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What is Sustainable Air Quality?

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Abstract

For 40 years or more air quality policy has been based on the paradigm of the Air Quality Standard as a uniform criterion of acceptable environmental degradation, built on the foundations of the precautionary principle. However, developments in health science have undermined some of the underlying assumptions of this paradigm. Standards have provided powerful stimuli for deep emission cuts, but these cuts have led to less impressive improvements in air quality, whilst more subtle adverse health effects continue to be identified. Successes in technological emission control have continually been offset by growing economic activity.

More recently, atmospheric carbon has overshadowed and been in conflict with the substantial contribution local air quality policy can make to transforming urban societies. Current trends are towards increasingly demanding notions of what constitutes acceptable air quality. Future air quality standards could require a revolution in urban form as the plans of today will define the air quality of the future for generations. We need a new paradigm – sustainable air quality.

NIWA-led scientists have begun to explore what that paradigm might look like. In order to seed further discussions amongst stakeholders this paper discusses the need for a new paradigm and what sustainable air quality management might hope to achieve. It is suggested that a more holistic approach must better integrate economic/infrastructural and especially social determinants, constraints and goals. A recommendation to further such an approach is

1. to enable a more explicit consideration of how air quality interacts with the economy, the environment and with society.
2. to describe how further downward pressure can be exerted on emissions through urban form, urban design, transport infrastructure, energy strategy, etc.
3. to explore how social factors can be better integrated and considered in policy appraisal and in redefining what is meant by acceptable air quality.

Introduction

In discussions about sustainability ‘clean air’ is regarded as a natural asset (if is mentioned at all), an environmental ‘capital’ which is to be maintained or improved upon for future generations. However, ‘air’ has numerous aspects – it hosts the climate, it provides a pathway for global biogeochemical cycles vital for life, as well as being a medium by which human economic activity impacts human health.

Why do we manage air quality? Globally, air quality is one of the greatest threats to community health and a major cause of avoidable death (WHO, 2006). In New Zealand, it has been estimated that poor air quality represents a risk to health on a similar scale to road traffic accidents (Fisher *et al.*, 2007). Yet these estimates are potentially the tip of the iceberg, with a rapidly growing body of research uncovering ever more subtle but pernicious influences on chronic health and vulnerability (e.g. Morawska *et al*., 2008, Morgenstern *et al.*, 2008).

How do we manage air quality? The fundamental basis for current air quality management is air quality standards. These standards (or guidelines), which first emerged at a national level in the US in 1971, specify maximum permitted concentrations of certain ambient air pollutants which must not be exceeded. In New Zealand this takes the form of the Air Quality National Environmental Standards (AQNES), introduced in 2004 within the RMA, which specify maximum concentrations of five pollutants. There is a large degree of international consistency in these standards/guidelines, with most countries following the comprehensive guidance provided by the World Health Organisation (WHO, 2000, 2006).

The track record of Air Quality Management

From an economic viewpoint it has been shown that industrializing societies have tended to suffer worsening air pollution until a certain level of wealth is achieved, beyond which that society finds it can afford to manage its pollution problem without hindering continued economic activity (Mage *et al*., 1996).

Managing air quality has been primarily achieved through reduction in emission factors rather than reductions in the emitting activity. Emission factors are the quantity of emissions per (economic) "activity" (such as kilometres travelled or amount of product manufactured). They are effectively a measure of emission efficiency. Emission factor reductions have been somewhat easier to achieve as technology advances (cleaner fuels, improved combustion, exhaust after-treatment, etc).

Air quality standards have provided powerful stimuli for the technological advances needed to deliver these cuts in emission factors. After several decades of ambient air quality management in Europe and North America, the successes are very apparent. 'Killer smogs' are a thing of the past and emission factors for industry, power generation, and road vehicles have been slashed. Moreover, there is a wealth of literature to show how successful this approach has been in improving air quality evidenced by reduced ambient pollution concentrations whilst providing net economic benefits and during a period of growing transport use and energy production (e.g. Bachmann, 2007).

Challenges to current Air Quality Management

However, the improvements in air quality have not been quite as impressive as cuts in emission factors might suggest, and, more importantly, the health benefits of those emission reductions are highly uncertain. This is partly because there is a non-linear chain of processes that relate emissions to ambient concentrations and to health effects. (e.g. Harrison *et al*., 2008). Furthermore, health research has continued to identify a growing list of adverse health effects, even in cities where air quality easily meet established standards (e.g. Clark *et al*., 2010).

The other main reason for diminishing returns from cuts in emission factors is the relative failure to reduce emitting activities. For instance, the recent history of road traffic emissions in the developed world is characterised by significant reductions in emission factors (individual vehicles pollute much less than they used to) increasingly being offset by a huge growth in the number and use of road vehicles. In New Zealand, improvements in domestic heating technology are offset by resistance (social, cultural or economic) to wood-burner replacement and by population growth.

In general, reductions in the emitting activities have proved more difficult to achieve as such reductions are perceived to be in conflict with the prevailing imperative of economic development. However, this perception can be seen as a symptom of non-sustainable air quality management.

A narrow vision leading to conflict

In New Zealand, the core regulatory tool is the Air Quality National Environmental Standards, or AQNES (regulations under the Resource Management Act 1991). Ministry for the Environment documentation states that:

> "The primary purpose of the ambient standards is to provide a guaranteed level of protection for the health of all New Zealanders." (MfE, 2005)

Furthermore…

> "The ambient air quality standards are the minimum requirements that outdoor air quality should meet in order to guarantee a set level of protection for human health and the environment. The phrase 'set level of protection' is used quite deliberately – it does not mean that all adverse health impacts will be avoided. This is because some pollutants (e.g., PM_{10}) do not have a 'safe' threshold under which no adverse health impacts are experienced." (MfE, 2010)

The statement above about the AQNES makes it clear that we manage air quality (and management largely consists of various forms of 'interference' in the economy) primarily for health reasons, with other environmental effects (e.g. effects on visibility, the climate, vegetation, etc.) considered to be secondary or not relevant (and whether health effects are environmental or social effects is a source of unresolved confusion).

Cross-professional and administrative divides have reflected in low participation and involvement in air quality management by professionals outside air quality, and by the general population. This has led to biases in the system (mostly in favour of narrowly defined economic interests and against social/cultural considerations) and poor policy accountability.

As we transition towards sustainable development policy, conflicts resulting, in part, from this professional isolationism and systematic compartmentalizing are becoming increasingly apparent. Well-known examples include the promotion of diesel vehicles because of their low CO_2 emissions despite much higher emissions of a wide range of toxic air pollutants, including PM and NO_2 (Carslaw *et al*., 2007, Mazzi & Dowlatabadi, 2007). Also, wood-burning for domestic heating is promoted in New Zealand by some due to its (potential) carbon neutrality (EECA, 2005) despite being the major cause of breaches of the AQNES in New Zealand (Fisher *et al*, 2007). We propose that many of these conflicts arise because of the poor quality of connections between air quality, other aspects of the environment (such as climate and global biogeochemical cycles) and the economy, but especially with social and cultural considerations. Without the effective integration of air quality issues into sustainability in effective practice these conflicts appear irresolvable or are being addressed by solutions that could be inefficient at best and counter-productive at worst.

Weak consideration of social factors also lies behind the relative failure to restrict emitting activities. Industrial emissions, motorised travel, space heating, etc. arise from economic activity and social desires, circumscribed by the environment. They involve cultural worldviews and norms, public perceptions, behaviour and personal choices. Efforts to reduce emitting activities at both an individual and community level, pose (or are perceived to pose) a threat to personal freedom and economic prosperity. It appears to us that the key to unlocking the potential in reducing emitting activities is to holistically consider the interplay between social, economic and environmental drivers, limits and opportunities.

What's wrong with air quality standards?

When searching for something to represent the 'bottom line' for clean air in sustainability appraisal, air quality standards appear to be the default choice, largely because of the absence of any alternative. However, we propose that current scientific evidence is stubbornly opposed to the notion of an evidence-based fixed threshold of acceptable degradation of air quality.

The first problem before us is that the effects of ambient air quality on health at normal urban concentrations are subtle and challenging to quantify. The WHO provides guidance based on available research, but there is much that is unknown or uncertain, and the science is rapidly evolving. Air quality standards are a combination of current 'best guesses' of health effects, a precautionary stance, and a consideration of motivational achievability. Thus we have to take account of the fact that we have a bottom line which is likely to move and continue to move as new heath evidence emerges.

Secondly, we cannot yet define a single bottom line. Air is a complex mixture and there is no single measure of its cleanliness. In Europe long-term standards for nitrogen dioxide (NO_2) and fine particles ($PM_{2.5}$) are seen as the most challenging. New Zealand has not adopted any long-term standards, and we conventionally view our air quality challenges in terms of short-term peaks in fine particles. In California it is the ozone (O_3) standard which is seen as the main challenge.

What O_3, NO_2 and PM have in common is that they are not discrete individual pollutants, but are strongly inter-related through chemical and physical processes in the atmosphere. Attempts to find ways to manage all of these substances together in a single multi-pollutant framework, which may require a single measure of air quality, have begun. However, they are held back by large knowledge gaps, particularly surrounding how we describe exposure to, and the health impacts of, complex multipollutant mixtures (Hidy & Pennell, 2010).

The third main problem with specifying a bottom line for air quality is the inability if health scientists to find any 'zero-effects threshold' for PM or other multi-pollutant mixes. For instance, the UK's Committee on the Medical Effects of Air Pollutants recently stated:

> "In general, it is accepted on the basis of time-series studies that no threshold of the effect of particulate matter on mortality can be defined for the population as a whole. This has caused some difficulties for toxicologists asked to explain effects at very low concentrations, but the likely distributions of exposure, together with the sensitivity of some individuals across large populations, make it plausible that there is some risk to some individuals even at very low background concentrations…We found that no evidence of a threshold has been produced – nor is there any sign of the line representing the association decreasing in slope as it approaches very low concentrations." (COMEAP, 2009)

So, adverse health effects appear to be linearly and continuously related to the magnitude of exposure. Thus, we set an effectively arbitrary threshold (the standard) to regulate a non-threshold risk. This arbitrariness makes it vulnerable to attack. This has already happened in

New Zealand where some of the stringency of the PM_{10} Standard is proposed to be relaxed (MfE, 2010) on the basis of cost-benefit analyses which are biased in favour of saving costs to the formal economy (councils and businesses) and against realizing poorly defined social benefits. These analyses also revealed the weak hand held by 'society' because they refused to consider the benefits of seeking air quality which is better than the Standard.

Re-thinking air quality in a sustainability context

Although air quality policy actions have been found to improve air quality (by some measures) it remains unclear if current, planned or alternative actions are the most effective or efficient, or whether they are actually delivering the ultimate desired outcome, which is (or at least it appears to be) improved health (e.g. Thurston *et al.*, 2009). However, confusion reigns once we start to consider how much we are willing to pay for that improved health, and where the socially acceptable balance lies between competing goals.

The system needs an overhaul. Can a new approach to air quality management be formed which is consistent with (and complementary to) the goals of environmental, social and economic sustainability? An approach which is progressive, pro-active and future-focussed? One which, as far as possible, is built-into - rather than imposed upon - society?

This paper represents an early stage in developing a concept for a new approach to air quality management. At present the ideas described hereon should be taken as being suggestive.

What, ultimately, do we want from air quality management? We propose that our ultimate aim might be to provide thriving human societies with clean air whilst requiring as little management as possible. We seek to engineer the adaptation that allows poor air quality to be evolved-out of urban society. We seek to achieve this consistently with the goal of providing inter- and intragenerational equity of the capitals associated with the four pillars of environmental, social, cultural and economic sustainability. Specifically this may include:

- (Environmental): protection of the biosphere, minimizing the effects of emissions on the atmosphere;
- (Social): minimizing adverse impacts on human health and wellbeing, including annoyance and stress; promoting social capital, cohesion and political participation;
- (Cultural): pride in local air quality;
- (Economic): removing restrictions on economic activity which is not in conflict with environmental and social goals, boosting urban vitality and supporting low-impact tourism and leisure.

At NIWA our approach is to firstly reveal how air quality interacts with these four pillars, to highlight existing policy biases and highlight previously under-exploited links and their associated policy options. Secondly, we aim to enable a flow of meaningful inter-disciplinary information along the links identified. Where possible we aim to select, adapt or devise metrics and indices to enable a working, dynamic system.

In doing so, there are some key aims which arise from specifically addressing the weaknesses of the current system described above. These may include:

a) to strengthen the consideration of social constraints and goals
b) to improve the ability of society to reduce its emitting activities
c) to explore the suitability of air quality standards, and consider alternatives

d) to improve the flow of information generally, enfranchising more stakeholders and facilitating community participation

A suggested sustainable air quality management system

The core of this initial proposal is to explicitly disaggregate air quality into the causal chain of emissions, air quality and exposure. Each part of this chain interacts independently with the economy, the environment, society and culture, and it is proposed that untangling and describing these interactions is the key to resolving the failings and conflicts described above. Hitherto, exposure has been the weak link between air quality and health (and other social impacts) and its management has been an under-exploited option. In its simplest form, exposure is the coincidence of a hazard (poor air quality) and an unprotected population. To take an extreme example, a total switch to electric vehicles may not change total emissions (emissions are involved in generating the electricity, and also in the production of the vehicle, etc.) but could substantially improve local air quality and radically reduce exposure of people who spend time in or near traffic.

Figure 1 shows how interactions and feedbacks between the four pillars are mediated by the emissions-air quality-exposure chain as both cause and effect. Emissions are caused by social and economic needs (work, comfort, access to goods and services, social interaction), constrained by the available infrastructure (energy, transport, urban form), social constraints on available choice (e.g. affordability) and influenced by the climate (primarily in the case of domestic heating or air conditioning demand, but also influencing transport use and modal choice). The environment also provides natural emissions in the form of dust, volcanic emissions, sea spray and other forms. The impacts of emissions are mediated via 'air quality' (leading to impacts on the natural environment) or exposure (impacts on humans, i.e. society). These social impacts include ill-health but also stress arising from the fear of pollution, or lack of control over one's exposure, perceptions of injustice arising from inequitable exposure being that real or perceived. Social (status, lifestyle) and economic factors also influence exposure by constraining where/how one lives, travels and consumes, controlling therefore who is exposed to what, and when. Poor air quality imposes economic costs (independently of health costs) through impacts on agriculture, and potentially lost economic activity due to lost investment in an environmentally unattractive location. Costs are also imposed when poor air quality triggers policy restrictions on industry.

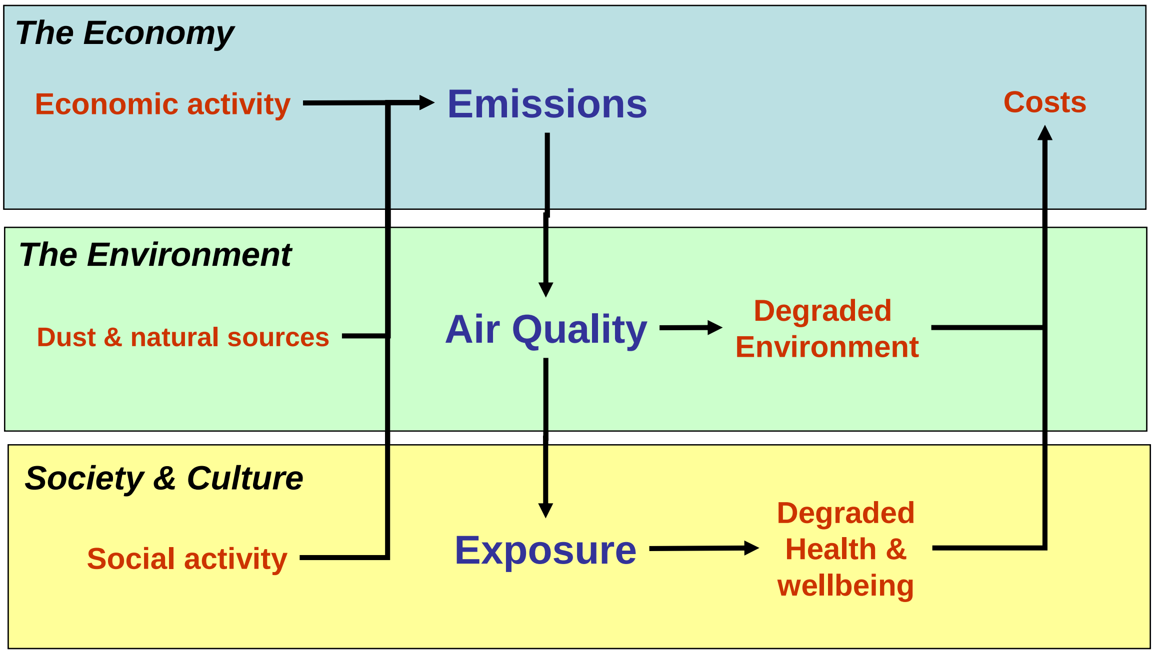

Figure 1: A conceptual illustration of forcing and feedbacks between the emissions-air quality-exposure chain and the economy, environment and society.

Our goal is to develop tools to understand and manage this system, central to which is the flow of information. Scrutiny into the role of information is particularly crucial for our aim of exploiting the role of personal choice in determining emissions. From a simplistic economic point of view people (on average) are likely to make rational choices that will benefit the whole population, if they possess sufficient information. That those promoting the reduction in emissions and those resisting the reductions appear to be reaching incompatible conclusions may suggest an imbalance in the information each group possesses (or has access to). For the general population the most readily available form of information on emissions tends to focus on CO_2. This is unfortunate from an air quality point of view as CO_2 is relatively unique amongst urban emissions because it is non-toxic and its impacts are diffuse and distant while most other combustion products have impacts which are local and immediate. They affect the person causing the emissions and the community they live in. What difference might information describing these relationships make in terms of perceptions, and emitting behaviour?

Substantial amounts of air quality data are available in the public domain and recent advances in information technology are making it ever more discoverable. However, experience here and abroad has shown that much of this data, in the way it is normally presented, has little meaning for the most of the public and is ineffective in encouraging environmentally sustainable behaviour (Johnson, 2003, Blanken, *et al*., 2001). Yet the potential of abundant data may be unlocked if its role in a more holistic approach to sustainability is borne in mind when it is upgraded from data into information.

Implementation and the future of Air Quality Standards

Within a framework like the one discussed here it is hoped that actions to reduce emission factors can be made consistent (e.g. we don't reduce emission of one pollutant for health reasons at the expense of raising emission of another climate-impacting pollutant). It is also hoped that actions to reduce emitting activities can be better co-ordinated, better communicated (and debated) and better embedded in urban infrastructure so that the more desirable choice is more often than not the most rational choice.

The implication of such an approach is that the main point of leverage for managing air quality is at the point at which the economy and its underlying infrastructure influence emissions. Thus, air quality policy might be enabled in urban planning, architectural design, transport design and energy infrastructure as much as by explicit environmental management.

It was noted above how the setting of an air quality standard is far from an exact science, with notions of achievability and the need to avoid stifling economic growth being prominent considerations. Most standards around the world are 'static' in that once they are met there is no incentive to seek further improvements. However, recent developments are tending towards increasingly demanding notions of acceptable air quality. The European Union has recently adopted an 'exposure reduction' approach to $PM_{2.5}$. This requires that a Standard is not just met, but that the average exposure of all urban citizens is continually reduced beyond compliance with the Standard's limit value (EU, 2008). In 2010 the USEPA proposed a reduction in the 8-hour ozone standard. This standard is so demanding that it has been stated that the South Coast Air Management District (which is responsible for air quality in Los Angeles) will need to convert to a zero-emissions transport system, supported by a revolution in land-use to reduce transport demand to comply.

We know that the health effects of PM cannot be explained by the chemical toxicity of its individual constituents alone (Valberg, 2004). There is now overwhelming evidence that particle size is crucial and that ultrafine particles (smaller than 0.1 μm) exhibit enhanced toxicity combined with the ability to be penetrate deep into the lung and translocate throughout the body (Stone *et al.*, 2007). We still await the epidemiological evidence that could inform an air quality standard. However, initial evidence has led leading experts to suggest that the only credible 'bottom line' for UFP is the regional background level, i.e. a level which **all** urban areas currently exceed (Morawska *et al.*, 2008).

These developments indicate how standards are being used abroad as progressive tools which are evolving within their own policy and cultural environment. As we transition to a sustainability-based approach to policy air quality standards can either remain as static relics of an obsolete philosophy, or adapt to become valuable and enabling signposts towards the kind of society we want.

Conclusion

This paper has highlighted that the current paradigm of air quality management has brought about major successes in reducing emissions, mostly through technological advances in fuels, combustion efficiency and after-treatment. However, there are two major weaknesses:

- a failure to deliver commensurate improvements in air quality, health and the wider environment
- a failure to ensure continuing downward pressure on these impacts for future generations.

It is proposed that these failures arise from

- lack of success in reducing (or constraining) growth in emitting activities
- inappropriate use of health-based air quality standards as environmental 'bottom lines' for which they are poorly suited.

- policy conflicts and counter-productive actions arising from trying to tackle inter-related issues in isolation

In essence, the current system seeks to deliver the minimum for the present. It is reactive and fundamentally unsustainable.

At a deeper level it is proposed that all of these problems can be traced to

- lack of clarity over policy objectives
- particularly poor consideration of social and cultural goals and constraints and a bias towards a narrow view of economic imperatives in policy and project appraisal
- uncertainty over what is a socially acceptable level of degradation of air quality

This paper is intended to seed discussion on what might be required to integrate air quality management into sustainable environmental management and to help broaden the range of stakeholders. It is suggested that a more holistic approach must better integrate economic/infrastructural and especially social determinants, constraints and goals. A recommendation to further such an approach is

1. to enable a more explicit consideration of how air quality interacts with the economy (through emissions), the environment (through ambient concentrations) and with society (through exposure).
2. to describe how further downward pressure can be exerted on emissions through urban form, urban design, transport policy and projects, energy strategy, etc.
3. to explore how social factors can be better integrated and considered in policy appraisal, in resolving policy conflicts and in redefining acceptable air quality.

A basic degree of clean air should rightly be viewed as a vital natural asset that everyone has a right to. There seems to be no reason why that right should not extend indefinitely into the future. In the spirit of sustainability, however, and in light of the substantial burden polluted urban air currently places on health, can't we do better than just the 'bottom line' and aim to gift future generations with better air quality?

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