Pastoral agriculture AND CARBON NEUTRALITY

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Definition (Wikipedia):

Being 'carbon neutral', or having a 'net zero carbon footprint', refers to achieving net zero carbon [dioxide] emissions by balancing a measured amount of carbon released with an equivalent amount sequestered or offset, … extended to include other greenhouse gases measured in terms of their carbon dioxide equivalence.

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Conventional carbon neutrality

The net result of carbon (C) transfer from and back to the atmosphere through the pasture-ruminant-human food-chain is that for every 20 t(C) as CO_2 (ie, for every 73 t(CO_2)) that is photosynthesised only 0.2 t(C) is not returned to the atmosphere as CO_2. That 0.2 t(C) is returned as CH_4: (see figure).

Atmospheric CH_4 eventually oxidises in situ to CO_2 (Box 1.1). But CH_4 is the more potent greenhouse gas (GHG), molecule for molecule, due to its stronger absorption from Earth's outgoing radiation spectrum. By how much? Sanctioned answer uses the GWP for CH_4 (Box 2): each kg(CH_4) emitted is "equivalent" to 21 kg(CO_2).

Thus, pastoral agriculture is not "carbon neutral" (unless a substantial part of the "respiration & decay" flux can instead be "sequestered" long-term in pastoral soil). This is NOT due to imbalance of C atoms, but because the 0.2 t(C) emitted as 0.27 t(CH_4) is "equivalent" to 5.6 t(CO_2) (Box 2). Thus of the 73 t(CO_2)/ha/yr sucked out of the atmosphere, an extra 5.6 t (CO_2-equivalent)/ha/yr is returned there.

In addition to CH_4, pastoral agricultural also releases N_2O, a very potent GHG that arises from the cycling of nitrogen (N). Of plant-N consumed by the animal, dietary excess is excreted onto pasture soil. Fertiliser-N is also spread directly onto pasture soil. Of that applied N, ~1% is transformed biologically into N_2O, most from urine deposits. The mean N_2O flux of ~6 kg(N)/ha/yr is "equivalent" to ~2.9 t(CO_2-equivalent)/ha/yr.

Are GHGs really CO_2-equivalent?

For most GHGs, the atmospheric concentration is controlled by past and present emission rates and any changes to their removal rates. The critical exception is CO_2:

- human activities are adding fossil CO_2 to the labile C cycle (Box 1.3)
- total C in labile reservoirs is therefore steadily growing
- atmospheric CO_2 level is controlled by cumulative anthropogenic CO_2 emissions.

Recent computer modelling of emission reductions needed to avoid dangerous interference with the climate system (eg, limit global temperature rise to 2°C) find:

- that it is necessary to limit cumulative fossil CO_2 emissions (Allen *et al*. 2009, England *et al*. 2009, Matthews *et al*. 2009, Zickfeld *et al*. 2009)
- that continued CO_2 emissions will induce irreversible climatic change (Matthews & Caldeira 2008, Solomon *et al*. 2009)
- that the economically-optimal balance between emission reduction of CO_2 and of non-CO_2 GHGs changes over time with the latter becoming more efficacious as a target date nears (e.g., Manne & Richels 2001, van Vuuren *et al*. 2006)
- that GHG fungibility using standard GWPs (Box 2) may not lead to climatically optimal, nor economically optimal, outcomes (e.g., Fuglestvedt *et al*. 2000, Johansson *et al*. 2006, Shine 2009)

There is a great need for similar computer modelling to be applied to the NZ circumstance in which non-CO_2 GHGs account for more than half of the CO_2-equivalent national emission inventory, rather than act as little more than adjustments to the dominant CO_2 emission as applies to all other OECD countries. Such an approach has the potential to require that more attention be directed to the faster growing CO_2 emission as part of an optimal mitigation strategy.

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BOX 1

Background Science: greenhouse gas cycling

1.1 Methane (CH_4)

The rate of removal of CH_4 from the atmosphere is proportional to its concentration there (first-order in-situ process). Mass balance ➠

$$\partial C / \partial t = S - \lambda C$$

where

- $S(t)$ is the global CH_4 source strength
- λ is the fractional CH_4 removal rate (oxidation to CO_2)
- $\tau = \lambda^{-1}$ is the mean atmospheric residence time for CH_4

In recent decades S appears to be varying only slowly (≈ 600 Tg/yr, ~40% natural), and the removal rate, mainly by photochemically generated OH radical, seems remarkably stable ($\tau \approx 8.5$ yr). Solution to above equation is:

$$C(t) = S/\lambda + (C_o - S/\lambda)\exp(-\lambda t)$$

where the first term is the steady-state value and the second term describes how $C(t)$ transiently approaches steady state from a previous state. Atmospheric CH_4 is currently close to global steady state at a level 2.5 times higher than pre-industrial levels (1800 versus 700 ppb).

Ruminant livestock globally emit ~90 Tg/yr, ~15% of the total CH_4 source (~25% of the anthropogenic source), so account for ~15% of atmospheric CH_4. NZ ruminants emitted ~1.1 Tg CH_4 in 2007.

1.2 Nitrous oxide (N_2O)

An identical formalism as for CH_4 but different numbers: $\tau \approx 114$ yr, $S \approx 18$ Tg(N)/yr (~60% natural, ~15% from agriculture). N_2O is removed by photolysis in the stratosphere. Growth in atmospheric N_2O started in early 1900s, now 18% higher (320 versus 270 ppb). Even with unchanging sources, atmospheric N_2O will continue to rise toward a steady state near 450 ppb later in the millennium.

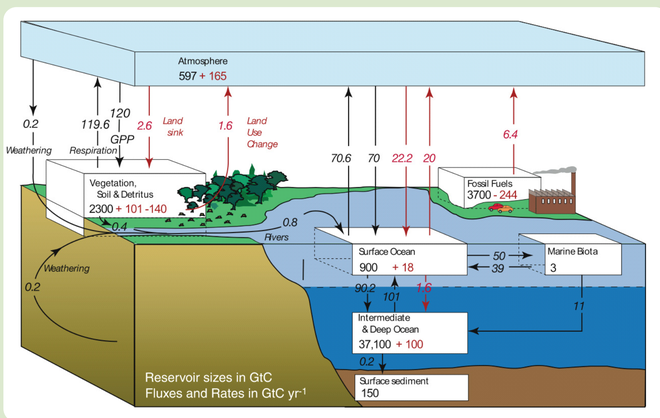
1.3 Carbon dioxide (CO_2)

The situation for CO_2 is very different from CH_4 and N_2O:

- Atmospheric removal is only through net exchange with other C reservoirs on many time scales (see schematic)
- CO_2 exchanges rapidly with surface ocean and with the biosphere: total ~200 Pg(C)/yr (the "labile" C cycle)
- Labile C exchanges over a few centuries with deep ocean
- Labile C exchanges over millennia with carbonate and silicate rocks and with ocean sediments
- "Fossil" C laid down in geological deposits (coal, oil, gas) eg, in carboniferous era (>10^8 yr BP) is relatively isolated from above reservoirs except through human intervention that is returning fossil C to the atmosphere

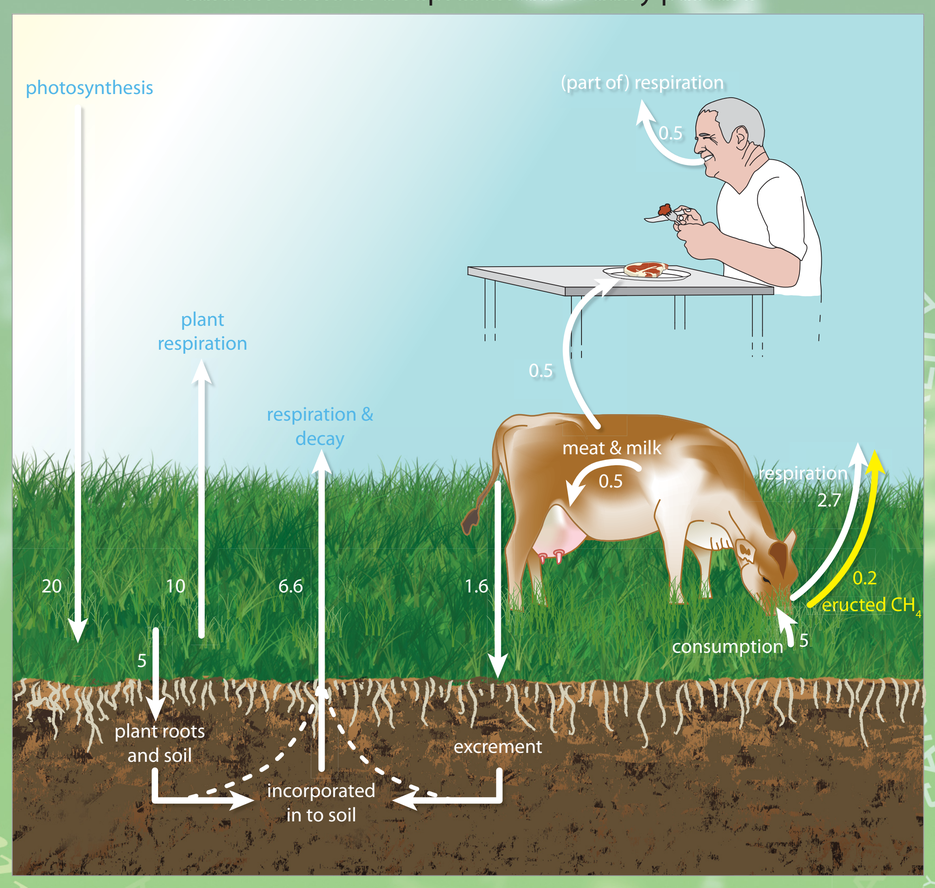
An individual CO_2 molecule resides for ~5 yr in the atmosphere, but a perturbing net "slug" of CO_2 persists much longer: model ➠ ~20% still airborne after 10^3 yr, >10% after 10^4 yr (Archer 2005, Archer & Brovkin 2008, Tyrrell *et al*. 2007).

Such longevity of a net slug of CO_2 cf CH_4, N_2O ➠ impossible to equate non-CO_2 emission to a universal "equivalent" CO_2 emission.



Schematic of the global carbon cycle for ca 1995, showing reservoir sizes in Gt(C) (1 Gt ≡ 1 Pg ≡ 10^9g) and the main annual fluxes in Gt(C)/yr: pre-industrial natural fluxes in black and anthropogenic fluxes in red. Gross fluxes generally have uncertainties of more than ±20%. (Source: IPCC/AR4-WG1, 2007).

Carbon flows in a representative dairy pasture



Carbon flows reflect a near-steady state (units: t(C)/ha/yr). Flows to/from atmosphere are CO_2 except where indicated. (Source: Tony Parsons, AgResearch, based on Parsons & Chapman (2000)).

References cited

Allen, M.R. *et al*. (2009). *Nature 458*: 1163–1166.
Archer, D. (2005). *J. Geophys. Res. 110*: C09S05, doi:10.1029/2004JC002625.
Archer, D. & Brovkin, V. (2008). *Climatic Change 90*: 283–297.
England, M.H. *et al*. (2009). *Proc. Nat. Acad. Sci. 106*: 16,539–16,140.
Fuglestvedt, J.S. *et al*. (2000). *Geophys. Res. Lett. 27*: 409–412.
Johansson, D.J.A. *et al*. (2006). *Climatic Change 77*: 291–309
Manne, A.S. & Richels, R.G. (2001). *Nature 410*: 675–677.
Matthews, H.D. & Caldeira, K. (2008). *Geophys. Res. Lett*. 35: L04705, doi:04710.01029/02007GL032388.
Matthews, H.D. *et al*. (2009). *Nature 459*: 829–832.
Parsons, A.J. & Chapman, D.F. (2000). In: Hopkins A. (ed) *Grass*. Third Edition. British Grassland Society. Blackwells Scientific Publications, pp. 31–89.
Shine, K.P. (2009). *Climatic Change 91*: 467–472.
Solomon, S. *et al*. (2009). *Proc. Nat. Acad. Sci. 106*: 1704–1709.
Tyrrell, T. *et al*. (2007). *Tellus 59*: 664–672.
van Vuuren, D. *et al*. (2006). *Energy Economics 28*: 102–120.
Zickfeld, K. *et al*. (2009). *Proc. Nat. Acad. Sci. 106*: 16129–16134.

BOX 2

Global Warming Potentials and CO_2-equivalent emissions

A GHG in the atmosphere absorbs and re-emits energy from Earth's outgoing infrared (IR) spectrum that would otherwise escape to space. Prior to industrialisation, no net radiant energy left the Earth-atmosphere system, and GHGs in that atmosphere (mainly H_2O, CO_2, CH_4, N_2O) kept Earth's surface >30°C warmer than it would otherwise have been (natural greenhouse effect). Since then, anthropogenic GHGs have altered this energy balance, the alteration being measured by the "radiative forcing" of each such GHG.

So how can we inter-relate the radiative impacts of two GHG emissions to the atmosphere? The answer is encapsulated in the GWPs of each gas:

$$\mathrm{GWP}_X = \frac{\text{Radiative forcing of 1 kg } X \text{ integrated over ensuing time } T}{\text{Radiative forcing of 1 kg } CO_2 \text{ integrated over ensuing time } T}$$

where X denotes the particular gas, and CO_2 is the common "reference gas". Thus, the GWP accounts for both the IR absorptivity of the gas and its net atmospheric persistence throughout T (Box 1). The "time horizon" T could be infinity (to capture radiative impacts over all time), but this would give a near-infinite (and poorly determined) denominator. The GWP for CH_4 includes "indirect effects" but excludes the role of the eventual CO_2 oxidation product.

Parties to the UNFCCC, including to the Kyoto Protocol (KP), agreed to use the GWP for $T = 100$ yr to construct a common CO_2-equivalent scale for all GHG emissions. The KP prescribed GWPs for CH_4 and N_2O of 21 and 310 kg/kg respectively. Thus, an emission of 1 kg CH_4 is deemed equivalent to an emission of 21 kg CO_2 (or 7.6 molecules of CO_2 per molecule of CH_4). These GWP values have since been re-evaluated at 25 and 298 for CH_4 and N_2O (IPCC/AR4-WG1, 2007).

A common emission scale allows GHG substitution ("fungibility"), enabling a country to adopt a least-cost approach to reducing her CO_2-equivalent emission.