CO₂ emissions and climate - nature's prospect on Green Growth

Thomas Anderl (✉ thomas.anderl@hotmail.de)

BHU Research

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Abstract

The atmospheric treatment of extra CO₂ input (additional to the natural source-sink mechanisms) is revealed to follow a simple function during the industrial era. This function is interpreted as useful tool for projections at the optimistic boundary. For instance, the atmospheric CO₂ concentration may be contained within about 500 ppmv if mankind's future carbon emissions remained constant at the present level; in tail, the related temperature contribution will become contained. In this context, the prospect from the transition to renewables is explored. In result, realistic estimates point at precluding positive economic growth for the foreseeable future if temperatures are to be given a reasonable chance to become sustainably restrained within sensible limits.

1. Introduction

Society is being acquainted with the extraordinary climate role of CO₂. For participation in discussions and decision making, reproducibility and transparency is prerequisite on the information received. In a previous article [1], the temperature impact from the atmospheric CO₂ concentration has been constrained, mainly from observations on the past 400 Mio. years. In the present article, the starting point is to examine the response of atmospheric CO₂ concentration upon mankind's carbon emissions. In a second step, this knowledge is used to size mankind's options for the future.

Atmospheric CO₂ has natural sources and sinks, with equilibrium conditions when sources and sinks are balanced (zero net flow). Interesting examples for natural long term net CO₂ flows are the drastic abundance exchange between O₂ and CO₂ in Earth's history, and the long-term net sequestration during the Eocene.

The current eon is judged rather quiescent related to natural net atmospheric CO₂ flow. Driven by the temperature alternations in the current ice ages, observations reveal atmospheric CO₂ concentration to follow temperature change by 20 ppmv / 1°C. The present work presumes equilibrium for the preindustrial atmospheric CO₂ concentrations, and this natural equilibrium being left unchanged through the industrial period. Displacement from equilibrium is considered by a yearly average of volcanic activities and by the human-induced carbon flow.

2. Anthropogenic Carbon Emissions And Atmospheric Co Concentration

The human CO₂ entries into the atmosphere are judged well known. For the present estimates, the data for carbon emissions from fossil fuel burning and cement production [2] is multiplied by a factor of 1.2 to account for CO₂ input from land use change and in addition, is incremented by 200 Mt CO₂/year to consider volcanic activities.

The measured atmospheric CO₂ concentrations [3, 4] can be reproduced by applying an annual removal (uptake) rate of 3 %/year to the extra CO₂ emissions, as shown in Fig. 1. The emissions-derived concentrations (dashed red line) agree well with the measured concentrations (solid blue line). As sensitivity check, the uptake rate has been changed by ± 1 %; the results are depicted via the dotted (upper) and the dot-dashed (lower) orange lines.

While the removal of 3 %/year gives a coherent description of the past, there is no scientific base for its use in projections. The 3 %/year uptake rate relates to a lifetime of approximately 35 years for the extra (mainly anthropogenic) CO₂ contributions. To the current knowledge, this is too low given the time spans of the relevant underlying natural processes. In consequence, it needs to be anticipated that the annual removal rate may significantly decrease in the future and thus the atmospheric concentrations to evolve larger than determined by the 3 %/year uptake rate. Nevertheless, the estimate scheme applied for Fig. 1 appears appealing due to its simplicity and good measurement agreement. It may serve as a useful tool for projections, however always recalling that the optimistic boundaries are being explored.

For instance, it is indicated that the atmospheric CO₂ concentration may be contained within 500 ppmv if the present anthropogenic emissions were held constant for the future. The related equilibrium temperature contribution is to be anticipated with 3.9°C (given by the 'Eocene relationship' [1]). Since the ocean heat uptake is markable at the time of an atmospheric CO₂ input and steadily diminishing afterwards, about 1.3°C are rather contemporarily expected as concentrations start being constant (rule of thumb [5]).

3. Growth Potential From The Transition To Renewables

The CO₂ concentration limitation below 500 ppmv in case of constant future emissions raises the question: Which economic growth rate will be possible from the intended transition to renewables?

To pursue a calculational example, the constant emissions scenario is considered as target. Furthermore, the total CO₂ emissions are considered as originating from fossil material usage, land use change, and cement manufacture. Land use change and cement manufacture are estimated to contribute with 17 % and 6 % to the total emissions, respectively. Additional contributions from volcanoes are negligible and therefore disregarded. As mentioned, natural intake and uptake of atmospheric CO₂ are presumed to be in unchanged balance since pre-industrial times.

Details on the world energy consumption are taken from [6, 7], the respective CO₂ allocations from [2]. For year 2020, the total globally delivered energy is estimated at 119,000 TWh per year, with a share of 23 % in electric energy and 77 % in direct primary energy (Fig. 2). The latter comprises the fossil material usage for other applications than electricity generation. Of the electric energy, 65 % is generated from fossil fuel and 35 % by the further technologies, i.e. particularly hydropower, nuclear energy, wind, biomass, photovoltaics, and geothermics. The present growth rate of annual energy demand is of the order of 1,6 % per year.

As renewables scenario, it is assumed that all electricity generation from fossil fuel is being replaced by renewable technologies at constant pace within 25 years. Taking CO₂ investments for provisioning of the renewable equipment into account, the CO₂ emissions typically are reduced by 43 % within the first 25 years, and by 95 % afterwards. These figures are derived for average total CO₂ emissions of 30 g CO₂ per renewables-generated electric kWh. This emissions value has exemplary character, representing the actual low end for photovoltaics and 1.5 times the anticipated conditions for wind power. The renewables electricity generation is taken continuous, disregarding the need of a buffering system. Within this parameter set, the implicit optimistic and conservative biases are expected to be balanced.

At present, 27 % of the total annual global CO₂ emissions originate from fossil fuel electricity generation. The above-mentioned emissions reduction of 95 % in this sector corresponds to a reduction of 26 % with respect to the total emissions. On a time horizon of 100 years, this reduction corresponds to an annualized reduction rate of 0.3 %/year. In result, the transition from fossil fuel to renewables in electricity generation opens an overall growth allowance of the order of 0.3 %/year.

Due to the efficiencies of fossil fuel usage in electricity generation, about 2.8 times the generated energy needs to be provided by the raw material. In applications others than electricity generation, this efficiency factor is highly specific to the particular process, rendering its explicit consideration inappropriate for an order-of-magnitude view; hence, the delivered energy is taken as the energy contained in the raw material. On this base, the residential and commercial sectors are estimated to contribute 7 % to the total CO₂ emissions. If – to explore the extreme – all these emissions were eliminated and this regarded on a 100-years horizon, it would translate to an annualized reduction rate below 0.1 %/year relative to the total present emissions.

Presently, 66 % of the total energy consumption originate from the non-electricity applications in the sectors industry and transportation, corresponding to 43 % of the total CO₂ emissions. Replacement of fossil techniques by low-emission ones appears less straightforward than in other application areas. As indication, we know of the difficulties to size the real CO₂ footprint of electric vehicles. Also, new technologies in heavy transportation are hardly in sight yet, and the ship engines are just at the verge of a first transformation stage. In the industry sector, e.g. existing process heat techniques may need to be migrated to new methods which is to be considered challenging.

Assuming 30 % of the CO₂ emissions in these two sectors (industry and transportation) can be reduced within 30 years – perceived achievable – this corresponds to a reduction of 0.4 %/year relative to the total emissions, bearing an overall growth allowance of the same size.

Since 23 % of emissions originate from cement manufacture and land use change (see above), reductions in these areas can add valuable additional growth allowances. A detailed elaboration is disregarded in lack of currently imaginable reduction mechanisms.

The thus described transition to renewables leads to carbon emissions as summarized in Fig. 3, relative to the present emissions. The residual emissions from electricity production as well as in the sectors residential and commercial nearly vanish; the sectors industry and transportation retain 30 % of current levels; emissions from cement manufacture and land use change are carried forward from the present as reasoned; 46 % are considered as feasible reduction relative to the present.

Conclusion: A total economic growth window of 0.8 %/year may be opened by the migration from fossil material usage to new techniques. This growth allowance represents the upper boundary of 'Green Growth', first due to the optimistic translation from carbon emissions into atmospheric CO₂ concentration. Second, the upper limit of 500 ppmv for the future CO₂ concentration has exemplary character; the temperature projected for this concentration may need to be judged too high as a target to aim for. Third, presumption is that carbon emissions remain constant from the presence which may be assessed unrealistic. Fourth, effects not regarded, e.g. from induced ice/snow albedo change, are to be accounted for with further temperature contributions (from risk point of view, of the order 1 to few °C, perhaps partly substantiating on the long-term horizon).

Of the total growth window, about 40 % is anticipated from the renewables migration in electricity generation. To 50 %, the growth allowance is attributed to migration efforts in the sectors of industry and transportation. This reveals that transitions in these sectors are an important key if mankind is to continue their abiding striving for economic growth. Regarding the existing societal mechanisms, globally homogeneous taxation of CO₂ emissions appears as a viable tool to stimulate potential transformations.

4. Discussion

Methodologically, the present study is based on the principle that the determining forces of a certain natural phenomenon are (1) few and (2), clearly visible. The present subject is how nature deals with the extra anthropogenic carbon input into the natural processes. Strongly observation-based, a simple description has been extracted for the emissions-to-CO₂ concentration relationship, providing a handy tool for projections at the optimistic boundary. This tool is applied to explore the prospects of Green Growth.

Since focusing on the driving forces, a sophisticated error calculation is regarded subordinate. A sensitivity analysis is given on the emissions-to-CO₂ concentration relationship. In general, the presented study is based on long-term trends. The approach presumes that the degree of agreement between approximation and observation is clearly visible in the long-term pattern.

In the very brief conclusion, it is hard to anticipate compatibility of further economic growth with climate change confinement, even assuming the potential transition from fossil material usage to renewables. The presented framework shows viable reference points when regarding geoengineering solutions.

Declarations

Supplementary Material: All data and code are available: Simplified climate modelling.

Conflicts of Interest: No conflict of interest is to be declared.

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Figures

Atmospheric CO₂ concentration

Figure 1

Atmospheric CO₂ concentration for the industrial era; blue solid line: measurement data [2, 4]; dashed red line: computed based on emissions [2] with 3 %/year uptake rate of the added emissions; dotted orange and dot-dashed orange lines: uptake rate changed by $\pm 1\%$

Global annual energy supply by source type

Figure 2

Atmospheric CO₂ concentration for the industrial era; blue solid line: measurement data [2, 4]; dashed red line: computed based on emissions [2] with 3 %/year uptake rate of the added emissions; dotted orange and dot-dashed orange lines: uptake rate changed by $\pm 1\%$

Figure 3

Potential CO₂ reduction scenario, fractions relative to present total CO₂ emissions after reduction. 95 % reduction in electricity generation leading to a residual emissions contribution of 1 %, reduction in the sectors residential and commercial taken as 100 % with a residual of 0 % contribution, reduction in the sectors industry & transportation 30 % from present levels leading to a residual of 30 % CO₂ emissions contribution, contributions from cement manufacture and land use change retained from the present due to the lack of prognosis quality, total reduction of CO₂ emissions 46 %