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The Good, the Bad and the Ugly: Natural Gas, Oil and Coal

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Abstract

Our article includes numerical analysis of one narrow slice of a complex phenomenon called the greenhouse effect. We consider the most important fossil fuels: natural gas, crude oil and coal, and calculate their impact on the average concentration of carbon dioxide in the Earth's atmosphere if all the known reserves of these fuels were burned out altogether. Our calculations are based on the known amounts of the reserves and stoichiometric burning of the fuels. We do not take into account any cumulative effects and time related processes in the biosphere. The calculations yield that the largest effect would come from burning all the known reserves of coal, and the smallest effect would result in from burning all the known reserves of natural gas. The average concentration of carbon dioxide would increase from the present value of 405 ppm-v to about 873 ppm-v if all the known reserves of all these fossil fuels were burned. Our analysis has its roots on a cynical approach to the human race: it is totally possible that all the fossil fuels will be totally burned, sooner or later. It is important to have numerical analysis on such a worst-case scenario now when we still have massive reserves left in the ground and in vast stocks.

Keywords

Greenhouse Effect, Fossil Fuels, Carbon Dioxide

1. Introduction

Today, the young generation is perhaps more anxious about their future than ever before. The reason is obvious: the greenhouse effect has mercilessly penetrated to everybody's life, causing fear of the future and turning the attention of the young from pleasures of their lives to horrifying doomsday scenarios. In this situation, it is the obligation of the scientific community to offer ordinary people simple and concise facts on global warming caused by the greenhouse effect, so that the young can easily draw relevant conclusions about the future of our planet. These facts must be offered in a way, which does not require that the recipients of the information have expertise in the field, or complex and deep analytical thinking. Only this way we can make our children sleep better and be more aware of our common future from the atmospheric point of view. By offering such knowledge, we do not wipe away the warmly welcomed awareness of saving our planet from destruction. In contrast, the authors of this article are convinced that honest facts and knowledge can never make anyone turn their sight away from sustainable living practices, antipollution and avoiding all kinds of damage to the nature.

In our article, we make a worst-case scenario of the future. We try to find out what will happen if all the presently known crude oil reserves are burned altogether. We want to discover how much this would affect the average concentration of carbon dioxide in the Earth's atmosphere. Further, we want to find out if this would lead to suffocation of mankind and all the breathing animals on the planet, or could we still survive if the human race went this far in destroying the nature. We repeat these considerations and the associated analysis also to natural gas and to coal. It will be interesting to find out if natural gas will have the smallest effect, since this fossil fuel is typically considered as the good one among the available carbon-based fuels [1]. Oil is usually blamed quite heavily for the greenhouse effect [2], and hence it should appear very bad in our analysis. However, without calculation, it is impossible to say that this will eventually be the case. Finally, coal's contribution will be addressed similarly. Coal is typically understood as the ugliest of all the options in the family of fossil fuels [3]. How much will it affect the average concentration of carbon dioxide in the atmosphere if all the known coal reserves are burned? This is the third question we want to answer in this article. We ask and answer clear and easily understood questions on the greenhouse effect too seldom, and this is why we find such questions valuable for those who are hungry for knowledge.

2. Related Work

During the past two decades, the greenhouse effect has been discussed very intensively in all the different kinds of media. This applies as well to scientific publications as to popular articles, television programs, radio broadcasts, social media, and all the other digital forms of sharing information to masses. This easily leads to a conclusion that the greenhouse effect, and the associated global warming, is a newly appeared phenomenon. Perhaps something that has arisen in the 21st century. Obviously, this is not true. The relationship between the concentration of carbon dioxide in the atmosphere and the atmospheric temperature was reported already in 1896 by a Swedish professor Svante Arrhenius [4]. He based his studies on the calculations made by Jean-Babtiste Fourier, published in 1827 [5], and on the studies of Samuel Pierpont Langley [6] [7]. Fourier had studied the problem that was widely debated among the 19th century scientists: Do the atmospheric gases affect the average temperature of the ground through absorption of heat by the molecules in the atmosphere? He concluded that "the atmosphere acts like the glass of a hothouse, because it lets through the light rays of the sun but retains the dark rays from the ground". It is worth noticing that Fourier gave such a correct analysis even though the celebrated thermal radiation theory of Gustav Robert Kirchhoff [8] and the even more famous thermal radiation experiments of Max Planck had not been published at Fourier's time [9].

After the studies of Fourier, Arrhenius, Kirchhoff, Planck, Tyndall, Langley, Paschen and others, hundreds of scientific research papers have been published on the greenhouse effect. Hence, the scientific community has become unanimous about the existence of the effect. The mechanism of the greenhouse effect has been studied intensively, and the understanding of it has been evolving gradually during the past decades. First, scientists concentrated on the resonant frequencies of the atmospheric molecules. These molecules absorb heat from the photons emitted by the Sun and from the photons emitted by the Earth. The effective surface temperature of the Sun, when approximated as an ideally radiating black body, is some 5778 K [10]. According to Wien's displacement law [11], [9], the Sun therefore emits thermal radiation with the highest intensity at the wavelength of 502 nm. The Earth's average surface temperature, however, is only about 9˚C [12]. This yields that the maximum intensity of thermal radiation emitted by the Earth is found at 10.3 μm. The corresponding photonic frequencies are hence 5.97×10^{14} Hz (the Sun) and 2.91×10^{13} Hz (the Earth). The analyses have revealed that the most important atmospheric gases in this respect are H_2O, CO_2 and CH_4.

Later on, scientists understood that global warming of the atmosphere is more complex a process and the scientific community turned their attention to all the relevant processes that affect atmospheric warming. Scientists started to discuss the Earth-atmosphere energy balance [13]. Today, we understand the processes underlying global warming so that from the photonic energy entering the Earth's atmosphere from the Sun, only 47% is absorbed by the Earth's surface. From the entering energy, 19% is directly absorbed by the atmospheric molecules and 4% is absorbed by the clouds. Thus, 23% of the energy of the incoming solar radiation is directly absorbed by the atmosphere. About the same amount of (short wavelength) radiation energy is reflected by the clouds back to the empty space, and 7% of the incoming (short wavelength) energy is reflected by the Earth's surface. [13]

Because of the low temperature of the Earth's surface, it emits mostly long wavelength thermal radiation. The amount of energy emitted by the ground is 1.16 times that of the amount of energy entering the atmosphere in the form of solar radiation. The reason for this seemingly contradicting fact is that also the atmosphere itself warms the surface of the Earth. The energy emitted by the atmosphere is about 1.56 times that of the entering solar radiation energy. About 63% of this is absorbed by the Earth and the rest is emitted to the empty space. About 90% of the thermal energy emitted by the Earth is absorbed by the atmosphere and the remaining 10% is emitted to the cold, empty space. [13]

Thermal radiation is not the only mechanism through which the Earth's surface looses its thermal energy. Vaporisation of water requires latent heat, which is partly absorbed from the ground. Convection by rising air is another means of loosing thermal energy from the ground. Together, these two ways are estimated to be responsible for energy loss worth about 29% of the energy entering the atmosphere in the form of solar radiation. [13]

Looking at all we know about the reasons that affect the average temperature of our atmosphere, we understand that the average concentration of carbon dioxide is only one part of a complicated puzzle. However, if we ask ourselves what mankind can do in order to affect the phenomenon, we realize that our means are very limited, indeed. We cannot directly change the average concentration of water vapour (or liquid water) in the atmosphere at all, and we cannot affect the natural interaction between different kinds of photons and the atmospheric molecules. The only effective means that will be left for us is to decrease the relative amount of carbon dioxide in the atmosphere. And this can be done by burning less and less fossil fuels, *i.e.*, hydrocarbons. This is difficult, because our energy technology is based on fossil fuels so strongly. In the 19th century, industrial revolution was not yet too advanced, and the contribution of energy technology was mild when compared to it at the moment. During the past 70 years, however, energy-technology-related industry has become to play more and more important a role in strengthening the greenhouse effect and in speeding up global warming.

Today, quite contrary to the times of Fourier, Kirchhoff and Arrhenius, we want to know more and more about the influence of energy technology to the greenhouse effect, or in a larger context to global warming or to climate change. We do believe in the effect itself, but sometimes people (even at high political positions) claim that people's actions do not have, practically speaking, any effect on it at all. In this article, we want to find out the worst possible effect of the three main fossil fuels on the greenhouse effect. We ask ourselves: What will happen to the average amount of CO_2 in the atmosphere if all the known crude oil reserves are burned altogether? The same question is also repeated for natural gas and for coal.

3. The Worst-Case Scenario

3.1. Natural Gas

Today, the total volume of known natural gas reserves is about $196.1 \times 10^{12}\ m^3$ [14]. By the known reserves of natural gas we mean the quantities of natural gas, which are estimated to be commercially recoverable from now on. The estimation is based on geological, engineering and economic data, and the estimation is considered to have a high degree of confidence.

Natural gas contains mainly methane, CH_4. In addition to this, natural gas is also made of ethane, propane, butane and some other molecules. The composition of natural gas depends quite strongly on the location it was produced. The amount of methane in natural gas varies from about 81 mol-% in Libya to almost 100 mol-% in Alaska [15].

Natural gas reserves are given under NTP conditions, *i.e.*, assuming the pressure of the gas is 1 atm and the temperature of the gas is 0˚C [16]. Using the Ideal Gas Law, it is now possible for us to calculate the number of moles in the known natural gas reserves:

$$n = \frac{pV}{RT} = \frac{1.013 \times 10^5 \times 196.1 \times 10^{12}}{8.314 \times 273} = 8.752 \times 10^{15} \text{ mol} \quad (1)$$

Russia alone owns about 24.4% of the world's natural gas reserves, and therefore Russian gas is the most representative for our calculations [14]. The second largest and the third largest natural gas reserves are owned by Iran, some 17.1%, and Qatar, about 12.4% of all the world's reserves [14]. These three locations represent about 53.9% of the world's natural gas reserves, and we hence take a closer look at the composition of natural gas in these three locations. The Russian natural gas (from Sakhalin) contains 92.54 mol-% of CH_4, 4.47 mol-% of C_2H_6, 1.97 mol-% of C_3H_8 and 0.95 mol-% of C_4H_{10} [15]. For natural gas from Iran, these relative amounts are, respectively, 89.80%, 5.01%, 1.77% and 0.30% [17] and for natural gas from Qatar, these relative amounts are, respectively, 90.90%, 6.43%, 1.66% and 0.74% [15]. We may now use the compositions of natural gas representing about 54% of the world's natural gas reserves and calculate the weighted average of the hydrocarbon components in natural gas, which we will use in our calculations. The relative amount of CH_4 in our model natural gas is:

$$\frac{24.4}{53.9} \times 92.54 + \frac{17.1}{53.9} \times 89.80 + \frac{12.4}{53.9} \times 90.90 = 91.29 \text{ mol-\%}$$

Similarly, one can calculate the relative amounts of ethane, propane and butane. The calculations yield:

$$c_{CH_4} = 91.29 \text{ mol-\%}$$

$$c_{C_2H_6} = 5.09 \text{ mol-\%}$$

$$c_{C_3H_8} = 1.84 \text{ mol-\%}$$

$$c_{C_4H_{10}} = 0.70 \text{ mol-\%}$$

with these results, we can calculate the number of moles of different molecules in the known natural gas reserves:

$$n_{CH_4} = 0.9129 \times 8.752 \times 10^{15} = 7.990 \times 10^{15} \text{ mol}$$

$$n_{C_2H_6} = 0.0509 \times 8.752 \times 10^{15} = 4.457 \times 10^{14} \text{ mol}$$

$$n_{C_3H_8} = 0.0184 \times 8.752 \times 10^{15} = 1.606 \times 10^{14} \text{ mol}$$

$$n_{C_4H_{10}} = 0.0070 \times 8.752 \times 10^{15} = 6.087 \times 10^{13} \text{ mol}$$

When these hydrocarbon molecules burn under optimal conditions, they produce water and carbon dioxide. The number of produced CO_2 molecules is the same as the number of carbon atoms in natural gas. Hence, the number of CO_2 moles produced if all the known natural gas reserves are burned is:

$$n_{CO_2} = n_{CH_4} + 2 \times n_{C_2H_6} + 3 \times n_{C_3H_8} + 4 \times n_{C_4H_{10}} = 9.607 \times 10^{15} \text{ mol} \quad (2)$$

Under NTP conditions, this amount of CO_2 gas will occupy a volume:

$$V_{CO_2} = \frac{n_{CO_2} RT}{p} = 2.153 \times 10^{14} \text{ m}^3 = 2.153 \times 10^{5} \text{ km}^3 \quad (3)$$

In order to have a concrete understanding of the amount of carbon dioxide that would be emitted into the atmosphere according to our worst-case scenario, we calculate the thickness of the layer of this NTP CO_2 gas, if it was distributed evenly onto the surface of our planet Earth of radius R_E:

$$V_{CO_2} = \frac{4}{3}\pi\left(\left(R_E + h\right)^3 - R_E^3\right) \Rightarrow h = 42.2 \text{ cm} \quad (4)$$

At the moment, the average relative amount of CO_2 in the Earth's atmosphere is about 405 ppm-v [18]. In order to find out the present volume of atmospheric CO_2, we need to calculate the volume of NTP atmosphere of the Earth. This can be found by dividing the mass of the atmosphere by its density. The mass of the Earth's atmosphere can be calculated by using the normal atmospheric pressure and the average radius of the Earth, $R_E = 6371 \text{ km}$ [19]:

$$p = \frac{mg}{4\pi R_E^2} \Rightarrow m = \frac{4\pi R_E^2 p}{g} = \frac{4\pi \times \left(6.371 \times 10^6\right)^2 \times 1.013 \times 10^5}{9.80665} = 5.269 \times 10^{18} \text{ kg} \quad (5)$$

From the Ideal Gas Law and the definition of density, we may derive an equation for the density, ρ, of a given gas in terms of its absolute pressure, p, its molecular mass, M, and its absolute temperature, T. The obtained formula can be used to calculate the density of NTP atmosphere, using $M = 28.95 \text{ g/mol}$ for the average molecular mass of the atmosphere [20]:

$$\rho = \frac{pM}{RT} = \frac{1.013 \times 10^5 \times 0.02895}{8.314 \times 273} = 1.292 \text{ kg/m}^3 \quad (6)$$

With Equation (5) and Equation (6), we can calculate the volume of the Earth's atmosphere:

$$V = \frac{m}{\rho} = 4.078 \times 10^9 \text{ km}^3 \quad (7)$$

At the moment, the volume of CO_2 in the atmosphere is hence:

$$V_{CO_2,\text{now}} = 405 \times 10^{-6} \times 4.078 \times 10^9 = 1.652 \times 10^6 \text{ km}^3 \quad (8)$$

If this amount of carbon dioxide gas was evenly distributed onto the surface of the Earth, the gas layer would be 3.238 m thick.

If all the known natural gas reserves were been burned corresponding to the worst-case scenario, the volume of CO_2 in the atmosphere would be:

$$V_{CO_2,NG} = 1.652 \times 10^6 + 2.153 \times 10^5 = 1.867 \times 10^6 \text{ km}^3 \tag{9}$$

The average relative concentration of carbon dioxide in our atmosphere would then be:

$$c_{CO_2,NG} = \frac{1.867 \times 10^6}{4.078 \times 10^9} = 458 \text{ ppm-v} \tag{10}$$

The average atmospheric ppm-v value of CO_2 would hence increase by 13.0% if all the known natural gas reserves were burned. Even though this result seems to indicate that burning all the known resources of natural gas would not cause any dramatic effects, it is impossible to judge whether such a change could give rise to some significant atmospheric processes, which would speed up the climate change more than this number suggests by itself.

3.2. Crude Oil

During the past decades, more and more oil reserves have been found around the world. For example, the proved crude oil reserves in Canada were estimated to be only 4.9×10^9 barrels in 2002, but the following year this skyrocketed to 180×10^9 barrels [21]. A similar sudden increase in the proved crude oil reserves has happened also to Saudi Arabia in 1990, to United Arab Emirates in 1988, and to Venezuela in 1988 and then again in 2011 and in 2013 [21]. Therefore, it is somewhat risky to claim that at the moment we know the final total volume of crude oil reserves in the world. Naturally, to some extent, this applies also to the total reserves of natural gas and coal, too. Today, the world's total crude oil reserves have been estimated to be between 1661×10^9 barrels [21] and 1730×10^9 barrels [22]. In our calculations, we will use the larger estimate in order to avoid underestimating the amount of carbon dioxide produced into the atmosphere if all the known crude oil reserves were burned.

The chemical composition of crude oil is very complex [23]. Despite the chemical complexity, it is known that average crude oil contains about 84 mass-% of carbon [24]. Further, it is known that the density of crude oil typically varies between 839 kg/m^3 (North Sea Brent) and 909 kg/m^3 (Venezuela Heavy) [24]. We calculate the mass of crude oil in the presently known proved crude oil reserves using the average of these two values for its density, 874 kg/m^3:

$$m_{oil} = \rho V = 874 \times 1730 \times 10^9 \times 0.1589873 = 2.404 \times 10^{14} \text{ kg} \tag{11}$$

The mass of carbon in this vast amount of crude oil is then:

$$m_C = 0.84 \times 2.404 \times 10^{14} = 2.019 \times 10^{14} \text{ kg} \tag{12}$$

The number of carbon moles is hence:

$$n_C = \frac{m_C}{M_C} = \frac{2.019 \times 10^{14}}{0.012} = 1.683 \times 10^{16} \text{ mol} \tag{13}$$

Under ideal conditions and stoichiometric burning, every carbon atom will result in one carbon dioxide molecule. Therefore, we know that the number of moles of CO_2 molecules, if all the known crude oil reserves were burned, would be:

$$n_{CO_2} = 1.683 \times 10^{16} \text{ mol} \tag{14}$$

According to the Ideal Gas Law, the volume this amount of NTP gas will occupy is:

$$V_{CO_2} = \frac{n_{CO_2} RT}{p} = \frac{1.683 \times 10^{16} \times 8.314 \times 273}{1.013 \times 10^5} = 3.770 \times 10^5 \text{ km}^3 \tag{15}$$

Again, in order to have a concrete understanding of the amount of carbon dioxide that would be emitted into the atmosphere according to our worst-case scenario, we can calculate the thickness of the layer of this NTP CO_2 gas, if it was distributed evenly onto the surface of our planet Earth:

$$V_{CO_2} = \frac{4}{3}\pi\left(\left(R_E + h\right)^3 - R_E^3\right) \Rightarrow h = 73.9 \text{ cm} \tag{16}$$

If all the presently known crude oil reserves were been burned, corresponding to the worst-case scenario, the volume of CO_2 in the atmosphere would be:

$$V_{CO_2,OIL} = 1.652 \times 10^6 + 3.770 \times 10^5 = 2.029 \times 10^6 \text{ km}^3 \tag{17}$$

The average relative concentration of carbon dioxide in our atmosphere would then be:

$$c_{CO_2,OIL} = \frac{2.029 \times 10^6}{4.078 \times 10^9} = 497 \text{ ppm-v} \tag{18}$$

The average ppm-v value of CO_2 in the Earth's atmosphere would hence increase by 22.8% if all the known crude oil reserves were burned. Again, we understand that even though the relative increase in the ppm-v value of carbon dioxide seems relatively low, it is beyond the scope of this paper to discuss any potential atmospheric effects this increase could bring about.

Our analysis reveals that the volume of carbon dioxide gas, which all the known reserves of crude oil could release to the atmosphere, is 75.2% higher than the volume of carbon dioxide gas that would be released to the atmosphere if all the known reserves of natural gas were burned altogether.

3.3. Coal

Coal exists in different forms in the nature. About 70 mass-% of coal is in the form of anthracite and bituminous, and the remaining 30 mass-% of coal is in the form of sub-bituminous and lignite [22]. Anthracite contains about 92 - 98 mass-% of carbon, bituminous coal contains carbon about 60% to 80% of its mass, and the carbon content of lignite is about 25 - 35 mass-% [25]. Based on these numbers, we may conclude that the average concentration of carbon in coal can be estimated as follows:

$$c_C = \frac{0.95 + 0.70}{2} \times 70 + 0.30 \times 30 = 66.8 \text{ mass-\%} \tag{19}$$

At the end of year 2018, it was estimated that the mass of proved reserves of coal in the world is 1.055×10^{15} kg. These are resources, which can be recovered in the future from the presently known coal reserves with a reasonably high certainty under present economic and operational conditions. This estimation is based on the best geological and engineering information available at the moment. [22]

The total mass of carbon in the presently known coal reserves is thus:

$$m_C = 0.668 \times 1.055 \times 10^{15} = 7.042 \times 10^{14}\ \text{kg} \tag{20}$$

The number of carbon moles in this mass is:

$$n_C = \frac{m_C}{M_C} = \frac{7.042 \times 10^{14}}{0.012} = 5.868 \times 10^{16}\ \text{mol} \tag{21}$$

If we consider the worst-case scenario and stoichiometric combustion, the amount of emitted carbon dioxide gas is the same as the result calculated above. Under NTP conditions, this amount would take the following volume in the Earth's atmosphere:

$$V_{CO_2} = \frac{n_{CO_2} RT}{p} = \frac{5.868 \times 10^{16} \times 8.314 \times 273}{1.013 \times 10^5} = 1.315 \times 10^6\ \text{km}^3 \tag{22}$$

If this vast amount of NTP CO_2 gas was distributed homogeneously over the surface of the Earth, it would form a layer of thickness:

$$V_{CO_2} = \frac{4}{3}\pi\left(\left(R_E + h\right)^3 - R_E^3\right) \Rightarrow h = 2.578\ \text{m} \tag{23}$$

This is such a large thickness, that it can be compared with the corresponding thickness of the present average concentration of carbon dioxide in the atmosphere, 3.238 m. We may conclude that if all the known coal reserves will ever be totally burned according to our worst-case scenario, the ppm-v value of CO_2 would almost double. To be more exact, we can now calculate the ppm-v value of carbon dioxide in the Earth's atmosphere if all the presently known coal reserves were burned:

$$V_{CO_2,COAL} = 1.652 \times 10^6 + 1.315 \times 10^6 = 2.966 \times 10^6\ \text{km}^3 \tag{24}$$

$$c_{CO_2,COAL} = \frac{2.966 \times 10^6}{4.078 \times 10^9} = 727\ \text{ppm-v} \tag{25}$$

According to this calculation, the average atmospheric concentration of CO_2 would elevate to unprecedented magnitude under our coal-related worst-case scenario, to as high as 727 ppm-v. The relative increase in the atmospheric average ppm-v value of CO_2 would be as high as 79.6% if all the known coal reserves were burned. This is more than six times the increase if all the known natural gas reserves were completely burned, or about 3.5 times the relative effect if all the known crude oil reserves were burned altogether.

4. Summary

The analysis presented in this research report is made from a very narrow point of view. For example, we have not discussed the very long time it would take to actually burn all the presently known reserves of natural gas, crude oil and coal. We all know that this would take at least several tens of years, perhaps even two hundred years. During such a long time, photosynthesis would fight against the released carbon dioxide by converting that into oxygen, thus helping the atmosphere cope with the results of combustion of the fossil fuels under consideration. On the other hand, during such a long period of time, it would be more than reasonable to assume that new pockets of oil, gas and coal are found all around the world. So, it might be possible that photosynthesis and new findings of fossil fuels compensate each other's effect, hence making our analysis fairly relevant after all.

Further, we have not considered the speed at which CO_2 molecules would diffuse along the atmosphere. If this speed is slow enough, local concentrations of carbon dioxide might be significantly higher at certain places, and lower at some other places. However, carbon dioxide is a well-mixed gas. Turbulence and weather systems effectively mix CO_2 globally over a timescale of days to weeks.

We have ignored the fact that oil products are used also in plastic industry, which means that less oil will be left for burning because of plastics [26]. On the other hand, perhaps all the plastics will be burned eventually. Also asphalt roads consume vast amounts of oil [27]. It is also true that combustion of the three fossil fuels does not usually occur perfectly stoichiometrically, which means that most probably less carbon dioxide will be released than what is suggested in our calculations.

Our report does not discuss the huge amounts of carbon dioxide released by volcanic activity [28], because we wanted to concentrate on the three fossil fuels only. This way, we aimed at a more focused analysis on something that is easy to understand. Neither did we take into account the effect of aerosol particles on the warming of the atmosphere. Also the emission of CO_2 by human and animal breathing has been ignored, as well as the emission of carbon dioxide by vast amounts of forests burning at the moment in Brazil and in Australia. One should note that when forests are burning, they not only release all the carbon dioxide gas they have absorbed during the whole of their lives, but it is also possible that frequent and severe forest fires burn generations-old carbon stored in the soils of boreal forests [29] [30]. This enhances the total negative effect related with forest fires. Further, a burned tree does not absorb carbon dioxide from the atmosphere anymore.

If all the presently known reserves of natural gas, crude oil and coal were totally burned, the average concentration of carbon dioxide in the atmosphere would skyrocket to 873 ppm-v. This can be considered as the ultimate worst-case scenario (WCS). See **Figure 1** for illustration of the carbon dioxide's ppm-v value today (Present), after all the natural gas reserves were burned (Natural Gas), after all the known crude oil reserves were burned (Crude Oil), after all the coal reserves were burned (Coal), and after all the known reserves of all these fossil fuels were burned (WCS). Our calculations clearly show that all

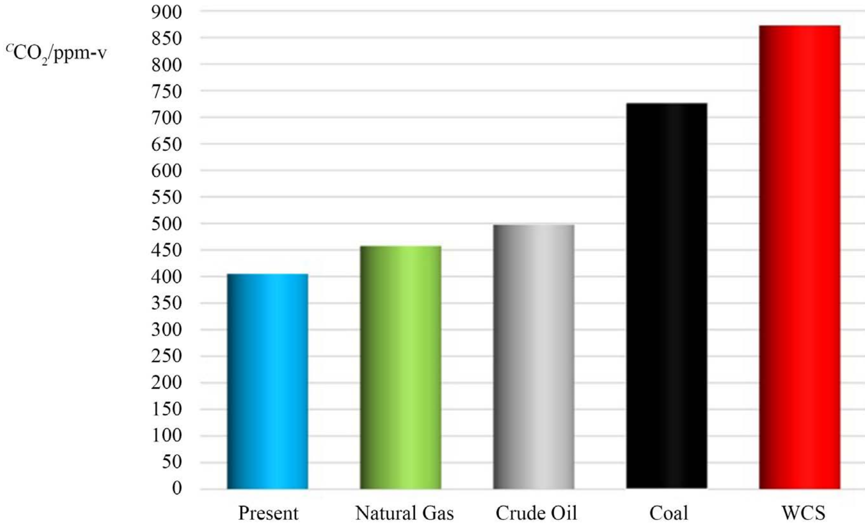

Figure 1. The average atmospheric concentration of CO_2 under the worst-case scenario related with burning all the presently known reserves of natural gas, crude oil and coal, and all of them, corresponding to the ultimate worst-case scenario.

the possible political efforts should be aimed at preventing burning of coal. This is of the highest importance, as long as fossil fuels are being discussed.

The Intergovernmental Panel on Climate Change (IPCC) has published estimates for the average concentration of carbon dioxide in the Earth's atmosphere in the year 2100 [31]. Our WCS result lies between the two worst possibilities discussed in the reports of the IPCC, the SRES series A1 emission scenario and the SRES series A2 emission scenario [31]. This is interesting, because our analysis is very straightforward, and the IPCC analyses are extremely thorough and include hundreds of experts around the world. For example, we have not taken into account the effect of the oceans. They can absorb huge amounts of CO_2 and CH_4 by dissolution, and under suitable circumstances, they can also release these gases into the atmosphere [32].

All in all, our analysis can be considered as the worst-case scenario of the effects the three fossil fuels can have onto the average concentration of CO_2 in the atmosphere. It will be highly unlikely to produce more carbon dioxide into the atmosphere by combustion of natural gas, oil and coal than what is presented in our calculations.

Even if the highest possible ppm-v value of CO_2 in the atmosphere, 873, was achieved, the human race and the breathing animals would not perish. It has been estimated that chronic exposure to about 1000 ppm-v of CO_2 might cause some health issues, such as inflammation, reductions in higher-level cognitive abilities, bone demineralization, kidney calcification, oxidative stress and endothelial dysfunction [33], but it would not be fatal.

When one burns natural gas, a very strong greenhouse gas, methane, is converted into a less dangerous greenhouse gas, carbon dioxide. Therefore, if there is a need to use one of the fossil fuels discussed in this research report, one should select natural gas instead of the other two options.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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