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# INVESTIGATIONS ON ATMOSPHERIC CO2 IMPACTS OF THE ENERGETIC USE OF BIOMASS BY GLOBAL CARBON CYCLE MODELS

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*Abstract*: Energy intensive activities such as drying are in the focus of attention of CO2-reduction schemes. Origin and quality of the energy used are key issues for the development of the atmospheric CO2-content. Biomass as energy source is discussed as a possibility to reduce atmospheric CO2. However, the line of logic comes from simple static balances. Yet, CO2 is part of the Global Carbon Cycle which is a large, global, dynamic network. This paper presents a simple but globally accurate dynamic model of this cycle and develops scenarios to look at the biomass arguments from a dynamic point of view.

*Keywords*: energy intensive, drying, biomass, global carbon cycle, dynamic model

## INTRODUCTION

Industrial processes with a high amount of energy use per unit output, such as drying, are in the center of the discussion concerning higher energy efficiencies. Also, origin and quality of the energy used are of key interest, as they affect the output of CO2 by the process in question. Biomass is generally seen as a possible energy source, it is mostly used in combustion processes to generate energy (e.g. bio-fuels), it contains high amounts of carbon which react with oxygen and thus CO2 is one of the "products".

On the other hand, the atmospheric CO2-content and its future development is one of the main issues of today's climate debate, as CO2 is an essential part of the greenhouse effect. Most of the present CO2 in the air has come from industrial processes (deducted from carbon isotopes distribution, see Klump, 1991) thus is of human origin. Therefore, energy intensive human activities such as drying will play a mayor role how this critical concentration will evolve. Simulation models may help to predict this further development of atmospheric CO2 and enable conclusions for the present.

The Earth may be regarded as very complex physical, chemical, biological dynamic system, consisting of material reservoirs acting as sources or sinks and material flows among the reservoirs. The Global Carbon Cycle (GCC) is one of the identified subsystems, which are of ongoing scientific interest. However, the term "cycle" is misleading, as such subsystems are no closed cycles but usually open, multidirectional, dynamic networks. Only in the last 20 years, the availability of computing power made it possible, to develop and solve such dynamic network models .

## THE SIMPLE BALANCE ARGUMENTS

The energetic use of biomass or products made out of biomass (i.e. bio-fuels) is generally discussed as a possibility to reduce CO2 concentrations in the atmosphere (Alt, 2010, Murray & Dey, 2006). However, this effect is mostly derived from simple material balances put into sentences, not equations, such as "only the carbon the biomass has taken up from atmosphere is released" or "further planting of biomass will offset today's releases".

These arguments compare in a static way two amounts of carbon like two weights hanging on a T-bar-balance in rest (Fig. 1). If these two weights grow and shrink in different, but characteristic ways, i.e. are carbon flows rather than just fixed amounts of carbon, the balance will no longer be in rest but will start moving. To describe the movement of the whole balance, a dynamic approach is now necessary. If the integration of the dynamic movement over longer periods of time leads to a statistical equilibrium, the simple balance can be applied as a good average representation, but this has to be proven. This paper will try to make that test.

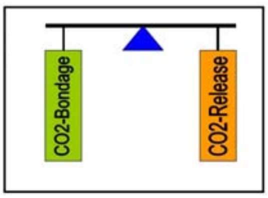


Fig. 1: Principle of simple, static CO2-balance

Also it has to be noted, that CO2-bondage (mostly by photosynthesis) and CO2-release (mostly combustion) are only two elements of a much bigger system which is known today as The Global Carbon Cycle (Heimann, 1991)

## A SIMPLE MODELL OF THE GLOBAL CARBON NETWORK

The Earth is commonly divided into several subsystems which are known as geospheres. These are: the hydrosphere (water), the atmosphere (air), the biosphere (living matter), the lithosphere (land , soil) and the kryosphere (ice). Various substances flow back and forth among theses geospheres with a wide range of velocities, creating dynamic networks. One such material flow system is that of the carbon, generally known as the Global Carbon Cycle (GCC) with first models published by Heimann (Heimann, 1991). A common graphical representation of this cycle is shown in Figure 2 (courtesy of UNEP, 1996).

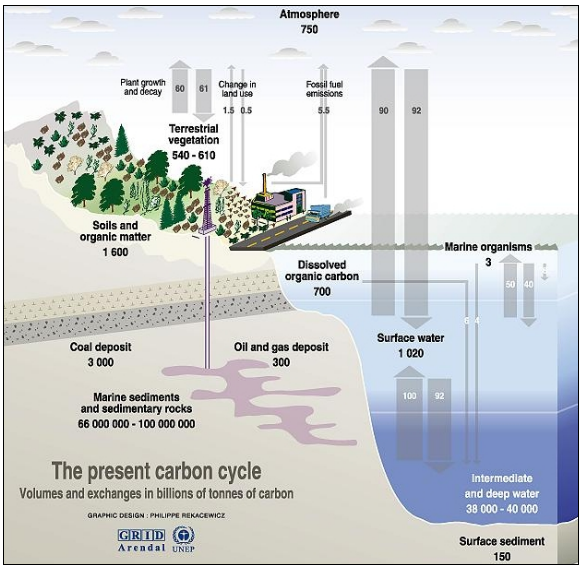


Fig. 2: Common graph of the Global Carbon Cycle (courtesy of UNEP, 1996). Numbers refer to averages of period 1980 to 1989.

The basic principle for the models of the GCC is to define reservoirs of carbon associated to the geospheres (only the kryosphere is neglected, as there are only marginal amounts of carbon in the ice) and to connect these reservoirs with the relevant carbon material flows (see Figure 3).

A basic model for the Global Carbon Cycle was taken from literature (Heimann, 1991, Bice , 2007) and critical elements investigated and improved (Ringer, 2007, Corbyn, 2009). The developed Improved Simple Global Carbon Model (ISGCCM) is used in this paper and consists of the following main elements (details see Corbyn, 2009, or upon request from the author):

*Reservoirs*

(Names and initial masses of carbon, in units GtC):

- Atmosphere (ATM, 600, at year 1850)
- Biosphere (BSP, all living matter above soil, 610)

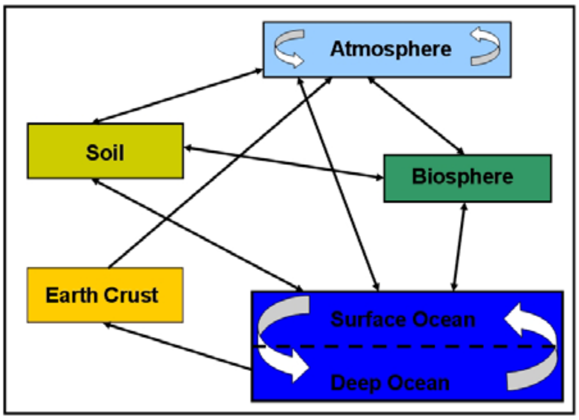


Fig. 3. Simple design of the Global Carbon Cycle as dynamic network. Rectangles ➔ carbon reservoirs, arrowed lines & bends ➔ main flows of carbon

- Soil (SOL, the first few meters with living matter, 1580)
- Surface ocean (USO, the upper layers of the ocean comprising the thermocline with all living matter there (see Bigg (2003) and Marshall (2007), 891)
- Deep ocean (DO, the vast part of the ocean, 38000)
- Earth crust (EC, very large reservoir, source of fossil carbon and final carbon sink, set at 40000 for numerical reason, probably much larger)

The reservoirs are all global ones and assumed to be well mixed tanks with no inner gradients.

*Main carbon material flows*

(Names and initial flows of carbon, in GtC/yr):

- Photosynthesis (ATM ➔ BSP, 100)
- Plant respiration (BSP ➔ ATM, 50)
- Natural CO2 (by volcanoes and other natural sources, EC ➔ ATM, 0,6)
- Litter fall (shed leaves and similar events, BSP ➔ SOL, 50)
- Soil respiration (SOL ➔ ATM, 49,4)
- Runoff (erosion by water, SOL ➔ SOC, 0,6)
- ATM-SOC-exchange (absorption and release of CO2 by seawater, in equilibrium at start, ATM ⇔SOC, 0)
- Downwelling (large scale downward water flow, SOC ➔ DO, 90,6)
- Upwelling (large scale upward water flow DO ➔ SOC, 100)
- Biopump (downward carbon transport by remains of ocean animals, SOPC ➔ DO, 10)
- Sedimentation (carbon deposition on ocean floor, DO ➔ EC, 0,6)

The carbon material flows are assumed to be global ones and to connect the reservoirs as indicated.

This set of data forms a numerical equilibrium model and is the start point for all simulations. The start point in reality is set at year 1850, as global temperature measurements begin there (HADCRUT3 dataset, 2009) and human influence seems still negligible although not zero. Thus a natural near equilibrium seemed to have existed there too. Compilations further back resulted in no significant differences.

Beginning at year 1850, the record of human activities and resulting CO2-emissions into the atmosphere is taken into account and further carbon material flows have to be added to the model:

- Fossil emissions (EC ➔ ATM, from Boden, 2009)
- Changes of land use (from Houghton, 2008)

The land use carbon flux is divided into:

- Burning (BSP ➔ ATM, 0,75 of land use changes)
- Soil disruption (SOL ➔ ATM, 0,25 of land use changes)

Changes in land use diminish the available area for photosynthesis, which is reflected in the used model (see Corbyn, 2009).

Adding these human made carbon flows over time to the model sets the network gradually into non-equilibrium and the carbon starts moving among the reservoirs (dynamic network).

Apart from the reservoirs and carbon flows, quite a number of parameters and equations has to be added to the model to describe the time dependent changes of the carbon material flows (i.e. sea water CO2 chemistry). They are too many to fit in this paper and the reader is kindly referred to the cited literature (original equations see Bice, 2007, improved equations see Corbyn, 2009). All changes are assumed to be long term (several years) and seasonal changes can then be neglected.

For building the model and compiling the simulations, a commercially available dynamic network simulation tool named GoldSIM® was used.

## COMPARISIONS WITH HISTORICAL DATA

After the usual numerical stability tests, the improved model was tested against datasets for the development of CO2 in the atmosphere and the so called Global Mean Surface Temperature (GMST). From the available datasets in literature, the following were chosen:

- The ice core dataset from the Law Dome site in Antarctica, reaching back more than 1000 years, ending around 1950 (from Etheridge, 1998)
- The dataset of directly measured atmospheric CO2 from the Mauna Loa site, starting at 1950 (from Keeling, 2009)
- The HADCRUT3 dataset for the GMST from the University of East Anglia, GB (2009)

The model calculations start at the year 1850 with an atmospheric CO2 concentration of 285 ppmv and a GMST of 13,56 °C, which were taken from the above named datasets. Figure 4 shows a comparison of calculated values and historical data for the atmospheric CO2 concentration and Figure 5 for the GMST.

As can be seen in Figure 4, the comparison of histori-

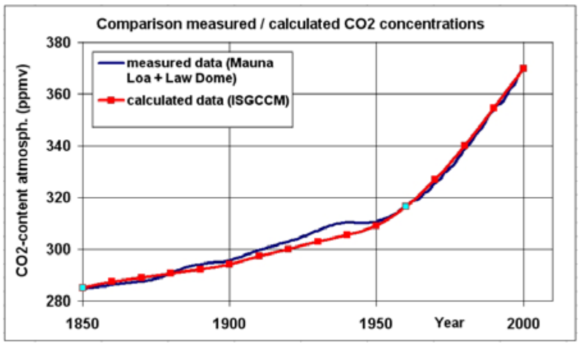


Fig. 4. Comparison of historical, measured data (Law Dome and Mauna Loa, yearly means) with results from model calculations using the developed ISGCCM

cal data and calculated values is remarkably good for a simple model. The comparisons end at year 2000 due to graphical reasons and with regard to the following scenarios. The comparison continues to be of same quality also for the data available till 2008. Similar tests were also made with a more complex model of the Global Carbon Cycle (see Bice, 2007), but these more complex model gave less agreement with the historical data. This might be due to the fact, that more complex models use more reservoirs (divide the above named reservoirs to be more in accordance with Earth's shape) and thus have to define more carbon streams among them. However, the parameters to these more complex carbon flows are still not very well known.

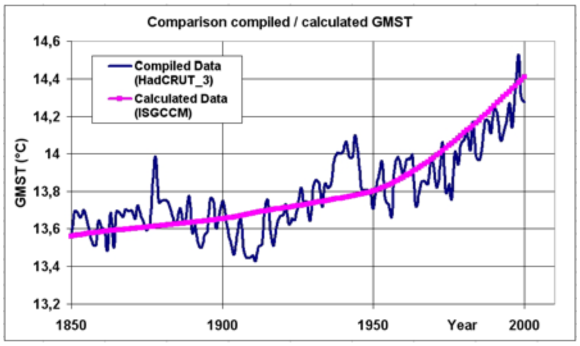


Fig. 5. Comparison of historical Global Mean Surface Temperature data (GMST, HADCRUT3 dataset, yearly means) with results from model calculations using the developed ISGCCM

Figure 5 shows the comparison with GMST data. It can be noted that the general trend of the temperature is in good accordance with the calculated data. However, it is not possible to simulate the large fluctuations in temperature (remark: actual IPCC models are also not able to represent these large and quick temperature changes). It also can be seen from the historical data, that the fluctuations in GMST are quite large and that a general trend can only be deduced from data sets comparing at least 20 years or even more. So interpreting some few yearly averages as "new trends" in global temperature development seems to be premature.

## LOOKING INTO A FOSSIL FUTURE

With the successful test against historical data, the model was suitable to evaluate future scenarios. The scenarios are meant to be trend calculations (what if) and not simulations of really possible developments.

The look into the future was limited to 100 years due to the assumptions made and increasing possible uncertainties with longer simulation periods.

The basic scenario 0 was set up the following way: starting at year 2000, a linear increase of fossil fuel Emissions, as seen in Figure 6 was used. The slope of the increase was taken from the increase of CO2 emissions from 1995 to 2005 (see Boden, 2009) and extrapolated. CO2 emissions from changes in land use were set constant at year 2000 levels.

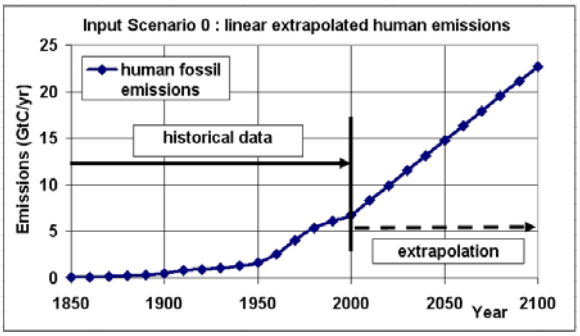


Fig. 6. Representation of data input to the ISGCCM for scenario 0: linear increases of human CO2 emissions since year 2000

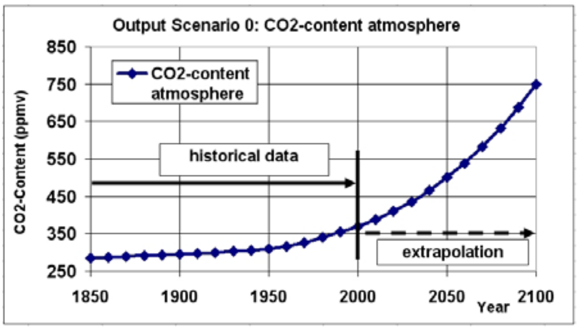


Fig. 7. Calculated data with the ISGCCM for scenario 0. Note the exponential system response to a linear input (see Figure 6)

The dynamic answer of the carbon system can be seen in Figure 7. It should be noted that the linear input to the system resulted in an exponential output. This is probably due to the fact, that the carbon system is already quite away from the equilibrium at year 2000 and the system then reacts to further increases in CO2 in sort of a run away answer.

## BIOMASS AS FUTURE ENERGY SOURCE AND ATMOSPERIC CO2 CONCENTRATIONS

The energetic use of biomass or fuels derived from biomass is generally seen as one of the remedies to avert further CO2 increases in the atmosphere. To test this hypothesis, scenarios were set up the following way:

*Scenario 1:* at year 2000, as switch of the source of CO2 emissions is assumed from burning fossils (source reservoir Earth Crust) to burning biomass (source reservoir Biosphere). The increase in emissions is the same as in scenario 0 (see Figure 8) and also the CO2 emissions from changes in land use are kept constant at year 2000 levels. This should be the extreme test what CO2 from biomass use will do to the CO2 content in the atmosphere. Limits on biomass production were not taken into account, as this should be an extreme test case.

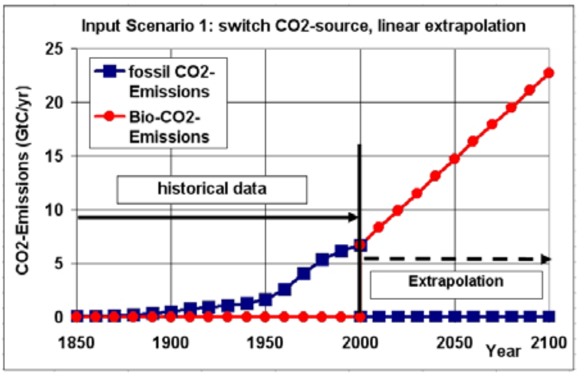


Fig. 8:. Representation of data input to the ISGCCM for scenario 1: switch of CO2 source in year 2000 from fossil to biomass, linear increasing bio-CO2 emissions since year 2000 with slope as in Fig.6

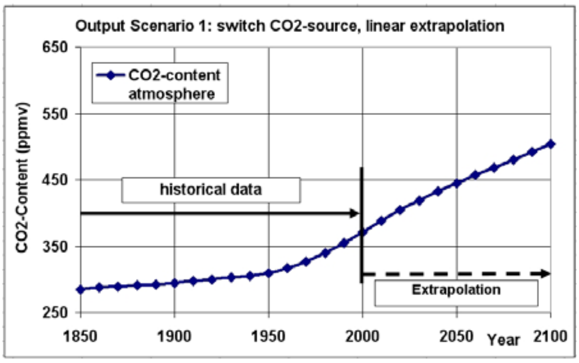


Fig. 9. Calculated data with the ISGCCM for scenario 1. CO2 increases in atmosphere despite biomass as CO2 source, increase is softer as with fossils

The answer of the dynamic carbon system to this extreme scenario can be seen in Figure 9. Even after all CO2 fed to the atmosphere comes from biomass (i.e. from the reservoir Biosphere), the increase of CO2 in the atmosphere continues. However, it is not as extreme as with fossils but only abates to a lesser, nearly linear increasing slope. This is a clear indication that CO2 emissions from biomass are not climate neutral. The energetic use of biomass will not "cure" the carbon system by itself but has to be coupled with other measures. This will be tested in the next scenario, which might be more close to possible real developments.

*Scenario 2:* in this scenario, $CO_2$ from fossil use is reduced in linear way to zero within 100 years. On the other hand, $CO_2$ from biomass use is linearly increased within 100 years to reach 50% of $CO_2$ emissions of the level of year 2000, which gives a net reduction of $CO_2$ emissions of 50% within 100 years (see Figure 10). $CO_2$ emissions from changes in land use are again kept constant at year 2000 levels.

Figure 11 then shows the answer of the carbon system to this input. The increase of $CO_2$ in the atmosphere slows down and seems to reach a peak within 100 years. Thus reducing $CO_2$ emissions seems to be the most effective measure to curb $CO_2$ accumulation in the atmosphere.

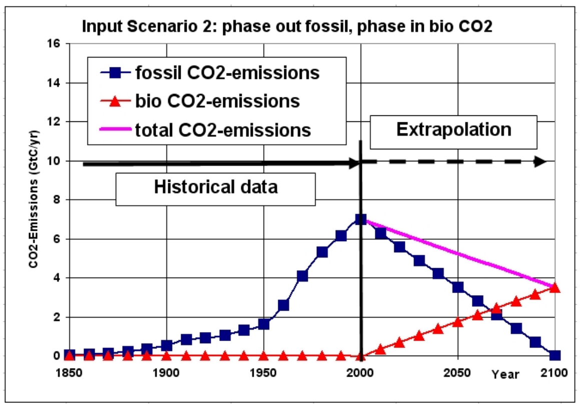


Fig. 10. Representation of data input to the ISGCCM for scenario 2: fossil $CO_2$ is linearly reduced to zero within 100 years, biomass $CO_2$ increased within 100 years to reach 50% of level 2000 $CO_2$ emissions

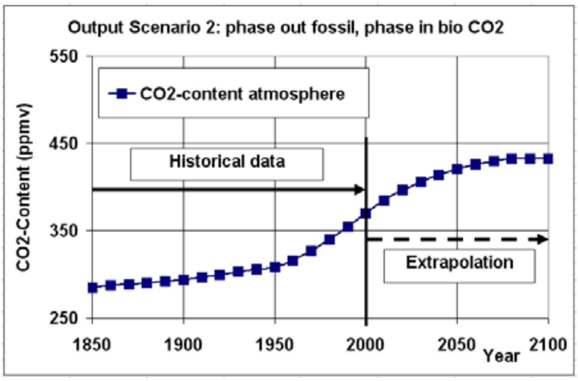


Fig. 11. Calculated data with the ISGCCM for scenario 2. $CO_2$ increase in the atmosphere seems to reach a peak within 100 years

Simulations of scenario 2 with further looks into the future indicate a return to $CO_2$ emissions to the level of the year 2000 beyond year 2200, if the $CO_2$ emissions are kept constant after 2100. The return to more tolerable levels of $CO_2$ in the atmosphere could be accelerated if $CO_2$ emissions from the change of land use are also reduced and additional programs to increase biomass (regrowing forests) are actively and consistently pursued.

## CONCLUSIONS

Drying is an industrial process used for many products and also a very energy consuming one. Hence, origin and quality of the energy source for the drying process are vital points of discussion and improvement. Biomass or products out of biomass (i.e. biofuels) are possible energy sources but their actual use in combustion processes also generate $CO_2$, thus linking energy use to climate problems.

The energetic use of biomass is also publicly seen as a means to directly reduce $CO_2$ concentrations in the atmosphere. The reasoning stems from simple, static material balances. Mandatory addition of bio-fuels to fossil fuels in Germany is driven by such logic. However, the $CO_2$ content in the atmosphere, one of the drivers of the green house effect, is part of a dynamic, thus time dependent global material flow network, called the Global Carbon Cycle. The paper presents a simple model of the Global Carbon Cycle, which is tested against historical data with very good agreement. Thus scenarios were set up to test the answers of the model to "what-if"-questions. The base scenario (linear future increase of fossil emissions) showed an exponential response ($CO_2$ increase in the atmosphere) of the model within 100 years.

The extreme test of replacing these future fossil emissions by $CO_2$ emissions coming from the energetic use of biomass (scenario 1) showed only a reduction of $CO_2$ increases to a lesser and linear slope, but no trend reversal. Only the coupling of reduced fossil emission, increasing energetic use of biomass and overall reduction ($CO_2$ from fossils and biomass combined) seem to result in a peak of $CO_2$ in the atmosphere within 100 years.

Thus dynamic simulations of the Global Carbon Cycle can not support the simple reasoning. The energetic use of biomass is a step in the right direction, but to have a reducing effect to atmospheric $CO_2$ levels, it has to be combined with drastic reductions of $CO_2$ emission, regardless of the $CO_2$ source. It seems best to head for an industrial future without carbon combustion.

## NOMENCLATURE

GtC Gigaton of carbon (= $10^{12}$ kg)


## ACKNOWLEDGEMENTS

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REFERENCES

Alt, F. (2010), home page "WWW.sonnenseite.com" Aktuelles, "Holzhauseffekt statt Treibhauseffekt"

Bice, D. (2007), "The Global Carbon Cycle : Lecture notes", in *Dept. of Geology* edited, Carleton College, Northfield.

Bigg R G.(2003) "The Oceans and Climate", 2nd Ed. Cambridge Univ. Press, ISBN 052101634

Boden, T.A. et. al. (2009), "Global, Regional, and National Fossil-Fuel CO2 Emissions", Carbon Dioxide Information Analysis Centre, Environmental Sciences Division, Oak Ridge Nat. Laboratory, USA

Corbyn S. (2009), "Improvements on a Simple Model of The Global Carbon Cycle", BSC Thesis, Murdoch Univ., Perth, Australia

Etheridge, D. M. et al. (1998), "Dataset of Historical CO2 records from the Law Dome DE08, DE08-2, and DSS ice cores", Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy.

HADCRUT3 dataset (2009), Climate Research Unit, Univ. of East Anglia, UK

Houghton, R. A. (2008), Dataset - Carbon Flux to the Atmosphere from Land-Use Changes: 1850-2005, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory.

Heimann, M., editor (1991), "The Global Carbon Cycle", Springer book, ISBN 3-540-54586-7

Keeling, R. F. et al. (2009), "Dataset of Atmospheric CO2 records from sites in the SIO air sampling network - Mauna Loa", Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy

Kump, L. (1991), "Interpreting carbon-isotope excursions: Strangelove oceans", Geology, pp. 299 ff

Marshall J. and Plumb R. A. (2007), "Atmosphere, Ocean, and Climate Dynamics – An Introductory Text", Academic Press / Elsevier, ISBN 13: 978-0-12-558691-7

Millero, F.J., editor (2006), "Chemical Oceanography", 3rd Ed., CRC-press, ISBN 0-8493-2280-4,

Murray, J. and Dey, C., (2006), "Carbon neutral – sense and sensibility", ISA Research Report 07-02, ISA, Centre for Integrated Sustainability Analysis at the University of Sydney, Australia

Ringer D.U., (2007), "$CO_2$-Neutralität bei der energetischen Nutzung von Biomasse – eine genauere Betrachtung", Horizonte 31, HS Mannheim, Germany

UNEP and WMO, (1996), 2$^{nd}$ IPCC report, Cambridge University Press, UK