Physical and robust forecast of the climate

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Kurzfassung

Unser Klima ist ein Thema für alle. Deshalb sollte jeder in der Lage sein, den Klimawandel zu verstehen und nachzuvollziehen. Zu diesem Zweck entwickeln wir eine Reihe von Modellen für die zeitliche Entwicklung des Klimas. Auf diese Weise können diese Modelle schrittweise und in einem reibungslosen Lernprozess verstanden werden. Außerdem organisieren wir die Modelle so, dass eine robuste und überprüfbare Vorhersage möglich ist. Wir führen genaue Analysen durch, indem wir unsere berechneten Daten sorgfältig mit gemessenen Werten vergleichen. So kann jeder seinen persönlichen CO2-Ausstoß überprüfen und konkrete Maßnahmen ergreifen.

Abstract

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1. Introduction

Anthropogenic climate change is a change in global temperature caused solely by humans. From the beginning of industrialization until the year 2000, it increased by about 0.5 – 1.0 Kelvin (K). The Problem of the climate change is the leading to rising temperatures and is already causing noticeable effects such as extreme weather events, rising sea levels and changes in ecosystems. It is a global problem that urgently requires global solutions.

We want to show, that the climate change is a big problem und the temperature will rise in the next few years to levels, where these extreme weather conditions will cause serious issues.

The aim is to develop a generally comprehensible and verifiable core climate model based on the Stefan-Boltzmann law. Mathematical and model-theoretical approximations are necessary for every climate model. In the current project, these are systematically and robustly designed and presented in a comprehensible and verifiable way. We compare the calculations with measured values such as the Keeling Curve. We will also make optimizations by adding further greenhouse gases and feedbacks. A decisive aspect is the relevance in the context of current political and social global climate goals and includes the prognosis of how far these are in line with reality with our calculations. Achieving the climate targets of the Paris Climate Agreement is the minimum that we as the Earth's population must achieve to ensure that the Earth remains liveable and that we have sufficient living space to feed ourselves by preserving agricultural land. There is only one atmosphere for all the earth's inhabitants. It therefore makes no sense for only individual countries to agree and comply with climate agreements, as CO2 savings must be achieved as a whole. We will use transparent programming and presentation so that the modeling process is comprehensible. People without specific specialist knowledge can check their personal and social CO2 emissions and derive concrete measures for action. In this way, we not only want to draw attention to previously neglected savings measures, but also motivate people to change their everyday habits by rethinking. Various “CO2 footprint calculators” are already available on the Internet for this purpose, for example from the WWF or the Federal Environment Ministry of Germany.

2. The calculation of the climate

2.1. Calculations using the Stefan-Boltzmann law

The aim of us is to calculate the climate with natura and anthropogenic greenhouse effect in 4 models. We calculate these climate changes with the Stefan-Boltzmann law, see Carmesin et al. (2018, p. 160-167).

The Stefan-Boltzmann law says that a body with a temperature T emits thermal radiation, thereby the power density S is:

$S = \sigma \cdot T^4$ {1}

Sigma (σ) is the Stefan Boltzmann constant:

$\sigma = 5.67 \cdot 10^{-8}\ \frac{W}{m^2\,K^4}$ {2}

This new variant of the long-term calculation also allows us to determine the tipping point at which the temperature rises inexorably. For this tipping point not to occur, we must stay below 3 degrees of global warming.

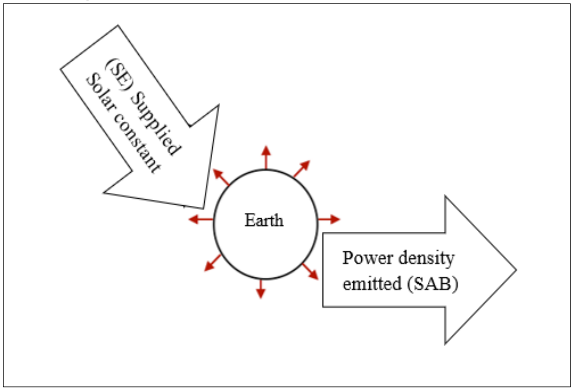


Fig. 1: Global radiation balance of absorption and emission: The Earth´s sun rays correspond to the supplied solar constant (S_E) = Power density of the sun´s rays. The energy radiated from the earth corresponds to the power density emitted (S_{ab})

The four models of the Stefan-Boltzmann law:

1. Earth without atmosphere
2. Earth with natural atmosphere and natural greenhouse gases
3. Earth with natural atmosphere, natural greenhouse gases, and anthropogenic greenhouse gases
4. Emission of CO2 in the coming years (with a solution approach)

2.2. **Overview of all models of the method:**

The following is a general overview of the models by first explaining all important measured data and then analyzing and calculating them. All four models refer to the Stefan-Boltzmann law, which forms a robust basis for my calculations.

Supplied solar constant = Power density of the sun's rays for the earth corresponds to $S_E = 1367\frac{W}{m^2}$

The power density emitted corresponds to $S_{ab} = 341.75\ \frac{W}{m^2}$ $S_E = 1367\frac{W}{m^2} : 4 = 341.75\ \frac{W}{m^2}$

Model 1: Earth without atmosphere

Emitted power density $S_{ab} = 341.75\ \frac{W}{m^2}$: temperature (T) = 5.48 C°

Model 2: Earth with a natural atmosphere

Typical emitted power density $S_{ab} = 391.75\ \frac{W}{m^2}$: temperature (T) = 15.16 C°

Model 3: The earth with a natural atmosphere ($391.75\ \frac{W}{m^2}$) out of model 2, plus the anthropogenic greenhouse effect ($2.7\ \frac{W}{m^2}$).

Emitted power density Sab = $391.75\ \frac{W}{m^2} + 2.7\ \frac{W}{m^2} = 394.45\ \frac{W}{m^2}$

Increase in temperature (T) = 0.5°C

These are the results for the first three models. We have decided to create a much more complex climate modeling in model 4.

3. **Complex physical and mathematical climate model with future forecast (model 4)**

The focus of our project will be the fourth model, we want to mark the focus on the climate forecast, which shows the CO2 emissions in the coming years and have a solution approach. In model four we will have a fusion of a physical model and a mathematical model.

3.1. **Application of the power series**

In climate modeling, the choice of mathematical method is crucial to adequately account for the complexity and diversity of climatic phenomena. While a Fourier series is often used to approximate periodic functions, when modeling the climate system or geophysical system, we encounter non-periodic phenomena that cannot be effectively described by a Fourier series, see Gönnert, et al. (2004). Therefore, the power series offers a more suitable alternative to model such non-periodic phenomena.

The power series provides a flexible approximation to non-periodic functions by using polynomials with arbitrary powers of the independent variables. This allows us to capture complex relationships between different factors, such as the course of temperature in the past, in a mathematically precise way and to model them in the future. In contrast, the Fourier series is limited to the representation of periodic functions and cannot adequately account for non-periodic variations in the climate system.

A central physical law, which is also of crucial importance in climate modeling, is the Stefan-Boltzmann law. This law describes the radiant power of a blackbody as a function of its absolute temperature. By using the power series in conjunction with the Stefan-Boltzmann law, climate models can provide a more realistic representation of the climate system and take into account complex phenomena such as the greenhouse effect and feedback mechanisms. By combining mathematical principles with physical laws, this approach allows us to model the climate system more accurately and comprehensively.

3.2. **Basics of the long-term forecast**

3.2.1. **Application of greenhouse gases**

The first model calculations were carried out using the global average of CO2 emissions (4.8 tons). We also included other relevant greenhouse gases for optimization purposes. Using the graph figure 2 from the Federal Environment Agency, see Federal Environment Ministry of Germany (2018), we calculated a percentage value for the individual other greenhouse gases. This source is a reliable and robust representation of global greenhouse gas emissions, but it was only available as a graph.

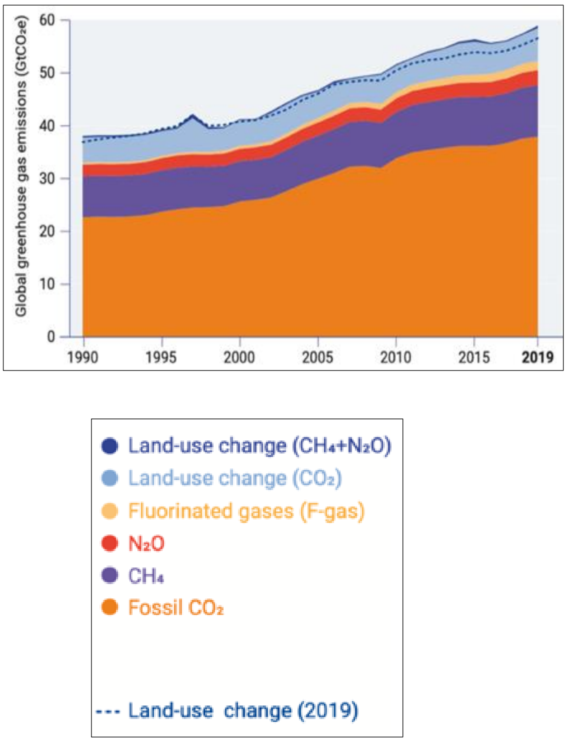


Fig. 2: Graphic from the Federal Environment Ministry of Germany. The graphic is a serious and robust representation of global greenhouse gas emissions.

We have therefore calculated our own percentage values for the individual gases, in which CO2 emissions represent 100%. By using a ruler as an aid and read off the graph in cm and converted it into a percentage using a calculator. Thus, we get a gas factor that reflects the other greenhouse gases. The gas factor of 1.5547 summarizes the five other relevant greenhouse gases and optimizes my long-term forecast. This is multiplied by the CO2 emissions, resulting in an average global CO2-equivalent emission of 7463 kg.

3.2.2. Application of the Keeling Curve

In the extensive Excel spreadsheet, we applied the Keeling Curve, an extremely fascinating and scientifically sound representation of measured data that has tracked CO2 levels in our atmosphere since 1959, see Earth observatory NASA (2005). This curve, named after the renowned scientist Charles David Keeling who created it, provides a remarkably accurate snapshot of changes in the concentration of carbon dioxide in our air. Its data is the centerpiece of the research and analysis, and we use it as the primary source for all "ppm" (parts per million) values, which describe the proportion of CO2 in the atmosphere in particles per million.

In addition to the continuity of the Keeling Curve, we also draw on a variety of other data sources to enrich my analyses. These sources include data from ice cores, which provide valuable insights into past climate conditions. From this data, we not only extract information, but also obtain key values such as the initial value for ppm (ppm_0), which represents the current CO2 content in the atmosphere.

Another important parameter that we derive is my factor, which is given as 1.0031. This factor represents the annual rate of temperature change and serves as a measure of the average annual temperature increase. It is of crucial importance for the analyses, as it is applied annually to the global average CO2-equivalent emissions. It is both multiplied and divided, especially when we retrospectively refer to.

The integration of all these different data sources and the consideration of parameters such as the factor and the ppm_0 value from the Keeling Curve allow me to examine complex relationships related to climate change in detail. Our analyses not only provide insights into past developments, but also forecasts for the future based on a solid scientific foundation.

3.2.3. Calculation of the temperature

This Excel program for climate prediction focuses on the calculation of the emitted power density (Sab) and the resulting temperature development. The temperature is calculated using the previously calculated emitted power density and the Stefan-Boltzmann law. The following formula applies:

$$T = \left(\frac{S_{ab}}{\sigma}\right)^{\frac{1}{4}} \qquad \{3\}$$

Therefore, σ is the Stefan-Boltzmann constant.

In summary, the visual comparison of the calculated temperature differences from the Excel program with the measured values shows that the model provides a plausible approximation of the actual climate changes. The graph illustrates the importance of such forecasting models for understanding global climate change and underlines the need for continuous monitoring and improvement of precision.

4. Methods, results and goal achievement

4.1. Goal achievement

The goal is to develop a comprehensible and verifiable climate model. We succeeded in doing this with the Excel spreadsheet for the long-term forecast and the resulting findings (point 4). We produced very accurate analyses by mathematical and physical modeling, taking into account robust laws of nature and measurement data that are precise and generally recognized in science. The data of the Keeling Curve, the Stefan-Boltzmann law and the addition of further greenhouse gases have been explained and incorpor ated in a comprehensible manner.

The results of this climate forecast reflect the goal of precise climate modeling. By creating a graph that compares the calculated temperatures from the Excel program of my long-term climate modeling with the actual measured values of the temperature, see Fig. (6), a remarkably small deviation from reality was achieved.

4.1.1. Problem

Mankind has existed for more than 4 million years and learns through experience. When a dangerous situation is suspected, neural areas are activated that activate people to protect themselves from them. These assumptions create problem solutions that start a learning process.

By resolving other similar situations, the brain stores successful behaviors as experience and can then recall them more automatically in the future because the synaptic connections required for this strengthen. At the same time, unsuccessful processes are forgotten again.

We will take these neural learning processes into account and apply them to the development of the climate forecast by first presenting the basic problem and then using a guess based on previous knowledge to check it, which will lead us to the solution. This method is called hypothetic deduction.

The basic problem now is that the following gap forms in our equation.

$C(t) \rightarrow \Delta S_{ab}(c) \Rightarrow \Delta T(t) = Climate\ forecast$

$\rightarrow: Power\ law$

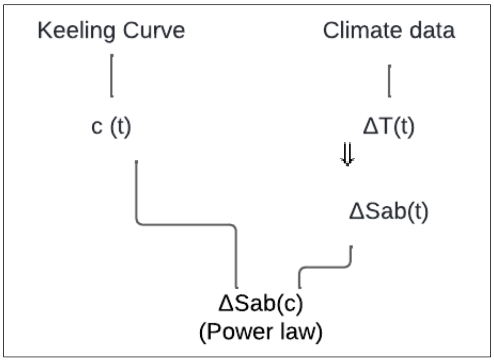
$\Rightarrow: Stefan - Boltzmann\ law$

Our power law, shown here in green, is uncertain and incomplete. Delta S is missing, so the equation is not complete, and the calculations have not yet been finalized. This completion of the equation is a crucial point for the climate forecast.

4.1.2. **Guess/Assumption (Flowchart)**

To solve the equation and find the missing delta S, we create a step-by-step method by calculating all the components for the equation. This is the representation of our assumption taking into account our previous knowledge.

This is a brief overview of the following method and the basic foundation of climate modeling. Here, the climate modeling method is explained step by step in a flowchart. Each step is then explained individually.



$\Rightarrow: Stefan - Boltzmann\ law$

$-: Regression$

Fig. 3: The flowchart

The flowchart shows the individual steps for developing the climate forecast. Starting from presenting the problem and developing a guess as to how a solution can be achieved, to checking our assumed solution approach as a regression and finally checking the solution. With this procedure, which is shown as a flow chart, we want to solve the problem mathematically and physically. We were stimulated by the physical laws of the tidal range of water levels as a function of time. We used a power law as a mathematical method. The Fourier series helps represent complex periodic phenomena but is replaced by the power series because the Fourier series does not take non-periodic aspects into account precisely enough.

With this method we assume that we solve the equation and thus develop the climate forecast.

$C(t) \rightarrow \Delta S_{ab}(c) \Rightarrow \Delta T(t) = Climate\ forecast$

$\rightarrow: Power\ law$

$\Rightarrow: Stefan - Boltzmann\ law$

4.1.3. **Verification as regression**

Now we performed the steps in the flowchart.

4.1.3.1 **Measured values 1959-2022**

This first calculation examines the relationship between the Keeling Curve, which represents the concentration of CO2 in the atmosphere in parts per million (ppm), and our calculated temperature data in degrees Celsius. The Keeling Curve, named after the American scientist Charles David Keeling, is a fundamental tool for monitoring CO2 concentrations in the atmosphere and is considered an important indicator of anthropogenic influence on climate.

We create a regression using the year 2000 as reference date and the value 369.55 ppm as reference value for CO2 (reference value depending on reference date).

$$c(t) = 0.0128t^2 + 1.8636t + 370.31 \qquad \{4\}$$
$$R^2 = 0.9995$$

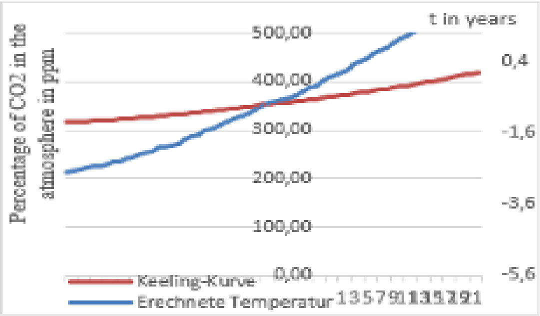


Fig. 4: Graphical representation of the measured values from 1959-2022 as a regression. The Keeling Curve (orange) is shown for comparison with the temperature we calculated (blue) from climate modeling

4.1.3.2 **Temperature anomaly**

Following the analysis of the Keeling Curve and its relationship to the temperature data, we examined the temperature anomalies in the period from 1959 to 2022. The year 1981 from the data from the German Weather Service DWD was used as a reference point and the temperature anomalies were calculated relative to this reference date, see German Weather Service DWD (2024). The reference value was set at 278.283 Kelvin to ensure a uniform basis for the analysis. The results of this analysis led to the derivation of a precise equation {5}.

$$\Delta T = 0.0002t^2 - 0.0112t + 0.0275 \qquad \{5\}$$
$$R^2 = 0.9465$$

This equation provides a fundamental basis for further investigation of temperature dynamics and helps to deepen our understanding of the mechanisms of climate change.

With the equation we have just found, which gives the delta of the temperature as a function of time, we can now continue our calculations using the Stefan-Boltzmann law. Using the temperature data given by equation {5}, we can calculate the power density Sab. We arrive at the delta of the power density Sab as a function of time.

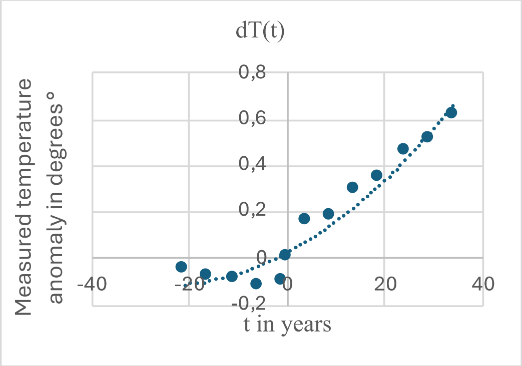


Fig. 5: Graphical representation of the temperature anomalies (x-axis) in the period from 1959 to 2022 (y-axis)

4.1.3.3 Power density and power series

Now that we have a data value for the CO2 concentration in each year (step 1) and a value for the temperature anomaly in each year (step 2), we can now form the unique power series. This says that the delta of the power density Sab is dependent on the CO2 concentration.
$\Delta S_{ab}\,(c) \rightarrow T(c)$
Now that we have the emitted power density as a function of the CO2 concentration see {6}, we can calculate the temperature as a function of the CO2 concentration. This is done with the Stefan Boltzmann law.

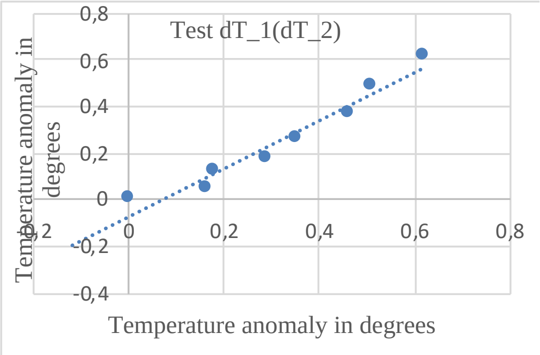


Fig. 6: Very good test regression in relation to the given initial data. On the y-axis we have the measured temperature anomaly in degrees and on x-axis we have the calculated anomaly in degrees.

Before we determine the power series, we test in graph (6) whether our previous calculations are accurate. We do this by comparing the two temperature anomalies in a regression. Since the regression value is close to 1, this is very accurate and we can now determine the power series in graph (6).
From the regression between the delta of the temperature and the CO2 concentration we get our equation {6} which forms the power series.

$$\Delta S_{ab} = 0.0002c + 0.0545c - 0.0646 \quad \{6\}$$
$$R^2 = 0.9989$$

This is the calculation basis that we use for the later climate forecast.
We now switch from regression as the basis of the calculation to the power series, as regressions are potentially erroneous due to their data-based nature.

4.1.4. Solving of the problem

By applying the method used in the previous section, we have now found the solution for the procedure and can now carry out a climate forecast
$C(t) \;\rightarrow\; \Delta S_{ab}(c) \;\Rightarrow\; \Delta T(t) = Climate\ forecast$
$\rightarrow: Power\ law\ (complete\ Solution)$
$\Rightarrow: Stefan - Boltzmann\ law$

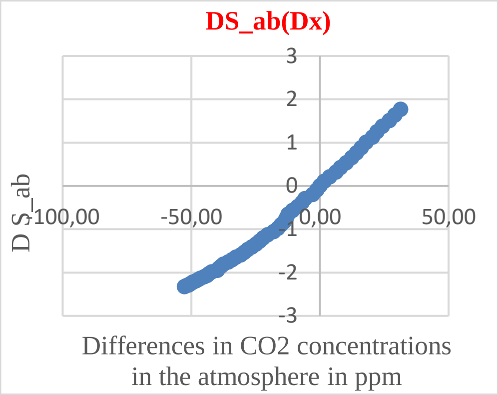


Fig. 7: We create a graph from the data values for the CO2 concentration and the difference from the power density in Watts per square meter and on the x-axis the difference in CO2 concentration in the atmosphere in ppm.

4.2. Graphical representation of target achievement (forecast)

Our aim is to develop a comprehensible and verifiable climate model. The model should be able to make precise climate forecasts for the future. By developing a mathematically and physically correct climate model, the years up to 2100 were modeled and thus a climate forecast was created. Graph (9) first shows the temperature development in the past (1959-2023) and then models the temperature change up to the year 2100. It can be seen that the 1.5 degrees limit will be exceeded in 2045 and thus compliance with the agreed 2 degrees target of the temperature increase of the Paris Climate Agreement, see United Nations, Collection of International Treaties: Paris Agreement (2020) will be broken. In 2100, the temperature increase will be around 3.7 degrees, which will have fatal consequences for humans and their environment.
Climate change, mainly caused by human activity, is leading to rising temperatures and extreme weather. Its consequences are manifold: rising sea levels threaten coasts, biodiversity loss endangers ecosystems, food shortages threaten, health risks increase and economic damage is significant. There is an urgent need to reduce our CO2 emissions and take adaptation measures to mitigate these consequences.

4.3. Solution

In this Solution, we present a climate prediction program developed to reduce the global temperature increase by simulating annual savings. Increasing global warming is one of the most significant challenges of our time. In order to tackle this phenomenon effectively, it is crucial to develop innovative solutions.

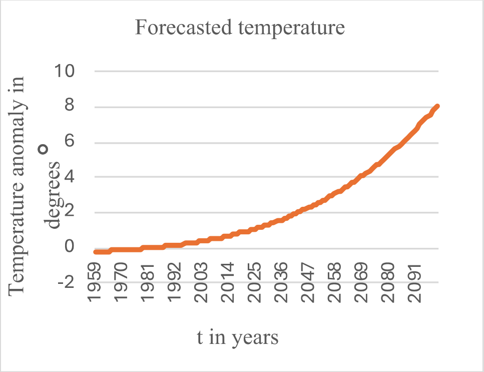


Fig. 8: Forecast temperature until 2100. On the y-axis we have the temperature in degrees Celsius and on the x-axis the time in years.

4.3.1. Solution approach 1: Temperature behavior without greenhouse gas savings

Our approach is based on a specific factor that can simulate annual savings. This factor is 1.0031 if no greenhouse gases are saved per year. This factor is derived from the trend of the Keeling Curve.

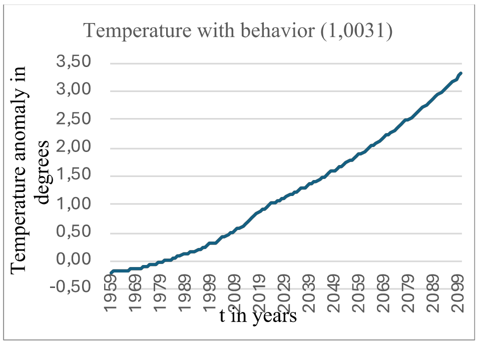


Fig. 9: Temperature behavior without greenhouse gas savings (3.1‰). On the y-axis we have the temperature in degrees Celsius and on the x-axis the time in years.

4.3.2. Solution approach 2: Temperature development, with yearly savings in all greenhouse gases

By being able to manually adjust the factor, we can now model the climate forecast by taking annual savings into account. As an example of such an adjustment of the factor, we consider the transition from the normal state (1.0031) to the factor 1.001, which corresponds to an annual saving of 2.1 per thousand.

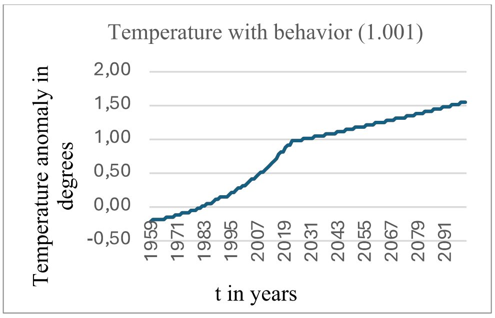


Fig. 10: Temperature behavior with greenhouse gas savings from 1 per million every year. On the y-axis we have the temperature in degrees Celsius and on the x-axis the time in years.

5. Didactic concept

The limitation of climate change is a present – day key topic (Klafki 1993). However, the decision makers in most institutions failed to achieve an effective limitation of carbon dioxide emissions. As a consequence, the permanent increase of the average temperature of the atmosphere is not limited. This ineffectiveness is especially clear, as the fact of the anthropogenic climate change by carbon dioxide emissions is known for more than 100 years, see Arrhenius (1896).

Thus, the limitation of climate change requires a broader basis: In the topic of climate change, most individuals should be able to distinguish facts from mere opinion or even fake news. For it, most individuals should be able to trace the arguments and calculations of a robust climate model. For it, most people should take part in the enlightenment, see Kant (1784), in order to overcome their immaturity, at least in the topic of climate change.

For it, a robust model has been developed, in which students can trace all steps from the only used nontrivial physical law, the Stefan Boltzmann law, to the calculation of anthropogenic climate change, see Carmesin et al. (2018). Thereby, in addition, the students can confirm the robustness of the result. In order to understand the economic mechanisms underlying climate change, mathematical game theory, including Nash equilibria, has been used as a basis for a climate game, see Carmesin and Rumpel (2019). With it, students can discover the essential economic effects and they can calculate the respective Nash equilibria.

In this paper, we improve the robust climate model, so that a robust forecast becomes traceable and calculable for most individuals.

6. Experience with teaching

The robust model has been tested in physics courses in classes 10 or 11.

In the first 90 minutes, IR radiation is explored experimentally, and the power density

$$S = \frac{P}{A}$$

is introduced. This lesson is valuable, as it provides many applications and a useful basis for the following.

In the second 90 minutes, the Stefan Boltzmann law is discovered experimentally, and the Stefan Boltzmann constant is measured. For it, a thermometer is used, see Carmesin et al. (2018), or an IR camera is applied. This lesson is insightful, as it shows a universal source of radiation, in contrast to particular radiation emitted by atoms and molecules.

In the third 90 minutes, radiation equilibria are investigated experimentally and theoretically, see Carmesin et al. (2018). This lesson provides a robust, useful and confirmed concept of equilibria underlying local and global climate.

In the fourth 90 minutes, the climate is derived for several planets without considering the atmosphere. Hereby, also the habitable zones of extrasolar planets are explored. This lesson provides a robust, empirically confirmed and extendible concept of climate models.

In the fifth 90 minutes, Wien’s displacement law is discovered experimentally. This law is essential for the greenhouse effect.

In the sixth 90 minutes, the natural greenhouse effect of Earth is derived and investigated. This lesson provides a confirmed and clarifying concept of the realistic climate at Earth.

In the seventh 90 minutes, the anthropogenic climate change is derived and explored. This model is enlightening, as it provides a deep and robust understanding of climate change.

In the eighth 90 minutes, the students calculate climate forecast. For many students, this lesson is still surprising, as it shows how fast the temperature increases and the climate changes. This founded realization causes consternation by some students.

In the ninth 90 minutes, solutions of the climate change based on solar power are explored, see Carmesin (2009), Carmesin, Martens, Rösler (2012).

In the tenth 90 minutes, solutions of the climate change based on wind energy are explored, see Carmesin et al. (2017, page 52).

When the topic is taught at this pace, the students are enabled end enlightened in the topic of anthropogenic climate change. The examination at the end of this teaching unit regularly showed good results. In order to explore economic mechanism underlying climate change, a climate game can be played additionally.

7. Didactic concept for cyber space

The project aims to provide learners with a basic understanding of the links between their individual behavior and global climate change. Through the use of interactive and customizable climate modeling, learners can simulate their own CO2 emissions based on personal behaviors and observe the impact of these choices on the climate. This allows learners to visually and quantitatively understand the direct consequences of their actions on the environment, promoting a change in climate-damaging behavior through reflection.

This project is particularly valuable didactically because it breaks down abstract concepts of climate change to a tangible, personal level. Instead of viewing climate change as a distant, global problem, the simulation allows learners to experience the direct link between their everyday lives and the resulting climate changes. The interactive nature of the simulation encourages active learning, enabling learners to gain knowledge independently through experimentation and observation. Furthermore, reflecting on the results deepens understanding and encourages learners to adopt more sustainable behaviors in their own lives.

By combining theoretical knowledge with practical application and reflection, this project serves as an effective didactic method for raising awareness of climate change and promoting behavior change. It enables learners not only to acquire knowledge, but also to see themselves as active contributors to a more sustainable future.

8. Summary of the results

Through the publication on my homepage http://jannesvonbargen.de and various public lectures, including at school events and poster presentations at the German Physical Society (DPG), It is possible to present these calculations. This means that anyone, even without in-depth specialist knowledge, can understand and try out the necessary savings in general CO2 emissions for our planet.

We created a transparent programming and presentation. This means that anyone can check their personal and social CO2 emissions and derive specific measures for action. The total savings targets can be transferred using “CO2 footprint calculators”, for example from the WWF or the Federal Environment Ministry of Germany, and a change in your own everyday habits can be derived from this. The comparison to check climate modeling in relation to current political and social global climate goals is of crucial importance.

The results of the recently concluded World Climate Conference in Dubai and the Paris Climate Agreement should become verifiable through this modeling to what extent agreed targets are in line with reality. Achieving the climate targets of the Paris Climate Agreement is the minimum that we as the Earth's population must achieve to ensure that the Earth remains livable and that we have sufficient living space to feed ourselves by preserving agricultural land.

There is only one atmosphere for all the earth's inhabitants. It therefore makes no sense for only individual countries to agree and comply with climate agreements, as CO2 reductions must be achieved as a whole.

Continuing from the dissemination efforts and implications of this calculation, it is imperative to underscore the broader societal implications of climate modeling and carbon reduction efforts. By democratizing access to climate data and empowering individuals to actively engage in emission reduction measures, we lay the foundation for collective action towards a sustainable future.

The comparison between the outcomes of climate modeling and the global climate goals outlined in significant agreements such as the Paris Climate Agreement and the results of events like the World Climate Conference in Dubai serves as a crucial checkpoint for assessing progress and ensuring accountability. Verifying the alignment between modeled projections and real-world outcomes not only enhances the credibility of climate science but also informs policy decisions and shapes international cooperation in combating climate change.

Furthermore, the imperative of achieving the targets set forth in international climate agreements cannot be overstated. These targets serve as a baseline for collective action aimed at preserving the habitability of our planet and ensuring the availability of essential resources such as agricultural land. Recognizing the interconnectedness of global climate systems underscores the necessity for comprehensive and coordinated efforts towards emission reduction on a global scale.

The didactic concept focuses on enabling individuals to distinguish facts from opinions through a robust climate model based on the Stefan-Boltzmann law and game theory to understand economic impacts. In experience with teaching, a ten-step lesson plan leads students through experiments and theory to grasp climate change and explore solutions like solar and wind energy. The didactic concept for cyberspace uses interactive simulations to link personal behaviors with climate impacts, promoting active learning and sustainable behavior.

In conclusion, the pursuit of climate targets outlined in global agreements necessitates a paradigm shift towards collective responsibility and action. By bridging the gap between climate modeling outcomes and real-world implications, we pave the way for informed decision-making and concerted efforts towards a sustainable future for generations to come.

9. Literature

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