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Direct and indirect metabolic CO_2 release by humanity

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Abstract. The direct CO_2 released by respiration of humans and domesticated animals, as well as CO_2 derived from the decomposition of their resulting wastes was calculated in order to ascertain the direct and indirect metabolic contribution of humanity to CO_2 release. Human respiration was estimated to release 0.6 Gt C year^{-1} and that of their associated domestic animals was estimated to release 1.5 Gt C year^{-1}, to which an indirect release of 1.0 Gt C year^{-1}, derived from decomposition of the organic waste and garbage produced by humans and their domestic animals, must be added. These combined direct and indirect metabolic sources, estimated at 3.1 Gt C year^{-1}, have increased 7 fold since pre-industrial times and are predicted to continue to rise over the 21st century.

1 Introduction

Rapid increase in atmospheric CO_2 has prompted intense research efforts to elucidate and quantify the sources and sinks of CO_2. The depictions of the global carbon budget consider the role of humans through the CO_2 released from fossil fuel combustion and changes in land use (IPCC 2001), but does not explicitly estimate the metabolic CO_2 released by respiration by humans, as well as the CO_2 derived from the decomposition of their wastes. In addition, humans maintain a large livestock population to feed themselves as well as a large number of domestic animals for other services, which release CO_2 both via direct respiration as well as via the decomposition of their wastes. We assess here the magnitude of these combined direct and indirect metabolic CO_2 sources and their likely increase since pre-industrial times, to ascertain their role on the global CO_2 budget.

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2 Methods

Per capita respiration (R, in watts) and excretion (E, in watts) rates by humans and domestic animals were derived from body weight (W, in kg) using allometric relationships that depict standard metabolic and defecation rates as a power function of body weight as: R=3.89$W^{0.79}$ and defecation rate E=3.82$W^{0.63}$ (Peters, 1983). For comparison, we also estimated the per capita rate of respiration as the product of average breathing frequency (10 min^{-1}), tidal volume (0.5 L) and average CO_2 concentration of the air expired (3.5%; Marrieb, 2000), yielding an average individual rate of about 251 g C d^{-1}, nearly identical to the estimate of 257 g C d^{-1} derived strictly from allometric relationships. The similarity of these two estimates strongly suggests that the allometric approach gives reasonable values. We further estimated the overall uncertainty in the global respiratory CO_2 emissions from the inherent statistical uncertainty of the allometric relationship of 0.1 log (base 10) unit (Robinson et al., 1983, equivalent to a coefficient of variation of about 25%) and by assuming that the FAO statistics on the number of individuals of each species are precise only to within 20% (as coefficient of variation, CV). The compounded uncertainty was estimated to be 32% for each species, as calculated from $CV(x_1x_2) = \sqrt{CV^2(x_1)\cdot CV^2(x_2) + \cdot CV^2(x_1) + \cdot CV^2(x_2)}$, and standard error propagation of these uncertainty estimates yielded an overall expected coeefficient of variation of the global emissions of direct and indirect human-derived metabolism of 17% (calculated as the sum of individual variances and expressed as CV).

Per capita organic waste production was extrapolated from Organization for Economic Co-operation and Development figures (OECD, 2002). Human population size was derived from estimates of the past, present and projected estimates (Cohen, 1995, Population Division of the Department of Economic and Social Affairs of the United Nations

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Table 1. Estimates of direct and indirect metabolic CO_2 release by humans and associated animals. Figures correspond to 2003.

		Weight kg	Population (millions)	Respiratory Gt C yr^{-1}	Excretory Gt C yr^{-1}	Total Gt C yr^{-1}
Direct						
	Humans	70	6100.00	0.57	0.28	0.86
Indirect						
	Cows	891	1349.00	0.94	0.31	1.26
	Goats	89	740.00	0.08	0.04	0.12
	Sheeps	50	1050.00	0.08	0.04	0.12
	Horses	794	58.00	0.04	0.01	0.05
	Pigs	200	1000.00	0.22	0.09	0.31
	Chickens	2.1	15090.00	0.09	0.08	0.17
	Buffalos	350	165.90	0.06	0.02	0.08
	Turkeys	11.5	242.90	0.01	0.00	0.01
	Geese	5.2	238.80	0.00	0.00	0.01
	Ducks	2.6	917.70	0.01	0.01	0.01
	Camels	140	19.40	0.00	0.00	0.00
	Cats	2	1100.00	0.01	0.01	0.01
					Total ind.	2.14
Non-metabolic waste production						0.10
					Total	3.10

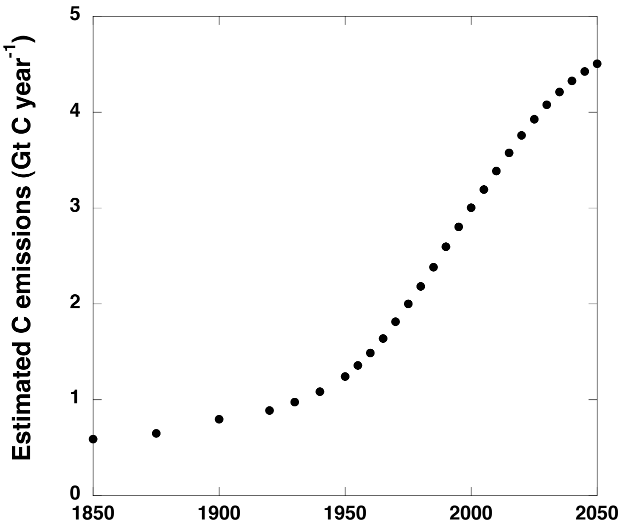

Fig. 1. Estimated human-derived direct and indirect metabolic CO_2 release from pre-industrial to year 2050.

Secretariat, 2002), and the abundance of livestock was derived from 2004 FAO statistics (http://www.faostats.org).

3 Results and discussion

The estimates of the metabolic CO_2 release from human respiration obtained as the product of present human population size and per capita respiratory CO_2 release estimated either from allometric relationships or from direct respirometric measurements were 0.6 Gt C $year^{-1}$ and 0.57 Gt C $year^{-1}$ (Table 1), respectively. We estimated that respiration by decomposers of the excreted organic matter releases an additional 0.29 Gt C $year^{-1}$ (Table 1). Humans also produce non-metabolic organic waste (as garbage) amounting to about 0.1 Gt C $year^{-1}$, which must again be largely decomposed to CO_2 by bacterial respiration.

The population of domestic animals maintained by humans exceeds human population by three fold (Table 1). The combined respiratory CO_2 release by domesticated animals is estimated at 1.5 Gt C $year^{-1}$, and decomposer respiration of their excreted products adds about 0.6 Gt C $year^{-1}$. The total metabolic release by domesticated animals of 2.1 Gt C $year^{-1}$, must be considered an indirect human metabolic CO_2 release, for these animals only exist in such large numbers to provide food and service to humans.

The total direct and indirect metabolic CO_2 release by humans amounts to an estimated 3.1 Gt C $year^{-1}$ (Table 1). This figure is a conservative estimate of the metabolic CO_2 release associated to human activity, for humans now use about 3–4% of the terrestrial (Vitousek et al., 1986) and 8% of the marine (Pauly and Christensen, 1995) net primary production, most of which is eventually decomposed to CO_2.

The calculated direct and indirect metabolic CO_2 release by humans represents about half of the CO_2 released from fossil fuel combustion, and nearly twice that released from changes in land use (IPCC, 2001). Whereas the role of the CO_2 released by fossil fuel combustion has been extensively discussed, that of the anthropogenic metabolic CO_2 release has not. This is likely because anthropogenic metabolic CO_2 release may be considered just an intensification of cycling processes between the atmosphere and the biosphere via enhanced crop and pasture production. This is an important distinction. In an equilibrium situation, the calculated emissions do not represent a new, unaccounted flux to the atmosphere. Instead, it provides a first-order estimate of the surprisingly large magnitude of a component embedded within the net exchange of CO_2 between the Earth and the atmosphere. However, the replacement of natural ecosystems by pasture and crops also represents a net human-induced CO_2 emission through a decline in sink capacity, as essentially all of the production of crops and pastures is cropped and eventually decomposed to CO_2 (Gitz and and Ciais, 2004). Although the quantification of this sink loss is beyond the scope of this paper, we submit that acknowledging this to be a result of metabolic CO_2 release by humans provides a more direct identification of source components and a better appreciation of the consequences of demographic changes on this source component.

Whereas the increase in atmospheric CO_2 resulting from different scenarios of CO_2 emissions from fossil fuel combustion have been discussed extensively (IPCC, 2001), all of them underestimate the likely increase in atmospheric CO_2 concentration by failing to account for demographics effects on the metabolic CO_2 release. The demographic effects on metabolic CO_2 release were examined by combining estimates of past, present and future human population with the per capita rates of direct and indirect metabolic CO_2 release derived here. Direct and indirect metabolic CO_2 release by humans has been increasing through time from a calculated value of 0.44 Gt C year^{-1} in 1800 to an expected 4.4 Gt C year^{-1} by year 2050 (Fig. 1), assuming that per capita rates are maintained constant. The realized increase may well exceed this estimate, since changes in diet and consumption habits are leading to a rapid increase in human body weight and food ingestion, and therefore per capita metabolic CO_2 release. In addition, the number of domestic animals per capita and per capita waste production are also increasing, and are expected to continue to do so in the future (OECD, 2002; Tilman et al., 2002).

Metabolic CO_2 release can only augment as population size increases in the future. This is a component of the CO_2 flux that must be recognized in future analyses of global CO_2 dynamics and that must be considered to represents a component of the perturbed C cycle, as human population has increased – and will continue to increase – greatly since pre-industrial time. Yet, the direct and indirect metabolic CO_2 emissions by humans is not considered explicitly in the scenarios conducted by the IPCC (2001), and is not incorporated, therefore, into current strategies to mitigate the climatic consequences of greenhouse gas emissions.

The absence of explicit consideration of metabolic human CO_2 emissions may be a symptom of a tendency to perceive humans as separate entity to other species, which impacts on the biosphere involve their technology, whereas the results presented here clearly indicate that human demography and metabolism may be important factors involved in greenhouse gas emissions. Whereas metabolic CO_2 release maybe far less amenable to change than emissions derived from deforestation, cement production or fossil fuel use, different human choices can affect human metabolic CO_2 release. The indirect metabolic CO_2 release may be reduced through the promotion of behavioral changes to reduce the per capita consumption of meat and organic waste production, and the direct metabolic CO_2 release may be reduced by adjusting human ingestion to requirements, avoiding the excess food ingestion affecting much of the population in developed societies, and that represents a health hazard as well, responsible for more than 1 in 10 deaths in the EU and USA (Banegas et al., 2003). In contrast, however, per capita food intake is predicted to increase by about 10% from a present average value of 2803 Kcal year^{-1} person^{-1} to 3050 Kcal year^{-1} person^{-1} by 2030 in industrialized countries (FAO, 2002). In summary, human metabolic CO_2 release, direct and indirect, is an important and growing component of anthropogenic CO_2 emissions. Explicit consideration of this component may help improve current emission scenarios and mitigation strategies.

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