The environment, the gas bill and the route to sustainable anaesthesia

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In the context of life sciences the term 'sustainable' refers to being maintained at a steady level without exhausting natural resources or causing severe ecological damage. In 1987, the Brundtland Commission of the UN defined sustainable development as development that meets the needs of the present without compromising the ability of future generations to meet their own needs, in particular the essential needs of the world's poor, and the idea of limitations imposed by the state of technology and social organisation on the environment's ability to meet present and future needs. In the setting of the NHS, sustainability refers to the balance required between social, financial and environmental factors in order to ensure that future generations do not suffer as a result of the way we behave today. It is intimately related to minimising the environmental impact of healthcare delivery, greenhouse gases (GHG), global warming and climate change.

The route map to sustainable health

The Sustainable Development Unit (SDU) of the NHS published the Route Map for Sustainable Health in 2011[1] for individuals, hospitals and networks to help work towards the delivery of sustainable healthcare. The six themes cover individual and societal attitudes and behaviours, governance and use of resources against standards, and innovations in care and technology. The route map is used to define where one is at present, what is the destination and by which route. The progress along the route begins with getting started during which sustainability is understood, progressing to a transition to the expectation that sustainability is becoming the norm and finally to a transformation in which sustainability is routine and culturally embedded and self-regulated. By starting with individuals' behaviour, the route map places the onus on all of us.

Individual behaviours

Many anaesthetists have made practical changes to their own homes and in their own lives to reduce energy consumption. Aside from acknowledging the ever increasing size of the gas or electricity bill or gloating at the amount of money earned from the feed in tariff from the solar PV system, does one actually examine and analyse year on year the energy one's home has used? Without doing so, how can we know how much energy has been saved by our extra layers of loft or cavity wall insulation? As one of the management adages states: 'You can't manage what you don't measure'. Unless you measure energy consumption you are unlikely to make the effort to reduce it.

Energy consumption and CO_2 production

Energy to power our homes and hospitals comes predominantly from the combustion of fossil fuels; the more energy we use the greater the CO_2 production. Our utility companies inform us that 1 kWh of energy (3.6 MJ) from gas combustion is enough to heat a radiator for an hour or cook a family meal. The heating value of methane is 50 MJ/kg, i.e. about 14 kWh/kg or 72 g (4.5 mol) methane per kWh. As the reaction is $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$, complete combustion of 4.5 mol methane will produce 4.5 mol of carbon dioxide, very nearly 200 g. Electricity production has inherent losses in generation and transmission and the figures for the CO_2 production per kWh from gas and from coal generated electricity are 355 g/kWh and 886 g/kWh respectively. The average for all fossil fuels is 660 g/kWh.[2] Since the energy production required to power our homes produces six tonnes of CO_2 per home per year[3] and the atmospheric concentration of

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CO_2 is rising by 1.9 ppm/year, then perhaps the first individual action we should make is to begin to record, graph and act upon our domestic energy use rather than just settling the bill or direct debit.

Departmental behaviours

Much has been written on the subject of efforts to reduce the environmental impact of anaesthesia practice.[4–7] Mostly qualitative, the authors make many useful and practical suggestions. Taking the analogy with our homes though, are there quantitative measurements we could make in order to manage and minimise our environmental impact?

Embedded carbon

At every stage of manufacturing processes, energy is required. The SDU has addressed this[8] and the breakdown for pharmaceuticals is in Box 1.

Box 1 The process outline from development to end of life for pharmaceuticals described by the Sustainable Development Unit

- Research and development
- Clinical trials and marketing
- Manufacture of active pharmaceutical ingredient (API)
  - Material and chemical inputs
  - Material and chemical transport
  - Energy/fuel generation and consumption
  - Waste disposal
  - Solvent manufacture, use and disposal
  - Catalyst manufacture, use and disposal
  - Solvent recovery and incineration
  - Process emissions from synthesis
  - Chemicals for cleaning
  - Sterilisation
  - Refrigerants
- Preparation of the product form
  - Tablet, injection
  - Production and disposal of consumables
- Manufacture of drug delivery system
  - Syringe, syringe driver, vapouriser
- Packaging
- Distribution
- Administration
- Disposal/end of life

Carbon dioxide equivalents (CO_2e)

The impact of the release of GHGs other than CO_2 is expressed in terms of the amount of carbon dioxide that would need to be released to have the same warming effect as the GHG in question. In other words, carbon dioxide equivalent is the product of the mass of the gas released multiplied by its global warming potential (GWP).

The GWP of inhalational anaesthetic agents

In general the GWP is expressed over the 100 year time horizon (GWP_{100}) and is influenced by the agent's absorption of IR radiation and the atmospheric life time. The GWP_{100} of CO_2 is by definition 1. The GWP_{100} of nitrous oxide is 298, sevoflurane 130, isoflurane 510 and desflurane 2540.[9] The disposal to the atmosphere of inhalational anaesthetic agents is of far greater impact than the manufacturing process, especially if those agents are co-administered with nitrous oxide.[10] Using modelling techniques the authors calculated the CO_2e to provide one MAC hour of anaesthesia. Table 1 is derived from their data. Desflurane and nitrous oxide cause the most warming and sevoflurane the least. Once the mass of each anaesthetic vapour agent used is known, the CO_2e can be calculated. The comparative values for the CO_2e for inhalational anaesthetic agents are presented in Table 2.

Calculating the annual CO_2e for inhalational anaesthesia

Hospital pharmacies have accurate records of the numbers of units of each drug issued each year. Obtaining accurate records of medical gases delivered may require some detective work. As part of medical gas suppliers' corporate and social responsibility should each hospital and anaesthetic department be issued with an annual statement of nitrous oxide delivery? Inserting the values in Table 3 will give the total CO_2e for each anaesthetic department.

Within my own Trust, the decision to remove sevoflurane vaporisers from all but paediatric theatres in 2010–2011 resulted in a fall in the drug bill as less sevoflurane was used but a rise in the environmental burden of agents with higher GWP (Figure 1).

On course to embedded sustainability

Championed by a departmental lead for sustainable anaesthesia, measurement, recording, and acting on environmental data will not just raise awareness but serve to change departmental behaviour to minimise fresh gas flows and think more widely about sustainable anaesthesia. Once established, standards can be set and the tool used to measure and compare

Table 1 Comparative values for the CO_2e (g) of manufacturing and disposal of anaesthetics to provide a one MAC hour of general anaesthesia. The upper value for nitrous oxide reflects the higher FGF required for sevoflurane anaesthesia. (Derived from Sherman et al[10])

Agent	Manufacturing process CO_2e (grams)	Atmospheric disposal CO_2e (grams)
Nitrous oxide	130–260 g	22,000–44,000 g
Isoflurane	50 g	1500 g
Sevoflurane	150 g	1250 g
Desflurane	370 g	33,000 g

Table 2 The CO_2e of the vapour from the contents of a single size E nitrous oxide cylinder and single bottle of commonly used anaesthetic agents

Agent	CO_2e (kg)
Size E nitrous oxide cylinder (3.4 kg)	1013 kg
Isoflurane (250 ml)	190 kg
Sevoflurane (250 ml)	49 kg
Desflurane (240 ml)	886 kg

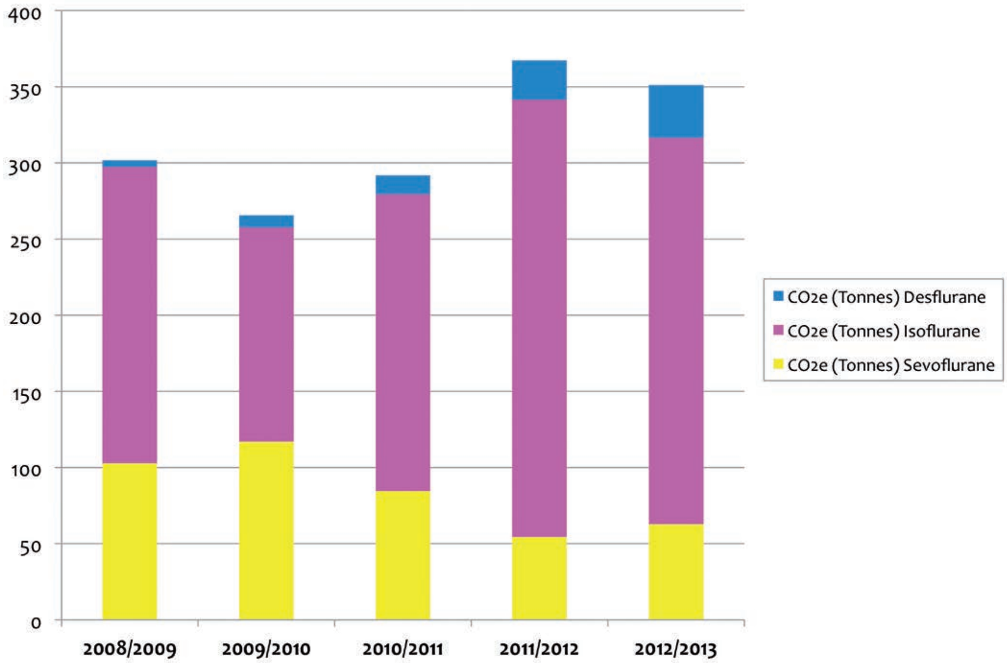
Table 3 The formula to calculate the CO_2e for anaesthetic agents. Inserting the values for number of each agent used and multiplying across the rows gives the CO_2e

Agent	Volume per bottle (L)	Density (kg/L)	Number of units used	GWP	CO_2e
Isoflurane	0.25	x 1.496	x	x 510	=
Sevoflurane	0.25	x 1.52	x	x 130	=
Desflurane	0.24	x 1.456	x	x 2540	=
	Mass (kg)				
N_2O E size	34 kg	---------	x	x 298	=
N_2O G size	17 kg	---------	x	x 298	=
N_2O J size	34 kg	---------	x	x 298	=
Entonox	Mass used	x 0.58	x	x 298	=
TOTAL					

performance over time. Technological innovation from anaesthesia workstation manufacturers such as low flow reminders and the matching of FGF to end tidal concentrations will further refine the delivery of minimal flow sustainable anaesthesia.

It is unlikely that top down enforcement will bring about behaviour change. More effective, is the application of science to our anaesthesia practice and to leave the planet a little less jeopardised than it potentially might be.

Figure 1 The trends in CO_2e over the financial years 2008–2012 for a university hospital NHS trust. The removal of sevoflurane vaporisers from all but the paediatric theatres in 2010 saved money but increased the CO_2e (1 tonne is 1000 kg)



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