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Uncertainty of climate models and policy implications: A European perspective

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Abstract

In this paper we show that both climate models and economic models studying the effects of climate change are characterized by high uncertainty. Hence, far reaching policy implications such as the net zero goal lack a definite scientific foundation. Neverthelss, it cannot be excluded that the continued global warming will go along with high damages in the future. Therefore, decreasing greenhouse gas emissions could be justified due to the precautionary motif. However, there are strong signals from non-European economic regions that they definitely put a higher weight on economic growth rather than on greenhouse gas mitigation. Since reductions in the European Union cause tremendous costs without influencing the climate on earth, the net zero goal of the New Green Deal of the European Union is to be seen sceptical.

Keywords: Climate models, uncertainty, economic policy
JEL: Q54, Q58

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1 Introduction

The satellite based measurements of the temperature of the lower troposphere indicate that the rise of the average temperature on earth has been between 0.15 and 0.22 °C per decade since 1979 when the satellite based measurements started.[1] One reason for that development is very likely the accumulation of greenhouse gases (GHGs) in the atmosphere, like carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4), just to mention the most important ones. For example, the concentration of CO_2 rose from about 336 ppm in 1979 to 420 ppm in 2024.[2]

It is well known that a rising GHG concentration in the atmosphere increases the back radiation giving rise to a higher average surface temperature of the earth. The quantitative effect of a rising GHG concentration can be determined with the help of climate models. The simplest model is a zero dimensional one with the earth as a point in space and where the climate system is modelled in terms of its energy balance (see Greiner and Semmler, 2008, p. 60-62). More complex models take into account the interactions between the atmosphere, the land surface and the oceans among others. But, already the zero dimensional model makes it clear that the numerical values of the parameters in the equations play a vital role as regards the sensitivity of the climate with respect to the GHG concentration. The numerical values of some parameters are known, such as the Stefan-Boltzmann constant for example, while others are uncertain or even non-observable (cf. Mauritsen et al. 2012) which represents one source of uncertainty. Climate change may also go along with economic damages, in particular if it causes more extreme weather events. Hence, it is not only the natural environment that will be affected, but, the economic system could be impacted, too. Therefore, it could be rational to reduce GHG emissions although this causes non-negligible costs to society.

At the 21st United Nations Climate Change Conference in 2015 196 parties adopted the so-called Paris Agreement that pursues the goal of limiting the temperature increase to at most 2 °C (cf. United Nations, 2015). To achieve that aim the parties have agreed to reduce net emissions of GHGs to zero in the second half of this century, i.e. to reach a

[1] See https://www.nsstc.uah.edu/climate/2024/March/GTR_202403MAR_v1.pdf (accessed 20.04.2024) and https://images.remss.com/msu/msu_time_series.html (accessed 20.04.2024).

[2] See https://gml.noaa.gov/ccgg/ (accessed 20.04.2024), ppm denotes parts per million, i.e. 10^{-6}.

balance between emissions by sources and removals by sinks (net zero). Although legally binding there are no sanctions in case countries fail to reach the net zero position (see United Nations, 2015, Art. 15). This objective should always be considered ahead of the current level of knowledge regarding the climate. In order to comply with the Paris Agreement, the European Union (EU) passed the New Green Deal in which it states that the net zero goal is to be achieved by 2050 in the EU.[3]

The climate system of the earth is an extremely complex system and has by far not yet been completely understood. Consequently, models representing the climate system of the earth are necessarily subject to uncertainties. The same holds for economic models that intend to study the economic effects of climate change. In this paper paper we want to highlight those uncertainties and its implications for policy. In particular, we argue that far reaching policies that go along with huge costs need a sound scientific basis which is not the case when the underlying models are highly uncertain.

The rest of the paper is organized as follows. Section 2 gives a brief survey of how climate models are set up and points out the sources of uncertainties underlying those models. Section 3 illustrates the uncertainty that characterizes economic models analyzing the impacts of global warming, and section 4 shows the implications for policy resulting from those uncertainties. Section 5, finally, concludes the paper.

2 Uncertainty of climate models

Climate models are large computer programmes that simulate the climate of the earth. Global climate models (GCM) are divided into modules that model the atmosphere, the ocean, the land surface, the sea ice and glaciers. The modules are described by mathematical equations that represent the oceanic circulation and the heat transport within modules and the exchange with other modules. To solve these equations GCMs partition the earth into a three dimensional grid system, where each cell of the grids consists of a certain horizontal and vertical length. The equations, then, are solved for each cell of the grid for a certain time period (see e.g. Curry, 2017, p. 1 and Meinshausen et al., 2011, for a detailed depiction of a GCM including the mathematical equations).

[3] See https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en (accessed 20.04.2024).

GCMs are partly based on well-established physical laws and partly on heuristic methods that approximate the unknown process (see for example Hourdin et al., 2017). These processes are represented using parameterisations. These parameterisations are tuned to improve the match of the GCM to historical observations. When a model configuration is fixed, tuning consists of choosing the parameters of the model in a way such that a certain measure of the deviation of the model output from selected observations is minimized. But, proceeding like that helps to mask structural errors or deficiencies of the climate models and climate modellers are well aware of that problem (see Mauritsen et al., 2012, p. 14 and Hourdin et al., 2017, p. 591).

One of the few well-established facts in the climate science is that a rise in the greenhouse gas concentration in the atmosphere of the earth increases radiative forcing, leading to higher temperatures with the relation described by an approximately linear relationship. However, the radiative forcing of the main GHGs, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), is a strictly concave function of the GHG concentration. For example, for CO_2 it is given by the natural logarithm of that GHG relative to the pre-industrial level and all other GHGs can be converted into CO_2 equivalents, see Greiner and Semmler (2008, p. 61), and for more details the natural science literature cited there. In 2016, Etminan et al. (2016) demonstrated that for very high values of the GHGs, the relation changes. But, the basic form remains the same, i.e. for CO_2 it is given by the natural logarithm and for N_2O and CH_4 by the square root. This implies that the temperature does not rise linearly with a rising GHG concentration as erroneously stated by SRU (2019, p. 36), but, the increase is smaller the higher the GHG concentration is. However, even if there is very strong evidence that the accumulation of GHGs raises the average surface temperature on the earth (see e.g. Arias et al., 2021), it must be stated that the climate system is an extremely complex system such that there is strong uncertainty as regards its sensitivity with respect to higher GHGs.

There are two fundamental sources of uncertainty regarding climate change. First, natural phenomena may be poorly understood so that their modelling may be difficult. An example is provided by cloud formation that is difficult to reproduce. Thus, Stevens and Bony (2013, p. 1054) state: "There is now ample evidence that an inadequate representation of clouds and moist convection, or more generally the coupling between atmospheric water and circulation, is the main limitation in current representations of the climate system.". Recent studies support that view because the feedback effects of clouds that exert a strong effect on the climate have not yet been completely understood and give rise to strong uncertainties in climate models (see for example Mülmenstedt et al., 2021, Furtado et al., 2023, Goren et al., 2023, Hill et al., 2023). Vogel et al. (2022) refute an important argument for a high sensitivity of the climate to variations in GHGs. They detect that the feedback effect of a larger GHG concentration is much smaller than assumed in those climate models that predict a high temperature rise. The reason for that result lies in the fact that real-world observations suggest that a weak trade cumulus feedback, i.e. cloud feedback, is more plausible than a strong one. Another source of model uncertainty is given by the unpredictability of volcano eruptions and by the complexity of processes linking the eruption to the climate response (cf. Chim et al, 2023, and Zanchettin, 2023). Further, some authors argue that GHGs receives too high a weight in climate models, while natural factors receive too little attention, see e.g. Gervais (2016), Ollila (2017), Lightfoot and Mamer (2017), Stefani (2021), Kim et al. (2022), Omrani et al. (2022), Connolly et al. (2023). Smirnov and Zhilyaev (2021) state that the greenhouse effect of CO_2 is heavily overestimated in climate models since those models do not take into account the thermodynamics of the atmosphere and radiation field. Thus, they ignore the Kirchhoff law (Kirchhoff, 1860) pointing out that radiators are absorbers at the same time.

The second source of uncertainty is of methodological nature. Lewis (2023) reanalysed the influential contribution by Sherwood et al. (2020) cited in the Intergovernmental Panel on Climate Change (IPCC) 6th assessment report that reports a likely range (34-66%) of 2.5-4.0 °C with respect to the equilibrium climate sensitivity (ECS)[4] (see Chen et al., 2021, p. 183, table 1.2). In Sherwood et al. (2020) the likely range (34-66%) of the ECS amounts to 2.6-3.9 °C, the very likely range (10-90%) is 2.3-4.7 °C and the median of the temperature increase is reported as 3.1 °C. Those results were obtained with a Bayesian statistical method where the prior distribution was subjectively selected by the investigator. Lewis (2023) resorted to an objective Bayesian method with computed, mathematical priors and obtained a median of 2.16 °C and a 17–83% range of 1.75–2.7 °C and a 5–95% range of 1.55–3.2 °C. This demonstrates that an objective Bayesian method

[4] Roughly speaking the ECS gives the increase of the average surface temperature due to higher GHGs in equilibrium.

yields a lower ECS and the confidence intervals are clearly smaller.[5] Uncertainties in GCMs also arise from model parameters and from initial conditions[6] (see Curry, 2017). As mentioned above tuning is used in order to find parameter values that are not known. However, performing continuously ad hoc adjustments of parameters may mask structural deficiencies in GCMs as already pointed out.

The climate system of the earth is a highly complex system and as with all complex systems there exist so-called "unkown unknowns" and "unknown knowns". With "unkown unknowns" one denotes effects that exist, but, that are not yet known so that their repercussions on the climate system can of course not be determined. An example for that is the degradation of methane that is set free by melting permafrost soils. That methane released is reduced almost to zero in the long-run by plant cover and microbial communities so that its effect on the climate is smaller than previously thought (cf. Keuschnig et al., 2022). With "unknown knowns" one refers to phenomena that are known, but, the effects of which have not yet been completely determined. Two examples are provided by the Gulf Stream that is assumed to be affected by a climate change, possibly up to a complete collapse (see Fox-Kemper et al., 2021, S. 1320-21), and by volcanos the activities of which are difficult to represent in climate model projections.

These considerations show that climate models are subject to uncertainty. That result is underlined by some problems associated with GCMs. Irving et al. (2021) demonstrate that models of the Coupled Model Intercomparison Project Phase 5 (CMIP5), resorted to by the IPCC for its 5th assessment report published in 2013/2014, do neither conserve mass nor energy. This implies that they violate the first law of thermodynamics, a fundametal principle in physics. As regards CMIP6 models these have improved in some respect, e.g. as to the net top-of-the-atmosphere (TOA) radiation, but are worse for time-integrated ocean freshwater and atmospheric moisture fluxes or little changed regarding ocean heat content, ocean mass, and time-integrated ocean heat flux, while closure of the ocean mass and energy budgets after drift removal has improved. Frank (2019) detects that CMIP5 models produce a systematic calibration error in simulated tropospheric thermal energy flux. Similar to that Olonscheck and Rugenstein (2024) show

[5] Further, there is a coding error in Sherwood et al. (2020) that, however, does not affect their main results (cf. Lewis, 2023, p. 3162).

[6] See Deser et al. (2020, p. 281) how initialization is performed in climate models.

that climate models underestimate the observed global TOA radiation trend for the period 2001-2022. Models that represent the TOA radiation better are characetrized by a relatively low ECS.

To evaluate the performance of GCMs the model output can be compared to data obtained from the measuremnet of real world observations. An important role plays the ECS and the transient climate sensitivity (TCS). For example, Lewis and Curry (2018) demonstrate that both the ECS and the TCS of the majority of CMIP5 models do not match the observed warming during the historical period. McKitrick and Christy (2018) compare the model projections of CMIP5 models with the actual temperature of the troposphere in the tropics and reach a similar conclusion. They demonstrate that most of the models are characterized by a significant and large warm bias in that layer. That problem still holds for most of the CMIP6 models. Voosen (2022) cites a U.N. report stating that many climate models predict temperature increases that are not compatible with actual temperature measurements. Therefore, the results of studies that predict drastic effects and that resort to some of the next-generation climate models that forecast a fast rise of the surface temperature should be considered with care. He proposes to switch from a "model democracy" to a "model meritocracy" when projections regarding climate change are made.

Another paper has been presented by Scafetta (2023) who analyses 38 models from the CMIP6 and divides them in 3 subgroups, a subgroup forecasting a low ECS, a subgroup with a medium ECS and one consisting of models predicting a high ECS. He detects that only the models of the low subgroup can replicate the surface-based temperature increase between 1980-1991 and 2011-2021, while none of the models is compatible with the satellite-based temperature record of the Earth System Science Center at the University of Alabama in Huntsville (UAH). McKitrick and Christy (2020) find that the bias in CMIP6 models does not only occur for the troposphere in the tropics, as with CMIP5 models, but that it is observable globally as well in CMIP6 models and not only in the tropics. Regarding precipitation, Vrac et al. (2023) examine whether CMIP6 models are able to correctly simulate changes in the temperature-precipitation correlations as a result of global warming and find that those models fail for the period 1980-2019 and are biased. They suggest that the models should not only be improved as regards their ability to forecast univariate variables, such as the temperature, but with respect to multivariate biases, too.

McCarthy and Caesar (2023) analyse whether the ensemble of CMIP5 and CMIP6 models can replicate the Atlantic Meridional Overturning Circulation[7] (AMOC) that is a crucial element of the climate system of the earth. They demonstrate that both the magnitude of the trend in the AMOC over different time periods and often even the sign of the trend differ between observations and climate model ensemble mean. The authors, then, ask whether one can trust AMOC projections of models that cannot replicate the past. In addition to that, one could wonder how reliable model projections of the entire climate system of the earth are if those models are not capable of replicating the evolution of an important subsystem of the climate.

Those considerations show that climate models are subject to quite a large degree of uncertainty. Therefore, the statement that there exists a certain concentration of GHGs that must not be exceeded to limit global warming to 2 °C should be considered with caution or even with scepticism from a scientific point of view.[8] Probalistic statements such as a doubling of GHGs leads to a certain temperature rise with a specific probability does not improve the situation either since those statements are based on the validity of the underlying model that by itself is subject to uncertainty.[9] Climate models suggest a degree of knowledge and precision they cannot deliver due to the uncertainty inherent in GCMs.

3 The economics of climate change

The last section has shown that the are many sources of uncertainty in GCMs. Nevertheless, the measured increase in the average temperature of the lower troposphere since 1979 is real and global warming may go along with reduced economic growth due to damages as a result of more extreme weather events. That holds although it must be stated that the empirical evidence for more extreme weather is small or even non-existent, except for heatwaves (see Ranasinghe et al., 2021, p. 1856, table 12.12, column 3, Alimonti and Mariani, 2023, Zhang et al., 2023, and similar Lomborg, 2020). The adaptation to a changed

[7]The Gulf Stream is a part of the AMOC.

[8]That goal has no scientific basis and was set more or less arbitrarily, see Jaeger und Jaeger (2011).

[9]See Meinshausen et al. (2009) for a clear representation of how such a probability distribution is derived.

climate may require resources that cannot be used for investment and, consequently, can affect economic growth.

There exist quite a many empirical contributions analyzing the impact of climate on economic activity and output. A survey of approaches can be found in Kolstad and Moore (2020), for example. But, as with climate models economic models may be subject to uncertainty that is still larger than for the climate models which is reflected by the wide range for the estimates of climate related damages. For example, Newell et al. (2021) resort to cross validation to evaluate 800 model specifications where they use GDP growth and, alternatively, the level of GDP as the dependent variable that is explained by the temperature, by the change of temperature, by precipitation and by time fixed effects and by country-specific time trends. They detect that the models go along with large uncertainties which is reflected by the fact that the 95% confidence interval for GDP impacts in 2100 ranges from losses of 84% to gains of 359%. GDP level models imply less uncertainty and have a smaller 95% confidence interval between -8.5% and +1.8%, centered around losses between 1-3%.

Large uncertainties, however, raise the question of how reliable and valid the model results are. As regards that problem Leamer (1985, p. 308) states that "We must insist that all empirical studies offer convincing evidence of inferential sturdiness. We need to be shown that minor changes in the list of variables do not alter fundamentally the conclusions, nor does a slight reweighting of observations, nor correction for dependence among observations, etcetera, etcetera.". In particular, when the model results form the basis for policy recommendations that go along with tremendous costs, this is of utmost importance in order to avoid huge welfare losses.

Barker (2022, 2023, 2023a) describes three examples where he points out that methodolgical flaws in the studies he reanalyses give rise to wrong conclusions. The frequently cited paper by Dell et al. (2012) e.g. regresses growth on temperatures and finds a causal relationship between them in which higher temperatures reduce economic growth. Barker (2023a) argues that the latter paper uses an unacceptable method of classifying countries by income and using a different and more plausible method makes their results disappear. Further, their results are influenced by a small number of observations with unusual characteristics and by arbitrary methodological choices. When alternative data are used, the result that a higher temperature reduces economic growth cannot be confirmed. Thus, the paper by Dell et al. (2012) is misleading and cannot serve as an argument for negative growth effects resulting from global warming.

Besides methodological problems in empirical studies relating economic growth to climate change the problem of missing variables arises. Often such studies resort to climatic variables as regressors only, such as temperature, change of temperature, precipitation, and neglect economic variables at all that have turned out to be important in explaining economic growth. Even if that problem can be overcome technically in fixed effects panel regression models by introducing dummies, as noted in Kotz et al. (2021, p. 326) for example, the question regarding the theoretical foundation of those models remains open. The philosopher Kant stated that theory without empirics is empty and empirics without theory is blind, "Gedanken ohne Inhalt sind leer, Anschauungen ohne Begriffe sind blind." (Kant, 1787, p. 91).

In addition, neglecting economic variables as regressors in the equation to be estimated ignores all the knowledge that has been gained since econometric methods have been resorted to in research on economic growth. That line of research started in the 1950's with a seminal paper written by Solow (1957) who implicitly builds on Tinbergen (1942) who was the first to integrate a time index in the aggregate production function. In particular, in the 1990's many efforts have been made to identify robust variabels in explaining economic growth (see e.g. Levine and Renelt, 1992, and Sala-i-Martin, 1997). More recently, Bruns and Ioannidis (2020) analyse whether the forces of economic growth change over time or whether they remain unchanged independent of which time period is considered. Greiner et al. (2023) apply panel estimation techniques and find that climatic variables are not robust in explaining economic growth in European economies from 2002-2019, whereas institutional and macroeconomic control variables, such as the rule of law, the fiscal variable and the output gap, are statistically significant and the relation is robust. Those authors apply panel fixed effects and GMM estimations and estimate 42 specifications with different control variables with one, three and five year growth rates of GDP as the dependent variable.

Our considerations up to now have demonstrated that both climate models and economic models analyzing the growth effect of climate change are characterized by possibly large uncertainties. In the next section we deal with policy implications of that outcome.

4 Policy implications

As concerns the axiomatic foundation of economic policy we assume a utilitarian perspective as pioneered by Bentham (1789). Hence, the goal of the government should be to maximize welfare in the society with welfare being a function of utility of individuals. As this is a rather abstract goal, it needs to be operationalized in order to be applied to real economies. In Germany, for example, this is done in § 1 of the Act to Promote the Stability and Growth of the Economy (Gesetz zur Förderung der Stabilität und des Wachstums der Wirtschaft)[10], where economic and fiscal policies should lead to a stable price level, to a high level of employment and to an external balance with steady and appropriate economic growth. When it comes to evaluate specific projects at the disaggregate level, a policy measure is beneficial if the Kaldor-Hicks criterion is fulfilled, i.e. if its benefits exceed its costs.

In the last sections we have seen that climate models are subject to high uncertainty. The same holds for economic models dealing with global warming. In particular, there is no robust evidence that climate change has reduced economic growth in European economies. Therefore, it is hard to justify costly policy measures aiming to decrease GHG emissions in the EU from a scientific point of view. The reason for this outcome is that those policies cause tremendous costs, implying a loss of welfare according to the Kaldor-Hicks criterion which is supported by Tol (2023), for example, who points out that the costs of meeting the targets set out in the Paris Agreement exceed the benefits unless the risk aversion is large and the discount rate is small. As regards the EU, Tol (2021) states that the total costs of reducing GHG emissions exceed their benefits by a factor of ten.

Nevertheless, it cannot be excluded that damages of global warming increase and catastrophic events cannot be excluded either when the greenhouse gas concentration in the atmosphere continues to rise, even if the empirical evidence for that up to now is small as pointed out in the last section. Therefore, from a precautionary point of view it may be rational to reduce GHG emissions to zero by the mid to end of the century. However, such a policy will affect the climate on earth only if the world cooperates and all large countries aim for that goal. But, there are serious signals that this does not hold and,

[10] See https://www.gesetze-im-internet.de/stabg/BJNR005820967.html (accessed 20.04.2024).

in particular, developing and emerging countries put more emphasis on economic growth than on environmental concerns.

The African Energy Chamber (AEC) declared that African producers of oil and gas are strictly against a phase-out of fossil fules and they would agree to a phase-down only if their economic development allows to do so (cf. AEC, 2023). The reason for that is that oil and gas play an instrumental role in the development of African economies. The Indian government declared that it intends to raise the use of coal for energy production from currently 0,821 billions of tons per year to 1,404 billions by 2025 and to 1,577 billions by 2030 (see TOI, 2023). China made clear that China alone determines how fast the country tackles the challenge of global warming and its policy will not be influenced by other countries (cf. Shepherd et al., 2023). The G20 countries declared that they intend to support the production of carbon-free energies, but, they could not reach an agreement regarding the phase-out of fossil fuels (see Arasu, 2023). Finally, Russia announced that it opposes any plans to stop the use of fossil fuels in principle (cf. Mooney und Williams, 2023). Therefore, it is to be expected that the GHG concentration will continue to rise, independent of any measures taken by EU countries, since EU GHG emissions make only about 8% of world wide emissions (see Pritzl and Söllner, 2021).

Consequently, it is very doubtful whether the policy measures aiming to reduce GHG emissions in Europe, the costs of which amount to trillions of euros, yield welfare gains. This holds because the resources spent, although formally investments, do not necessarily raise the productive capital stock and, consequently, not future production possibilities. Therefore, not only the current generation is worse off but future generations, too, since they cannot profit from higher production possibilities, on the one hand, and the climate on earth will not be affected, on the other hand. Future generations in Europe will be confronted with great challenges since they will have to cope with quite a many problems such as the lack of a qualified workforce, high government debt, an increase in the percentage of elderly people and possibly necessary measures to adapt to the climate change, just to mention a few. Only if future generations dispose of sufficient economic and technical means they can meet those challenges. But, mastering those challenges would require huge investments in factor augmenting technical progress and in a growing capital stock already now. That, however, is not the case because a large amount of the resources is spent for GHG reducing policies. This clearly illustrates that the opportunity costs of

GHG reducing measures are enormous. In addition to that it should be pointed out that a couple of policy measures of governments that aim to reduce GHG emissions are highly inefficient (see e.g. WBBMWA, 2004, EFI, 2014, p. 52, Schmalensee and Stavins, 2017, Greiner, 2024). These considerations make clear that, from an economic point of view, it is difficult to justify the net zero goal of the EU New Green Deal that intends to reduce net GHG emissions in the EU to zero by 2050.

5 Conclusion

In this paper we have shown that both climate models and economic models analyzing the effect of global warming are characterized by high uncertainty. In particular, there is no robust evidence that global warming has negatively affected economic growth in Europe so far.

Nevertheless, it cannot be ruled out that negative effects of climate change will occur in the future. But, strong signals from other countries suggest that those definitely put a higher weight on economic growth rather than on reducing greenhouse gas emissions. Consequently, unilateral measures in the European Union will have no effect on the climate on earth, but, only require resources that can neither be used for investment in factor augmenting technical progress nor for raising the aggregate capital stock. That would be of utmost importance for Europe due to the many challenges this continent has to face already now and even more in the future.

Further, from a welfare theoretic perspective the net zero goal is to be rejected because it makes this goal an ultimate goal serving as an end in itself instead of maximizing welfare of current and future generations of people. Therefore, the net zero goal of the EU New Green Deal is to be seen sceptical.

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