A Novel Model to Assess the Greenhouse Effect

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Abstract

The greenhouse effect is the warming of the earth's surface due to the presence of greenhouse gases in the atmosphere. It is said to be 33 °C, but we cannot measure this value because we cannot create the state “without greenhouse gases”. We therefore have to rely on calculations, although these are controversial. In the climate debate, this lack of measurements is often denoted as a major shortcoming. As a remedy, a novel model is proposed here, which proves the fundamental existence of the greenhouse effect beyond doubt, and which makes it possible to determine its real size from well-known measurements. Additionally, this model makes it possible to reject some other arguments against the greenhouse effect in a better way, such as an alleged contradiction to the 2nd Law of Thermodynamics, or an allegedly far too low concentration of greenhouse gases.

This model consists of a row of bodies, the first one heated, the last one cooled, those between freely adjusting their temperatures. When an additional body is inserted into that row, a temperature spread develops in it, so that the body before the new one must warm up by half of this spread and that behind it must cool down accordingly. Applied to the earth, the temperature of the earth’s surface is warmer with greenhouse gases in the atmosphere than without by half of the temperature spread in the atmosphere. This value is well-known and confirms the 33 °C cited above for the “natural greenhouse effect” surprisingly well. The weakness of the model is that it is too coarse to make a statement about the increase of the greenhouse effect when the CO_2 concentration is enhanced (“additional greenhouse effect”). Lessons learned, limits, related problems, and open questions are discussed.

Key words

Back-radiation, carbon cycle, climate model, CO_2-concentration, global warming, greenhouse effect, greenhouse gases, latent heat removal effect, saturation of absorption, Second Low of Thermodynamics.

1. Introduction

Let's start with a few definitions to avoid misunderstandings:

- The “greenhouse effect” is the (actual or postulated) warming of the earth's surface due to the presence of “greenhouse gases” in the atmosphere. A distinction is made between the “natural greenhouse effect”, which is the warming before human intervention, and the “additional (or “anthropogenic”) greenhouse effect”, which is its increase due to human releases of “greenhouse gases”.

- “Greenhouse gases” are usually defined as gases with different optical properties: Transparent for visible light (from the sun) and largely opaque for IR-radiation (from the earth’s surface). But due to the high share of low-frequency IR-radiation in the sun’s spectrum, the limit should be set at a slightly longer wavelength: There, where the intensity of heat radiation from the earth's surface outweighs that of radiation from the sun. Then, “greenhouse gases are those gases, which reduce the radiation from the sun less than they reduce the IR-radiation from the earth”. According to its absorption bands, CO_2 definitely is such a “greenhouse gas”.

- “Back radiation” is any radiation that is generated as a result of IR-radiation from the earth's surface and that is returned to the earth's surface by some process. The process that causes this in the greenhouse effect is described in section 2.1.

- "Climate sensitivity" is the warming of the earth's surface due to a doubling of the concentration of CO_2 in the atmosphere.

The "greenhouse effect" has been controversial ever since it was postulated. There seem to be good arguments in favor of the effect, but apparently, they are not good enough to convince sceptics. An end to the dispute is not in sight. In this paper, first a brief synopsis of some important issues in this debate is provided to clarify the starting position for the novel model (section 2). Then, this model is presented (section 3). It is easy to understand for everybody, it easily can be performed as a real experiment, it clears the facts, it makes the existence of the greenhouse effect easier to understand, and it allows to quantify this effect from well-known measurements, so it actually should be some improvement. Subsequently, constraints, limitations and open questions are discussed. Summary and conclusions complete the paper (section 4).

2. The deadlocked debate

2.1. Classical description of the greenhouse effect

The sun warms the earth. The earth's surface adapts itself to that temperature at which it radiates the same amount of energy per second into space as it receives from the sun. According to Stefan-Boltzmann's law, this temperature should be 255 K (= -18 °C) (solar constant 1364 W/m^2, 30 % albedo). But what we measure is about 288 K (= +15 °C). The difference of 33 °C is called the "natural greenhouse effect". It comes about because water vapor, CO_2, and some others ("greenhouse gases") absorb more outgoing radiation from the earth's surface than incoming radiation from the sun.

Physics (Kirchhoff's law of radiation) tells us that every body that absorbs radiation also emits radiation, the same amount as it absorbs, only in all directions. This also applies to greenhouse gases in the atmosphere. Therefore, half of the energy absorbed in these gases is radiated back to the earth's surface ("back-radiation"; the other half goes out into space), adding energy to it, additional to the energy from the sun. Both energy flows together heat up the earth's surface to higher temperatures.

It's only this warming by 33 °C that makes the earth inhabitable, we should be grateful for it. But when the atmospheric concentration of CO_2 rises, the warming span rises too. This "additional" or "anthropogenic" greenhouse-effect is usually quantified by the "climate sensitivity". A high climate sensitivity leads to strong warming when the CO_2 concentration is increased. But the amount of this sensitivity is only known very imprecisely: Previously, IPCC stated 2 to 4.5 °C [1,2,3], only in its last report, AR 6 [4], IPCC reduced the range to 2.5 to 4.0 °C. But even that is still almost a factor of two. Others claim even higher or lower values. This wide range despite decades of intensive research efforts is striking. Perhaps it is one of the reasons for continued doubts about the existence of the greenhouse effect?

2.2. Classical counterarguments

As already mentioned, the greenhouse effect is controversial. Four counterarguments are picked out here and examined in more detail. The selection was made not only because of the relative frequency of these arguments, but also because they can also be assessed using the novel model presented in section 3. And finally, it should also be noted that many other arguments against the greenhouse effect are based on similar basic ideas as those four selected here, so that the assessment of the latter automatically makes statements about the justification of most of the other counterarguments. The four arguments selected are:

1. All attempts to prove the greenhouse effect experimentally have failed. It is therefore nonsense to make this model the basis for any decisions, some people say, others even believe that something that cannot be measured cannot exist at all.

2. Warming of the warm earth by the cold atmosphere gives a perpetuum mobile, prohibited by the Second Law of Thermodynamics. This law stipulates that heat can flow spontaneously only from warm to cold, never in the opposite direction. Consequently, back-radiation, if it exists at all, can perhaps slow down cooling, but never can warm a body. Therefore, it is said that the greenhouse effect cannot exist in principle.

3. The concentration of CO_2 in the atmosphere is still in the range of 0.04 %, much too small for a detectable effect, it is said.

4. Temperature is an “intensive” variable, and therefore, it must not be averaged. Explanation: “Extensive” variables depend on the quantity under consideration, mass or volume are examples; “intensive” variables do not depend on this, temperature is an example. If a body is cut into parts, the masses of the parts must be added to get the mass of the initial body. But the temperatures must not be added to get the temperature of that initial body. From this then the general ban on averaging temperatures is derived. It is hard to understand the logic behind that, but this argument is put forward again and again. And the “natural greenhouse effect” of 33 °C is even the difference between two averaged temperatures, that of the earth’s surface with the real atmosphere, and that without an atmosphere (or without greenhouse gases in it). Two averaged temperatures, this concept is inadmissible from its fundamental approach, it is said.

2.3. Classical rejections

These counterarguments are not new, and they have already been rejected a thousand times:

1. Lack of experimental evidence: In literature, many experiments can be found that allegedly prove or disprove the greenhouse effect. In all cases, the respective opposing side argues that the result is determined by other effects and does not allow any reliable statement regarding the greenhouse effect. This is not surprising, because it is impossible in principle to put the whole earth into a laboratory and make a controlled experiment. But without controlled experiments, experimental proof is very rarely possible, and refutation is even impossible in principle. Perhaps, we just haven't done the right experiment, at least not with sufficient sensitivity. Experimental evidence can perhaps prove the existence of an effect, it may also prove that the effect cannot be very large, but it can never prove its non-existence. Lack of experimental proof is no valid argument against the existence of the greenhouse effect. Ther are many physical effects, whose experimental proof

was only possible many years after their postulation, but of course these effects already have existed before that.

2. Second Law of Thermodynamics: The above argument with a prohibited perpetuum mobile is based on a doubly false understanding of this law: First, this law does not prohibit heat transfer from cold to warm, it only requires that more heat is transferred from warm to cold simultaneously. In other words: The Second Law only regulates the *net* transfer of heat. Principally, every body emits radiation according its temperature, and when two bodies irradiate each other, each transfers heat to the other, from warm to cold and also vice versa. The Second Law only determines the sign of the difference. And whenever a body hit by radiation absorbs at least a part of that radiation, this means heat supply to that body (conservation of energy!). Second, this law states that a colder body never can warm a warmer body "of itself". "Of itself" means, within a closed system. But neither the atmosphere alone nor earth and atmosphere together are a closed system. They continuously get energy from the sun. The warming of the earth's surface does not happen "of itself", but through a continuous supply of energy from the sun. The Second Law does not prohibit the greenhouse effect. Theis effect only shifts the temperature of the boundary between the earth's surface and the atmosphere, without reversing the direction of the net heat transfer.

Regarding slowing down of cooling contra warming: This line of argument is inadmissible from its basic approach. If back radiation has any effect, this effect cannot vanish just because the affected body got its actual temperature as equilibrium between heating and cooling instead of cooling down from higher temperatures. There is only one difference: When the effect is cooling, the energy added through absorption of back radiation slows down that cooling if the added energy is small, and if it is large, it changes the effect into warming. But when there is equilibrium as starting point, even the smallest addition of energy causes warming.

One more thought on that: The earth together with its atmosphere is the body between sun and space. Replace it by a two-layer structure. The interface between the two layers has a certain

temperature. Now reduce the thermal conductivity of the outer (and cooler!) layer: The temperature of the interface will rise. The warming of the earth's surface by greenhouse gases in the atmosphere is not much different.

3. Small concentration: Does not tell much. For example, 0.04% of alcohol in blood can already impair a person's fitness to drive. Or, regarding computer chips: Doping of semiconductors in much lower concentrations changes their properties decisively. A concentration of only 0.04% definitely is no generally valid argument against a substantial effect, it depends on the physics behind it. Computer models do show large effects of small concentrations of CO_2. These models may be wrong, but that must be discussed in detail, a general statement is not permissible. For example, it could be that the models are right in principle, but exaggerate in size.

4. Averaging temperatures: Mathematically, all numbers can be averaged, even if they represent intensive variables. Calculation errors left aside, this average is trivially correct. Only its physical meaning must be examined on a case-by-case basis. Some deductions make sense, others don't.

However, regarding the greenhouse effect, temperatures are indeed a problem: To get today's value, we calculate an average of measured temperatures. That would not be a big problem for dense, evenly distributed, and homogenous measurements. But we only have very sparse measurements with very irregular distributions, and with different local influences (sea level, vegetation, constructions, etc.). Consequently, we need corrections and weight factors, and therefore, the average value always involves arbitrariness.

But the average value is at least an approximation that is sufficient accurate for coarse considerations, and its uncertainty is definitely much smaller than that regarding the 255 K (-18 °C) calculated for an earth without atmosphere (or without greenhouse gases in it). Here, we have no measured temperatures we could average, we instead calculate the energy balance of the earth between sun and space, and therefrom we calculate the earth's temperature via Stefan-Boltzmann's law. But the "constant" used in that law isn't really a constant, it rather depends inter

alia on temperature. Therefore, exact calculations require bodies with the same temperature everywhere, a prerequisite earth does not show. Even more important: It is the local temperature (which is influenced by vegetation, wind, rain, etc.) that dictates the local radiation intensity, not vice versa. Therefore, instead of calculating the average temperature and taking the fourth root therefrom for calculating the radiation intensity (Stefan-Boltzmann's law), one should first take the fourth root of local temperatures and only thereafter calculate the average. This reverse order of root formation and averaging inevitably results in a lower average temperature, that's just mathematics. For example [5] calculates the radiation balance without an atmosphere in this way and receives an average temperature of -129 °C instead of -18 °C. This more than quadruples the warming, from 33 °C to 144 °C! But this much higher value cannot refute the principle of the greenhouse effect, as many skeptics claim, sometimes with reference to [5]. If a more detailed calculation shows a larger value than a rough estimation, this confirms the existence of the effect and does not disprove it.

Note: This way of arguing is not even so rare: One shows that it is difficult or even impossible to calculate the greenhouse effect accurately, only to then claim that for this reason the effect cannot exist at all. This conclusion is simply forbidden by logic.

2.4. Interim result

There are various descriptions of the greenhouse effect in literature, but they differ only slightly. The essential content of all these definitions is shown in section 2.1. The objections raised against this effect are somewhat more diverse but are also based essentially on a few fundamental views, described in section 2.2. These counterarguments have already been rejected many times (section 2.3.). But that doesn't help, the same counterarguments are put forward again and again, undeterred. As a possible remedy to this deadlocked debate, a novel model is presented in section 3, which perhaps makes it a little bit easier to find the correct understanding of how the greenhouse effect works, and which allows us to estimate its size from well-known measurements.

3. Possible remedy: Bodies arranged in a row

3.1. Thought experiment

In view of the statements made, the existence of the greenhouse effect should be undisputed, but the debate continues. And regarding the size of the effect, the missing measurements are a problem in any case. As a remedy, let us try a thought experiment: Take a row of bodies, all of the same size, for example four bodies, one behind the other, as sketched in Fig. 1, upper line. The first body is heated to temperature T_h (h for hot), the last one is cooled to temperature T_c (c for cold). Aside from that, each one only receives energy through radiation from its neighbors. In equilibrium, the temperatures from left to right form a sequence of steadily decreasing numbers.

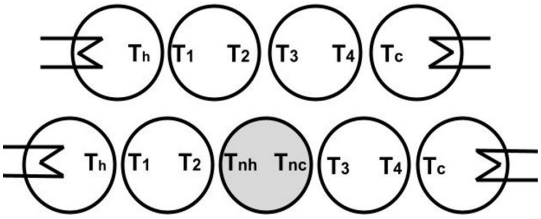

Figure 1:

Bodies in a row. The first one is heated, the last one is cooled, T_h and T_c are kept constant. The other bodies adjust their temperatures in equilibrium of heating and cooling. Upper line: Four bodies as an example. Lower line: One more body, inserted in the middle of the row, grayed out to highlight it. It develops a temperature spread (T_{nh} - T_{nc}). The body before it warms up by half of this spread, that behind it cools down by the same amount.

Now we add a fifth body in the middle of the row (Fig. 1, lower line). Starting cold, it warms up by radiation from its neighbors, more on the left side than on the right. In equilibrium, it shows a temperature spread of (T_{nh} - T_{nc}) (n for “new body”). Since the total temperature difference (T_h - T_c) remains unchanged, the body before the new one must have warmed up, and that behind it must have cooled down. For small gaps between the bodies, the temperature drop mainly occurs inside the bodies, so that the cold side of the body before, T_2, rises by about half of the temperature spread within

the new body (T_{nh} - T_{nc}). To put it bluntly: The body in the row before the new one *has warmed up as a result of the addition of a cooler body!* Its temperature rose by about half of the temperature spread in the new body! That's exactly the process of how the greenhouse effect works. With this novel model, we can understand it better.

3.2. Lessons learned

What can we learn from this novel model for the real world? In the latter, if we think away the atmosphere for a moment, we have a row of three bodies: Sun, earth, and space. The first two are spheres, the third is a hollow sphere, surrounding the other two. Hence, the middle body, the earth, is reduced to its surface, which exchanges radiation with the sun and with space (note: the mass of the earth does not matter here, because we only look at equilibrium conditions). And if we add the atmosphere (including its greenhouse gases) as an additional body, it is essentially transparent for sunlight but absorbs a crucial part of the earth's radiation. Therefore, its correct place in the row of bodies is that between the earth's surface and space. And due to its direct contact with the earth's surface, its warm temperature, T_{nh}, is practically the same as that of the earth's surface (288 K = +15 °C). And its cold temperature, T_{nc}, is that of the upper part of the dense atmosphere (about 10 to 15 km height), from where radiation (from CO_2 and from other greenhouse gases) is emitted directly into space. This temperature varies depending on location and season but is roughly in the range of -50 °C to -80 °C. Therefore, the addition of the atmosphere warms the earth's surface by about 40 °C! This is not speculation, nor is it an uncertain calculation based on assumptions that are difficult to understand, it is simply a measurement that has long been available.

So much as an introduction. Now to the assessment of the four examined counterarguments by means of that novel model:

- Counterargument 1 (lack of experimental evidence) becomes obsolete because the proposed thought experiment could easily be carried out as a real experiment. If the hot temperature, T_h, is high enough, it is not necessary to use a vacuum to prove the effect of warming a warm

239 body by a colder one unambiguously. The result is improved if cubes (or plates) are chosen
240 with only small gaps between them instead of spheres.

241 • Counterargument 2 (contradiction to Second Law) becomes invalid, because in an open
242 system a colder body may indeed warm a warmer one, simply by its presence (verifiable by
243 the described experiment, for the earth physically explainable by absorption and re-emission
244 of radiation in/from greenhouse gases and absorption of back radiation by the earth, in
245 addition to the ongoing radiation from the sun).

246 • Counterargument 3 (too small a concentration) becomes invalid, because even a small change
247 in the concentration of an additive can significantly influence the thermal conductivity of a
248 body, and when this happens, the temperature spread in that body changes too. More precisely
249 for the atmosphere: There always must pass the same amount of heat energy through it, from
250 the earth's surface out into space, as the earth's surface receives from the sun. And if the heat
251 permeability of the atmosphere is decreased by more CO_2 (because it absorbs more radiation),
252 then the temperature spread in the atmosphere increases. And this inevitably causes an
253 increase in the temperature of the earth's surface.

254 • Counterargument 4 (averaging of temperatures) becomes invalid, because it is no more
255 necessary to calculate the temperature without greenhouse gases with the large uncertainties
256 involved in that calculation as mentioned above, rather the looked-for temperature difference
257 with and without greenhouse gases is half of the temperature range in the atmosphere, which
258 has already been measured 1000 times.

259 And it should be pointed out again that most of the other counterarguments to the greenhouse effect
260 are grounded on similar trains of thought as in the four counterarguments rejected here. With their
261 rejection, these other counterarguments are invalid too. There is every indication that the greenhouse
262 effect actually exists.

However, the new model not only proofs the existence of the greenhouse effect in principle, it also confirms the classically calculated value of 33 °C for the "natural greenhouse effect" by an approach completely different: the temperature spread in the atmosphere. But on a closer look, the warming of "about 40 °C" attained in this way is not simply the greenhouse effect, caused by back radiation from greenhouse gases in the atmosphere, but rather it is the consequence of all changes that are caused by adding the atmosphere, including formation of oceans, distribution of heat by mechanical currents in air and water, vaporization, cloud formation, and so on. Which part of these "about 40 °C" is really the greenhouse effect due to back radiation, cannot reliably be determined by this. But the overall value of 33 °C is well confirmed.

Regarding the "anthropogenic (or "additional") greenhouse effect", the indicated restriction of the information provided by the novel model is much serious: This additional effect is much smaller, so inaccuracies, and possibly also other effects, play a much larger role. Quantitative statements cannot be obtained in this way. To make this problem more transparent, one such other "possible effect", the "latent heat removal effect", shall be discussed in more detail.

3.3. Latent heat removal effect

Energy is radiated from the earth's surface towards space. Part of this radiation is absorbed in greenhouse gases in the atmosphere, bringing energy into the atmosphere. This energy is then re-emitted in all directions, 50 % of it towards the earth, warming its surface. This is the "greenhouse effect", we had this already. But this process is not the only process that transfers heat from the earth's surface into the atmosphere: This is also achieved by conduction, by convection, and, above all, by vaporization (latent heat). We always have this additional import of heat into the atmosphere (additional to the import via radiation), but without greenhouse gases, we have no emission of radiation from the atmosphere, and therefore, none of the heat imported by these processes can dissipate into space. All of it only can be delivered back to the earth's surface via material-bound processes like conduction, convection, rain or hail. But with greenhouse gases, part of this heat is radiated into space. In other words: Whenever greenhouse gases exist in the atmosphere, they not only

bring about the "greenhouse effect", but rather also *open up a second path* to transport heat from the earth's surface into space. The first section of this second path is conduction, convection and latent heat, the second section is radiation. In the scientific literature, this second path is of course described, but I have not found a name for it. In [6] I just named it after its largest contribution "Latent Wärme Abfuhr Effekt" (German, in English: "latent heat removal effect").

To make it very clear: We can only have the two effects together: The greenhouse effect as warming via back radiation, and the latent heat removal effect as cooling via additional heat dissipation into space. We know that the "greenhouse effect" is much stronger at low concentrations. We know this because of the large "natural greenhouse effect". But when the concentration rises, saturation effects of the absorption of radiation should gain weight (more than 100 % absorption is not possible!), which should not exist for the "latent heat removal effect" (practically unlimited availability of water!). Therefore, these two effects should balance each other out at a certain concentration. Above that concentration, the "latent heat removal effect" should even predominate, resulting in an overall cooling by additional greenhouse gases. Today, probably no one can say for sure where this transition point lies. With regard to the large "natural greenhouse effect", this is meaningless. But it prevents a reliable statement regarding the much smaller "additional greenhouse effect". Neither its existence nor its size can be evaluated in this way (for clarification: The "additional greenhouse effect" is in any way more than one order of magnitude smaller than the "natural greenhouse effect").

In short: "Bodies arranged in a row" do prove the "natural greenhouse effect", however, it is an inappropriate model to judge the existence and the size of the "anthropogenic greenhouse effect".

3.4. Supplementary remark

The bodies arranged in a row and the other considerations above seem to resolve two issues finally: First, the "natural greenhouse effect" exists, and it is really this effect that warms the earth to habitable values. We should be thankful for its existence. And second, additional CO_2 causes additional

warming, but it inevitably causes cooling simultaneously. Soberly, there is great uncertainty as to which effect predominates under which conditions.

So far, so good, but if we cannot yet say anything precise about the effects of more CO_2, it is all the more urgent to think more fundamentally about this CO_2. Therefore, a supplementary remark seems to be appropriate: We should pay attention to causes! What is the real cause of the rise in CO_2 concentration?

Reasoning: As shown above, additional CO_2 in the atmosphere *can* warm the earth ("additional greenhouse effect"). The importance of this "*can*" (in contrast to "cannot") is derived from the widespread fear of manmade climate catastrophes: To avert such risks, we must stop our emissions of CO_2 as soon as possible completely, it is said. But even if the net effect of additional CO_2 in the atmosphere really is warming (for some of the uncertainties see above, another one is the climate sensitivity of CO_2, which is highly disputed), even if it is substantial warming (that's what computer models predict), the described fear and the requested countermeasures can only be justified when the increase in the concentration of CO_2 is essentially manmade. Otherwise, if it is not manmade, any resulting warming, however big it may be, is in any case a natural effect about which we can do nothing except prepare for weather extremes. This seems to be simply dictated by logic (and it is the closer reasoning why climate sensitivity is not discussed in detail in this paper).

Therefore, *„manmade or not"* is the question! Most experts see it as proven: The increase in the atmospheric concentration of CO_2 *is manmade*. Since humans have emitted twice as much CO_2 as has accumulated in the atmosphere, these emissions are the only cause of the increase in concentration, it is said. But there are also dissenting opinions, few, but they do exist, for example [7-14]. And scientific correctness does not result from democratic votes, but only from the quality of arguments.

The central issue of this paper is the impact of CO_2 on temperatures. But in view of the enormous importance of its origin, the main points of the discussion on this origin should be presented at least very briefly:

The atmosphere is an open system where the outflow of CO_2 rises with concentration. And in such a system, two statements always apply:

1. Whenever the inflow is kept constant, the concentration adjusts itself to that value, where outflow equals inflow.

2. When the inflow rises by x %, the concentration can only rise by x % as well (in equilibrium, before even less).

Both statements seem to be dictated by logic, as long as the outflow really rises with concentration; and that seems to be warranted because the two main processes that accomplish this outflow, dissolution in ocean water and photosynthesis of plants, become stronger with increasing concentration.

As is well known and confirmed by measurements that the concentration of CO_2 has risen by 50 %. Statement 2 above demands that this only could have come about when the total emissions have also grown by 50 %. But anthropogenic emissions contribute only 5 %, far too small. It therefore looks as if increases in emissions from natural sources must have contributed the lion's share, whatever the cause. Anthropogenic releases just occurred simultaneously, probably purely by chance; they contributed but they have not been the main cause. But what then? Well, global warming has certainly contributed (solubility of gases in water, enhanced turnover of CO_2 in plants and animals), and other possibilities exist too, for example volcanoes, or shifting of ocean currents with different CO_2 concentrations. The necessity seems to be clear, but further research is needed to find out what the sources really are. However, it is certainly not necessary to fall back on the completely unknown for an explanation.

So much as a brief overview regarding the problem of origin, for more details see the cited literature. The conclusions drawn seem to be dictated simply by logic, but of course, there are also rejections in the literature. It’s only that I have not found any that disprove the considerations above. Maybe I just have overlooked them, but a thorough and unbiased review of these considerations seems to be

urgently needed. If it confirms the results found here, global warming is either caused by naturally released CO_2, or it is not caused by CO_2 at all, but rather by completely different triggers. In both cases, a reduction of the anthropogenic emissions of CO_2 makes little sense. If such a review can be carried out easily, it should be possible to finish it with minimum effort and in a short time, and if it is not so easy, it is all the more necessary.

4. Summary and Conclusion

The existence and the size of the greenhouse effect have been heavily disputed for decades, with only small chances of an agreement soon despite good arguments. As a remedy, a novel model is suggested: A row of bodies, one after the other, one end is kept constantly warm, the other constantly cold, the bodies between adjust their temperature freely. Then, another identical body is inserted into that row and the temperatures are observed. It is demonstrated that this model clearly proves the existence of the greenhouse effect, and it also allows a rough confirmation of the usually mentioned value of 33 °C for the size of the natural greenhouse effect by means of a completely new approach. As a consequence, this part of the discussion can hopefully be considered settled.

The question of how much we increase the global temperature by emitting *additional* CO_2 ("additional greenhouse effect") is more difficult to answer. Here, even the suggested model does not help much, because the uncertainties are too large. Even more so, because there are also doubts about the true origin of the recent increase in CO_2-concentration. Is it manmade or predominantly natural? This is mentioned here as an open question with some reasoning as to why it seems to be natural, but a detailed discussion goes beyond the scope of this paper.

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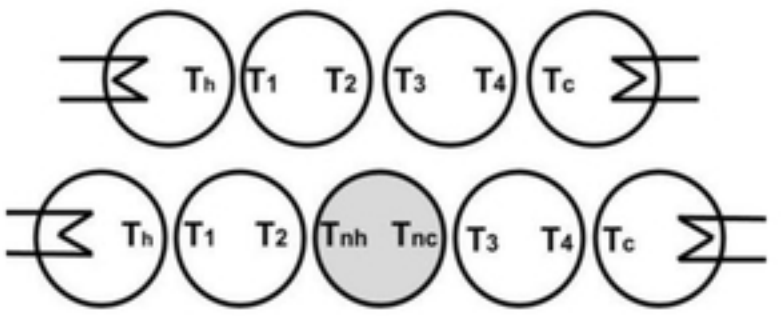

Figure