CORPUS PUBLISHERS

Environmental Sciences and Ecology: Current Research (ESECR)

ISSN: 2833-0811

Volume 3 Issue 6, 2022

Article Information

Received date : August 23, 2022

Published date: September 05, 2022

***Corresponding author**

Francisco Castro Rego, Professor at the Instituto Superior de Agronomia, Tapada da Ajuda 1349-017, Lisboa, Portugal

Keywords

Concentrations of CO_2, Water Vapor, Global Warming, Atmosphere

Mini-Review

Links between Carbon Dioxide, Water Vapor and Global Warming: A Simple Exercise

Francisco Castro Rego*

Professor at the Instituto Superior de Agronomia, Tapada da Ajuda, Portugal

Introduction

Many studies have addressed changes of the Earth´s atmosphere in the last decades, focusing on its average temperature and on concentrations of CO_2, sometimes with H_2O. Most of the studies indicate significant increases in the three variables during the last decades and many agree in that they are associated. In this study, we present a simple exercise and discuss the nature of those associations. The most common association is the proposed cause-effect relationship where increases of CO_2 (together with other greenhouse gases as methane, Chlorofluorocarbons CFCs and Nitrous Oxide) are considered as the primary responsible for the observed global warming. This increase of carbon dioxide concentrations in the atmosphere is known to result from emissions associated to human activities and their consequence on air temperature are explained by the so-called "enhanced greenhouse effect", as referred in all the works of the Intergovernmental Panel for Climate Change [1]. The association between H_2O and atmospheric temperature is also described, with indications that 1°C of warming results in potential increases of 4.9% in global surface air humidity [2]. However, in spite of the recognition that water vapor is by far the most important greenhouse gas, the nature of this association is different from that proposed for CO_2. Contrary to what happens with CO_2 concentrations, the high spatial and temporal variability of water vapor in the atmosphere makes it difficult to establish an association with human activities. However, also contrary to the effect of carbon dioxide, the influence of water vapor is not considered as a direct cause but only as a positive feedback on surface temperature [3]. The process is explained in two consecutive steps: the first where water vapor increases in response to global warming, and the second where these increases of water vapor in the atmosphere further enhance the greenhouse effect and global warming [1]. However, the direct effect of increased water vapor resulting from combustion as a cause of increased surface temperature is not considered. A summary of the accepted relationships between human-caused emissions, carbon dioxide, water vapor and global warming is depicted in (Figure 1). These relationships created the scientific basis of the main global discussions and negotiations related with climate change.

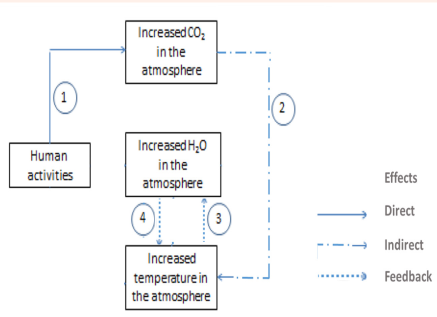

Figure 1: Simplified diagram with the accepted relationships between human activities, concentrations of carbon dioxide and water vapor, and temperature of the atmosphere in the "enhanced greenhouse effect".

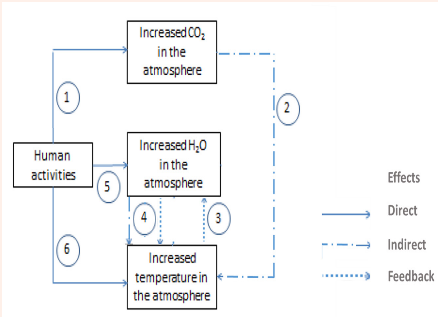

Figure 2: Diagram showing the direct and indirect effects of human activities in the temperature of the atmosphere.

Some of the assumptions of the current model have been questioned but it is particularly noticeable that only recently some authors suggested that energy usage and anthropogenic heat should be directly associated with global warming and integrated in global climate models [4-7]. In this study, we provide some simple calculations that suggest that the accepted model probably oversimplifies reality. We propose a more complete system with direct and indirect effects of human activities, including feedbacks. The direct effects are the results of the combustion of fuels on CO_2, H_2O and heat released in the atmosphere (Arrows 1, 5 and 6 of Figure 2). The indirect effects are those related with the "greenhouse effect" of increased concentrations of carbon dioxide and water vapor in the atmosphere (Arrows 2 and 4 of Figure 2) or with the positive feedback of increased temperature in water vapor of the atmosphere (Arrow 3 of Figure 2).

Some Results

Considering only the consumption of fossil fuels we can approximate their combustion by the chemical equation for burning of octane (C_8H_{18}). We can then estimate the release of CO_2, H_2O and heat per mole (or gram) of fuel burned, as shown in (Figure 3).

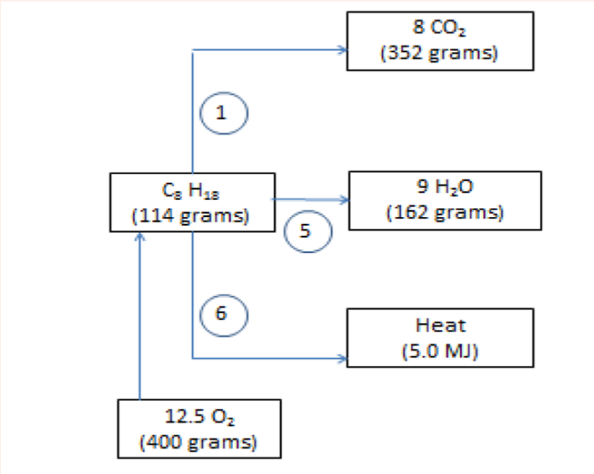

Figure 3: Diagram showing the chemical equation for the combustion of octane (C_8 H_{18}), and the resulting products CO_2 and H_2O, together with the energy produced.

From this equation, and following arrow 1 in (Figure 3), it is possible to convert grams of octane in grams of carbon dioxide released using the ratio 352/114=3.09 as a multiplier. Using a similar analysis for water vapor, following (arrow 5 in Figure 3), we can now use the conversion rate of 162/114=1.42 as a multiplier. Finally, we can make a similar analysis for heat produced. Following (arrow 6 in Figure 3), we can compute the energy release by gram of fuel by using the conversion factor 5.0MJ/114grams or 44kJ/gram, similar to the value of 42kJ per gram of oil equivalent (oe) used in energy studies (e.g. BP 2022). Using these conversion values, we can estimate what would be the likely consequences of a rapid release of CO_2, H_2O and heat in the atmosphere. For that simulation, we use the main statistics on energy consumption [7], indicating that about $0.50x10^{15}$kg of oil equivalent were consumed from 1965 to 2020. The emissions caused by burning this amount of fuel would be around $1.54x10^{15}$ kg CO_2, $0.71x10^{15}$kg of H_2O released as water vapor, and $21.0x10^{18}$ kJ of heat released in the atmosphere. If these releases were rapid, the potential consequences of these emissions in the atmosphere can be estimated by knowing that the atmospheric mass is around $5.1x10^{18}$ kg [8] and that the specific heat of the atmosphere is around 1.0 kJ/kg/°C (reference value for dry air at normal temperatures). With these values, we may compute the potential changes in concentration of CO_2, H_2O, and average temperature of the atmosphere.

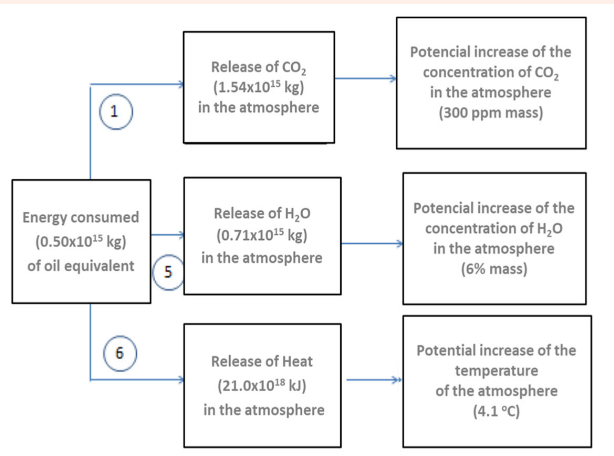

Figure 4: Simplified calculations for the potential impacts of burning fuel by human activities between 1965 and 2021 on concentrations of CO_2 (Arrow 1), of H_2O (Arrow 5), and on temperature of the atmosphere (Arrow 6).

The results from this potential rapid combustion exercise are very interesting. The potential increase in CO_2 concentration in the atmosphere due to burning fuel in the period 1965-2021 would be around 300 parts per million in mass (equivalent to around 200 ppm in volume).

As the actual measurements of the average atmospheric CO_2 concentrations indicate, for the same period 1965-2021, an increase of 94.5 ppm in volume (320.2 ppm to 414.7 ppm) it is concluded that about one half of the carbon dioxide emitted by humans in the last five decades moves to the land and oceans. The expected increase in H_2O in the atmosphere related to the amount of water vapor released by combustion during the period 1965-2021would be around $0.71x10^{15}$kg of H_2O or 140 ppm (mass). Taking into consideration that the mean mass of water vapor in the atmosphere is around $12.5x10^{15}$ kg [8] this release of water vapor resulting directly from burning fossil fuels corresponds to an increase of almost 6% of the mass of water vapor in the atmosphere during the period 1965-2021. Observed trends in specific surface humidity of the atmosphere for the period 1976 to 2004 indicate a global average increase of 0.06 % per year (Dai 2006) which would correspond to an increase of around 3.4% for the period 1965-2021. Similarly to what occurs for CO_2, the amount of water vapor released by human activity in that period is almost twice than its observed increase in the atmosphere. The movement of that water vapor as rain to oceans and land certainly explains these differences. The expected increase in atmospheric temperature caused by a potential sudden release of $21.0x10^{18}$ kJ, the total energy produced in the period 1965-2021, would result, for a specific heat of the atmosphere of 1.0 kJ/kg/ºC and an atmospheric mass of $5.1x10^{18}$ kg, in an increase of atmospheric temperature of 4.1ºC. Here, again, as with CO_2 and H_2O concentrations, the predicted impact is larger than the value of the observed impact that is "only" around 0.7 º C during that period. These calculations are summarized in (Figure 4).

In the case of heat release and temperature effects, the large differences between the potential consequences of direct heat release and the actual changes have two main reasons. First, a fraction of the energy consumed is efficiently used for human purposes, and this fraction is therefore not wasted by dissipation in the atmosphere [5]. This conversion efficiency is quite variable for different uses, with average OECD average values for thermal energy generation around 38%, equivalent to the values for electricity production referred by Chaisson (2008). More recently Bian (2020) [6], estimates that the current global energy´s conversion efficiency is about 20%, that is, only this small fraction is converted to new products and useful work, while the remaining 80% enters the climate system as "waste heat". He concluded that "waste heat" is the dominant cause of global warming. Even if we assume that "only" 62% of the energy consumed is directly lost as "waste heat", we conclude that, during the period 1965-2021, the release of energy as "waste heat" to the atmosphere is around $13x10^{18}$ kJ, potentially resulting in an increase of temperature around 2.5ºC, still very much above the observed value. Secondly, it is certain that, as with carbon dioxide and water vapor, a significant part of the energy released to the atmosphere has "moved" into the land and oceans increasing their temperatures.

Conclusions

This exercise, using similar analyses for carbon dioxide, water vapour and energy release in the atmosphere suggests that the three components may be modelled in a very similar way. The effects of the three components in the characteristics of the atmosphere indicate that the potential increases resulting directly from combustion of fuels are higher than the observed increases in the corresponding atmospheric variables. This suggests that potential direct effects that would occur under a sudden combustion release are moderated through time by interactions of the atmosphere with oceans and land. The results of this exercise suggest that a more complete model, including direct and indirect effects of the three products of combustion may provide a more complete picture and understanding of the main processes involved. This exercise only refers to energy consumption based on fossil fuels where the consequences of the release of the three components are naturally confounded. However, for other energy sources, as nuclear energy, with different consequences on CO_2, H_2O and heat releases, a model that distinguishes the different processes involved may allow for a much better understanding of the consequences involved in different energy options. Finally, the exercise indicates that direct heating of the atmosphere by burning fossil fuels is not negligible and may well be the dominant root cause of global warming, as suggested by Bian (2020) [6].

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