



Atmospheric Pollutant Emissions and Hydrological Data with Anthropocene Elements: Critical Theory and Technologies of Balance in the Climate–Economy–Society Axis [†]

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Abstract

The topic proposal concerns the axes of climate operation and modification, the consequences and/or benefits of the flow of the economy, as well as the risks to social security, amidst the evolution of human interventions, which the Anthropocene highlights. Atmospheric data demonstrates the interaction of gaseous pollutants and aerosols, with the contribution of different emission and pollution sources to its chemical composition. At the same time, satellite remote sensing of precipitation and the water cycle reveal an imbalance in components and effects, in an environment of rapid rates of commercial production and human mobility in the developed world. How does mobility prevent the full observation and modeling of the elements involved (in atmospheric and hydrological data)? What is the role of multi-sensor technologies for detecting gases and what are their applications in decontamination? With sources from bibliographic reviews, data were collected from the detection of point sources of gases and dynamic analyses of the extent of the water surface, in order to highlight the descriptive characteristics of the meteorological phenomena and their activity. The scientific approach to analyzing the individual data is based on the techno-scientific Actor-Network Theory, in order to test their connection and contribution to the overall problematic result. The aim of this study is to build an interdisciplinary analysis with documentation of vulnerabilities in the expression of weather phenomena, of the present geological time. The ambition of the study is to propose principles of regulation and precaution, related to the sustainable development of geo-resources and ways to reduce vulnerability.

Keywords: gaseous pollutants; solar radiation modification; water resources management; geoenvironmental technologies



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1. Introduction

According to prevailing approaches, we are in the geological time of the Holocene. The International Union of Geological Sciences [1] announced that geologists rejected the name of the Anthropocene, through a series of votes. However, in the hypothesis, the name “Anthropocene” indicates a historicity of human interventions in Earth and climate; in this study, atmospheric and hydrological data were sought, in order to create a picture of the

extent of human climatic interventions, the processes, and the results they bring, on the expression and evolution of the phenomena.

The increase in atmospheric temperature due to the trapping of infrared radiation, due to the emission of gases, is a complex phenomenon, which includes multiple mechanisms. Some responsible gases have a short lifetime (~12 years) and some, considerably longer (100+ years). Methane (CH_4) is found in the atmosphere as a short-lived pollutant which absorbs solar radiation, accelerating the melting of ice. Hydrologically, it causes rapid changes in precipitation and, during its oxidation, is also converted into carbon dioxide. Carbon dioxide (CO_2) as a component is considered a long-term pollutant since it remains in the atmosphere, gradually accumulating its thermal effect, despite its lower direct harmfulness-per-unit compared to methane. The aforementioned parallelism aims to highlight different needs for addressing the harmful components of the atmosphere. Short-lived but potent pollutants require immediate improvement interventions; for similar long-lived ones, their international and coordinated reduction could be a strategic survival option.

Considering that 90% of the released amount of atmospheric heat is absorbed by the oceans, one understands how biophysical systems are connected and interact. On this basis, the present study wanted to examine how biophysical systems and their social counterparts are connected to cultural trends, specifically with the habits that determine an upgraded social standard of living. Continuing, what does the ability of the above correlation, which deals with the uncertainty and disturbances of the present ecological system, bring to the surface? How does the economic factor become involve and determine the basic use of materials as its driving resources? How are resources channeled from the economy to social groups as economic benefits? Evidence of the sustainability of ecological–economical–social systems in the current geological time will follow and will be based on the belief that techno-scientific achievements (and their applications) are evaluated in relation to their influential role in human and non-human aggregates. The aim is to highlight how the aforementioned distinct aggregates could succeed with synchronized actions in challenges, amidst a period of critical climate decisions.

2. Gas Emissions—Human Intervention

Global measurements from space combined with large-scale computer models demonstrate climate evolution data that have no previous historical analogs for the state of the Earth-atmosphere system. Considering that the observation of the atmosphere is the central feature on which climate simulations can ultimately be validated, one understands that its material composition is of crucial importance. Its material composition is directly related to global temperature. According to the Reynolds–Eulerian stress-dispersion models, which study the effect of gas masses on atmospheric dynamics, a flow decomposition is observed in the general atmospheric circulation, thus setting the stage for baroclinic instability. Since the materials of the atmosphere affect global temperature and the aforementioned baroclinic instability is critical for the circulation of this heat and therefore for the creation of weather systems, one understands that based on measurement data, the worsening of extreme weather phenomena is a very likely scenario. Data from studies over decades have shown an imbalance in relation to the materials of gas emissions and instability in the heat flow that they produce within the atmosphere.

In the exhibition “Reflecting Sunlight” [2] the National Academies of Sciences, Engineering and Medicine of the United States report that solar geoengineering could reduce surface temperatures and potentially mitigate some of the risks of climate change. The proposed solar geoengineering is the injection of aerosols into the stratosphere. This is a process that uses a tethered balloon to place sulfate aerosols in the stratosphere. In this way, a cooling effect is created by reducing incoming solar radiation [3] However, the

geoengineering of solar radiation modification through aerosols to reflect sunlight back into the stratosphere can affect atmospheric dynamics and, together with it, the wind cycle. In addition, in the event of uneven cooling, it can cool the tropics more, changing the temperature difference between the equator and the poles. This affects the arrangement of atmospheric circulation cells, which determine the prevailing winds and their properties. Depending on the Solar Strategy Radiation Modification (hereinafter SRM), there may be changes in the location and extent of tropical cyclones. As winds are critical to the movement of ocean currents, a change in their strength or direction can affect the temperature distribution in the oceans, with consequences on the climate. SRM applications are a controversial choice with unbalanced and unpredictably influential impacts on the climate and on the livelihoods of social groups. The consequences of SRM include the following:

- **Spatial Heterogeneity:** They can create supercooling in some areas while others suffer increased drought or flooding due to shifted precipitation patterns.
- **Effect on the Stratospheric Ozone Layer:** Aerosols can slow down the reconstitution of ozone over the poles.
- **Modeling Uncertainty:** Climate models show that impacts depend on the amount and distribution of aerosols. An injection of SO_2 at the equator may have different impacts than the corresponding one at high latitudes.
- **Spatial Inequality:** The use of SRM can benefit some areas, by reducing temperatures in overheated zones, while harming others, through the collapse of monsoons.

Based on the previous reports, reasonable questions arise. Who decides where and how an SRM will be implemented? Can a technology of this magnitude of results be used unilaterally? In relation to the cultivation of a culture of reducing emissions of pollutants, how do exclusively technocratic solutions reflect? If the dependence of climate “remediation” concerns the applications of these and similar solutions, what happens in the event of a sudden technical failure or political decision? Finally, as for the morally responsible part of the process, what happens if the impact proves to be worse than predicted? The multitude of questions were created, considering that the conditions of planetary and scientific life are characterized by uncertainty, which is a fact that is also reinforced by the environmental data of the fluidity of human and productive activity.

3. Solar Radiation Management and Hydrological Data

Solar radiation management services to correct atmospheric behavior, including stratospheric aerosol injection, also affect terrestrial hydrological components. They affect the water cycle, sublimation, quality and management of reserves, in ways that can be profoundly disruptive.

Regarding the water cycle, aerosol injections can cause a change in rainfall patterns in tropical regions, due to the reduction in the land–ocean thermal difference [4] Tropospheric cooling can also shift precipitation zones to mid-latitudes (e.g., Europe) while reducing them in other areas (e.g., the Amazon). In addition, using SRM, there is a possibility of causing a decrease in evaporation due to cooling. As they can and do reduce surface temperature, less water will evaporate from oceans and lands. This can lead to drought in rural areas. Regarding water pollution from sulfate aerosols (SO_4^{2-}) that fall with rain, these have the potential to acidify water systems, affecting freshwater and wetlands. Additionally, there is a potential for toxic metal leaching, as acidification has the potential to release aluminum and heavy metals from soils into water resources, contaminating drinking water sources.

4. Global Water Resources and Sharing Activities

According to the Food and Agricultural Organization of the United Nations [5], annual global water withdrawal is ~4 trillion m³ with the following distribution in terms of consumption sectors:

1. Agriculture: 70%.
2. Industry: 19%.
3. Domestic Use: 11%.

The same publication notes that 2.2 billion people live in countries with water chaos related to pollution and reduced water reserves. The aforementioned number can be translated beyond a measure of ability or inability to access drinking water and into a social indicator, referring to individuals, groups, and the service of their needs. The need for scientific engagement with the problem probably depends on technologies of responsible solutions. Desalination in this case could have effective applications in relation to the existence of water and its utilization to meet the needs of societies. The greatest advantage of this technology is that it provides access to drinking water in drought-prone areas to address water scarcity. The example of Israel's management, where desalination covers >80% of household needs, provides some application information in relation to addressing water shortages in homes [6].

5. Mobility/Climate Models/Forecasting Technologies

The fact that human and economic productive activity are in constant flux, with their resource consumption needs and their corresponding footprints, offers a direct understanding that any relevant measurement encounters reasonable difficulties. By extension, any modeling of gas pollutant sources will also encounter obstacles, as the above activities are dynamic, unpredictable, and multidimensional in nature.

In terms of industrial production, the measurement shows alternating indicators with increases and decreases in emissions, which depend on demand and political decisions. In terms of supply chains, there are complex chains involving many countries, which have different methods of measuring CO₂ emissions. Furthermore, it is defined as problematic that countries report emissions asynchronously in annual reports and often provide incomplete data.

Modeling limitations, technological ones are also added: methane requires infrared detection sensors which have a high production cost. Potential technological solutions to these limitations exist. Improving existing models with a combination of AI and Big Data is a potential option for enhanced forecast accuracy. The use of these tools can provide real-time forecasts in areas that were previously absent, such as building and transport emissions. In this way, detection sensor technologies will be able to predict, control, and improve the management (not emission) of pollutants, before they become critical. Satellite systems can detect CO₂, NO₂, CH₄, offering the possibility of preventive measures (e.g., regulation of industrial emissions). IoT sensors (Internet of Things sensors coordinate communication between devices and networks in real time), installed in cities, can inform about pollutant exceedances, so that temporary measures can be activated. When all technological perspectives are combined with real-time monitoring and when restoration methods are carried out with decisions of sustainable but also economically accessible methods, they may be able to yield a generally beneficial result.

6. The Action of Networking and the Social Risks of the Economy

The sociological theories of Actor-Network [7] and Risk-Society [8] address the approaches to a sociology of associations. They can be combined to analyze technologies, natural resources, social capabilities, and forces that interact in risk management. The

Actor-Network theory [7] is able to provide evidence on how risk is created, while the Risk-Society theory of Beck [8] provides descriptive tools on who is responsible and who “pays” for the consequences of risks. The two theories combined provide evidence for understanding risks as dynamic networks, with real and moral consequences.

In the Actor-Network analysis [7], human and non-human networks interact on an equal footing, within a changing network of relationships. The analysis of large-scale technological developments here is based on the interplay of scientific, technical, legal, organizational, and political factors [9]. For example, the water shortage in California can be seen as a network that includes factors:

Non-Humans:

- Change in precipitation (climate change).
- Desalination technologies (factories and industries).
- Water legislation (California Water Rights).

Humans:

- Farmers (water use and agricultural needs).
- Companies (water brand owners).
- State officials/institutions (taking over political management).

By combining data concerning all actors, human and non-human, it could yield analyses and conclusions, as well as clarifications of how an existing issue is created and its evolution.

Beck's [8] risk perspective framework highlights how industrial societies can generate risks that threaten sustainability, while at the same time, an economy, as another “natural” system, continues to benefit from these crises. Beck does not claim that the risk of changing a natural function does not exist. What separates a natural from an artificial risk are the ways of managing and dealing with it, as well as the means. For Beck, risk generation in modern societies concerns global risks that cannot be controlled by states. In these, there is inequality, they do not affect everyone equally and the economic situation offers the possibility of exemption from them. In the case of economic capital management, the risks that threaten sustainability are transformed into sustainable opportunities, as well as opportunities for economic investment/return.

The following is a list of two events that are analyzed based on Beck's [8] theoretical tools of risk.

Air Pollution and Economy: CO₂ and SO₂ emissions from a South African power company's coal-fired plants are causing acid rain and respiratory problems. The same company is marketing “clean coal” technologies to other countries, thus profiting from the crisis in which it is involved in [10].

Water Resources Management/Pinochet, Chile: During the Pinochet dictatorship in Chile, water resources management was given to a private company. This led to increased prices, making water inaccessible to “underdeveloped” neighborhoods. The company then took on the role of controller-manager of the reserves, selling it to large food companies and supplying surpluses to large tourist resorts. The risk came with local farmers losing their previous access to water, while the management company was valued at billions of dollars in profits [11].

Thinking critically about the examples, if risk is also a modern profit model, what is it that separates real deficiencies or problems from artificial ones? As previously shown, the latter could operate on the basis of creating a problem, selling the benefits of solutions. Harvard's Solar Engineering Research Program calculated that the “return” of 0.5 million tons of SO₂/year in the stratosphere would cost \$2–8 billion/year for a basic program, which offsets ~1 °C heating [12]. The cost of implementation, however, as presented,

concerns financial protection from climate damage. It is not stated where the benefit of use will be attributed. Other costs and impacts related to climate damage and inequalities are not mentioned; as with SRM applications, there will be countries that “lose” rainfall and countries that will increase their health costs, since the increase in SO₂ is capable of causing an outbreak of lung diseases.

7. Concluding Remarks

In 2024, the name “Anthropocene”, which refers to a proposal to change the name of the current geological time was not ratified through voting procedures. However, the fact that the term highlights human interventions in geological processes makes it always relevant for scientific investigation. If the term “Anthropocene” is abandoned, geology itself may lose the possibility of modernization, in accordance with new interdisciplinary challenges.

Emissions of gas pollutants into the atmosphere and, by extension, the burden on its functioning, are a condition derivative of cultural characteristics. As long as these are intense and in action, it will be difficult for any technical intervention to achieve sustainable containment. The widespread (and economically advantageous) SRM technologies have been shown to have a disruptive effect on the global climatic and social system, but they have an immediate and locally limited economic return on protection from climate change. As technologies themselves do not have useful or harmful components, the way they are used gives them the corresponding ones; techno-science has already developed efficient solutions, such as, for example, the desalination of ocean waters, in order to cover overall social needs. An obstacle to the modeling and development of technologies for the prevention of critical limits is the rapid pace of mobility of the economy and human activity. In addition, certain administrative and operational ways of utilizing measurements leave room for delays and incomplete pollutant emission data.

The social and economic activity of networking people, methods, and situations can carry risks and hazards for other parties and other social groups. Thus, the gap created does not clarify what essentially constitutes a collective risk or which aspects actually concern a market for artificial solutions. Historical examples show that management buy-sell decisions have not corrected climate-generated social issues.

Basic precautionary principles are deemed necessary to communicate by decision-makers to social groups and vice versa. They relate to an overall culture of regulation of the components that affect the climate situation. Their primary concern is environmental policy processes. There is a difference between prevention and precaution. Prevention concerns known risks for which the relevant measures are taken, while precaution concerns measures whose aim is to minimize social risk due to weather phenomena. Scientific knowledge has a central role in the processes: foresight is not identified exclusively with making predictions but with understanding the complexity of environmental and climate problems. Inclusion could constitute another basic principle of regulation which is organically linked to the concept of predictability, as understood above. Clear communication of situations and needs are essential components of a coordinated effort to correct and halt climate problems by societies.

Finally, responsiveness is a characteristic of regulatory principles, where actors adapt to the process of scientific innovation based on the values and priorities that exist in a specific social context.

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