eventually converge in a single assembly process. Thus, it became imperative to find out just how close they might be. The exact level of warming required to trigger any specific tipping point is not clear. Some essential questions remain under investigation: *"What are the potential policy relevant tipping elements of the Earth system? And for each: What is the mechanism of tipping?"* [17]. These questions are not yet answered because the Earth's climate is governed by a great number of and various interconnected processes, many of which - like the dynamics governing the melting of the ice glaciers in the Arctic and Greenland, or the potentially cooling effects of the aerosols - are under unknown or little known consequences of natural (physical) uncertainties. Others, such as the formation of light-reflecting clouds, occur at scales too small to be properly incorporated into planetary models. *"To further complicate things, one tipping point can trigger another, domino-style"* [17].

As we are approaching various climate tipping points or worse, a global tipping point, hopefully not an inevitable truth, allow me to recall the Yeats' poem *The Coming of the Wisdom with Time: "Though leaves are many, the root is one; Through all the lying days of my youth / I swayed my leaves and flowers in the sun; Now I may wither into the truth"* [18].

Uncertainty, indeterminacy, randomness and contradictions appear, not as non-essential substances of debate to be eliminated by explanation, but as everlasting ingredients of our conception. There are compelling reasons to believe that it is impossible to make accurate, non-trivial predictions concerning human behavior. Certainly the economy is also speaking to us and, although we listen sometimes carefully to its signals, we fall, it seems inevitably, in their uncertainty traps. In many cases like these, statistically significant average bands based on the entire time-series of a certain natural phenomenon or a market fluctuation always show an essentially unpredictable event. The balance of risks in this case is severely damaged. In economic theory, the father of the fractal theory, Benoit Mandelbrot, already in 1967 indicated that the average values of small fluctuations in the stock market *"clearly say nothing about the rare big changes which make the great fortunes and the great ruins"* [19]. That's why, probably, there is no general law or an absolute statistical distribution model of the dynamics of stock markets or interest rates. In the context of statistical modelling commonly used in physics to be applied systematically in social sciences, Mandelbrot warned that *"For a science to be utilized as a prediction system it is indeed obviously necessary that small changes in the initial data will lead to small changes in the predictions - less in a small number of cases called critical points… The danger in this case is that we don't take into consideration enough the experiences concluding in failure"* [19].

Uncertainty is not necessarily the result of randomness; it is also lack of knowledge or lack of understanding [20]. That demands a sense of "feeling" the things before jumping to adopt and set a new stage or development of a business or a sophisticated system of interconnected businesses like tech and AI, armament and military logistics, welfare and marketing, health services and new medical devices, legal, agribusiness, shipping, education. Business is always business. But maybe we need a new organisation in human history. I prefer to quote here Paul Krugman [21], not without some sense of bitter fatality: *"My read of economic and financial history is that market pricing almost never takes into account the possibility of huge, disruptive events, even when the strong possibility of such events should be obvious. The usual pattern, instead, is one of market complacency until the last possible moment. That is, markets act as if everything is normal until it's blindingly obvious that it isn't".* John Maynard Keynes said something similar in Chapter 12 of his General Theory of Employment, Interest and Money. Market investors, he argued, pay little attention to the question of what assets are truly worth. Instead, they worry mostly about the market value of those assets a few months in the future. Markets, he insists, are less information processors than conventional wisdom processors. A good example of how to manage such situations is the statement made by Jerome Powell, the FED chairman, on the 22nd of August this year: *"Downside risks to employment are increasing. And if these risks materialize, they could do so quickly, in the form of a dramatic increase in layoffs and rising unemployment ... In the short term the risks of inflation are on the rise and those of employment are downward which is a challenging situation".*

Unpredictability forces us to use more imagination and creative thinking. Indeed, we are confronted with a new human landscape. It's that some anomalies become the new normal. Uncertainty remains one of the greatest obstacles to decisive action. In that sense many issues in logic today are no longer about central notions like truth or proof, but rather about processes of verification, argumentation, communication or general interaction and interdisciplinarity. Human knowledge itself is not certain. We can have only provisional truths. Therefore we must manage to reach a state of accommodation with uncertainty and unpredictability.

Theory and practice of economy is not essentially just analytics and predictive models; it is also about expectations, as a matter of fact. In the field of climate science the a priori, the necessary, and the analytic are coextensive. Philosophers consider that a necessary proposition must be analytic because otherwise we could imagine its being false. And an analytic proposition is commonly agreed to be a priori and apriority implies necessary. In the field of economics we could use, in the above mentioned framework, the concept of expectation as a very central one for the explanation of real-life behavioral phenomena as shown by psychology studies. We clearly know that expectations guide economic decisions. This is about many things: the decision-maker's assessment, the state of the economy, the political climate, the social environment, the nerves (Keynes wrote about that), the reactions of potential investors. As much as there is no profit without uncertainty, there is no economy without expectations trying to beat the uncertainties.

Expectation is not something next to inevitable. Essentially it is about how people act/behave now or will. From where do we derive our expectations? It doesn't matter that you wished something in the past; it matters that you wish that thing now. Like, metaphorically speaking, "the past praying for now". Triggered by a chance, sometimes we may develop our own expectations.

Expectations are part of a mental simulation which makes us more confident to envisage various futures and to imagine responses to them before they happen. Indeed, expectations express the inner freedom of people. People simply expect that all things will be at the right place, settled as known. Commonly they start their thinking supposing that the coming future does depend on their deliberation and action. This is at the core of human action, say the psychologists. Forecasting requires that humans gather a lot of information from various sources, weighing which sources to trust and how to resolve all these pieces believed to be knowledge. And today this process is much easier and quicker using Large Language Models (LLM).

Expectations and the state of confidence are especially important (again it's Keynes' opinion) in restraining a recession or promoting a recovery. But we must also take into account another essential and general feature: the competitive nature of interactions. Coevolution pushes towards stability, competition towards instability. They coexist. And we cannot ignore random fluctuations. "*Never bet on the stability of expectations either about inflation or employment"* would be a conclusion of long-term statistics. "*An emphasis on expectations is an emphasis on the uncertainty of decision-making, the frequency of mistakes, the need for time to adjust to unanticipated events and the disorder of economic systems. None of these are captured in the world of equilibrium analysis"* wrote Paul Heyne [22], who explained economics from the very practical side of the economy. The rational expectations process is based upon the available information, which is sufficient and of a good quality near the economic equilibrium. But when there is no available information about other potential situations of equilibrium, the understanding of the occurrence of a crisis is not compatible with rational expectations. For example, Heyne stressed in 1982 that: "*Particularly troubling is our inability to predict how much time it will take for a fiscal or monetary policy action to have its effects"* [ibidem [22], pag.444]. In our time this is also speaking about the deterioration of confidence related to regulatory and oversight institutions not showing themselves capable of solving the problems of the banking system.

The growth path of a given economy also depends on the institutional arrangement and we see today, probably more than 20-30 years ago, that markets and institutions cannot deliver equilibrium situations: *"if there is a huge institutional mistake, future uncertainty can no longer be managed, economic agents become conservative. Economic agents drastically reduce their transactions related to the future, and the economy enters a major crisis. Markets manage risk probability well; but they cannot manage uncertainty by themselves when the institutional arrangement makes a huge mistake"* [23]. This statement is certainly valid in view of the global response to global warming.

Simulation in social science, made much stronger through the use of LLM, is more capable of understanding how past experience/information may influence the thinking about possible futures. In our case we consider some strong evidence from climate science and also from ecology. Running on LLM is actually part of the scientific process.

5. The transition to sun and the markets

Climate change is a problem where complexity economics can have a big influence. As much as we are worried about the critical threshold in climate change as much we can imagine that a series of stages of climate related global economy leads to a "complexity threshold" meaning that above this we would see things or situations that are products of climate and life itself. Under the impact of climate change the economy is augmenting if not even maximizing the things that exist. And all these new objects are incredibly more efficient than the existing ones. We're going through transitions in our energy systems and food systems that are going to happen very quickly and are going to profoundly change the way we do things. While these are happening, we will be far from equilibrium, and standard economic approaches will be of limited value. The goal is to make a more just transition as rapidly as possible. *"Climate change is a great business opportunity rather than a worrying issue of great concern"* [10]. This ambivalence is well expressed adopting the Solomon Marcus (famous for his *Poetica Matematica*) idea that tangible existence and the intelligible are two different things: *"We are simultaneously in front of the "gates of the unknown" and the "threshold of the inexpressible"* [24].

My view is that the transition from fossil fuels to sun is necessarily about business confronting uncertainty in our time. This adaptation is not about too-muchness as they say, but too-littleness. That is, constantly trying to update what we are doing. In our time adaptation has to be rapid, rather a matter of weeks than months. Unfortunately but not unexpectedly arbitrary extreme uncertainty was added these days, inflicting on the economy. Ahir, Furceri and Bloom find that increases in uncertainty tend to be followed by *"significant declines in output"* [25]. A crucial importance acquires the process of approximation as a process of modelling the surrounding world. Theoretical models of natural phenomena and increasingly also in social sciences and climate science suffer from a lack of data on the basic parameters. Predictions of extreme natural events, including scenarios of events that have never occured, based on AI using huge amounts of data are becoming more efficient both in terms of the results and energy consumption. This is not climate science; it's statistics used to uncover patterns in climate change. But in our era this is a vast opportunity for building customized models in various fields like renewable energy, transportation, logistic and insurance companies as well as urban planning. Concepts are free to fly but concepts without approximation yield nothing that could stay in the realm of big business just as it is in science. So often we don't take crucial steps in the development of a great business in circumstances of our own choosing, but in circumstances created by accidents. The new message is that the chance of a coincidence rises quickly as the number of opportunities increases. Just an example. Investment spending is so important, but let's remember: it is an unstable force. To overcome such situations there is one tool: powerful models capable of simulating with sufficient accuracy real phenomena. Because of this and also because we have today the formidable force of analysis and calculation developed by AI, the demand for inference - the process of running financial models to evaluate risk in real time - is growing exponentially. Indeed, this is the *phase change*, from an era when humans explicitly programmed computers to perform tasks to one in which artificially intelligent systems could learn, infer, adapt, create and improve autonomously. And now every few months, they get better. A.I. models are not only getting better at understanding what we want; they are also getting better at scheming against us, pursuing hidden goals that could be at odds with our own survival.

Transition from fossil fuels to sun is necessarily about business confronting uncertainty in our time. The world is still running vastly on fossil fuels. The investment by banks offered to the big oil companies is over 5 trillion $, including the construction of pipelines and gas terminals. The technological energy transition is very much present in political debates and vast amounts of money are devoted to this purpose. Yet, we continue to burn more coal and more wood than before [26]. Uncertainty remains one of the greatest obstacles to decisive action. With the advent of the Trump presidency, the road ahead could be just a bifurcation and a chaotic outcome: global warming on its road and world energy production on another. And also the quasi parallel roads of fossil fuel and sun. That is, to continue the unsustainable trajectory of the global economy. The resolving of the problem lies in the markets and the development of future technologies. We cannot project green and clean futures ignoring that there are dozens of trillions of dollars incorporated in assets in the world markets. We already demonstrated that there are ways to avoid climate breakdowns through technological developments. Their transformation in exceptionally valuable economic tools is already a fact in some cases and this trend can be stimulated politically and morally. The emergence of a new form of capitalism, may be behind these shifts: "*On one side of the equation, firms are better than ever at dealing with shocks, meaning markets continue to function even at a time when politics breaks down. On the other side, governments offer their economies unprecedented levels of protection*" [27].

In 2022, solar power capacity surpassed 1 terawatt for the first time. Just two years later, it had doubled, generating 7 per cent of the world's electricity. When you include wind turbines (which also capture the sun's energy), the sun generated 15 per cent of Earth's electricity in 2024. The real reason solar power is taking off is because it has become the cheapest way of generating electricity almost everywhere. An energy transition led by solar power should become inevitable because the reduction in emissions might not happen fast enough to avoid the climate tipping points. We can even imagine the possibility of a second explosion of economic growth: *"If computing power brings about technological advances without human input, and enough of the pay-off is reinvested in building still more powerful machines, wealth could accumulate at unprecedented speed"* [27].

6. Conclusions

Of course, the world is entering in one of the greatest transitions in its history. It is about a sustainable global economy. What does sustainable development mean at present times? My definition is to reach net-zero carbon before a critical threshold of climate change occurs. Given the large uncertainty that remains about tipping elements, there is an urgent need to improve our understanding of the underlying physical mechanisms determining their behavior, so that policy makers are able ‘‘to avoid the unmanageable, and to manage the unavoidable’’. Transition from fossil fuels to sun is necessarily about business confronting uncertainty in our time. The world is still running vastly on fossil fuels. But also the accelerating development of the technological energy transition, very much present in political debates, and the vast amounts of money devoted to this purpose. This dilemma should be solved practically instead of indulging the inevitability of the two path way of energy production. The road ahead could be just a bifurcation and a chaotic outcome: global warming on its road and world energy production on another. That is, to continue the unsustainable trajectory of the global economy. The resolving of the problem lies in the markets and the development of future technologies. Can we systematically resolve all the complications, subtleties, and alarming signals occurring in the system? I think we could achieve a better understanding of the interconnectedness and coexistence in the overlapping of the uncertainties which inform the coexistence of climate change and the economy. Overlapping is also adding new ways of understanding the mechanisms determining the critical dynamics of both climate and economy. Business should be intimately associated with this goal. What kind of business environment would be one in which trust is related to uncertainty as a rule?

The world is or will be capable of stopping the perilous path towards a climate change tipping point, that is, before it is blatantly unsustainable. Before the End starts. In these unknown climate conditions I think there is more that unites us than divides us.
The transition from fossil fuels to solar energy introduces complex, overlapping uncertainties that challenge both economic theory and environmental policy. This paper has highlighted the entropic parallels between climate systems and market dynamics, emphasizing the need for interdisciplinary frameworks and advanced simulation tools. By treating adaptation as a dynamic business opportunity rather than a reactive burden, policymakers and industry leaders can foster more resilient responses to climate tipping points. A coordinated focus on innovation, institutional trust, and data transparency will be crucial in navigating this epochal shift.

References

[1] Bjørn Hallvard Samset, Laura J. Wilcox, The cleanup of air pollution in East Asia has accelerated global warming, Nature Communications Earth and Environment, 14 July 2025
[2] Petre Roman, On the Unreasonable Weak Effectiveness in Overlapping the Turbulent Flow Theoretical Models and the Prediction Models of Extreme Weather Events, American Journal of Modern Physics, Volume 14, Issue 4, 2025, pp.167-185
[3] Nicholas Georgescu Roegen, The Entropy Law and the Economic Process, Harvard University Press, Cambridge Massachusetts, 1971
[4] Nicholas Georgescu Roegen, The Entropy Law and the Economic Problem, Vanderbilt University, 1970, part IV, pag.7
[5] Nicholas Georgescu Roegen, comments in “ Sadi Carnot et l’essor de la thermodynamique”, CERN, Table Ronde, Ecole Polytechnique, Paris, 11-13 June 1976, pp. 349-355
[6] Timothy M. Lenton, Hermann Held, Elmar Kriegler, Jim W. Hall, Wolfgang Lucht, Stefan Rahmstorf, Hans Joachim Schellnhuber, Tipping elements in the Earth’s climate system, National Academy of Sciences of USA, PNAS, February 12, 2008 vol. 105 no. 6, pp. 1786-1793
[7] Martin E. P. Seligman, Peter Railton, Roy F. Baumeister, Chandra Sripada, Navigating Into the Future or Driven by the Past, Perspectives on Psychological Science, 2013, 8/2/pp.119-141
[8] Epictetus, Whatever is Rational is Tolerable, Penguin Classics, 2008, pag.17
[9] Petre Roman, Interdisciplinarity as a Tool to the Understanding of Global Behavior Under Uncertainty in Science and Society, International Journal of Philosophy. Vol. 11, No. 2, 2023, pp. 32-45. doi: 10.11648/j.ijp.20231102.14
[10] New Scientist, interview with J.Doyne Farmer, 20 April 2024
[11] A. N. Kolmogorov, V.A.Uspensky, Algorithms and Randomness, Theory Probability Appl., vol. 32, No.3, 1986, pp.389-395
[12] Letter of R.A.Fischer to W.S.Gosset, June 1927, in E.L.Lehmann, Student” and small-sample theory, Statist. Sci. 14, 1999, pag.15
[13] Fisher, R.A., The Arrangement of Field Experiments, Journal of the Ministry of Agriculture of Great Britain, 1926, 33, pp. 503-513
[14] A.N.Kolmogorov, Probability, Great Soviet Encyclopedia, 1951
[15] Noson S, Yanofsky, Kolmogorov Complexity and our Search for meaning, Nautilus newsletter, August 2, 2018
[16] Petre Roman, The Unpredictable Critical Threshold in COVID-19 Pandemic and Climate Change, International Journal of Environmental Monitoring and Analysis, Vol.9, No.4, 2021, pp.104-108, doi: 10.11648/j.ijema.20210904.12
[17] Timothy M. Lenton, Hermann Held, Hans Joachim Schellnhuber, Tipping elements in the Earth's climate system, PNAS, February 12, 2008, 105 (6), pp. 1786-1793, doi.org/10.1073/pnas.0705414105
[18] W. B. Yeats, Sailing to Byzantium, Penguin Classics, 2005, pag.20
[19] Benoit Mandelbrot, Sur l'épistémologie du hasard dans les sciences sociales - Invariance des lois et vérification des prédictions, in volume Logique et connaissance scientifique, Encyclopédie de la Pléiade, 1967, pp. 1097-1115
[20] K. J. Beven, Facets of uncertainty: epistemic uncertainty, non-stationarity, likelihood, hypothesis testing, and communication, Hydrological Sciences Journal, vol. 61, 2016, pp. 1652-1665
[21] Paul Krugman in Conversation with Barry Eichengreen - Crises, the dollar and more, 30 August 2025
[22] Paul Heyne, The Economic Way of Thinking, Mac Millan/Collier, 1987, pag. 424

[23] Carlos Federico Obregón Díaz, Today 's Problems in The Minds of The Great Economists, MPRA paper, no. 1224642021, 29 July 2021, pag.167)
[24] Solomon Marcus, The Loneliness of the Mathematician, Reception speech, Academy of Sciences of Romania, 2008
[25] Hites Ahir, Nicholas Bloom, Davide Furceri, Uncertainty about Uncertainty, IMF, F&D, September 2025]
[26] Ezra Klein, Derek Thompson, Abundance, Avid Reader, 2025, pag.24
[27] The Economist, War, geopolitics, energy crisis: how the economy evades every disaster, 15 July 2025