CURRENT SCIENCE

Volume 112 Number 7 **10 April 2017**

GUEST EDITORIAL

Why is a solution to climate change, environmental degradation and the sustainability crisis eluding us?

'Earth's 2016 surface temperatures were the warmest since modern recordkeeping began in 1880, according to independent analyses by NASA and the National Oceanic and Atmospheric Administration (NOAA)' declares the 18 January 2017 NASA news release. Estimates show that the global mean surface temperature in 2016 was 1.1°C above the pre-industrial levels. Further, 2016 was the third year in a row to set a new record for global average surface temperatures. The trends in global temperatures in the last few decades are of course consistent with the scientific consensus on climate change. The concentration of atmospheric carbon dioxide (CO_2), the main driver for the current climate change, has recorded a monotonic increase during the same period. It is now well past 400 ppm, about 120 ppm above the pre-industrial levels. Simple calculations based on radiative transfer in the atmosphere show that this increase in CO_2 causes a trapping of infrared radiation by about 1.8 Wm^{-2}. Integrated around the planet, this translates to a heating rate of approximately 1 PW (petawatt) by the enhanced atmospheric CO_2 since the pre-industrial period.

What is driving the atmospheric CO_2 concentrations upward? It is well established now that fossil fuel (mainly coal, petroleum and natural gas) burning is the major cause for the present increase in atmospheric CO_2. What is alarming is the rate at which the driver for the anthropogenic climate change is accelerating: the global energy consumption rate (mainly from fossil fuels) has tripled in the last 50 years. Global CO_2 emissions have increased by 65% since the early 1990s, when the Kyoto Protocol for CO_2 emission reductions was signed (recall Kyoto Protocol was a failure and is now replaced by the 2015 Paris Agreement). The annual emission rate has increased more than fivefold since 1900 – from less than 8 billion tonnes (mostly from deforestation) to about 40 billion tonnes of CO_2 today. The modern anthropogenic climate change is unprecedented in the history of our planet – such large rates of CO_2 and temperature change on centennial timescales cannot be found in palaeo records.

What are the main factors that drive CO_2 emissions? Knowledge on these drivers could provide simple insights into the sustainability and climate change mitigation problems. The CO_2 emission in any region or in the global domain is given by the Kaya identity:

$$CO_2 \text{ emission} = \text{Population} * (\text{GDP/person}) * \text{energy intensity} * \text{carbon intensity}.$$

The last two terms are related to efficiencies: energy intensity is defined as the amount of energy generated per unit GDP, and carbon intensity refers to the amount of CO_2 emitted per unit energy generated. Emerging economics, because of heavy industries usually have higher values of energy and carbon intensities when compared to developed economics. Therefore, as transition toward service sector-based economy takes place, these two quantities should decline as evidenced by a decrease in these variables on a global mean basis in recent decades.

That leaves population growth and GDP as the major drivers for CO_2 emissions in the last century. Global population was estimated at 1 billion in 1800 and it took 120 years to reach the 2 billion mark. In contrast, it took just 12 years recently to add 1 billion people on the planet. Global population is now 7.4 billion and it has increased by a factor of four in the last 100 years. Similarly, global mean GDP, which is a measure of standard life, has increased by a factor of five in the same period from US$ 1000 to 5000. No wonder global CO_2 emissions are now up by a factor of 10 (factors of four and five for population and GDP respectively, and a net gain of about 50% in efficiency) relative to the early 20th century.

Clearly, we are on a rapid growth trajectory. It is not just population, GDP and consequently CO_2 emissions that are steeply rising, at perhaps unsustainable rates. There are several other subsystems that have gone wrong with our global environment because of unsustainable use of natural resources. Nearly 35% of the land area today is cropland and pasture land created mainly by cutting down forests to make room for agriculture. Freshwater shortage, biodiversity loss, chemical air pollution, pollution of waterways by nitrates and phosphates because of fertilizer use in agriculture to boost the yields, Antarctic ozone hole and ocean acidification are a few examples of environmental crisis the planet is facing today.

Some recent papers have introduced an interesting concept called 'planetary boundaries' to characterize the status of various earth system components (Rockström, J. *et al.*, *Nature*, 2009, **461**(24), 472–475; Steffen, W. *et al.*, *Science*, 2015, **347**(6223), 1259855-1–10). According to

Rockström *et al.*, 'These boundaries define the safe operating space for humanity with respect to the Earth system and are associated with the planet's biophysical subsystems or processes'. When the anthropogenic perturbation is above a threshold, the resilience of a system is threatened. For instance, the Paris Agreement settled on 2°C global warming limit to avoid large damages related to climate change. The thresholds represent values of earth system metrics that are well above background values. There is some level of subjectivity in arriving at the thresholds – a CO_2 value of 350 ppm is defined as the threshold value for climate change in these recent publications, because the long-term climate feedbacks and the stability of the polar ice sheets are considered. According to these studies, perturbations to biodiversity and earth's nitrogen and phosphorus cycle have already crossed the thresholds that compromise the resilience of the earth system, and the level of current global warming is in the zone of increasing risk. It is likely that more earth system processes could breach their respective thresholds and resilience in several components may be compromised in this century.

Should we be concerned about our unsustainable journey? When the global population was 6 billion, James Lovelock (*Gaia: A New Look at Life on Earth*, Oxford University Press, p. 176) who proposed the Gaia hypothesis (which postulates that the earth system functions as a self-regulating single organism) had claimed 'A billion could live off the earth; 6 billion living as we do is far too many, and you run out of planet in no time'. How did human civilization then manage to survive and flourish? Science and technology (S&T) are the main reasons that the planet is able to support 7.4 billion today – that too on an average, comfortably when compared to the past. To give an example, the invention of the Haber–Basch process, an industrial process for producing ammonia from nitrogen and hydrogen, and the subsequent use of fertilizers in agriculture and crop yield boost have prevented mass hunger and starvation deaths. Modern healthcare system, another achievement of S&T, is responsible for longer lifespan. The benefits from S&T in the energy system are all too visible in our homes and transportation.

The gains from S&T in the 20th century have emboldened some to advocate artificial, large-scale engineering solutions to undo one of the major environmental crisis: global warming. The portfolio of such proposed solutions is collectively known as geoengineering (Caldeira, K. *et al.*, *Annu. Rev. Earth Planet. Sci.*, 2013, **41**, 231–256; Bala, G., *Curr. Sci.*, 2014, **107**(12), 1939–1940). They are broadly classified into two main categories – solar radiation management (SRM) and carbon dioxide removal (CDR) techniques. Some of the proposed SRM methods would place reflecting mirrors in space, increase the reflectivity of the planet by artificially injecting aerosols into the stratosphere, or brighten the marine clouds by seeding them with sea-salt aerosols. The basic idea is to reduce the absorbed solar radiation by an appropriate amount to cancel, fully or party, the temperature increase caused by anthropogenic greenhouse gases. The second class of techniques proposes to artificially remove CO_2 from the atmosphere using large-scale afforestation, ocean iron fertilization, accelerated weathering of silicate rocks, industrial chemistry to directly capture CO_2, etc. While CDR methods address the root cause of climate change, SRM geoengineering solutions are more like 'use one form of pollution to mask the effects of another', or a 'patch work' on the Earth system. Most of us would prefer to prevent climate change than cure a 'sick' planet.

This leads us to a more basic question of 'what is the fundamental reason for the environmental crisis, including air pollution and climate change?' Can S&T solutions solve environmental degradation? The answer can be found in 1960's paper in *Science* titled 'The tragedy of the commons' by Garrett Hardin (*Science*, 1968, **162**, 1243–1248). It refers to the tragic consequences that result when a property is common to all. In this context, the common property could be air, fresh water bodies, sea, or public property such as a national park. Hardin writes, 'The rational man finds that his share of the cost of the wastes that he discharges into the commons is less than the cost of purifying his wastes before releasing them'. On the similar issue of population growth, the author concludes 'The population problem has no technical solution; it requires a fundamental extension in morality'. The take-home message is that the problems of climate change, sustainability and environmental degradation do not have solution in natural sciences alone. We need morality, ethics, collective responsibility and cooperation at all levels to solve them. Mutual coercion such as legally binding protocols, fines and taxes agreed mutually by majority of the affected parties is probably the key tool. As a global community, we are yet to reach such arrangements.

To conclude, no natural system supports exponential growth forever. Sooner or later, systems that grow rapidly either reach saturation levels or crash. Optimistic projections show that the global population would stabilize around 9 billion, and the carbon and energy intensity factors in the Kaya identity could continue to decline as more and more countries become developed, while global mean GDP per person increases another five-fold to reach US$ 25,000 by 2100. We can be optimistic and hopeful for a stable future. However, after witnessing the jingoistic slogans such as 'my country first' around the world in recent years, it is worth recalling a quote by Lovelock, who had believed in rapid and dire consequences from climate change, on the claim 'the science is settled on global warming'. 'One thing that being a scientist has taught me is that you can never be certain about anything. You never know the truth. You can only approach it and hope to get a bit nearer to it each time. You iterate towards the truth. You don't know it'.

G. Bala

Centre for Atmospheric and Oceanic Sciences,
Indian Institute of Science,
Bengaluru 560 012, India
e-mail: gbala@caos.iisc.ernet.in