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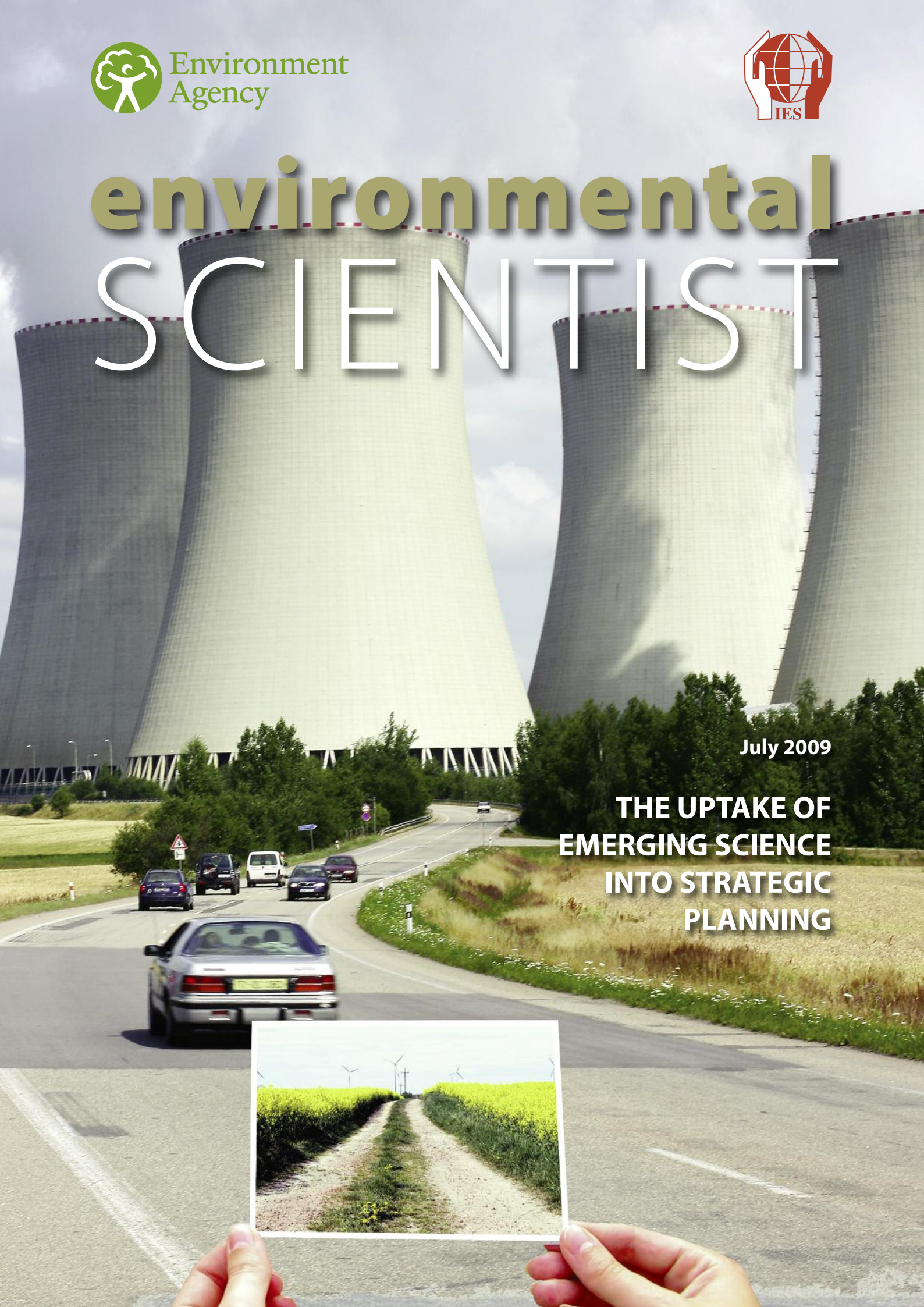

July 2009

THE UPTAKE OF EMERGING SCIENCE INTO STRATEGIC PLANNING

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Guest Editors: Mark Everard, Jimi Irwin and Adam Donnan

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INTEGRATING ENVIRONMENTAL 'FUTURES' INTO STRATEGIC PLANNING

Historically, we have tended to develop environmental legislation and policies in reaction to adverse consequences ranging from water pollution with its implications for aquatic life and disease transfer, health impacts arising from air pollution, radioactive risk, etc. However, as our understanding of actual and likely environmental risks grows, we are better prepared to address environmental management on a strategic basis. Increasingly, environmental professionals, particularly those in strategic planning roles, are becoming interested in 'environmental futures' that may suggest different emerging threats and opportunities. **JOHN SEAGER** (Environment Agency), **MARK EVERARD** (Environment Agency) and **KATHRYN MONK** (Environment Agency Wales) introduce this special edition of *Environmental Scientist* addressing the theme of *Integrating environmental 'futures' into strategic planning*, focused substantially on an Environment Agency research project to guide its developing corporate planning.

Since publication of the Environment Agency's last Corporate Strategy for the period up to 2010, the world has changed, and the pace of change is ever quickening. The Agency has subsequently recognised the need to address new and emerging challenges, and to address them in fresh and more flexible ways, for the next planning period. To inform the development of its new corporate strategy, *Creating a Better Place 2010-2015*, the Environment Agency sought to understand some of the range of pressures likely to result in environmental challenges that we may be called upon to face.

Of course, a number of better-understood pressing issues already appear to be unavoidable and we have integrated them into the five key themes of our new strategy: (1) act to reduce climate change and its consequences; (2) protect and improve air, land and water quality; (3) put people and communities at the heart of what we do; (4) work with businesses and the public sector to use resources wisely; and (5) be the best we can. These themes imply not only facing some new issues, but often also finding new and more effective ways of working with both familiar and novel issues. However, both within and beyond these broad themes, a wide range of less certain and emerging issues may also become significant in the future, as will our capacity to respond to the unforeseen and the unpredicted.

This is why the research reported in this special edition of *Environmental Scientist* has been so important in shaping our thinking. Problems associated with identifying the kinds of emerging issues that we might have to deal with do not stem primarily today from a deficiency in sources of information. For example, significant resources, both public and private, have been expended since the turn of the millennium upon horizon


Kathryn Monk


John Seager


Mark Everard

scanning, sector projections, scenarios and a range of other 'futures'-related research both in the UK and overseas. However, the diverse and dispersed forms of outputs from all this 'futures' research generally makes it hard for busy corporate and strategic planners, who cannot be expected to be experts in all specialist fields, to locate, understand the implications of, and apply this wealth of information.

Integration, prioritisation and comprehension of key elements of this body of work were the major purposes of the Environment Agency's science project SC070023: *Application of 'futures' research to strategic planning*. This work has directly underpinned the development of the Environment Agency's new Corporate Strategy. However, we aim to share this thinking and information with wider interested constituencies both within and beyond the Agency, and to present it in comprehensible and usable forms, via this special edition of *Environmental Scientist*.

This also further demonstrates the Environment Agency's commitment to achieving outcomes for the environment in partnership with other bodies, in this case with the Institution of Environmental Sciences (IES) as a key organisation in the environmental professional bodies sector.

This special edition kicks off with the article *Potential drivers of future environmental issues*, which summarises potential pressures likely to have environmental impacts arising not merely from traditional 'environmental' sources but stemming from a spectrum of political, economic, scientific and technical (PEST) drivers. Any of these individual issues, or combinations of them, could raise significant challenges for not only environmental regulation but also the nature of the regulator: should the Environment Agency be there only to manage consequences at end-of-pipe, or should it have a far more proactive role both in stimulating innovation and in shaping its development as part of a broader community of stakeholders?

Given the central importance of societal understanding and attitude towards the environment in bringing about a transformation towards sustainability, how proactive should the Environment Agency be in promoting environmental awareness and change in public opinion? What skills and other resources are required for this, and in what ways should it alter our mandate?

There then follow six chapters on specific issues as warranting particular, more detailed scrutiny. The selected issues are: ecosystem services; emerging energy futures; the low carbon economy; citizen and community issues potentially influencing the environmental agenda; uptake of new technologies within the Environment Agency; and managing the environmental impacts of new technologies. We provide an overview of each of these topics as well as thoughts about likely regulatory responses.

All of these six focal issues also raise challenging questions, not only about how to regulate, but also the ways in which we need to move beyond traditional regulation to be influential players, or enablers, for various citizen and community groups in the shaping of a more sustainable future. A low carbon economy, for example, will not just happen but will require considerable innovation and integration across policy areas, and the engagement of citizens and community for more equitable, sustainable and engaged outcomes. This may entail development of expertise in emerging social networking technologies as well as stakeholder engagement processes.

All of the six priority issues raise

• continued on page 14

POTENTIAL DRIVERS OF FUTURE ENVIRONMENTAL ISSUES

A significant part of the Environment Agency research project reported in this special edition of *Environmental Scientist* entailed collation of a broad range of issues likely to be influential on the environmental agenda over the next few years. These issues were culled from a variety of sources – horizon scanning, sector analyses, scenarios, etc – which were subsequently clustered and prioritised in project workshops with stakeholders. The most significant of these emerging drivers were classified using the PEST (Political, Economic, Social and Technological) framework. A detailed report about these drivers and their likely implications for the Environment Agency over the forthcoming corporate planning period was made available to the Agency's directors to help inform their thinking about the new strategy. A summary of key elements is reported here by **MARTIN DUCKWORTH, MARK EVERARD, JOE RAVETZ** and **JOHN REYNOLDS.**

Introduction

To understand how the environment may evolve over a timescale of decades, it is important to consider trends and projections in non-environmental factors which may have an impact on it over time.

This article reports on the PEST drivers likely to impact on the environment at a global or national level over the next decade or two. The list therefore does not include factors that are specifically environmental in nature, nor does it address flooding and the direct impacts of climate change which are covered directly by other Environment Agency planning activities in addition to pre-existing and ongoing expert reports.

Through a process of clustering and prioritisation, the 20 PEST issues in the table opposite were selected from a set of the 'top 100 drivers of change'. Those considered to have the greatest potential impact on the Environment Agency's strategy are highlighted in bold.

This is not intended to be an exhaustive list of all the factors which may prove to be important in the future. Neither is it predictive. However, it does reflect the outcomes of broad-scale information collation and prioritisation through this Environment Agency science project.

Political drivers of change

Global environmental policy – overriding the national

Environmental policy needs to globalise rapidly; transfrontier shipments, supply chain responsibility, permit and offset trading, each threaten to bypass or undermine national efforts. Current effects of economic globalisation are to increase the rate of ecosystems destruction and the power of transnational corporations. Such challenges cannot be faced at the national level alone.

There are many implications arising from the globalisation of pressures on the environment, including:

- Climate change is a multi-level issue which drives many other areas of environmental regulation, of which national-scale responses can only play a contributory part;
- Sustainable resource management in a globalised economy needs to respect the fact that resource extraction is globalised, as indeed is waste generation, so requires a different paradigm of regulation; and
- Greening of business must necessarily entail a total supply chain approach.

Public spending on the environment – more from less

The full extent of the 2008-09 credit crunch and the resulting economic downturn is not yet known, but it is likely that public spending and capital investment will be under significant pressure. It will undoubtedly be essential to do more with less.

This comes at a time when de-regulation is seen to be unduly risky, and also when international environmental agreements may gain in strength and credibility (stimulated significantly by renewed commitments in the USA in the wake of the Obama Presidency).

Some of the implications arising from the pressures on public spending include pressure to encourage the greening of business through voluntary measures and self-regulation, although there are associated risks of corporate capture of the regulatory process.

Corporate social responsibility – sharing the burden

Going beyond the 'end-of pipe' approach to environmental regulation, corporate social responsibility (CSR) brings great opportunities for environmental regulators. There are also challenges to ensure transparency, credibility and robust regulation.

The explosive global growth of CSR reporting over the last 15 years has been well demonstrated in the literature. This can be compared to the trend in actual economic losses to business of environmental damage over 50 years[1].

POLITICS	ECONOMICS	SOCIAL	TECHNOLOGY
◆ **Global environmental agenda** ◆ Public spending ◆ Business CSR ◆ Market based instruments ◆ Multi-level governance	◆ Energy futures ◆ Renewable energy sources ◆ Low carbon economy ◆ Global growth ◆ **Credit crunch** ◆ Environmental valuation	◆ Population ◆ Demographics ◆ Wellbeing ◆ **Public attitudes**	◆ **Pervasive ICT** ◆ Precision agriculture ◆ **Biotechnology** ◆ Nanotechnology ◆ New technologies

The implication is that CSR is not only about goodwill or image enhancement, but is a practical approach to risk management based on a compelling cost-benefit balance. Some of the implications arising from the emergence of CSR are:

- Climate change policy is now the primary application of CSR, and of the related Socially Responsible Investment (SRI);
- In terms of the greening of business, CSR and SRI should be built in to all parts of the supply chain; and
- To support sustainable communities, CSR should also be posited as a guiding force for local economic development.

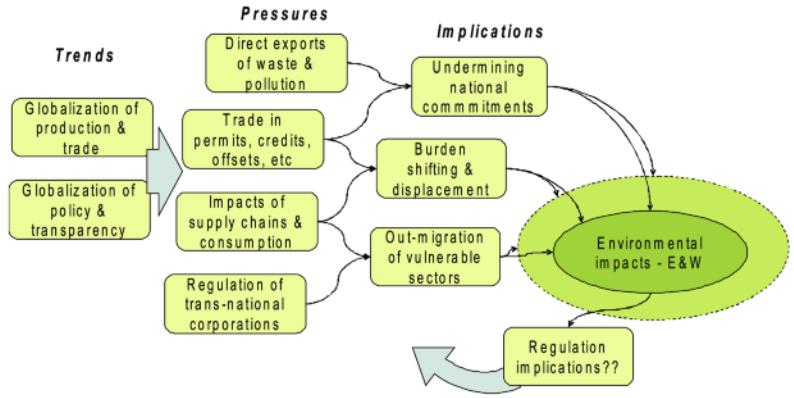

Figure 1: Causal map of globalised pressures on the environment

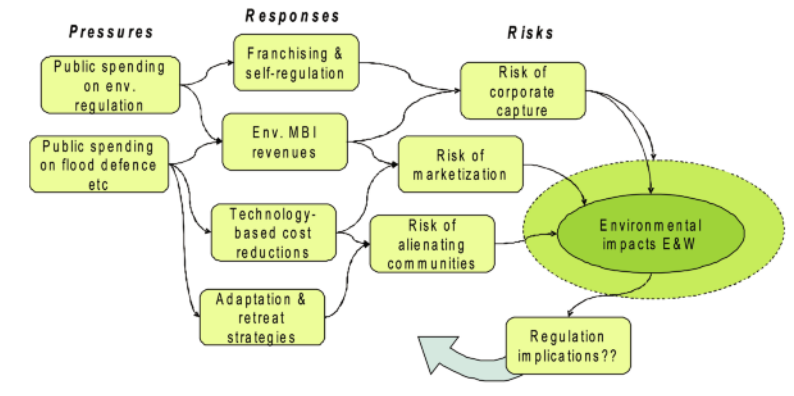

Figure 2: Causal map of driving forces arising from public spending trends in the UK

Market based instruments – the future of regulation?

'Market-based instruments' (MBIs) – such as taxes, charges, subsidies and tradable permits – help to take account of the hidden costs of production and consumption. Furthermore, compared to basic 'bottom up' regulatory standards, MBIs provide a basis for market-based innovation and offer market signals that give investors confidence. Credible MBIs must address social and economic impacts, so are likely to be significant for the future direction for the Environment Agency where these factors can be fully and transparently internalised.

In the UK, the level of total direct environmental taxation doubled between 1990 and 2000, but levelled off since 2000[2]. By contrast, global trends in carbon permit trading (project based) show rapid and continuing growth[3].

Climate change and energy are the targets of many current MBIs. Water, land and ecosystems have been the subject of trial MBIs in the USA, raising questions about valuation methods. However, there is a growth in paying for ecosystem service (PES) schemes globally[5]. In terms of greening business, there is an urgent need for internalising all environmental costs and benefits into all parts of the supply chain.

A MBI approach is likely to be a

significant facet of the future of mainstream regulation, operating within the market rather than as a post hoc constraint upon it. This will require regulators to have increased economic capabilities.

Multi-level governance – coordination at every level

Whilst the history of environmental regulation has been generally retrospective, responding to pressures as they have manifested in acute problems, there is an increasing need for a more coherent regulatory package that has clear goals and is also coordinated at every level. This should range from the global to the local.

'Governance' means something substantially more than government; NGOs, interest groups, media and cultural networks are all powerful forces with respect to the mobilisation of public values and commitment from different social groups. This is also allied with trends in communications, the internet, social networking and other technologies, which enable people to mobilise around common-interest causes.

Some of the implications associated with multi-level governance include:

- Climate change is currently the foremost multi-level issue for which there is a recognised need for a strong global policy framework that connects seamlessly with action at international, national, regional and local levels;
- The greening of business requires mechanisms to integrate the responsibilities and initiatives ranging from transnational corporations to local SME suppliers; and
- Sustainable communities require the building of trust at the local level, which can only work when fully and transparently linked to other levels of governance.

The challenge of effective multi-level governance will continue with further trends in the EU 'Open Method of Coordination', alongside distributed communications and deliberative decision-making.

Economic drivers of change

Energy futures – balancing the options

The UK is running out of oil[6]. It needs a range of new energy

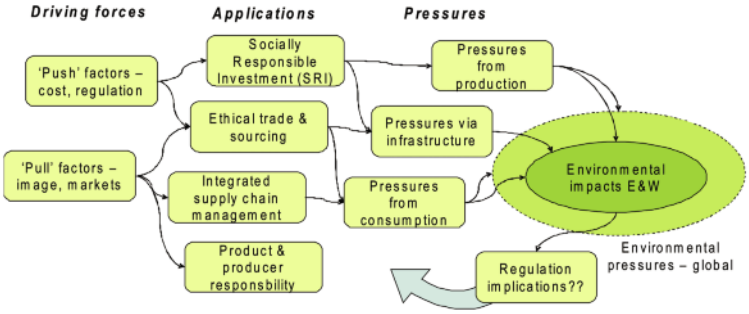

Figure 3: Causal map of implications of trends in business CSR

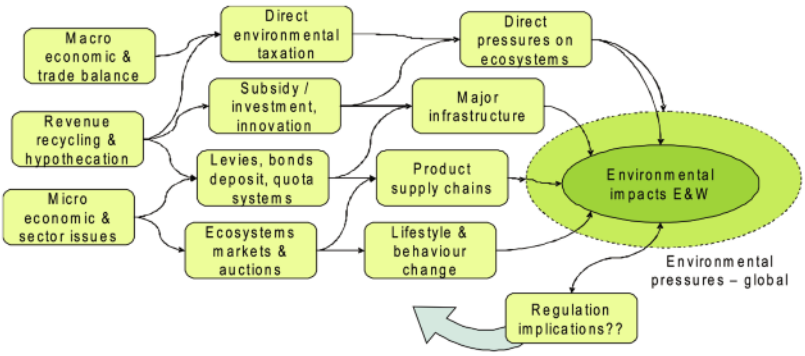

Figure 4: Causal map representing issues associated with MBIs (adapted from the European Environment Agency, 2006[4]).

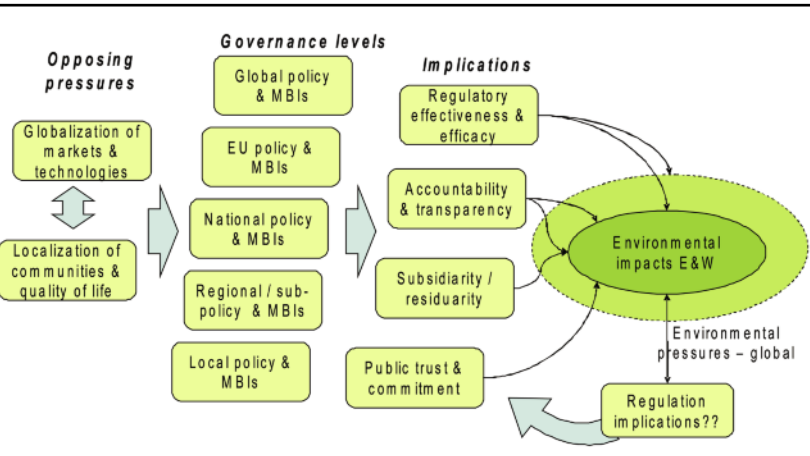

Figure 5: Causal map of issues associated with multi-level governance

technologies in the next 10-20 years, but each of the options – fossil fuels, nuclear or renewable sources – has diverse and often major associated environmental issues, alongside commercial and policy pressures. The future trajectory is highly uncertain: there are no clear projections in the 2007 Energy White Paper. With the UK's new 80% target for CO_2 reduction by 2050, urgent radical transformation is called for on all sides. A causal map of factors germane to this issue is presented in Figure 6. However, other articles in this journal tackle in more detail aspects of the *Emerging energy futures* and the closely-related *Low carbon economy* issues and their associated challenges for the Environment Agency.

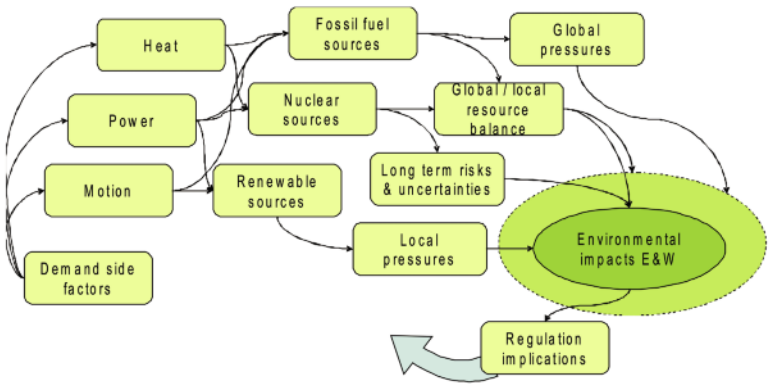

Figure 6: Causal map addressing energy futures

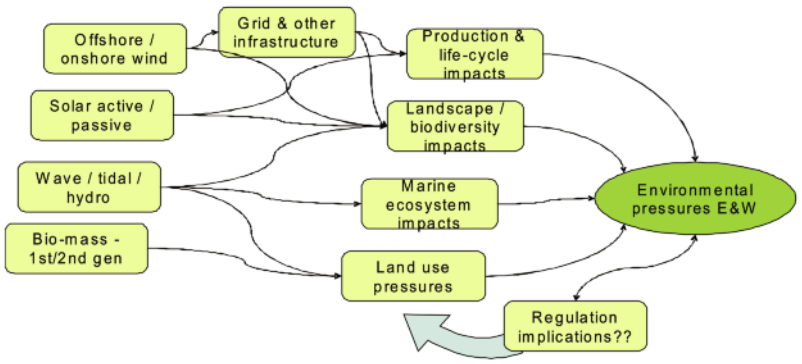

Figure 7: Causal map of issues associated with renewable energy sources

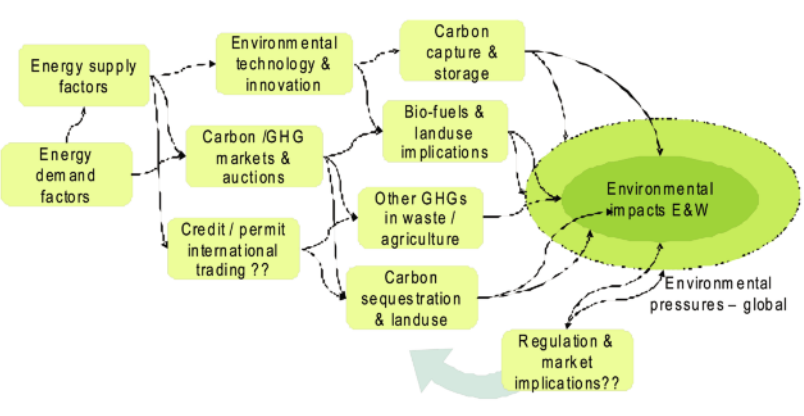

Figure 8: Causal map of issues associated with the low carbon economy

Renewable energy sources – the cost of going green

Part of the UK's contribution to the EU energy strategy is to increase its share of renewable energy by almost ten times to 15% of total energy by 2020. This target is potentially costly and land intensive, with potentially controversial impacts on landscapes and ecosystems. How do we balance the respective costs and benefits of 'going green' in our energy mix? A causal map of related issues is presented in Figure 7. However, far greater consideration is given to aspects of this nexus of issues in subsequent articles in this journal addressing *Emerging energy futures* and *The low carbon economy*.

Low carbon economy – a struggle to meet commitments

If the UK domestic energy supply moved totally away from fossil fuels, we would still struggle to meet the UK's target for 80% reduction in climate emissions by 2050. Radical changes are therefore required not only in technology but also in economics, resource flows and reuse, organisational governance and personal behaviour. An overview of key issues is presented in the causal map at Figure 8. However, the topic of the *Low carbon economy (LCE)* is the subject of a more detailed article in this journal.

Global growth – China becomes an economic superpower

By 2020, the economy of China will be as large as the American economy is now, and China will be on course to overtake the USA within another five years. Already, the annual increase in China's economic output is the

biggest single contributor to world economic growth.

Some of the associated implications of this include:

- China's carbon emissions may now exceed those of the US. As China grows, these can only increase, particularly when one considers the rich, carbon-intense coal reserves that China is exploiting to fuel its burgeoning economy. By setting an example with a low-carbon economy, and factoring 'carbon footprint' into the market, the West can hope to influence the pattern of Chinese growth;
- There will be increasing competition for the world's food supply and higher food prices for the foreseeable future; and
- Increasing competition for the world's raw materials and resources, as other economies grow faster than ours, means the UK will be able to afford a reducing share of the world's resources.

There are both threats and opportunities associated with all these implications. The Environment Agency is faced with daunting challenges by the futures that this issue suggests and the need to stimulate rather than stifle innovation.

Credit Crunch – cheaper works but scarce funds

The IMF has stated that: 'In advanced economies, output is forecast to contract on a full-year basis in 2009, the first such fall in the post-war period[9]'. The global recession will have a significant impact on many facets of life, with associated pressures on the environment. Environmental protection investment may be cheaper, but public funds are likely to be scarce.

Some of the potential environmental implications arising from the economic downturn include:

- We should expect reduced industrial activity and pollution, but there will be intense pressure to cut corners by distressed businesses;
- The civil engineering elements of any ten-year capital investment programme are likely to have lower real costs (and deliver earlier benefits) if undertaken in the next five years rather than in the second half of the programme. This is especially true of schemes requiring the compulsory purchase of urban land;
- Part of the UK government's plan to stimulate the economy – 'spending our way out of recession' – could include those related to flood risk management; and
- Though economic activity is currently depressed, are we positioning ourselves optimally for when economic activities accelerate again?

Environmental valuation – a necessary challenge

The economic valuation of environmental assets and impacts – driven particularly by the 'ecosystems approach' (see also the article in this special edition addressing *Ecosystem services*) – should help to inform and incentivise behaviour change. It is a means to internalise environmental and social costs and benefits progressively into a market system that currently externalises them.

The UN's Millennium Ecosystem Assessment (MA) provided a 'snap shot' of the generally negative trends in all major ecosystem types across the globe and the associated implications for future human wellbeing. The MA is completely unambiguous about the dangers of continuing to

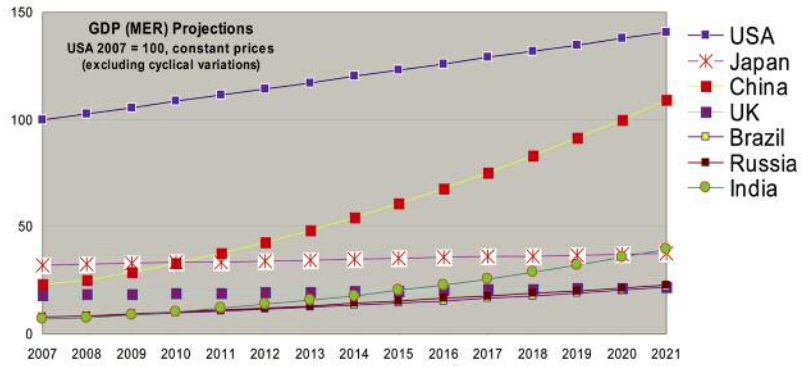

Figure 9: Projections of growth in national GDP[7] (excluding short term variations)[8]

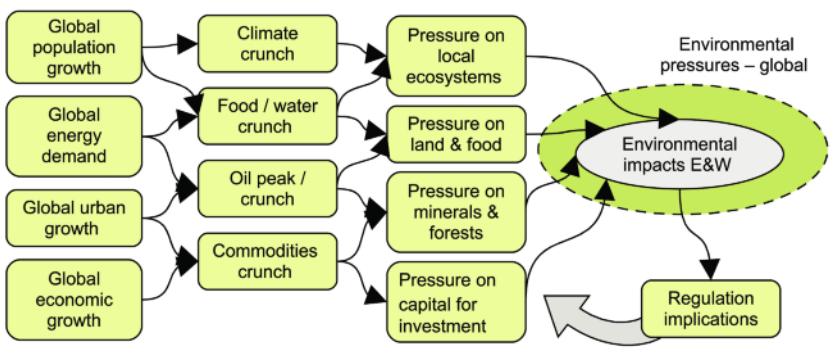

Figure 10: Causal map of issues related to global growth

externalise environmental values from the market and wider decision-making if the world is have a sustainable future.

Another trend is 'green' or 'sustainability' accounting, which sets positive measures of welfare against the negative costs of environmental damage and resource use. The ISEW (Index of Sustainable Economic Welfare) shows that real wealth has not increased since the mid-1970s. Data from ISEW analyses[10] shows that consumer expenditure is more or less balanced by environmental and social damage costs, and that the ISEW is roughly equal to household labour (i.e. 'interpersonal services'.

Some of the implications arising from economic valuation include:

- The Stern Review[12] estimates between 5-20% of global GDP is at risk from climate change on current trends;
- We are undermining the capacity of global ecosystems to support our needs into the future. We require rapid and substantial changes in the ways we value the environment, and to factor this into decision-making at all levels;
- There is a rapid evolution of methods to value ecosystem resources for water, natural landscapes and other ecosystems, particularly in the USA;
- PES, or 'paying for ecosystem services', is taking off in parts of the UK, US, South and east Africa and in other places around the world. This is a market mechanism to connect the consumers of ecosystem services with communities managing ecosystem resources to produce the services on a sustainable basis[13]. This internalisation of ecosystem values into real markets is essential if we are to aspire to sustainability; and
- It is essential to build environmental values into all parts of business supply chains if environmental costs are not to be overlooked.

The environmental valuation agenda needs to be fully embraced as a powerful lever for progress towards sustainability, and to enable the Environment Agency to deal more effectively with HM Treasury and other government departments. This has implications for the economic capabilities of the organisation.

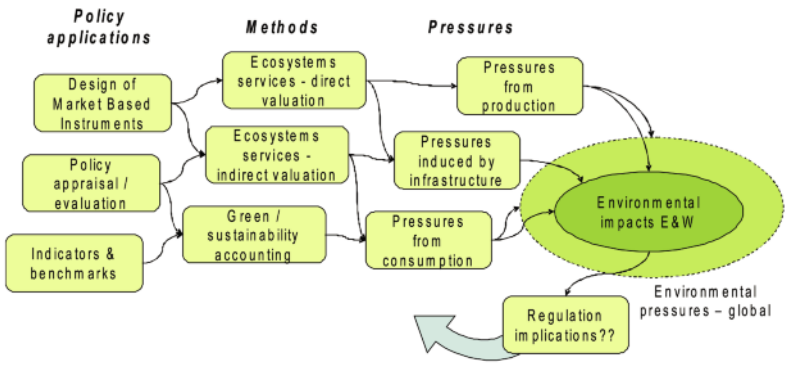

Figure 11: Causal map of issues associated with environmental evaluation (drawing significantly upon World Bank Paper 88, 2003[11])

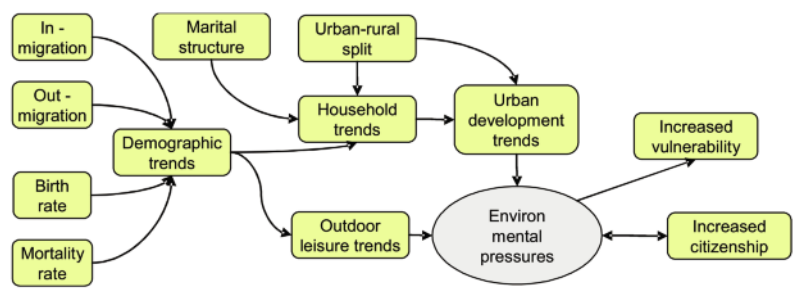

Figure 12: Causal map of implications associated with population growth

Social drivers of change

Population – continuing growth predicted

The population of the UK is projected to grow significantly over the next few decades, dependent on assumptions on inwards and outwards migration and increasing life expectancy. Other factors include expansion of the EU with the potential for economic migration into the UK, and environmental refugees flowing in from countries adversely affected by climate change and other serious environmental issues. Nearly all of this growth is expected to occur in southern regions of England[14]. Furthermore, the number of households is forecast to grow even more rapidly[15], causing widespread development pressures.

Some of the implications arising from continuing population growth include:

- Increasing pressure of water use, especially in south east England;
- Increasing development pressure on floodplains and other sensitive habitat; and
- Reduction in household size implies more use of resources per capita.

Demographics – living with an ageing population

The number of British pensioners now exceeds the number of under-16s for the first time ever; the biggest change in population profiles is due to the reducing mortality of the old and very old, rather than any change to the working age demographic[16].

Over the next ten years, employers will find it increasingly difficult to maintain their workforce as baby-boomers retire and there are fewer school leavers and graduates available. This is shown by the UK 'population pyramid' in 2006 (Figure 13), which will shift to the right as the years go by.

The implications stemming from these demographic trends include:

- Businesses and public sector organisations will no longer be able to depend on recruitment and graduate training to meet their skills needs. The main conclusion of the Leitch review[18] was that training and retraining of the adult workforce will be essential for the future prosperity of the UK; and
- The increased dependency ratio will put great strains on social services and the country's ability to finance the welfare state, with the potential for redistribution from other areas of public investment.

Wellbeing – an increasingly important objective

There is a trend across government towards promoting health and wellbeing of the population. Public sector bodies making this transition include:

- The **Health and Safety Executive** is moving from being a regulator *('Our mission is to protect people's health and safety by ensuring risks in the changing workplace are properly controlled.[19]')* to a vision which is *'to see health and safety as a cornerstone of a civilised society and, with that, to achieve a record of workplace health and safety that leads the world[20]'.*
- In addition to treating the sick, the **Department for Health** is migrating to focus on healthy lifestyles, through such things as the new obesity strategy: *'This strategy marks an important shift in our focus to support everyone in making the healthy choices which will reduce obesity[21]'.*
- The **Department for Work and Pensions** is also promoting the health and wellbeing of the working age population: *'Great progress has been made in improving health and safety at work. A new approach to health and well-being at work is now needed[22]'.* This is part of a cross government move is to promote the health and wellbeing of working age people. *'Our vision: We want to achieve a society where the health and well-being of people of working age is given the attention it deserves[23]'.*

Some of the implications of addressing this trend include:

- For water and land, there is a new focus on health-outcome measures rather than measuring performance on concentration level of various pollutants. (This is already the approach of the EU Water Framework Directive, focused on Good Ecological Status.)
- There is likely to be an increasing emphasis on local environmental quality.

Applying this philosophy to the work

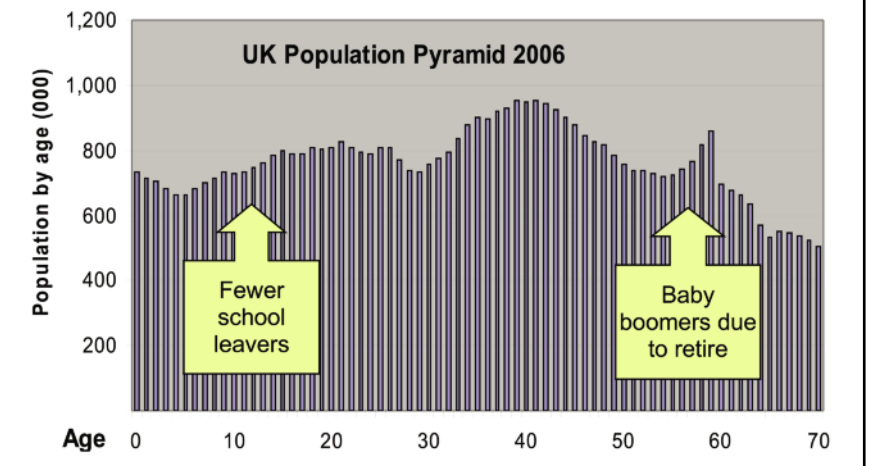

Figure 13: UK population age distribution, 2006[17]

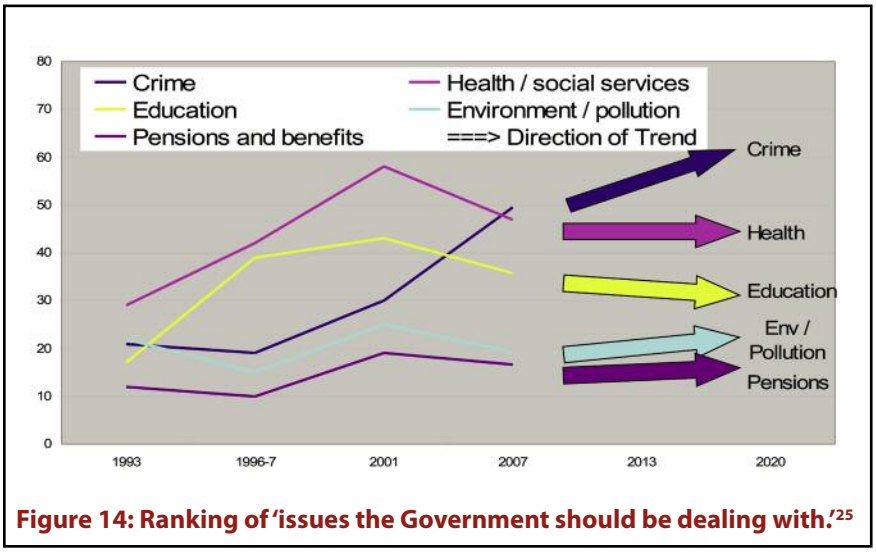

Figure 14: Ranking of 'issues the Government should be dealing with.'[25]

of an environmental regulator would transform it from an 'end-of-pipe regulator' to on organisation that promotes the vision that '*…a healthy environment is at the heart of a civilised society*'.

Public attitudes – need to justify rationale

15 years ago, the environment was as important in the minds of the general public as crime and education. But, by 2007, crime, health and education ranked far higher in people's minds as issues that the government 'should be dealing with'[24] (see trends presented in Figure 14).

If these relative trends continue, environmental regulators will need to articulate the rationale for environmental protection and justify the use of public resources more clearly than has been necessary to date. People also have rising expectations that the services they receive from these organisations include greater access to information and much higher degrees of personalisation in dealings.

Some implications arising from this include:

- Despite the media attention, getting the public to accept sacrifices to their lifestyles in the cause of climate change will not be easy. Perhaps the biggest challenge is to position the change as an 'opportunity' rather than as a 'sacrifice';
- There are likely to be greater expectations of protection from natural events such as flooding or coastal erosion; and
- Information expectations could include post-code level or even individual household-specific flood warnings.

Public attitude is central to public behaviour, with major ramifications for the environment as well as for social integrity. The Environment Agency should be proactive in response to the decline in prioritisation of environmental issues. This should inform the way that the organisation connects with the wider public, and the language it uses to relate environmental priorities to the day-to-day realities and expectations of society.

Technology drivers of change

More detailed consideration is given to aspects of this nexus of issues in the subsequent article in this journal addressing *Managing the environmental impacts of new technologies.*

Pervasive ICT – widespread monitoring and control

Pervasive environmental surveillance and data processing brings a massive increase in the ability to monitor, control and regulate, right across ecosystems and industrial supply chains. This creates opportunities to revolutionise the control and monitoring of the environment, similar to the way in which retailers have used ICT to transform their supply chains. However, there are also associated issues of privacy, vulnerability and technological lock-in to hyper-complex systems.

Some of the projections of the trajectory of ICT over the next decade are that:

- Radio frequency identification (RFiD) tags will be used on individual small consumer items (and not just used for expensive goods and tracking of pallets as they are today);
- Personal Environmental Monitoring will become more commonplace;
- Spectrometry on a chip will become available, enabling low-cost environmental monitoring by individuals;
- Improved sensor technology will extend this capacity; and
- Transition from internet IPv4 addressing (limiting the internet to just 4Bn connected intelligent devices) to IPv6.

Some of the implications arising from the trajectory of pervasive ICT include:

- Intelligent electricity meters to allow householders to monitor their energy usage and for distribution companies to reduce consumption at times of shortage;
- An abundance of environmental data and increased ability to monitor waste management. This will cause an explosion in data volumes and opportunity for the Environment Agency to use data-mining techniques to identify hazards and connections that were previously unknown (and an expectation by the public that the Agency will do so). Lower cost of monitoring means that NGOs and individuals will also have access to and will use the monitoring technology; and
- As with all public systems handling vast amounts of data that could be potentially linked to individuals, the issue of personal privacy will be extremely important.

Precision farming – high technology comes to agriculture

Precision agriculture brings the 'laboratory to the farm' with a range of high-tech methods and tools. It may also be seen as contributing to intensification of industrialised farming, with all the risks of corporate capture, intensive impacts, and displacement of rural economies and local food chains. Alternatively, it may increase the efficiency of low-intensity farming with a reduced impact on the environment.

The global demand for food crops is projected to grow by 70-85% to 2050, while much of the land best suited to cultivation has already been turned over to crop production (Millennium Ecosystem Assessment, 2005). There is also competition for land by non-food demands, particularly ethanol and bio-diesel. We also need to factor in growing recognition of the broader ecosystem services provided by land and landscapes, and the prioritisation of their protection (ass also the article in this journal dealing with Ecosystem services). It is therefore almost unavoid-

able that precision farming and intensive cultivation will be an essential.

Some of the implications arising from the trajectory of precision agriculture include:

- Biomass and biofuel crops can increase yields using precision farming techniques;
- Intensive (glasshouse) cultivation is demanding of water and treatment capacity;
- Environmental pressures will be affected by a wide range of issues including integrated food chain management, regulatory issues on data and intellectual property, managing innovation, financial structures, and the international 'footprint' of supply chains;
- Protection or restoration of formerly overlooked critical ecosystem services may change the pattern of land management, requiring new methods and technologies to ensure better-targeted and optimally multi-benefit land use; and
- Contributions to sustainable communities can be made by urban food growing.

Precision and intensive farming are already with us and the continued expansion is almost inevitable, bringing significant opportunities but also associated threats and challenges.

Biotechnology – rapid developments in the genetic sciences

The world is undergoing a biotechnology revolution that will have profound and unpredictable consequences. The first fully-synthetic organisms are expected soon, and the cost of genome sequencing will fall to the point that it is used for personalised medicine.

Some of the implications associated with the development and implementation of biotechnology include:

- New bioengineered organisms, or new combinations of existing organisms, could have new capabilities to undertake a wide variety of industrial processes. New processes imply new waste streams, but may also include new options for neutralising or handling waste. They also carry the theoretical risk of new diseases or other hazards;
- Employers may wish to screen staff for immunity to environmental hazards at their place of work. What does this say for exposure limits at work? What are the legal and moral implications?
- With more genetic knowledge, individuals will take more interest in environmental exposures. This may fundamentally change the relationship between individuals and the Environment Agency; and
- Environmental limits of pollutants are currently based on epidemiological studies of the whole population. Personal genetics will start to identify individuals that have higher or reduced sensitivity to particular

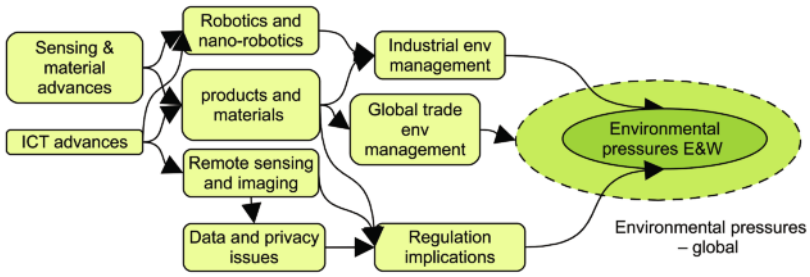

Figure 15: Causal map of issues related to pervasive ICT

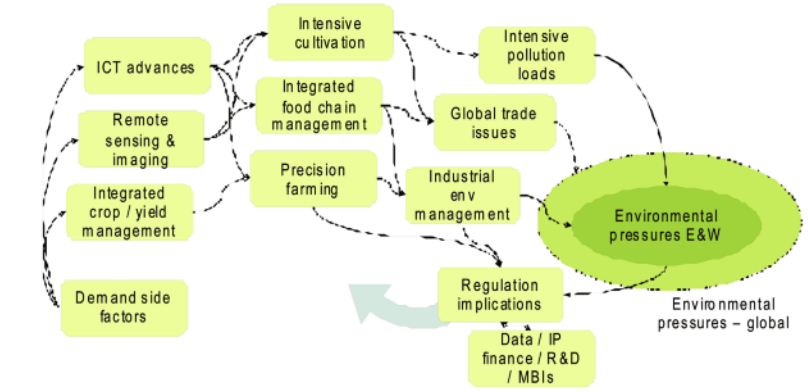

Figure 16: Causal map of pressures stemming from precision agriculture

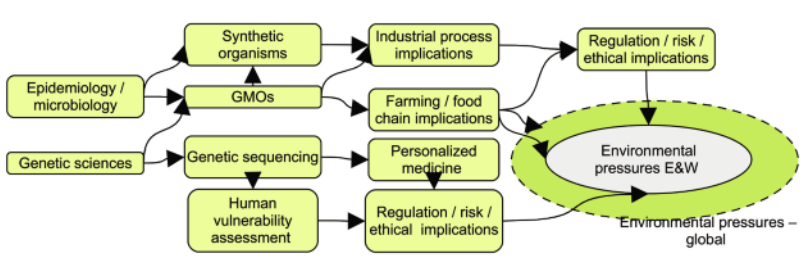

Figure 17: systems view of issues associated with biotechnology

environmental pollutants. What are the policy and legal ramifications?

Nanotechnology – still potential for future hazards

Nanotechnology is becoming ubiquitous, spreading from the electronics sector into health care, food, pharmaceuticals, clothes, household goods, etc.

Despite many studies into their regulation, there are still profound uncertainties about the behaviour of some types of nanomaterial in the environment or the risks that they pose for human health. Nanomaterials have significantly different properties from their bulk forms, yet the regulatory system is primarily focused on the bulk chemical properties of a material[26]. The topic of *Strategic responses to emerging technologies: Late lessons and regulatory steps for nanomaterials and synthetic biology* is the subject of a separate article in this journal.

New technologies – a need for continued scanning

There is a 'technology control dilemma' of how effectively to manage the environmental impact of new technologies without stifling the rate of innovation. This will get more complex, so there is a need for an adaptive management system responsive to early-warning signals and adequately reactive to implement timely controls.

It cannot be assumed that the established reactive regulatory regimes will fully address the emerging risks associated with all new technologies, necessitating a more adaptive approach. These approaches are compared below in Figures 18 and 19. Note that these are diagrams have a time dimensions, and are not simple causal maps.

Conclusions from consideration of issues using the PEST framework

The PEST framework ensures that representative types of issues are considered, helping to overcome any bias towards a particular set of potential drivers or else overlooking a particular category of potential driver. Whilst it would be unwise to try to predict the precise shape of the future, consideration of these diverse drivers demonstrates the breadth of issues with likely environmental impacts. These drivers will certainly shape our future, and therefore have implications for the Environment Agency's strategic plans.

In the following chapters, we outline selected issues in more detail before then summarising how a scenarios approach has been used to 'wind tunnel' the ways that some of these issues may play out in different futures as well as the implications of potential regulatory responses.

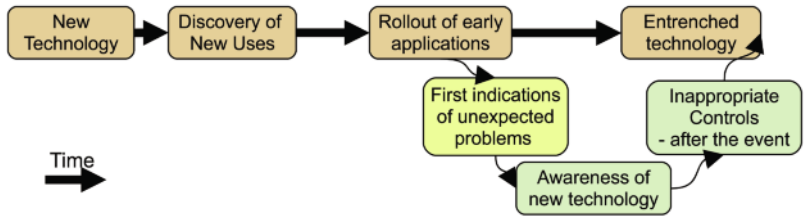

Figure 18: Time Diagram of Reactive Regulation

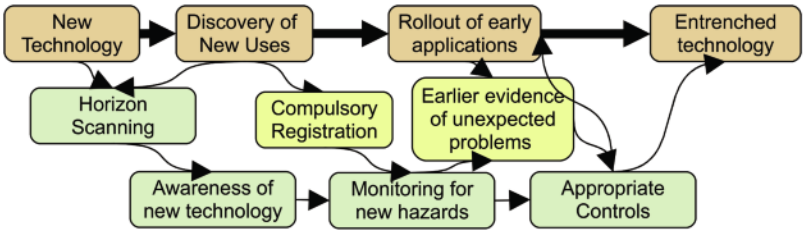

Figure 19: Time Diagram of Adaptive Regulation

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STRATEGIC PLANNING

• **continued from page 3**

difficult questions about mandate, political control, resourcing, breaking out of inherited regulatory habits and assumptions, and innovation of processes that accelerate progress towards sustainability rather than suppressing it through imposition of anachronistic rules. What is the role of the market, and what is our role within it? Underneath all this, how will we ensure the protection and restoration of ecosystems that are essential for the supply of 'services' beneficial to all dimensions of human wellbeing? Is our current thinking 'fit for purpose' in the light of the rather different futures that these issues portend, particularly when explored in the context of potential future scenarios using the 'wind tunnelling' process described below, or do we need to imagine new methods of promoting more rapid progress towards sustainability in ways that are equitable to all those we represent or affect?

We then conclude with an explanation of the process of 'wind tunnelling': a rapid assessment process whereby the implications of potential 'futures' issues can be tested for sensitivity to a set of scenarios, enabling us better to 'future proof' our considerations and policy responses. When applied to consideration of the priority issues in the preceding articles, 'wind tunnelling' did indeed prove illuminating about the breadth of challenges potentially facing us and the need to be both flexible and innovative in the face of significant uncertainty.

The central thread of research underpinning all of the issues reported in the articles in this special edition of *Environmental Scientist* also benefited from structured interviews with a wide range of people across UK society who are influential with respect to environmental management. The outputs of this strand of the research proved useful for informing internal Agency meetings, and have also influenced and grounded the issues-based articles in this journal.

◆ The authors would like to thank Natural England for collaboration and the two-way sharing of background knowledge and draft outcomes between this Environment Agency research and Natural England's own ongoing *Scenarios for England's natural environment to 2050* project, which has yet to report at the time of writing. Both projects are being undertaken by the same core contractor team comprising John Reynolds and Martin Duckworth (SAMI Consulting) and Joe Ravetz (CURE, University of Manchester). The Project Board steering this Environment Agency research comprised John Seager (EA Project Executive), Mark Everard (EA Project Manager), Sarah Bardsley, Malcolm Gorton, Richard Howell, Clive Kelman, Paul Morris and Robert Willows (all Environment Agency), Ceri Davies and Kathryn Monk (Environment Agency Wales), Fiona Lickorish (Defra) and Gary Kass (Natural England).

ECOSYSTEM SERVICES – JOINED UP THINKING IN AN INTERDEPENDENT WORLD

The 'ecosystem services' concept focuses on the multiple benefits provided to humanity by the functions of ecosystems with implications for the many, often formerly overlooked, societal and economic benefits and opportunities dependent upon them. The implications of the ecosystems services agenda for environmental governance, particularly under its management framework of the 'ecosystem approach', have been assisted significantly by the reclassification of ecosystem services by the Millennium Ecosystems Assessment, and are assessed by **MARK EVERARD** and **JOE RAVETZ.** This review also includes a 'future-proofing' approach, drawing on the Environment Agency's *Scenarios 2030* to explore the robustness and relevance of policies and programmes under alternative future conditions. Overall, this suggests new modes of environmental governance for a management of 'complex adaptive systems' that is both more responsive and amenable to optimising the sustainability and public value derived from ecosystems.

'The role of ecosystem services'

– Millennium Ecosystems Assessment, Board Statement, 2004

'In the streets of a crowded city, in the aisles of a giant supermarket, or on the floor of a gleaming electronics factory, the biological state of Earth's rivers, forests, and mountains may seem a remote concern.

'As forests and savannah made way for farms, as rivers were diverted to irrigate fields, and as new technology enabled fishing vessels to haul ever-greater harvests from the oceans, the recent changes made to natural systems have helped not just to feed a rapidly growing human population, but to improve the lives of billions.

'In the midst of this unprecedented period of spending Earth's natural bounty, however, it is time to check the accounts. That is what this assessment has done, and it is a sobering statement, with much more red than black on the balance sheet.'

Introduction

As environmental challenges mount in the 21st century, it is increasingly important to think of the integrity of whole functional systems rather than focus management on the utility of their components. We have to consider systemic interactions within and between ecosystems rather than isolated effects, and look at emergent, self-organising processes of change rather than linear mechanical cause-and-effect. These transitions can be grouped under headings such as 'ecological systems thinking'.

'Ecosystem services' describe the multiple benefits accruing to society (basic life support, economic, cultural and so on) from the functions provided by ecosystems. The concept can be applied within the management framework of an 'ecosystems approach' to environmental analysis, governance and management.

Many policy regimes take account of ecosystem services concepts, the most significant so far being the the EU Water Framework Directive (WFD). However, most inherited policy initiatives still focus on single or a few services, whilst substantially overlooking the whole and interdependent ecosystems providing these benefits. Even for policies based on ecosystem services, many challenges and questions remain:

- How can environmental regulation focused on discrete disciplines expand to fully incorporate the systemic emphasis of the ecosystem services concept?
- As more of the environmental agenda is globalised, how can ecosystem services thinking better support national level environmental policy responses?
- What associated methods and tools, such as valuation or functional analysis, are useful in the ecosystem services agenda?

This paper contains a brief review of the concept, an overview of a future-proofing exercise, and a review of the implications for environmental policy and management.

Ecosystems services

The 'services' provided to society and the economy by ecosystems are many, varied and substantially overlooked during industrial development with adverse consequences for supportive ecosystems. Collating many strands of ecosystem services thinking over the past 20 years, the Millennium Ecosystem Assessment (2005) re-categorised these services into four main functional groups:

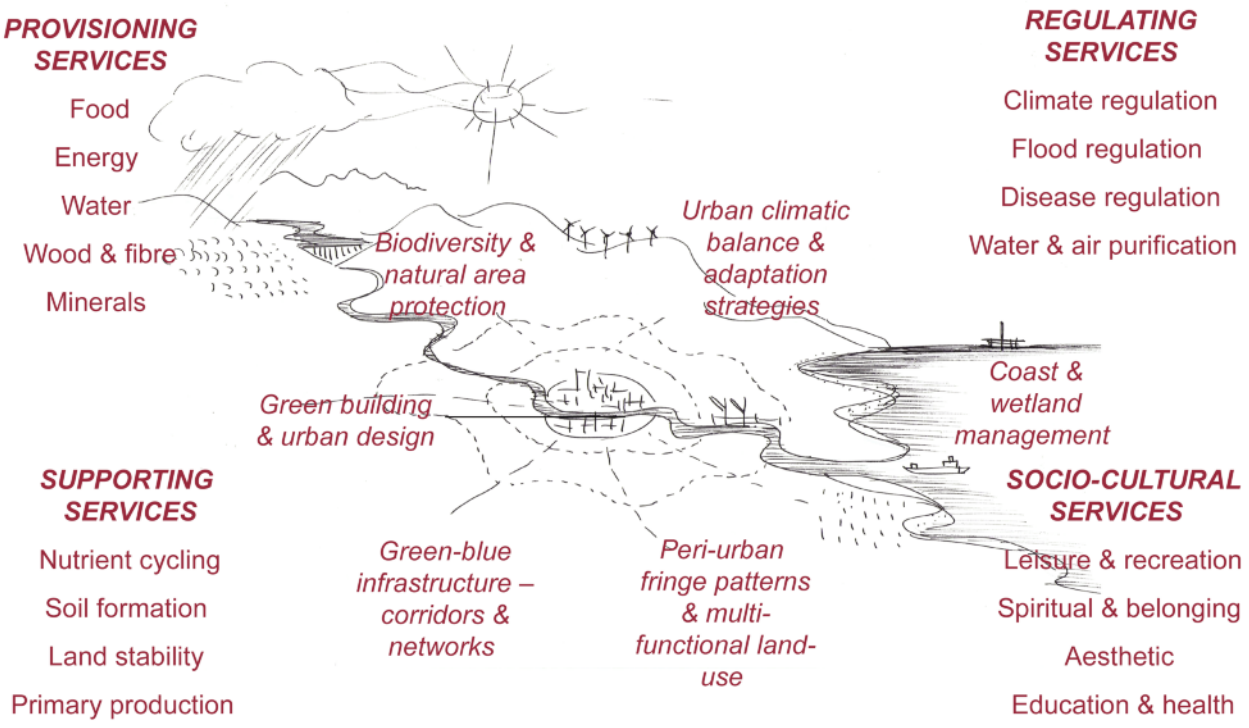
- **Provisioning services** producing tangible 'goods' (e.g. fresh water, food and fibre, genetic resources, etc)
- **Regulating services** (e.g. erosion regulation, climate regulation, air quality, etc)
- **Cultural services** (e.g. recreation and tourism, aesthetic value, etc)
- **Supporting services** that underpin ecosystem integrity and production of other services (e.g. soil formation, nutrient cycling, photosynthesis, etc).

Figure 1 illustrates a representative range of ecosystem services arranged around a hypothetical city-region, demonstrating typical approaches to safeguarding or enhancing selected services through planning and design of the city-region and its hinterland. These might include: patterns of urban design or landscape management; policies such as conservation and spatial zoning; or investment in networks such as 'green-blue infrastructure' (Roberts, Ravetz and George, 2009).

As emergent properties of ecosystems, the quality of ecosystem services depends upon the vitality of the whole system rather than of its parts in isolation. For example:

- If soil erosion accelerates in one location, there may be impacts on water quality, flooding, and biodiversity in many other locations;
- If CAP reform starts to reclaim even a small proportion of setaside land for agricultural production, there could be a large impact on biodiversity and catchment hydrology; or
- Failures or sudden transitions at the ecosystem level can have catastrophic and irreversible effects, as shown by historic experience of dust bowls, coastal dune collapse, lake eutrophication, and so on.

Climate change impacts are likely to be one of the major environmental drivers of ecosystem change and loss of services yet, simultaneously, ecosystems constitute the basis of resilience under a changing climate. Alongside this are powerful socio-economic driving forces and pressures, such as population growth and urban development, mobility and



Ecosystems services and urban-regional geography showing four main types of ecosystem services, together with urban and peri-urban responses. Source: adapted from Millenium Ecosystems Assessment, 2005: Ravetz, 2000

leisure, agricultural practices and land use change, or water resource demands.

Global linkages

The UK appears in many ways to be 'cleaning up its own back yard', as demonstrated by many environmental indicators showing positive trends over the last 20 years. However, such trends can easily conceal the role of the UK as an affluent developed nation, with a large and growing 'footprint' on the ecosystems of the developing world. The impacts of resource extraction and ecosystem damages are often magnified by poverty and political conflict, as identified by the Millennium Ecosystem Assessment, of which the food shortages of 2008 are a significant sign. Such global trends and pressures are likely to increase rapidly in the next 10-15 years, and some are life-threatening on a global scale. For example:

- Global climate change and ecosystems damage puts huge pressure on world food markets, with knock-on effects on UK farming and land use;
- EU energy policy may encourage a shift towards biofuel production, with growing pressures on UK farming, land and water use, landscapes and biodiversity; and
- Climate change impacts and adaptation strategies will put pressure on ecosystems and their services, such as coastal retreat, upland erosion, water shortages and urban green space.

This issue of global linkage poses major challenges for UK-based environmental governance. Should the Environment Agency take on the challenge of extended supply chains and of multiple indirect effects and offsets? What is its role in international issues which impact indirectly on domestic ecosystems services?

From principles to practice

Over the last decade, the EU, Defra (and its predecessor departments), the Environment Agency and others have already taken on the *principles* of an ecosystem services approach in many areas, such as:

- EU Water Framework Directive;
- EU Soils Directive and UK Soils Strategy; and
- The Defra (2007) *Action plan for embedding an ecosystem approach*.

However, in *practice*, it is virtually impossible to work in a systems approach from within entrenched policy 'silos' because:

- Each silo, both within and between organisations, operates to its own targets, budgets and performance measures and competes for priority and funding (e.g. the Environment Agency, Natural England, Forestry Commission, etc, and the various functionally-oriented departments within them);
- Many providers and users of ecosystem services are in the private sector (water supply, agricultural production, etc) and are driven by different incentives which are also poorly aligned with ecosystems thinking or wider public benefits;
- There are practical conflicts and trade-offs, e.g. between meeting local housing targets versus preservation of floodplains; and
- There are global linkages overarching all these, as described above.

Economic policy responses

One possible route is to recognise value and identify markets for ecosystem services. The progressive 'internalisation' of non-market ecosystem services is essential if society is to make balanced policy and business decisions. For example, newly-established carbon trading markets and emerging 'paying for ecosystem services' (PES) approaches to water management in catchments could, in principle, be extended to other ecosystem services (see Hirsch, 2007 and also IES, 2008 and Everard, 2009). Possible measures include:

- Reforming the system of subsidies to sectors responsible for significant production or loss of ecosystem services (e.g. agriculture and energy generation) to reflect the production of multiple ecosystem services and not single outputs such as food and fibre production;
- Developing markets for a wider range of ecosystem services (e.g. carbon, water services, nutrient recycling, or disease regulation);
- Using the taxation system to further emphasise activities damaging to ecosystem services (e.g. road transport, waste generation); and
- Offering direct subsidy for the protection and maintenance of landscapes and habitats (e.g. wetlands or forests) providing important and irreplaceable ecosystem services.

A systems overview is vital when considering market measures. For example, cost-benefit evaluations of already commercialised services (particularly 'provisioning services' such as production of food and fibre which already have established markets) must not be allowed to marginalise less readily-quantified and monetised services (such as natural hazard regulation, spiritual and religious value, or pest regulation). This creates institutional structural challenges relating to who makes decisions, and how those decisions are made and balanced, about innovations or trade-offs between services for wider constituencies of beneficiaries including the interests of future generations. As one example, dams may maximise local control of water resources and energy generation but also have major impacts downstream including the erosions of floodplain integrity and soil fertility, ecosystem and fishery integrity, likelihood of disease transmission, disruption of traditional livelihoods,

etc (WCD, 2000; WBCSD, 2007; Everard, 2009).

In all cases, ecosystem integrity and the rights of all who share it must drive decision-making on a precautionary basis; we must not fall into the easy habit of perpetuating the existing model of 'exploitation economics' wherein short-term, 'hard' societal economic benefits tend to outweigh uncertain, poorly-understood economic impacts and opportunities on issues such as ethics, aesthetics, culture, disease and pest control, and bequest values. In this regard, recent innovations in economic thinking are more sensitive to such issues, such as behavioural, institutional, evolutionary and complexity economics (Soderbaum, 2008). These can be coupled with methods such as fuzzy logic, multi-criteria decision analysis and soft systems methodology, for a more responsive mode of 'complex adaptive management' (Holland, 1999), although it is vital to engage all stakeholders as beneficiaries (or victims) of changes in services resulting from ecosystem management.

Other policy responses

Beyond the economic approaches highlighted above, the ecosystem services agenda also suggests other directions for policy development including:

- **Participation:** understanding public attitudes and community usage of ecosystem services is vital not merely for 'cultural services' but for all ecosystem services, as all support different facets of societal needs. This requires novel techniques, tools and processes to engender proactive participation.
- **Policy integration:** inter-unit working, policy appraisal and performance measures, multi-level and multi-lateral partnerships are all required to determine systems level impacts on all ecosystem services and their beneficiaries. Though self-evident in principle, this can be challenging to achieve in practice, even while there may be few alternatives to the challenge of 'anticipatory governance' (Fuerth, 2008).
- **Science, analysis and monitoring:** including increasing capacity to develop and support systems approaches, but also to determine appropriate indicators and non-negotiable thresholds and 'red lines' to safeguard ecosystems and their associated services.
- **Global-local linkages:** each of the above considerations also applies to international chains of cause and effect, such as waste transfer, long range pollution, marine conservation, energy infrastructure, and the over-arching agenda of climate change.

Future proofing

The ecosystem services agenda is shaped by a range of pressures including environmental challenges, environmental governance, cultural values, lifestyle choices, infrastructure resilience and so on. Responding to such uncertainty can be facilitated by a scenario approach, which explores alternative possibilities for strategic responses. As outlined in a subsequent paper in this journal – *Wind-tunnelling: the rapid scenario-based testing of emerging issues* – we used the Environment Agency's *Scenarios 2030* (Environment Agency, 2005) to explore how different combinations of trends in governance and social behaviour could impact on the interface of ecosystem services and regulation, which takes a very different path under the four scenarios:

- **'Restoration'** scenario *(sustainability-led governance/dematerialised consumption)*. Following mounting ecosystem damage, a more holistic systems approach becomes widespread. The Environment Agency will need to respond to rising expectations from society, but with scarcer resources, and to find ways of engaging with issues such as property rights and stewardship. In this scenario, ecosystem services thinking plays a leading role in society's quest for sustainability and equity.
- **'Alchemy'** scenario *(sustainability-led governance/material consumption)*. Ecosystem protection is taken up by policy, but with a reliance on technology 'fixes' and short term economic benefits. The Environment Agency will be pushed towards a hi-tech approach and will need to reinforce its public and community role in relation to ecosystem services.
- **'Survivor'** scenario *(growth-led governance/dematerialised consumption)*. Following some major collapses, ecosystems are now more protected, but on a patchy basis which is focused mainly on economic values. The Environment Agency will be pushed towards regulation on a cost-benefit basis, and cost-recovery for its slimmed down activities. Robust economic valuation of all ecosystem services will become essential if ecosystems are to be protected.
- **'Jeopardy'** scenario *(growth-led governance/material consumption)*. Ecosystems are under increasing pressures from material growth. In the UK, there is some protection, but this shifts the majority of the burdens to overseas. The Agency will be on the front line of the globalisation debate, in attempting to regulate long-range impacts and environment-trade issues, but from a relatively weak position. Ecosystem services thinking may take a critical role in highlighting equity and sustainability issues in global supply chains.

Implications for environmental governance

The Environment Agency and its partner organisations have to keep all of these possibilities open in the medium term. It is clear that the ecosystem services agenda is about better-connected ways of thinking and formulating policy, rather than focusing on single policies or problems in

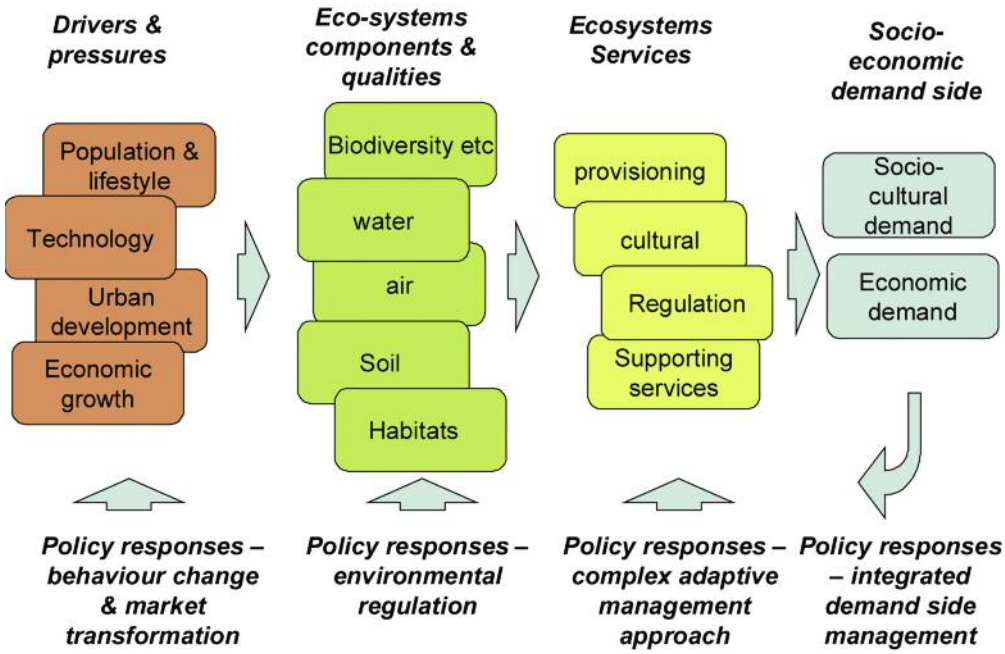


Figure 2: Ecosystems Services and causal chains
Concept mapping: adapted from DPSIR model (EEA, 1997: Ravetz, 2000)

isolation. Achieving this will require the breaking down of departmental boundaries, the interlinking of policy development between departments, and the collection and management of evidence on whole ecosystems rather than their parts. It will also entail the engagement of multiple beneficiaries of the services of ecosystems to attain sustainable and equitable outcomes.

Figure 2 illustrates the potential role of ecosystem services in this broader socio-ecological context, based on the DPSIR model. This shows how the drivers of population, economic growth, urban development cause direct impacts on ecosystem components and environmental media (air, water, land, biodiversity, etc) which in turn affect the functioning of those ecosystems, and so the production of ecosystem services across the four main categories (provisioning, regulating, cultural and supporting) thereby affecting associated socio-cultural and economic factors. Where there are problems, the response from policy can then take various forms:

- For the socio-economic driving forces, policy responses are likely to focus on behaviour change, market transformation, urban development, economic development and so on;
- For ecosystems components and qualities, the policy response can focus on regulation to protect critical ecosystem thresholds (standards for soil or water quality, etc). It can also look upstream, to the impact on ecosystems from societal activities such as land use, sourcing of raw materials, etc; and
- For the socio-economic demand side, the policy responses can focus on integrated demand side management. By looking for alternative transport policies, for instance, the impact of road-building can be reduced at source. Or, by working with garden supply companies, the impacts of peat extraction for compost can be much reduced.

Whilst the theoretical basis for these challenges is clear, the uptake by policy is as yet hesitant. For example, the Environment Agency's draft Corporate Strategy contains only one reference to aquatic ecosystems, and the major report on the Environment Agency's Water Resource Strategy of 2009 contains not a single mention of ecosystem services (Environment Agency, 2009a and 2009b). This is remarkable considering the central role of the concept in the major work done by the Millennium Ecosystem Assessment (2005) and others, and especially in the light of the clear guidance from DEFRA (2007).

This raises again the over-arching question on the Environment Agency's role and purpose. Is it to implement a regulatory regime addressing individual impacts, or to be a steward and champion of the environment as an integrated, functional ecosystem?

All of this raises significant questions about organisational structure, skills and experience, and the financial and human resources to enable the Environment Agency and similar bodies to make a proportionate response. It also raises questions about the adequacy of the current science and evidence base, in particular in relation to global-national-local linkages.

Conclusions and next steps

There are major challenges implicit in understanding, working with and protecting or enhancing ecosystem services, both locally and globally. From this brief review, a range of future directions begins to emerge:

- **Science and the evidence base:** build up the intelligence and analytical capacity based on whole systems, not just their parts. This involves both technical data and a wider, more participative mode of evidence-building, where lay experts, communities and citizens are also part of an adaptive system.
- **Capacity-building in governance:** this suggests a cross-cutting 'strategic intelligence' programme which links across current sectional and organisational silos. This should aim to mobilise and improve resources within regulatory organisations, including skills, experience, aspirations and incentives.
- **Regulation and market management:** new methods of valuation and trading may be needed for some ecosystem services whilst, for others, a more responsive and joined-up mode of regulation is required based on functions and performance rather than fixed thresholds. A sharper understanding is needed of how best to deal with each type of ecosystem service as part of a fully-interconnected whole.
- **Participation and networking:** there is a need to bring together each of the organisations involved in all branches of ecosystem services; possibly even to reform institutional arrangements overall. Other public agencies, the private sector, the civic sector and NGOs, research and technology, and even culture and media have major roles to play. This will contribute to extended monitoring, deliberative decision-making, and getting the public and community on board with environmental decisions affecting their future needs and aspirations.
- **Global-local linkages:** an extended global foresight-type intelligence base and policy coordination unit is proposed in order to track global trends, pressures, implications for UK ecosystems, and implications for regulator organisations. This would take the work of the Millenium Ecosystem Assessment forward into policy, and strengthen the national/EU/global linkages.

The ecosystem services agenda represents a paradigm shift, not a peripheral modification of pre-existing models of monitoring and regulating. This points towards new and more joined-up forms of environmental governance for a more interdependent and inherently sustainable 21st century.

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EMERGING ENERGY FUTURES: HARD CHOICES FOR SOFT ENERGY PATHWAYS

Energy supply technology of the UK is in the balance, with major changes expected within the next decade. Among many other effects, this will stretch the capacity of the regulators, in dealing with large complex infrastructures, new technological hazards, controversial policy regimes, uncertain markets, and extended life-cycle impacts. **JOE RAVETZ** reviews the implications of the 'Emerging Energy Futures' agenda for the forward strategy of the Environment Agency and similar public bodies. It is closely linked with the parallel paper in this edition of *Environmental Scientist* on the 'Low Carbon Economy'.

'White Paper leaves 2020 CO_2 target in doubt'

– ENDS Report 389, June 2007

'Only under the most optimistic scenarios will the Energy White Paper meet the national carbon dioxide emissions reduction target for 2020. A new nuclear programme is the government's favoured option to fill the policy gap. With its supporting documents, the Energy White Paper runs to 1,500 pages, but contains few new measures and fails to present the promised blueprint for a switch to a low-carbon economy.'

Introduction

The energy agenda is on the front line between environment, economy and society. Coming from a declining fossil fuel base, with increasing dependency on insecure imports, the UK will need to decide on its future energy mix. This involves a wide portfolio of new technologies in the next 10-20 years, including various forms of fossil fuels with various degrees of carbon capture, nuclear power, and a wide variety of renewable sources.

Each one of the plausible technology options causes some kind of impact or hazard ranging from climate change to land use, biodiversity, air quality, transportation, amenity, safety, hazardous substances and so on. Each is also vulnerable in some way, both to external threats (such as flooding, political insecurity or terrorism) and to internal problems (including technological failure, rising costs or public opposition).

The future prospects are quite uncertain. There is a widening gap between, on the one hand, the scientific evidence on climate change and resource depletion, and on the other, newly emerging policy and market regimes. Radical transformation is called for in energy technologies and markets, even while 'business as usual' appearances are needed for economic and social stability.

The Environment Agency and its partners in Defra's Delivery Network are key players in meeting the challenges of safety and sustainability in the energy sector. Broadly, there are two parallel agendas:

- How the regulators can best fulfil their statutory duties as delivery and management bodies; and
- How the regulators can best achieve their wider objectives as environmental champions, stewards, advocates and enablers.

This paper explores the contours of the debate, with a 'future-proofing' angle which draws upon the Environment Agency's *2030 Scenarios*. We do not aim to list here every possible technology with all its benefits and impacts. However, we do explore the wider implications for environmental regulators and similar public bodies.

Policy context

The Energy White Paper 2007 (EWP) summed up the agenda for the UK energy system in four main parts (BERR, 2007):

- **Energy security:** the UK changed from being a net exporter to a net importer of primary energy in 2003-04, and now relies on imports for around 25% of its primary energy needs. As North Sea oil and gas fields decline further, import dependency will intensify, with sources increasingly located in politically unstable regions.
- **Energy prices:** the 2008 energy price shock was seen by many as the first phase of 'peak oil': the situation in which rising demand overtakes falling supply (ITPOES, 2008). 'Peak oil' has finally been recognised internationally, if not yet fully by the UK government. China and India alone are projected to account for 45% of growth in world energy demand to 2030, and the stage is set for unstable and rising prices (International Energy Agency, 2008).
- **Economic competitiveness:** development of alternative sources of energy stimulates innovation and wealth creation, promoting environmental

industries and 'green collar jobs' (CEMEP, 2007).
- **Energy poverty:** even in 21st century Britain, this is a serious issue, with the population affected rising from 10% to 20% as a result of recent price rises.

Climate change is an issue overarching UK energy policy, and particularly the urgent need for 'decarbonisation' of the national energy mix. A wide raft of policies (with a broad lexicon of new acronyms to match) now includes:
- The carbon budgets under the Climate Change Act have set a trajectory towards a 2050 target of reducing emissions by 80% from 1990 levels (HM Treasury 2009);
- Large energy users have been subject to the UK's Climate Change Levy (CCL) and negotiated Climate Change Agreements (CCA) for a number of years;
- Large fossil fuel producers and suppliers are included in the EU Emissions Trading Scheme (ETS): phase 1 was problematic (for example due to the free allocation of allowances and the limited range of emissions addressed by this trial phase), but phase 2 is aiming to learn from that experience;
- Forthcoming UK energy efficiency and carbon trading programmes include the Carbon Emissions Reduction Target (CERT), Carbon Reduction Commitment (CRC), and the Code for Sustainable Homes (CSH);
- The UK Renewable Energy Strategy includes three principal fiscal mechanisms, the Renewables Obligation (RO), a forthcoming Feed-In Tariff (FIT), and the Renewable Transport Fuels Obligation (RTFO); and
- The nuclear programme for replacement of many existing end-of-life power stations was highlighted in the EWP 2007, and is now officially supported through the Nuclear Power Bill in the face of much controversy (BERR, 2008).

While the Environment Agency is the environmental regulator and manager of carbon markets, it has to interface closely with other organisations such as the Health and Safety Executive, OFGEM and OFGAS, the Nuclear Decommissioning Authority, Natural England and so on.

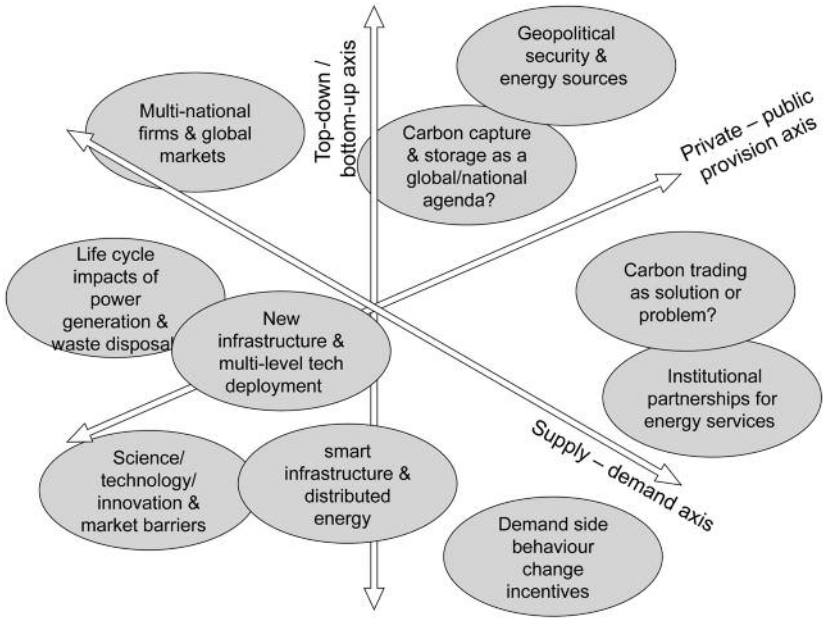

Figure 1: Dilemmas and paradigms in governance for emerging energy technology

Policy dilemmas

Overall, the need for a major transformation of the UK energy system is clear. However, there are major barriers to this including: uncertainty about global carbon policy and markets; lock-in effects of conventional energy technologies; shortages of skills and engineering capacity; consumer resistance; lack of political will; and what could be argued as a weak regulatory framework. Underlying these are technology-policy dilemmas and controversies that, by their nature, are not easily resolved. Some examples include:
- The nuclear dilemma. Should the energy gap be met with a replacement generation of nuclear power? There are many concerns about long-term waste storage, decommissioning costs, vulnerability to sabotage and proliferation, supply of uranium fuel and engineering capacity shortages;
- The carbon capture and storage (CCS) dilemma. At the time of writing there is great concern from the energy supply industry that the Environment Agency will be the arbiter of CCS viability. There are also wider concerns about this unproven technology, risk of cost escalation, long-term environmental impacts, and lock-in effects to fossil fuels and, post peak-oil, the use of secondary fuels with high impacts and low efficiency;
- The domestic action dilemma. Should the UK aim at domestic action for energy supply and carbon credits, or rely on buying in carbon emissions permits or offsets from overseas, or on the proposed EU supergrid importing

solar energy from North Africa?
- The technology platform dilemma. Hydrogen for example, could be a whole new national infrastructure with great potential benefits but, under current market conditions, it may be very difficult to build critical mass. With a technology-neutral mode of government support which is averse – possibly wisely – to 'picking winners', how can such a platform be established? The new interventionist industrial strategy stops short of the specifics (BERR and DECC, 2009); and
- Overall, the perennial dilemma of market versus state. While the energy suppliers and utilities are global corporations, many of them from less than friendly states, how far could or should the UK government intervene in matters of national security?

For such dilemmas, regulators such as the Environment Agency have a key role to play, both as delivery bodies and as environmental champions and advocates. Figure 1 shows the range of dilemmas for environmental governance, in terms of global-local scales, supply-demand chains, and market-state relationships.

Paradigm shifts

Behind such dilemmas, and also in response to the aspirations of the EWP for a '21st century energy system', there are also new ways of thinking – socio-technical paradigm shifts – for the role of energy, infrastructure and the supply-demand chain. Such shifts include:
- A shift from large-scale centralised generation and distribution to decentralised and, for many renewable sources, intermittent supplies;
- Integration of different energy carriers, conversion modes and distribution channels, such as the new co-generation and micro-generation technologies;
- The technical evolution of the power grid into a more responsive and intelligent form of infrastructure, which matches supply, demand, storage and price signals;
- Integration of supply and demand management, for example with the Energy Services Companies (ESCOs). These are highlighted by the EWP and other policies, but often struggle to get established in the face of regulatory and market uncertainty;
- The role of behaviour change and its implications for the energy gap. Numerous studies point out that a significant effort on energy efficiency would close the apparent national energy gap and, for example, remove altogether the perceived need for nuclear power replacement (Anderson and Bows, 2008); and
- Many technologies are often not discrete options, but are more like multi-level and interdependent platforms. For example, hydrogen supply and demand is interdependent with developments in fuel cells and catalytic pyrolysis. Carbon capture and storage (CCS) infrastructure may 'lock in' future fossil fuel use whilst the intermittent supply of some renewable sources will demand a re-engineering of power grid infrastructure, and possibly also of tariffs and payment mechanisms, to an extent not known until renewables are installed.

Implications for regulation

The Environment Agency and other regulators will be involved in these emerging energy futures as leading and proactive players. There are various crucial roles to be played:
- Regulator of environmental impacts of energy technology, and indirectly of technology deployment policy;
- Manager of new forms of markets, e.g. carbon trading and possibly ecosystems trading;
- Policy advisor and advocate for strategic choices in energy technology and infrastructure;
- Direct investment for protection of vulnerable or critical infrastructure, both public and private; and
- Assessor and arbitrator of competing claims and trade-offs, e.g. energy technology benefits versus biodiversity and landscape impacts.

In reality, there are major challenges in doing this. Energy options are often controversial and political. There may, for example, be backlashes, or even direct action from other sectors of society including trade associations, NGOs, lorry drivers and local groups. There are also major scientific uncertainties and ethical questions (such as how to value wetland habitats, or to assess the operational lifetime of a nuclear repository). There are huge commercial pressures to lower energy prices, increase energy security, and relax environmental standards. Meanwhile, the government has (until recently) preferred a relatively 'hands off' attitude to innovation, technology deployment and the activities of the privatised utilities. This may now change with the government's new approach to industrial partnership, and the challenges will alter accordingly (BERR and DECC, 2009).

Intelligent regulation will aim to look ahead of the technology curve, beyond the reactive 'end-of-pipe' approach. The new paradigm of diversified, networked, decentralised energy supply and demand implies a different model of regulation from that of the former CEGB-type large-scale fixed power generation. Energy demand and grid management will be as important as energy supply and fuel sources. Furthermore, the role of energy in the national carbon budget, and in the global carbon cycle, requires a radical departure from the former end-of-pipe regulation towards new forms of more proactive and more multi-level advocacy.

Future proofing

To explore some of the implications of these multiple sources of uncertainty, 'emerging energy futures' issues were tested via the 'wind-tunnelling' process (described

later in this journal in the article titled *Wind-tunnelling: the rapid scenario-based testing of emerging issues*). This process was based on the framework of the Environment Agency's *Scenarios 2030* (Environment Agency, 2006), producing some key implications including:

- **'Restoration'** scenario *(sustainability-led governance/ dematerialised consumption)*. Energy demand growth slows. With a strong climate policy, fossil fuels are phased out and renewable sources are developed rapidly. There will be an active trading market in carbon and possibly in ecosystem services. The regulators will need to manage the impacts, and ensure that local communities can benefit.
- **'Alchemy'** scenario *(sustainability-led governance/ material consumption)*. Energy demand continues to rise. There is a priority on new energy technology such as hydrogen and advanced biofuels, and a new generation of nuclear. The Environment Agency will need to manage and regulate new technological hazards and impacts, together with the nuclear programme and its radioactive waste.
- **'Survivor'** scenario *(growth-led governance/ dematerialised consumption)*. There are economic problems due, in part, to world energy markets. Clean technology investment slows down, while energy poverty rises. There are patchy localised solutions, many with polluting or dangerous energy sources. The Agency will be fighting a rearguard action on various fronts, with scarce resources.
- **'Jeopardy'** scenario *(growth-led governance/material consumption)*. With little efficiency investment, energy demand continues to rise. With a weak climate policy, there is a massive growth in imports of secondary fossil fuels (oil shale, bituminous coal, etc). There are air quality and climate emissions problems, as well as the impact of mining overseas. The regulatory issues will be more familiar, but now working in the global market of powerful multi-nationals, at a time of acute national energy insecurity and energy poverty.

This overview shows great uncertainty and variety in the different energy futures over the next 20 years, highlighting how responses will differ according to the conditions and pressures in each scenario. For example, under the 'Restoration' scenario, engagement of communities in biomass energy generation or the design and enforcement of air pollution permits will become more common. However, under the 'Jeopardy' scenario, there will be more reactive responses to 'tech-fixes' (such as carbon capture and storage) and industry-led standards relating to energy generation. Flexibility in response will be essential for the fast-moving global energy agenda.

Alternative modes of regulation

Underlying the challenges above are alternative regulatory models which recur throughout all the papers in this journal:

a) Conventional regulation, currently based on the Environmental Permitting and OPRA regime;
b) Extended forms of regulation, which use market measures, voluntary agreements, or BPEO type negotiations with major polluters;
c) A more networked and participatory mode, where the regulator is a partner and advocate not only of major polluters but also of civil society, of networks and communities, and of citizens and consumers. This may be enabled by new forms of technology and new social networking models; and
d) A further model takes this network approach into the 'post-normal' realm of scientific uncertainty and controversy, of ethical and political dilemmas, of structural power and ideological conflicts, and of irreversible decisions with unknown risks (Funtowicz and Ravetz, 1990).

The energy technology challenge may touch on each of these modes of regulation. For instance, the control of sulphur from large power plants needs the first approach, while the promotion of a new generation of power plants involves the second. New forms of distributed energy generation are also likely to need a more distributed and participatory form of regulation and management. And, finally, some of the new technologies (as well as perennial debates on nuclear power and nuclear waste management) raise many ethical, political and moral challenges, combined with high urgency and uncertainty.

Implications and ways forward

There are several directions which the Environment Agency and its partner regulators could take in response to such challenges:

- Widen their remit to look at the national energy portfolio, technology deployment curves, national carbon budget and its place in the global carbon cycle;
- Strengthen their participation processes to understand public attitudes, build local commitment, and test the ethical grounding of energy options;
- Extend the evidence base – both using horizon scanning, and technology assessment – on a comprehensive range of energy and fuel cycles, infrastructure issues, impacts/risks and costs/benefits;
- Build capacity for flexible responses in the face of new environmental challenges related to energy options (e.g. safety at Buncefield, critical infrastructure in Gloucestershire, or sea level rise at nuclear stations); and

• continued on page 30

TOWARDS THE LOW CARBON ECONOMY: TRANSFORMING THE WAY THINGS WORK

The low carbon economy (LCE) is a new and highly topical agenda with many dimensions. In particular, it aims to shift the 'problem' of climate change towards an 'opportunity' for business and economic development. While there is urgent activity on many levels in the public and private sectors, the role of regulation remains to be defined in detail. **JOE RAVETZ** reviews the implications of the LCE agenda for the forward strategy of the Environment Agency and similar public bodies. It is closely linked with the parallel paper in this edition of *Environmental Scientist* addressing the issue of *Emerging energy futures.*

'Energy price shock slow to spark new green plans'

– ENDS Report, 403, August 2008

'Record oil prices have pushed up the cost of fuel in the home and for transport. But calls for radical policy changes to accelerate the shift towards a low-carbon economy appear to be falling on deaf ears in Whitehall. There is scant discussion about encouraging all UK homes and businesses to use less fossil fuels, despite a growing number of reports making the case for ambitious decarbonisation.'

Introduction

The climate change agenda is now accepted across government, business and society, and the speed of take-up – at least of the rhetoric – by policy and markets is unprecedented.

However, on closer scrutiny, there is a widening gap between the scientific advice, new policy aspirations, and the actual rate of progress. The UK's Committee on Climate Change (2008) recommends an 80% cut in carbon emissions, with carbon budgets to include the effects of aviation and shipping as soon as practicable. Meanwhile many scientists, observing much higher rates of arctic ice melt and global greenhouse gas (GHG) emissions than previously anticipated, are now calling for reductions of 90% or more (Hawkins *et al*, 2008; Hansen *et al*, 2008). Such targets are not marginal adjustments to the energy system; they are more like a transformation across all sectors of production and consumption. This agenda is both radical and essential for survival.

The 'low carbon economy' (LCE) is a new and hugely topical agenda with many dimensions. It is now being framed in terms of shifting the 'problem' of climate change towards the 'opportunity' for business and economic development. But, while there is urgent activity on many levels in the public and private sector, the role and scope of environmental regulation remains to be defined in detail.

In the UK, there is a range of regulatory bodies in the Defra 'Delivery Network', of which the Environment Agency for England and Wales is the largest. The Environment Agency currently has some carbon-related functions in energy regulation and carbon market management. But to deal with the full range of problems and opportunities in the transition to a LCE it may need to adapt and extend its role to a more proactive and strategic approach. At the moment, there seem to be ad hoc allocations of responsibility from government; for example, at the time of writing, the Environment Agency seemed to be likely to undertake the responsibility for impounding high-emissions aircraft on the runway (*The Guardian*, 4th March 2009).

This paper takes a lateral and critical approach, supported by a 'future-proofing' approach that draws on previous work under the Environment Agency's *2030 Scenarios* to test policies and programmes under alternative future conditions. This scenario-based process helps to explore some leading questions for further discussion covering policy challenges and implications of the LCE, key technologies and market measures, and some major policy choices which are emerging. This work is also linked with the parallel paper in this journal addressing *Emerging energy futures.*

Policy context

To date, the elements of the LCE have been put together piecemeal from a series of emerging policy components, including:

- International climate policy programmes (the 'Kyoto mechanisms' at the time of writing, leading up to the Copenhagen meeting in late 2009);
- The EU 20-20-20 scheme for member states to produce an average 20% of all energy from renewable sources by 2020;
- The UK's Climate Change Bill and the Committee on Climate Change which supports it, with detailed

studies on the feasibility of meeting the proposed carbon budgets (HM Treasury, 2009; Committee on Climate Change, 2008);
- International and national carbon markets, including the EU Emissions Trading Scheme (ETS) phase 2 and the forthcoming Carbon Reduction Commitment);
- Energy supply policies, such as the Strategy and Microgeneration Strategy (Renewable Advisory Board, 2008);
- Sectoral initiatives in construction, transport, agriculture, industry, water, waste management and so on; and
- Strategy and mission statements from many trade and industry bodies including the CBI (2008), the Carbon Trust (2008) and the Global E-Sustainability Initiative (Climate Group 2009).

The Committee on Climate Change is now the key reference point in the UK, constituted as a statutory body from December 2008 when the Climate Change Bill became law. Its core function is to recommend the targets for the UK's 'carbon budgets'. These budgets are established by the Climate Change Act and will define the maximum level of CO_2 and (potentially) of other GHGs which the UK will aim to produce in each five-year budget period, beginning with 2008-12. To support this, the Committee has carried out modelling studies to show the feasibility of different pathways towards various long-term targets.

Achieving anything near the stated 80% reduction target is likely to require new ways of thinking about the LCE:
- There will be an accelerated push for zero carbon measures in many areas, such as energy supply technologies, infrastructure development, and building design;
- Each of these involves changes to capital investment, supply chains, infrastructure and organisations, each with long lead in times, so there will also be pressure on the demand side (i.e. behaviour change by consumers, independence of economic or policy incentives, etc);
- To provide incentives for all this, carbon will become not only an item with a price, but a kind of medium of exchange or alternative currency; and
- The problems of carbon 'leakage' (where emissions are displaced to overseas or non-regulated sectors), other GHG emissions and anthropogenic climate change effects, will increase rapidly in proportion to the diminishing carbon budget.

Broader challenges

It is becoming increasingly clear that the LCE is not only a matter of decarbonising the energy supply industry, but implies a much broader and deeper set of challenges. There is a technical agenda which covers many types of supply and conversion, greenhouse gas impacts, resource flows and supply chains. There is an economic agenda with the pricing and trading of carbon in a form of a parallel economy, and extending this to carbon-related policies and activities. To enable all of this, there is an institutional agenda for training, awareness-raising, and organisational change, as well as a social agenda in terms of mobilising citizens and communities. Looking behind the LCE rhetoric, there is a range of tricky issues that must be addressed:
- Although the ETS now covers half of all EU emissions, it has not yet begun to seriously reduce the 'cap' or availability of permits;
- If and when it does, the market only redistributes the permits, and does not in itself solve the problem of how to achieve drastic emissions reduction in any particular sector without large apparent costs and damage to certain sectors;
- Full marketisation of carbon is likely to lead to speculation, corruption, moral hazard, 'black market' trading, colonial-style biofuel plantations, and all the other likely spinoffs from markets (as it arguably has already) (Lohman, 2006);
- The general public is unlikely to change ingrained consumption patterns without coercion or without being provided with other viable alternatives, and that is likely to be financially costly and/or politically risky;
- Many LCE technologies have other major environmental and/or social impacts, such as controversies associated with biofuels, hydropower, and offshore or onshore wind;
- The likelihood is that the promised LCE will not happen, or will do so much more slowly than planned; recent trends are not (yet) encouraging; and
- It is also arguable that the UK can meet its targets only by large-scale purchase of credits from less affluent nations (which course of action has many critics).

Implications of the LCE vision

To meet these challenges, alternative visions for the LCE need to be explored. So far, the concept of the LCE has been developed in a relatively top-down and technical-economic policy frame. Regional and local authorities with aspirations to grapple with this issue often find they have few levers to pull, and communities or campaigners who attempt to respond, whether through Transition Towns or Climate Change Camps, are either marginalised or physically prevented. At every scale, there is much further to go in following through the LCE concept into the economy and across society and, in particular, the institutions and practices that underpin it (Ravetz, 2009). While the LCE technical and economic agenda has been

studied in detail, as yet the regulatory side is under-discussed. This raises a range of implications including:

- Firstly, an understanding of the multi-level carbon cycle and wider climate effects needs to be embedded and actively managed in all policies and activities in public and private sectors;
- The linking of carbon to the conventional business economy, through emissions trading and carbon-related fiscal measures, has hardly begun to address the market and non-market barriers and distortions;
- In the wider frame of the 'institutional economy', we need to explore possibilities for new kinds of incentives, organisations, partnerships or networks. For example, in raising the energy efficiency of the building stock, the current fragmentation between owners, mortgage companies, developers and utilities has to be overcome;
- Then, there is a powerful role for social enterprises of many kinds in raising awareness and turning apparent costs into benefits. For instance, the Transition Towns movement may enable, through social behaviour change, new levels of efficiencies in buildings, transport, or food production; and
- Finally, the international dimension is crucial. The LCE concept does not stop at national borders. Rather, it would aim to engage over the whole multi-level carbon cycle, and along multinational supply chains. This, of course, is intensely political in terms of EU and global policies and markets.

The Environment Agency and other regulators will need to raise awareness of the LCE visions, which are emerging from many corners of society. This will then support a more intelligent and proactive mode of regulation.

Environmental framework for the LCE

Meanwhile, there is a need for clarity on the 'environmental framework' for the LCE, in terms of drawing practical boundaries in a globally interconnected system of carbon flows and cycles (Figure 1). The agenda for carbon managers and regulators can be cross referenced to different layers of this complex system:

- Direct interventions in the carbon cycle: energy supply side actions such as carbon capture and storage;
- Indirect substitutions or displacements: renewable energy supply, or energy efficiency policies;
- Policy interventions: which cover a wider range including energy/carbon regulation or market measures that work on both supply and demand sides,

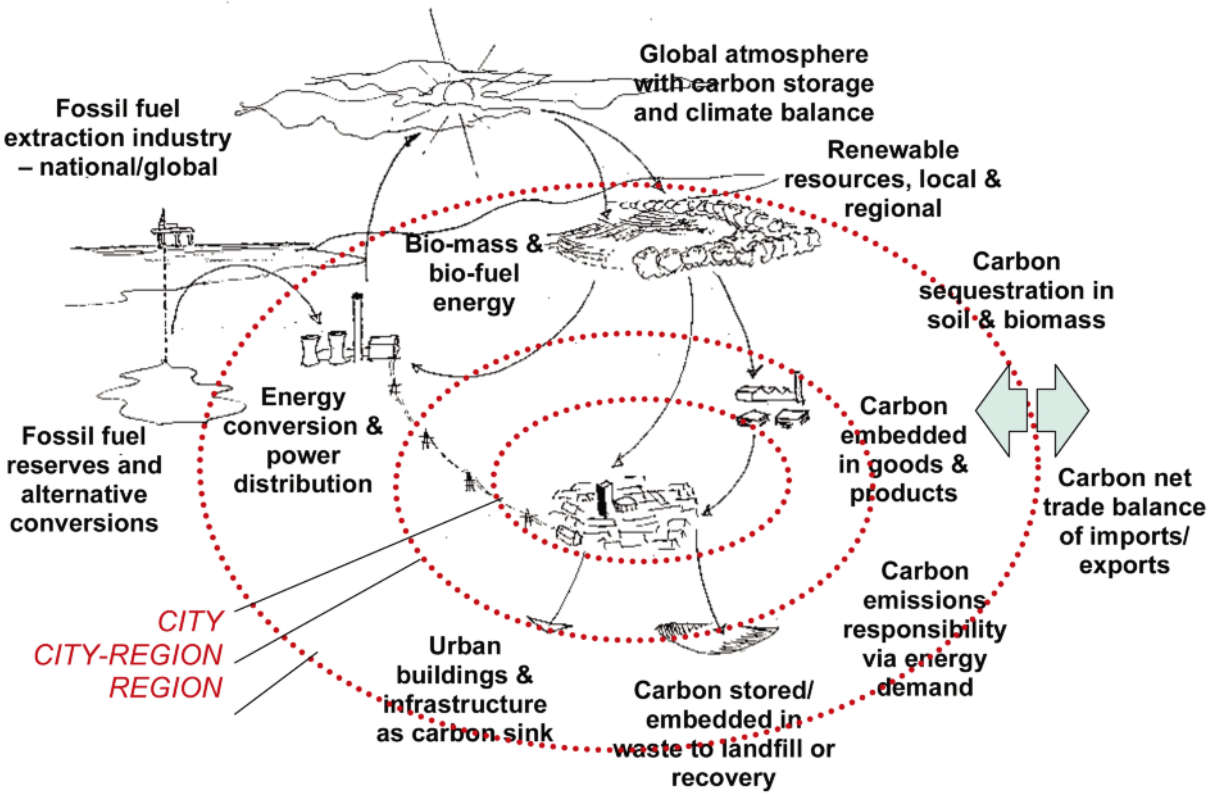

Figure 1: Environmental framework for the low carbon economy, showing carbon cycles, conversions and storage at the urban and regional scale, with alternative policy boundaries.

potentially extending to all kinds of goods and services;
- Carbon-related exchange or offsets: permit trading and offset schemes, such as the ETS or Clean Development Mechanism (CDM);
- Non-energy sector interventions: these include soil and agri-environment policy, forestry, and other land management options; and
- Climate adaptation measures, particularly where these overlap onto mitigation measures.

Each of these aspects of the LCE agenda has linkages with other sectors and policy areas.

Direct interventions are focused on the technology options (renewable energy issues are covered in the accompanying paper on *Emerging energy futures*). Carbon capture and storage (CCS) is seen as a positive solution, but it is still a long way from deployment and may bring new kinds of risks (leakage, infrastructure costs, etc). Biofuels have recently emerged as options for significant new carriers of energy, but as yet they are in competition with food production as well as displacement of biodiversity and consumption of critical resources such as water. There are new but, as yet, unproven possibilities with 'second generation' biofuels. Waste management is also an integral part of the carbon cycle, both in incineration options and in the wider implications for material supply chains and their embedded energy and carbon.

A wider agenda is focused on the environmental economy and market operations. The EU ETS Phase II is the world's largest such market, but is yet to start reducing the size of the cap. As the ETS matures and starts to 'bite', controversy and opposition can be expected and, with extension of emissions trading to other levels, there may be more complexity and scope for market abuse.

A further layer concerns non-carbon emissions, physical land use and quality, and the overlapping areas with climate adaptation policy. There are many GHG emissions from agriculture which need to be brought into agri-environment policy. In turn, this involves the question of the energy-intensive meat-based diet of the British consumer, and the need for a lower carbon food supply chain. Within the UK, land use, land use change and forestry represent a small component of the overall carbon cycle compared to energy supply, but are significant as a one-off carbon stock.

The low carbon economy paradigm

Underlying the LCE agenda are new ways of thinking – paradigm shifts – about the forthcoming transitions in the physical basis of economy and society. This points to the challenge for environmental governance: will the regulators 'pick up the pieces' of the problems after the event, or be an active partner in developing strategy and finding solutions? If the latter, this requires a new kind of 'strategic policy intelligence' including:

- Carbon accounting and trading is intended to become a parallel strand to the mainstream economy. This could be not so much a marginal adjustment as a new paradigm for economic activity and resource use, based on the requirements of living on a small and fragile planet. The 'carbon cycle' environmental framework above is the first point of reference for this;
- In parallel with this is the 'embedded carbon' concept, where imported goods or technologies can be allocated their share of carbon emissions which are generated at some distance along their supply chains. The implication is then for 'integrated chain management', for ways to manage the carbon effect and carbon cycle;
- This then implies a whole new generation of performance benchmarking and labelling for production processes, consumer products, consumer services, financial services, and so forth. In turn, there is a rapidly-emerging industry for monitoring, accreditation, evaluation, technology assessment, carbon credit banking, carbon insurance and so on;
- Carbon budgets have to be understood, measured and managed at many levels, from household to neighbourhood, local authority, multi-area, regional and indeed global scales. There are difficult choices concerning beneficial global effects and local actions and costs, and vice versa; and
- The emergence of 'Transition Towns' and 'Zero-Waste Neighbourhoods' shows the scope for mobilising public commitment and awareness. To follow through with their nascent promise, new kinds of regulatory or innovation strategies will need to be developed in a participatory and partnership mode of working.

Above all, there is the challenge of 'policy integration'. It is likely that carbon policy will be vastly more effective when linked to other sectors, such as construction and urban development, transport and accessibility, industrial competitiveness and product design, agriculture and landscape management, and so on. This breaks out of the conventional model of 'silo thinking' and departmental policy towards a more integrated model, which we are only just beginning to grasp.

Responses from regulators

So, what is the scope for environmental governance to contribute?

Current Environment Agency functions with relevance to the LCE include: ETS management; Climate Change Levies and Agreements; IPPC and LCP Directives; land and soil quality; waste incineration; agri-environment policy; local planning policy; and others. There is experience and organisational 'learning' in each of these areas, which needs to be further developed, both within existing

and across new disciplinary activities. The scope of the Environment Agency's remit may also need to be extended to address emerging areas, such as:

- Managing more extended forms of carbon markets, benchmarking and auditing;
- Biofuels assessment based on fuel life cycles, biodiversity and land management, carbon cycles and budgets;
- Land quality/carbon stocks and sequestration management;
- Extension of carbon budgets/quotas to local or regional policy, SMEs and householders;
- Life-cycle audit, or accreditation of external audits or labelling schemes, of embedded carbon in goods, products, infrastructure and services; and
- Promotion of low carbon energy generation, and management of the environmental consequences of novel technologies.

In practice, some of these could be very challenging. Carbon markets, as outlined above, can encourage speculation, corruption, and moral hazard. Intervention in land management could be in conflict with CAP reform, local planning policies and public interests. Extensions of carbon markets to the micro-level of SMEs and households could also be difficult or controversial due to privacy concerns, double accounting, carbon leakage, and various kinds of fraud or sabotage. The role of the regulators is, at the time of writing, in the spotlight for CCS, held up as the last great hope for fossil fuel use. Currently, it seems likely that the Environment Agency will be the final arbiter of CCS technology, a possibility which causes great concern to operators and investors (*The Guardian*, 12th May, 2009).

Future proofing

To explore such dilemmas and uncertainties, a 'future proofing' approach tests the range of uncertainty (as described later in this journal in an article addressing *Wind-tunnelling: the rapid scenario-based testing of emerging issues*). This scenario-based approach uses the Environment Agency's *Scenarios 2030* (Environment Agency, 2006) to test possibilities over the next 20 years. Each scenario raises questions on environmental governance for the LCE:

- **'Restoration'** scenario *(sustainability-led governance/ dematerialised consumption)*. The emerging carbon and ecosystems trading economy is focused on land use issues; the Environment Agency would have a central role to play, managing markets and meeting local community expectations.
- **'Alchemy'** scenario *(sustainability-led governance/ material consumption)*. The carbon economy takes a technological direction, with rapid development of CCS, hydrogen and fuel cells, alongside new conventional nuclear plants. Regulators will need to work with international carbon markets, and minimize perverse incentives and technology hazards.
- **'Survivor'** scenario *(growth-led governance/ dematerialised consumption)*. World markets could slow down in food, energy, commodities and investment. International carbon trading could be uncertain and fragmented. The Environment Agency will need to make the best of a difficult situation, and ensure that the LCE drive is not creating other problems.
- **'Jeopardy'** scenario *(growth-led governance/material consumption)*. With rising energy demand and weak governance, carbon targets are shoehorned into an international offset programme with minimal actions in the UK in order to protect economic growth and political stability. The Environment Agency will need to track the UK and global effects in parallel, and take a lead on a balanced approach to the LCE.

Overall, the future proofing exercise exposed a wide range of threats and possibilities, which are only just emerging. More detailed study is needed to identify the 'no-regrets' policies which are robust to future trends and surprises, in contrast to more narrowly-framed 'fragile' policies which may easily be blown off course.

Implications and ways forward

With these possibilities in mind, moving towards the LCE is clearly essential and urgent – however, as yet there is more rhetoric than practical action. Environmental governance has a key role to play in ensuring that the LCE is realistic and achievable, in managing carbon displacement and leakage, and helping to build the commitment of business, citizens and communities.

Again, the big question for regulators is whether to 'pick up the pieces' at end-of-pipe or, alternatively, to lead the way towards more sustainable solutions. These questions in turn raise issues of the capacity of bodies such as the Environment Agency to respond. Is there the right mix of skills and professional incentives? Is there enough evidence and an appropriate R&D base? Can the organisation generate a learning culture and innovation capacity to take on new roles? And, coming from Defra, DECC, BIS, CLG, DfT, HMT and other departments of government, is there the overall mandate, vision and resource to take a lead?

As set out in other papers in this journal, there are alternative responses from environmental governance:

- Conventional regulation as with the Environmental Permitting and OPRA regime; or, extended forms using market measures, voluntary agreements, or BPEO type negotiations;
- A more networked mode where the regulator is a partner and advocate, not only of major polluters but also of civil society, of networks and communities, and of citizens and consumers; or
- Responding to scientific uncertainty and controversy,

of ethical and political dilemmas, of structural power and ideological conflicts, and of irreversible decisions with unknown risks.

The scope of LCE governance touches on each of these models. While the LCE is often presented as a benign win-win policy aspiration, it is clear that real progress will sometimes involve political risks, hard decisions, economic change and social divisions. If the Environment Agency and partner bodies can anticipate these complexities, it will be better equipped to respond on the basis of a broad vision and sound capacity, and to play an active part in a low carbon future.

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- Develop the kind of 'corporate intelligence' which can respond to more complex challenges and more advanced modes of regulation, as seen in the later stages of the hierarchy above.

There are major challenges associated with fulfilling these goals. Have such regulators got the political mandate and strength to stand up to powerful interests? Are their technical, financial and human resources up to this? Does the organisation have the right skills and structures to encourage consensus and participation with multiple stakeholders? Are there mechanisms for developing 'strategic policy intelligence'?

Such questions will be up for discussion. Whatever the outcome, and whichever energy portfolio and scenario begins to emerge (most likely comprising parts of each scenario with other unpredictable developments also playing a part), the emerging environmental governance landscape will face new kinds of challenges and opportunities.

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COMMUNITY AND CITIZEN – EMERGING MODELS FOR SOCIALLY ENGAGED ENVIRONMENTAL GOVERNANCE

As the environmental agenda evolves, so do the attitudes and behaviours, values and expectations of citizens and communities. Such trends bring both risks and opportunities for 'next generation' environmental policy and regulation. **JOE RAVETZ** reviews the implications of the *Citizen and Community* agenda for the future of environmental governance. The case in point is the forward strategy of the Environment Agency and similar public bodies. This agenda is linked with parallel papers in this edition of *Environmental Scientist* on *New technology applications* and *Ecosystem services*.

'It's the ecology, stupid.'

– Sir John Harman
30th anniversary lecture, 24th November 2008
(ENDS Report November 2008)

'Most… (environmental policy)… advances have been made by the political classes with very little exposure to the will of the electorate. As seen from Westminster, the picture is one of conclusive science, emerging international pressures, a growing problem which has to be dealt with. But the public perception, even of human-induced climate change, is far less coherent. Surveys of media coverage still show a surprising parity between material supporting the reality of climate change and material denying it, or at least its human-induced component. To put it simply, the Government Chief Scientist may have the ear of the decision-makers but Clarkson and Wogan have the ear of a good part of the electorate.'

Introduction

Environmental policy starts and ends with people, in their various roles as polluters, the polluted, users, producers and stewards of local environmental resources and qualities. With the public on board, great progress is possible in areas such as recycling, transport, flood defence or land management. A regulatory regime that regards people as a 'problem' or an obstacle to progress can only alienate them, compounding the already complex problems of environmental management. In reality, both conventional environmental regulation and the wider role of the environmental champion depend upon a high level of public engagement.

With the improvement in environmental management of large polluters, individuals, communities and small businesses will make up an increasing proportion of environmental burdens. At any one moment, an average citizen or household may serve multiple roles with respect to the environment: as polluter; receptor of pollution; advocate; campaigner; reporter; monitor of its impacts; and so on.

As the largest environmental regulator in Europe with specific responsibilities for England and Wales, the Environment Agency is a major public body with many pressures on costs and performance. Founded on historic regulatory models, it is also not always well-equipped to deal with small and dispersed local issues. There is also a fine line between the Environment Agency's objectives of regulation and those of advocacy or campaigning, which are already carried out with great passion and vigour by NGOs or local action groups.

New technologies may have a significant role in this regard. If the Environment Agency aspires to be 'at the front of the social curve', it will need to be leading on Web 2.0 types of 'social technology' including, for example, Youtube, social networking, wiki-nomics, Google platforms and others (see the paper in this journal addressing *New technology applications*).

This paper sketches the outlines of this debate about citizen and community. It draws on previous scenario work, highlights some directions and opportunities, and explores the implications for environmental governance. The paper also links to others in this journal, particularly *Ecosystems services*, the *Low carbon economy* and *New technology applications*.

Context: socio-economic trends and debates

Environmental 'wellbeing', health and lifestyle are part of the 21st century *zeitgeist*. Topical media images, health products, tourist promotions and lifestyle advice often use a 'clean and green' environment as a backdrop. At the same time, there is a general expectation that affluence and material consumption will continue to rise (notwithstanding the current economic recession). There appears to be a powerful disconnection in the public mind between environmental improvements in the affluent UK, and the largely unwitting and overlooked destruction of ecosystems in other continents.

The climate crisis and the imminent 'peak oil' and food

crunch seem to be promoting a public agenda of global responsibility. However, this is not a simple trend. Rather, there are many barriers, controversies, misunderstanding and misinformation. The current realisation of the 'politics of climate change' shows how a scientific issue is being reconstructed as a deep socio-cultural trauma (Giddens, 2009).

The average citizen is today perceived to hold stronger environmental values and priorities than ever before (although the effect of the current recession is yet to be seen), and green NGOs are trusted almost more than any other sources. By contrast, there are various levels of alienation or distrust in government, business and science. Again, there is widespread 'dissonance' or 'greenwash', for example where sustainability values are proclaimed and token gestures are carried out, whilst high-impact consumption such as air travel continues to grow (Ravetz, 1999; Hajer, 1999).

Against this background, there are some deeper structural trends and tensions (Putnam, 2000; Florida, 2005; Tapscott and Williams, 2007):

- Trends towards individualism, for example in the 'iPod generation', which privileges the personal level of experience and consumption; and
- Trends towards collectivism, including new forms of social networks, mobile-enabled, cultural and media icons and, in some cases, a patchy and inconsistent global environmental awareness.

Environmental roles of citizens and communities

Citizens and communities play a wide range of different roles, often simultaneously, with respect to the environment. The 'ecosystem services' paradigm (see the *Ecosystem services* paper in this volume) provides valuable insights on such roles:

- Citizen as 'polluted': the text book case, where the public is the receptor of environmental pollution, and subject to various degrees of risk and hazard;
- Citizen as 'polluter': where the public or local business is the cause of pollution, through activities such as dog fouling, fly-tipping or the use of household chemicals;
- Citizens as 'participants': in environmental reporting and monitoring, they may be active advocates or campaigners;
- Citizens as 'stakeholders': as neighbours or investors in environmental assets, where physical qualities are part of social and economic development;
- Citizens as 'users': active enjoyment of environmental assets, through activities such as fishing, walking or other forms of leisure; and
- Citizens as 'beneficiaries' or consumers of ecosystems services, receiving food or materials directly, or other supporting services indirectly.

In parallel, 'communities' are often assumed to be homogeneous units, yet have equally diverse environmental roles. These include, for example: citizens and households; local small businesses and landlords; land owners, landlords or land users; civic bodies in health, education, housing, culture; media sport or leisure organizations; and local action or lobby groups. This is clearly a very wide spread of interests. What distinguishes them is that they are generally outside: (a) formal public governance systems; (b) larger corporate bodies; and (c) the community of 'experts'. Nevertheless, all are significant 'users' as well as 'influencers' or 'agents' in the environment.

Social roles in environmental governance

The Environment Agency, in common with similar 'non-departmental public body' (NDPB) regulators in the Defra Delivery Network, also plays a variety of roles in relation to the public including:

- Regulator and manager of markets;
- Enforcement for compliance and liability;
- Educator, awareness raiser or capacity builder;
- Scientist, analyst or data monitor; and
- Steward and champion of the environment.

For citizen and community engagement, these roles can take different forms: public participation and 'deliberative democracy'; organisational partnerships and negotiation processes; education outreach and capacity building; or strategic policy alliances. The boundaries between these are often unclear, both within and from outside the organisation, although some guidance has been set out by Defra's Third Sector Strategy (Defra, 2008).

The Environment Agency's Social Policy set out three principles (Environment Agency, 2006a):

1) understanding and communicating the social impacts of our work, including opportunities to deliver combined environmental and social benefits;
2) addressing environmental inequalities; and
3) transparency, information, and access to participation.

Since 1996, there has been an active work programme within the Environment Agency on citizen and community, with examples including:

- 'Building Trust with Communities' (Environment Agency, 2000a) addressing the general area of partnership and alliance for environmental action;
- 'Better Places' exploring the role of environmental actions in social and economic regeneration (Environment Agency, 2006b);
- Developing links with Local Strategic Partnerships and other arms of local government (Environment Agency, 2006c);
- Public participation including various studies on the evaluation and guidance for methods in public participation (Environment Agency, 2002); and
- Pilots on deliberative democracy for technology

challenges such as nanotechnology (Environment Agency, 2006d).

There is engagement with local governance at various levels, with a general duty to cooperate between the Agency and local authorities. Pilot programmes such as those in Sandwell showed the scope of active engagement, but these are resource intensive and priority is made for areas of highest deprivation. There are also prototypes for wider institutional engagement. For example, the 'water neutrality' concept in the Thames Gateway development area potentially involves utilities, developers, local authorities and Local Strategic Partnerships.

Community engagement can bring positive results particularly where applied to specific sectors. Flood risk management is increasingly coming to be seen as a 'people issue', which mobilised the commitment of technical and engineering staff (Environment Agency, 2006e: Colbourne, in press). Flood risk, vulnerability and impacts were each clearly dependent on social mix, diversity, disability, social cohesion and so on. 'Inequalities' work relating to flood risk (amongst other parameters) was also pioneering in its use of community mapping and the link to the Index of Multiple Deprivation (IMD) and other measures.

The 'Building Trust' programme was also active in community engagement (Environment Agency, 2000b). Part of this success may be due to many schemes involving partnerships with other funding, and/or a recognition that this investment would be better targeted and better maintained through community participation.

There are also cultural and institutional barriers. In water demand management, for instance, the agenda is still framed mainly as a technical issue which concerns household metering and tariff structures. There may be opportunities currently taken by bodies such as the Energy Savings Trust, for more effective and lower-cost demand management by getting the consumers engaged. However, there are problems of split responsibility between the Environment Agency, water utilities, OFWAT, housebuilders and other key stakeholders. Citizen environmental monitoring has not been followed through, notwithstanding its uptake in the USA and Canada. Environmental education has been left mainly to other organisations with the mandate and the resources.

There are also other sectors where there is potential but as yet little community engagement or mobilisation by the Environment Agency, for example in transport demand management, energy efficiency, and community recycling. In each of these there are functions in policy, regulation, demand management and outreach, and a better integration of these may be essential for the new national climate emissions targets, waste diversion targets, and other 'grand challenges' (see the parallel paper on the *Low carbon economy* in this journal). Overall, experience shows benefits from social engagement, but also the necessary investment of time and resource in building relations at the local level.

Future proofing

Such citizen and community roles are sensitive to social and environmental trends and 'wild cards' (unplanned events and changes which are volatile and impossible to anticipate). One source of uncertainty is the level of popular trust in governance. Throughout 2008, the global credit crisis helped to re-invent the role of public governance as the steward of last resort, not only in the economy but in other areas of public policy. But will the events of 2009 destabilise that volatile commodity of trust?

Meanwhile as the UK 'cleans and greens' itself (for the most part), the global agenda looms ever larger. However, the role of public regulatory bodies such as the Environment Agency is often unclear when dealing with such global chains of cause and effect.

As environmentalism emerged from activism, when will the activists bite back? The proposed third runway at Heathrow, for instance, shows signs of being a new battlefront between unreconstructed economic growth versus environmental capital. On the positive side, initiatives and networks such as the Transition Towns movement show new energy in mobilising local environmental action.

To explore the implications of such sources of uncertainty, alternative trends and futures in citizen-community relationships were tested in a 'wind-tunnelling' process, using the Environment Agency's *Scenarios 2030* (Environment Agency, 2006f):

- **'Restoration'** scenario *(sustainability-led governance/dematerialised consumption)*. Many communities and citizens are keen environmentalists, and their energies are easily mobilised. Regulation focuses on outreach and coordination.
- **'Alchemy'** scenario *(sustainability-led governance/material consumption)*. Most people are affluent consumers, relying on technology to clean up and sort out the environment. Regulation focuses on market-based credits and charges.
- **'Survivor'** scenario *(growth-led governance/dematerialised consumption)*. Many communities suffer depleted ecosystem services. Environmental policy focuses on surviving the worst impacts and reconstruction of ecosystems with strong regulation.
- **'Jeopardy'** scenario *(growth-led governance/material consumption)*. Most people are affluent consumers, relying on defensive anti-pollution measures. Regulation focuses on liability and enforcement, with priority given to resource protection.

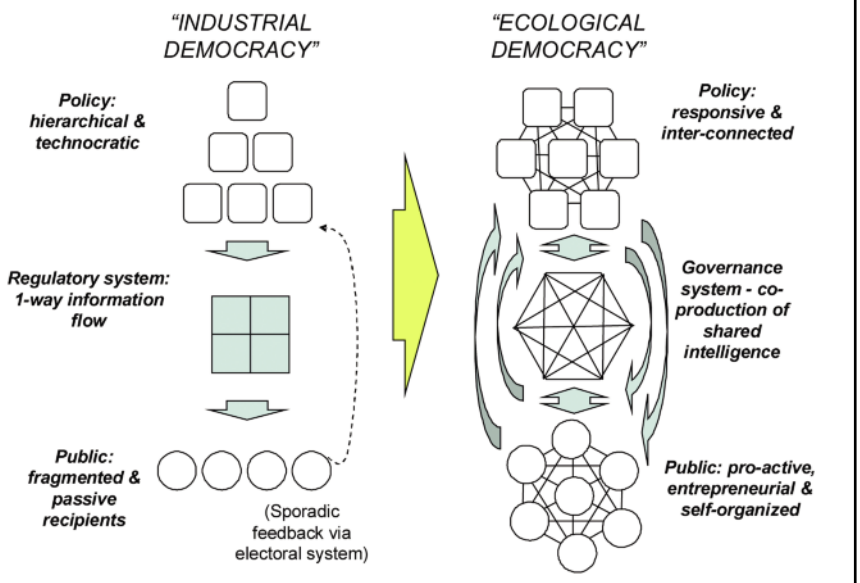

Figure 1: Shifting from 'industrial democracy' towards 'ecological democracy' in environmental governance

Implications for environmental governance

The 'citizen and community' agenda raises both threats and opportunities. On one hand, public engagement can be costly and may divert resources from apparently core tasks concerning 'real' polluters. On the other hand, failure to engage the various 'publics' can result in mistrusted or failed schemes. However, public participation can backfire if it is poorly executed, as evidenced by some flood risk management consultation schemes. Prioritising and adequately resourcing stakeholder engagement is essential.

Nevertheless, new requirements in environmental governance or spatial planning bring pressure for public participation. Highly significant in this regard is the Aarhus Convention (UNECE, 1998), which requires public participation in environmental decision-making, from the problem-framing stage, to options identification and appraisal, through to decision and implementation. Some more recent progressive environmental regulations, most notably the EU Water Framework Directive, already embody the requirements of the Aarhus Convention. However, it often appears that the comprehensive requirements of such frameworks are easily lost in transposition to policy and practice at the national and local level.

There are many opportunities and benefits stemming from public engagement. The public can be self-regulators, or constitute a voluntary monitoring force. The public can be self-motivated behaviour change agents, and campaigners to business, investors and other interests. The public can provide local expertise, for example on ecological design and stakeholder needs. These opportunities all highlight the need for a wider and more responsive system of 'public proofing' across many forms of environmental governance.

There is a wider context to this – the emergence of more responsive, participative and collaborative forms of governance, as seen in various forms in spatial planning, economic development, social policy and environmental policy (Healey, 1997; Ravetz, 1999). There is a shift from 'industrial democracy' towards a more 'ecological democracy', where policy-makers, citizens, communities and other stakeholders co-produce collective intelligence on needs and opportunities (Figure 1). This may be enabled by new forms of digital networking, alongside wider social trends and movements (Pezzoli, *et al*, forthcoming; Tapscott and Williams, 2008).

Alternative models of regulation

Underlying the above are alternative models of regulation, many of which have emerged over the last century or so of environmental policy development. As in the other papers in this volume, these can be seen in a spectrum, each enabling or limiting active and participative citizen and community engagement:

- Conventional 'top down' regulation, generally focused on 'end-of-pipe' solutions and currently based on the Environmental Permitting and OPRA regime, generally involves limited public consultation on 'expert' decisions already taken.
- Extended forms of regulation, which may look along supply chains and environmental pathways for a more rounded 'integrated assessment' (Bailey, 1997). These modes would tend to use market measures, voluntary agreements, or BPEO (Best Practical Environmental Option) type negotiations with major polluters. There are benefits stemming from public participation in monitoring and design of mitigation.
- Following this is a more networked mode, where the regulator is a partner and advocate, not only of major polluters but also of civil society, of networks and consumers, and of citizens and communities. Such diffusion can be enabled by new Web 2.0-type technologies, alongside new types of social

networking models. There is a broad movement for 'environmental citizen science' which actively involves citizens and communities for their local expertise, monitoring capacity, and mobilisation of responses (Irwin, 1995).

- A further level takes this network approach into the 'post-normal' realm of irreducible scientific uncertainty and controversy, of ethical and political dilemmas, of structural conflicts in power and ideology, and of irreversible and urgent decisions with unknowable risks (Funtowicz and Ravetz, 1990). At the core of this is the concept of 'deliberative, integrative, participatory, socially inclusive' ('DIPSI') methods, to resolve policy dilemmas which combine technical, political, economic and ethical issues (Forester, 1999).

Conclusions

Since its inception, there has been a proactive and self-aware programme of social policy development in the Environment Agency, matched in parallel by other bodies in environmental governance. Any conclusions here can only suggest key themes and directions in the light of the future-proofing process.

On a technical front, there are new modes of monitoring and information flows, for example enabled by Web 2.0-type spatial technology and social network-type engagement. On a policy front, there are new modes of negotiation and advocacy, enabled by new public agendas in education, health and regeneration. On a business and industry front, there is clearly a public role in reinforcing the shift towards corporate responsibility and consumer awareness throughout the supply chain.

Such new modes are based on new kinds of synergy and shared intelligence across the wider society. These include seeking opportunities and shared interests between citizens and communities, regulators, businesses and other stakeholders. Such processes can be summed up in broad and topical policy agendas, such as:

- 'Sustainable consumption and production': looking upstream from the 'end of pipe' towards a more integrated supply chain, including for over-arching global issues (Sustainable Development Commission, 2006);
- 'Natural economy': focusing on tangible ecosystems services, and their social and cultural dimensions (as on *www.naturaleconomynorthwest.com*); and
- 'Sustainable communities': a more pro-active role in economic and social development, and environmentally-led local regeneration (Academy of Sustainable Communities, 2007).

Each of these is reflected, at least in principle, in the Environment Agency's Corporate Strategy high-level themes, and particularly in theme 3 (Environment Agency, 2009):

> *'We want all sections of society to have opportunities to enjoy a safe environment that enriches people's lives and promotes wellbeing'*

However, this begs questions about the available resources and skills, and the organisational structure and incentives. There are questions on the role and remit of the organisation as a regulator or as a steward or champion of the environment. The latter implies taking greater account of the many interdependent beneficiaries of ecosystem services and social processes in 'environmental community action'.

It will be interesting to return in 10 or 20 years time and observe the shifts in regulation styles and relationships with citizens and communities. It is arguable that the overwhelming environmental challenges of the 21st century will demand a shift towards environmental governance which is based on participative advocacy and capacity-building at all levels of society.

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NEW TECHNOLOGY APPLICATIONS: RISKS AND OPPORTUNITIES FOR ENVIRONMENTAL GOVERNANCE

As the environmental agenda evolves, the opportunities and possible impacts of information and communications technology are no longer just a technical issue. For both the globalisation of environmental impacts and the localisation of 'quality of life' factors, there is a transformation in progress. The acceleration of data flows and processing powers is likely to help the restructuring of relationships between environmental managers, polluters, citizens and communities. **JOE RAVETZ** reviews the implications of new technology applications for environmental governance in the UK, using the Environment Agency as a specific case example. There are links to other papers in this edition of *Environmental Scientist* on *Citizen and community* and *Ecosystem services*.

'Cyber-infrastructure – carrier of the cyber-society?'

– Pezzoli *et al* (forthcoming)

'Remote sensing collects a torrent of data, the internet distributes knowledge to all, and new forms of semantic processing turns it into shared intelligence… at the current rate of progress every environmental facet of every square metre could be managed on a real time basis. A new generation of cyber-infrastructure, with hyper-bandwidth global distributed computing, promises bigger and better modelling of environmental challenges, from climate change to toxic accumulation, and from product supply chains to greening the local community.

'But is such a trend locking us in to a machine-based future, with all the problems of misuse, failure or sabotage? Will this replace the human element, and exclude the non-digital remainder? How should the institutions of governance build in the all-powerful technology dimension to their forward strategy?'

Introduction

New technologies offer new possibilities in data monitoring, information processing and social networking. For any public organisation, there is an over-riding imperative to increase efficiency and effectiveness, using information and communications technology (ICT) as a catalyst for wider organisational changes.

In practice, technology development is generally much more than a neutral technical issue; it tends to influence and catalyse change in management processes, organisational structure, and relations with stakeholders and clients. While the pace of technological change is rapid, it brings with it technical challenges, ethical dilemmas, as well as uncertain costs, benefits and evidence about further implications. Overall, this constitutes a classic dilemma for 21st century public policy.

This affects environmental governance as much as other areas. The Environment Agency is a good example of a large regulatory organisation, with a range of activities from advanced ICT to basic online techniques.

This report provides an overview and route map of the ICT applications debate, as a way to inform more in-depth study. It also draws upon scenario-based analyses to highlight potential directions of change and opportunities for environmental governance, particularly as these might affect the Environment Agency.

Scope of technology applications

Broadly, there are three types of technology agendas in view, of which we focus mainly on the first:

- Information and communications technology (ICT) as applied to environmental governance;
- Other technology developments which bear on regulatory operations, such as remote sensing, mobile telephony, satellite imaging, radio-frequency identification (RFID), robotics or nano-robotics, and genetic profiling; and
- Wider trends in new technology which may influence the Environment Agency's operations, ranging from biotechnology to robotics, nanotechnology, materials technology and synthetic biology.

Each of these raise both opportunities and challenges for environmental governance:

- Direct regulatory and operational efficiency and effectiveness in carrying out existing operations;
- New possibilities for extending the Environment Agency's remit and operations, in line with wider social and political concerns; and

- Wider concerns on technology-related impacts, including civil liberties and privacy, commercial confidence and market intervention, intellectual property, public participation, technology dependency, and vulnerability to breakdown or sabotage (Sardar and Ravetz, 1996).

Background: current technology development

Behind the innovation frontier in the Environment Agency is the continuous development of corporate information systems. Current developments include:

- Corporate IT support is being outsourced;
- The NetRegs online facility for small business provides basic environmental management and regulation information (*www.netregs.gov.uk/*);
- 'What's in your backyard?' provides access to environmental data for England and Wales at a local level (*http://maps.environment-agency.gov.uk/wiyby*); and
- A new online hub for environmental permitting, data reporting and payments aims to streamline regulation and reduce administrative burdens. This will unify regulatory activities into an online 'one-stop shop', allow the Agency to hone its risk-based regulation, and eventually allow charges to be based on whole sites rather than individual permits (ENDS Report, 2008).

Each of these is a modest advance in technology terms, which will undoubtedly improve efficiency and quality of regulation. They may also start to have wider effects, not only on the quantity but also the quality of information flows and on relationships between regulators, clients and other stakeholders.

The Environment Agency's Monitoring Technologies Roadmap programme aims at a strategic, long-term approach to developments in monitoring technologies. The current programme in 2008-09 includes workshops and desk studies on three main strands: (1) an overview of monitoring; (2) technology developments; and (3) implementation issues. These investigations cover the following areas:

- Sensors and instrumentation across air, land, and water monitoring;
- Developments in electronics and data processing techniques;
- Technology transfer from other fields such as healthcare and homeland security; and
- University activities in related fields (including UK, European and selected institutions globally).

In contrast, some senior sources internal to the Environment Agency have expressed concerns (deduced by interviews undertaken elsewhere in this research project) that:

- *'Basic water monitoring technologies have never made it to the front line.'*
- *'The EA does not have the understanding and the skills required.'*
- *'Finding material on the EA website is difficult.'*

Other prominent interviewees external to the Environment Agency have raised particular concerns about the customer interface:

- *'Focused on outputs not outcomes.'*
- *'Not winning the hearts and minds of regulated communities.'*
- *'Do not understand relationship with citizens.'*
- *'People hide behind documents rather than talk.'*

Clearly, an organisation the size of the Environment Agency will never perform identically across all of its functions and levels; in that regard the ICT should not be an end in itself, but an enabler of more effective communications and information flows, internally and externally. Again, this is a strategic organisational issue as well as a technology development question.

Upcoming technologies

One of various emerging ICT frontiers relates to the functioning and use of the 'semantic web', and the opportunities this raises for organisational intelligence and knowledge sharing. The Environment Agency might learn from others about its many potential applications. For example, the global consultancy Ove Arup has developed internal systems which enable complex problem solving, not with a large central database but through networked interest groups, knowledge chains and clusters. Potential implications of this technology approach include:

- Within ten years, the semantic web concept may be commonplace across the public sector. The information retrieval functions are relatively straightforward, but the visualisation and assembly of semantic data is still challenging.
- Grid Computing (where large numbers of work stations act together on shared functions) may be invaluable for forecasting and incident management, for instance in floods and other extreme events. Supercomputing can also provide real-time modelling and forecasting, combining 3-D modelling and visualisation, LIDAR topographic data, other environmental flows and pressure data, with real time telemetry sources.
- The prospect then extends to combining other data from government or third parties, and constructing 'mashups' of agglomerated datasets. This could for instance overlay epidemiological data, lifestyle and monitoring data, to identify new toxicological hazards and pathways.

In principle, the inter-operability of public sector data and particularly spatial data is a key to this. In practice. many datasets need costly adaptation and smoothing in order to fit together. A further challenge is that of resilience, such as

in real-time incident management where the practical reliability and bandwidth of mobile communications is crucial.

Longer-range trends

Such trends raise broader questions about technology applications, in relation to emerging policy agendas. Integrated Catchment Management (ICM), for instance, is not only an internal function to the Environment Agency, but relies on interactive collaboration with a wide range of stakeholders. This points clearly towards emerging social network technologies. If the Environment Agency aims to be leading rather than following the technology curve, it would explore the Web 2.0 types of 'social tech' such as Youtube, networking, wiki-nomics, Google applications, virtual worlds, and distributed game environments (Gordon and Koo, 2007). These offer a broad spread of technologies which enable and encourage new forms of engagement in a networked society (Albrechts and Mandelbaum, 2006):

- open source geo-spatial platforms and shared applications, e.g. Googlemaps and Google Earth, on the 'neogeography' principle (Hudson-Smith, 2008);
- file sharing and 'homepaging', comprising person/object-oriented platforms where individuals build up unlimited digital profiles of experiences, needs and wants, problems and opportunities;
- the 'wiki-nomics' principle involving mass collaboration and shared intelligence, as in the cases of Wikipedia and many varieties of blogging (Tapscott and Williams, 2007);
- 'cyber-infrastructure' and large scale grid computing, enabling modelling of global environmental effects such as climate change, food shortages, water management and forestry management (Pezzoli *et al*, forthcoming);
- 'integrated rule-based object-oriented databases' (IRODS), involving integration of large datasets into a seamless data-rich environment, which enables exchange between many government, industry and third sector resources (Sharpe and Hodgson, 2008).

ICT potential: incremental and evolutionary change

Clearly, desktop computer databases in planning are helpful, and web access for downloading documents and uploading applications is also useful. However, environmental management often struggles to keep up with commercial developments in interactive spatial databases. For instance, Google Earth and parallel systems enable instant access to customised ranges of property types, linked to maps and aerial photography, and keyed to localised and real-time data on public services and business opportunities. We can follow this curve towards an online future of baseline data, scenario visualisations, learning packages,

Perspective	Characteristics	Examples
Perspective 1: ICT potential = incremental changes	This focuses on incremental enhancements and enlargements to conventional systems of business and governance.	◆ Transaction costs minimisation; ◆ Enlarged markets and audience types; ◆ Information access efficiency and transparency.
Perspective 2: ICT potential = evolutionary divergence	This concerns the emergence of new 'spaces', alongside the destruction or subversion of 'old spaces'. Such evolutionary spaces can be seen now in many areas and applications, where the literature is generally way behind the frontier.	◆ Social spaces – MSN, MySpace, etc; ◆ Trading spaces – Ebay, Amazon, etc; ◆ Media sharing spaces – file sharing and peer-to-peer, e.g. Napster, Limewire; ◆ Multi-media spaces – Youtube, etc; ◆ Decision-making spaces – YouGov, etc; ◆ Consumer profiling spaces – e.g. online customisation and ordering of many items; ◆ Virtual world gaming and trading spaces – Second Life, World of Warcraft, etc; ◆ Informational spaces – Wikipedia and others, where knowledge is accumulated, edited and refined through a community of interest.
Perspective 3: ICT potential = evolutionary convergence	Elements of 'convergence'. Such trends might focus on the technology or the platform, such as the combination of images, music and internet on the mobile phone. It also involves convergence between a range of applications, and the 'space' which they enable and evolve, particularly between providers, intermediaries, consumers, 'peers', and other actors. Such convergence can also generate fierce conflicts, on copyright, licensing, privacy and so on.	◆ 'Commercial' advertising helps to fund 'social' spaces, e.g. on MySpace; ◆ 'Trading' spaces become leisure and lifestyle spaces, e.g. on Amazon; ◆ 'Virtual reality' spaces, e.g. in Active Worlds, become trading spaces, exchanging real or virtual goods with real or virtual currency.

Table 1: ICT Potential: incremental, evolutionary and convergent (based on Pezzoli *et al,* forthcoming)

stakeholder views, management processes, business opportunities, consumer needs and so on (Leinen, 2004). The recent evolution of ICT development through three stages is illustrated in Table 1.

We can see this evolutionary model of 'emergence' and 'convergence', on both the technology side and the applications side of a universal 'cyberinfrastructure' (Figure 1). Technical convergence between various forms of hardware and software is familiar to developers:

- Mass collaboration, shared editing and collective semantic platforms (Wikipedia, Flickr, etc);
- Peer-to-peer, user content and file-sharing platforms (Napster, Youtube, MySpace etc);
- GIS/Virtual Reality platforms (Google Earth, Second Life, etc); and
- Trading, auctioning and market exchange platforms (Amazon, eBay, Zopa, etc).

For instance, Amazon is very successful at bringing user content and collaborative editing into the trading platform, and at open-sourcing many third party innovations (widgets), as part of the global API (applications platform interface). Some of this is also driven by innovations such as distributed high-capacity data and processing capacity, geo-referenced and immersive VR platforms, and multiple and mobile communication channels and interfaces.

Looking at wider trends suggests not only convergence but 'emergence' of new forms of community and collective intelligence for both policy-makers, producers and consumers. There are many examples of this, including:

- Governance and management: participatory decision-making, decision-support, planning, and monitoring and evaluation systems for public, private and social sector organisations (Brail and Klosterman 2001).
- Enterprise and value generation: market trading and auctioning systems, collaborative exchange networks, and innovative service sector business models of all kinds (Ravetz, 2005).
- Lifestyle and content generation: social networking, virtual game communities, media file-sharing, and special interest communities of all kinds.
- Participation and empowerment: shared digital spaces for special interest and marginalised communities and sub-groups (Curwell *et al*, 2005)

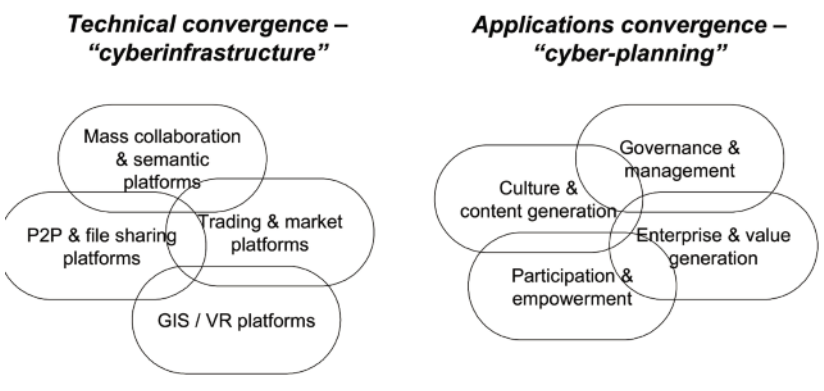

Figure 1: Convergence and emergence in cyberinfrastructure and cyber-planning. New digital spaces emerging through concergence on technical side (cyberinfrastructure) and on applications side (cyber-planning). Source: adapted from Pezzoli *et al* (forthcoming).

Developing a 'digital workbench'

One example from California shows a state-of-the-art toolkit on a digital 'Regional Workbench' (Pezzoli *et al*, forthcoming; further details can be found at *http://regionalworkbench.org/tools/main.php*). The Regional Work Bench Consortium combines GIS and Scientific Visualisation in three main areas:

- developing state of the art 3-D visualisation technologies, to create a 'Transborder City-Region Visualisation Theatre' and making 3-D interactive tools available online to academics, community, industry, and government.
- On-line Interactive Mapping for easy visual integration of data from multiple Internet information sources, including tools that will link Superfund toxicants data from many sources, 'quality of life' indicators, and cross-border demographic, health and water pollution data.
- Regional Planning Chronologies: comprising new Web-based methods to provide integrated views of regional planning history, with online primary regional historical planning sources to inform citizens, academics and community groups, as well as planners and decision-makers.

Future proofing

Clearly the future of ICT applications holds great promise and uncertainty. This suggests the need to 'future-proof' current programmes against alternative futures. Here we draw on the Environment Agency's *Scenarios 2030*, which provide four widely different perspectives for the next 20 years (Environment Agency, 2006), each with implications for technology development and application:

- **'Restoration'** scenario *(sustainability-led governance/*

dematerialised consumption). Technology innovation is slower with more emphasis on human-scale local solutions. We could expect more environmentally-focused personal pages and social networking.

- **'Alchemy'** scenario *(sustainability-led governance/ material consumption)*. Technology developments are more rapid, with a focus on hi-tech solutions to environmental pressures. This puts the emphasis on the technology hardware of monitoring and tracking, and particular applications in online market pricing and trading systems.
- **'Survivor'** scenario *(growth-led governance/ dematerialised consumption)*. Technology developments are slow and fragmented, and not necessarily benign. Many applications could follow the agenda of surveillance and social engineering.
- **'Jeopardy'** scenario *(growth-led governance/material consumption)*. Technology innovation is very rapid, globalised and led by economic growth and material consumption, to the detriment of environmental priorities. Technology applications under this scenario could be in a defensive role, catching up with environmental impacts on a global scale.

Key questions and challenges

Technology development is rarely neutral. Rather, it raises challenges for operations and management, policy development, and external relations including:

- Pervasive/real time/automatic sensing and monitoring: what are the implications for surveillance and civil liberties? (Sardar and Ravetz, 1996)
- Third party data collection: what are the implications for quality assurance, data protection and commercial confidence, user-generated content, file sharing and mass collaboration?
- Regulatory performance: is there a risk of over-reliance on technological solutions, marginalising issues which are not easily digitised and excluding users without ICT access on the other side of the digital divide?
- Management issues: from experience, what are the major risks of large-scale public ICT contracts, including corporate capture by data and systems providers?
- Can the regulatory technology applications also contribute to the environmental technology sector?

Overall, ICT development is crucial for the relationships between citizens and communities, regulators and businesses (Kingston *et al*, 2000). If the Environment Agency and its partners aim to be at the 'front of the curve', it will pursue Web 2.0 'social tech', such as Youtube, blogging, wikinomics, Google applications and others in a broad spread of platforms and technologies which enable new forms of engagement between regulators, polluters and stakeholders.

ICT development is also crucial to the R&D and analytic functions of environmental monitoring and regulation. Particularly for SMEs, there is scope to extend conventional regulation towards a more proactive system for environmental advocacy and guidance, which may be better suited to their needs.

Conclusions

This brief review has explored the scope for technology applications in the medium term, where even five years is a long time in technology development. From current trends, we are likely to see:

- Diffusion and embedding of more advanced Web 2.0 semantic and georeferenced knowledge management and social networking;
- Supercomputing and/or grid computing will enable real time 3-D modelling and visualisation of major incidents, and active linkage of social/economic/ environmental processes; and
- Ongoing advances in monitoring through satellite imagery, telemetry, robotics, genetic tracking and others.

Each of these has implications for strategic policy intelligence in environmental governance. There are urgent and creative opportunities on both the monitoring and the social networking side, which may be crucial in helping to mobilise social and economic stakeholders for a more proactive role in environmental stewardship and 'next generation regulation'. As in any public organisation, strategic policy developers and operational planners should not simply assume that advancing technology will help them do 'the same jobs better'. They will need to explore the opportunities of emerging and converging technologies to do 'new kinds of jobs', that may enhance the environmental governance response to new challenges.

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STRATEGIC RESPONSES TO EMERGING TECHNOLOGIES: LATE LESSONS AND REGULATORY STEPS FOR NANOMATERIALS AND SYNTHETIC BIOLOGY

New technologies offer great promise, but regulatory lag can often leave the environment exposed. **SARAH BARDSLEY, JENNIFER DE LURIO** and **SARAH WEBB** look at how lessons can be learnt from the past and applied to emerging science.

Technological innovation offers significant potential benefits for society and the environment. However, the regulatory framework is not always flexible enough to keep up with the rapid pace of technological change. Frequently, regulation is introduced only after the 'horse has bolted', and regulators are generally unable to act without the authority of new legislation.

It is the role of government to encourage innovation while protecting against harm, but how do governments support innovation that is good for society while ensuring risks are minimised even when they are uncertain or unknown? What can we learn from management of previous emerging technologies, like nanotechnology, to help prepare for those coming over the horizon, like synthetic biology?

Nanomaterials: lesson from the last decade

Recently, a commentator on BBC Radio 4 remarked that asking if nanotechnology is safe is like asking if lunch is safe. The temptation to regulate nanotechnology as one entity contributes to the confusion that regulators are feeling; it is unrealistic to apply a uniform response to the many types of nanotechnology applicable in so many different fields. Yet, a decade and more on from first commercialisation and its now widespread use, regulatory decisions on nanotechnology have yet to be made despite repeated reviews.

Current evidence

Nanotubes and other nanoparticles are diverse categories of nanomaterials that carry different risks even within each category. Nanoparticles (matter divided into sizes in the scale of nanometres to tens of nanometres) and nanotubes (cylindrical structures most commonly made from carbon) can be made of a wide variety of materials. The key risk from nanoparticles stems from what makes them useful: their small size, high surface area and biological compatibility. One nanoparticle, nanosilver, has received the highest degree of regulatory reaction thus far (see Box 1) due to its wide application; for example, in suntan lotions, odour-suppressing additives to clothing and biocides. The key risk from nanotubes is from their high aspect ratio, for which asbestos is a likely risk model.

Responses

The UK has been criticised for failing to embrace the early chance it got with the Royal Society/Royal Academy of Engineering report on nanotechnology risks in 2004 (The Royal Society, 2004). The report was groundbreaking and made specific recommendations on regulatory action and nanotoxicological testing.

In response, the Government formed the Nanotechnology Issues Dialogue Group (NIDG) that committed the Government to a regulatory review, but did not allocate any resource or research funding although the NIDG has a sub-group (the Nanotechnology Research Coordination Group or NRCG), which uses the UK Research Councils' existing responsive funding programmes to develop research into human health and environmental risks, public dialogue and social research. In addition, the Environmental Nanoscience Initiative was set up in 2006.

Following consultation, Defra ran a two-year Voluntary Reporting Scheme (September 2006 to September 2008)

Box 1: Nanosilver – size added-risk to a known material

Current evidence

Use – 20% of nanotechnology products (PEN, 2008)

Risk – indiscriminate antimicrobial (McKenna, 2008, Rundle, 2006)

Impact – harm to beneficial bacteria (Okkyoung *et al*, 2008; Jones, 2008)

Pathway – laundering of treated fabrics, washing of wounds treated with nanosilver plasters, directly from washing machines equipped with nanosilver or from production facilities

Toxicity – solely from ionic silver dissolved from the surface of nanosilver particles or from a mixture of ionic toxicity and direct nano-form toxicity

Responses

Europe

- under REACH with no reference to size
- Swedish ban on nanosilver washing machines (Nanowerk, 2006)

United States

- nanosilver washing machines designated as pesticide delivery devices (Berube, 2006)
- silver ions (Morrow,2007) and silver nanoparticles redesignated as pesticides under the Federal Insecticide, Fungicide and Rodenticide Act (CBCNews, 2006; ABA, 2007)

Recommendation

- research and monitor nanosilver in sewage treatment works before 2012 REACH negotiations

for research organisations, universities, commercial producers, commercial users and importers of 'free' engineered nanoscale materials up to 200 nm in size. Defra had intended for the scheme to build an evidence base on which to construct regulations. However, by 2008, it had received just 11 submissions. Similarly, the US EPA's voluntary Nanoscale Materials Stewardship Program (NMSP) received only 29 submissions covering just 10% of commercially-available nanomaterials by 2008. This response implies that mandatory regulation may be needed in the first instance to establish a culture of compliance. Canada took this approach in 2009, requiring all Canadian companies to report any physical, chemical and toxicological information that they hold for nanomaterials made or imported in quantities greater than one kilogram.

The UK Government's progress was formally reviewed by the Council for Science and Technology (CST) in March 2007. CST concluded that, while the Government succeeded in the areas of standards, industry dialogue, public dialogue and workplace exposure, a reliance on the Research Council's responsive funding programmes has led to a dearth of fundamental research into toxicology, health and the environment.

The Royal Commission on Environmental Pollution (RCEP) undertook yet another review in 2008, examining the properties of nanomaterials. RCEP found no clear evidence of harm, but concluded a plausible cause for concern over nanosilver, carbon nanotubes and Buckminsterfullerenes. These recommendations largely repeat those of the first Royal Society report and other reviews by stressing the need to categorise nanomaterials on the basis of function (what they do and how they do it) rather than size or manufacturing process.

In the US, the American Bar Association (ABA) Section of Environment, Energy, and Resources (SEER) outlined key steps for regulators that include:

- distinguishing between types of nanomaterials;
- identifying which nanomaterials pose actionable risk;
- determining regulatory approaches for each nanomaterial category;
- developing sampling, analysis and control methods for each category;
- quantifying nanomaterials by number rather than mass; and
- developing strategies to prevent nanomaterial emissions.

The Organization for Economic Cooperation and Development (OECD) Working Party on Manufactured Nanomaterials (WPMN) has taken the first of these steps by identifying 14 manufactured nanomaterials for environmental health and safety testing.

REACH legislation currently overlooks the change in properties that substances may take on in the nanoform. REACH's Competent Authorities Subgroup on Nanotechnology (CASG Nano) is considering setting lower tonnage thresholds for nanomaterials to draw them under REACH control, or requiring all commercial nanomaterials to be notified so that use can be tracked. The next REACH negotiations are in 2012.

Key messages emerging from this review of regulatory responses include:

- Nanomaterials cannot be considered as one regulatory substance;
- Regulation needs to break the legacy of assigning limits by mass;
- Reviews will continue to ask the same questions – it is time to start finding the answers;
- Voluntary reporting programmes are unlikely to provide the information needed to define the extent of the potential environmental risk or lack thereof;
- Despite identification of regulatory gaps, no regulation exists that will specifically deal with nanoparticles until at least 2012; and
- Improved monitoring technologies are needed to detect nanomaterials in order of their abundance, starting with the most widespread application of nanosilver.

Synthetic biology: a strategic challenge for the next ten years

Synthetic biology will allow bioengineers to design and create bespoke life forms to perform novel jobs (Figure 1). It builds upon genetic engineering, bringing together existing disciplines and also incorporating new technologies made possible by the increasing availability and falling cost of technologies for sequencing genomes and synthesising DNA. No true synthetic organisms have been built yet, but significant developments over the past decade are building momentum such that the research market for synthetic biology was valued at £300m in early 2009, with a predicted rise to £1.8bn over the next decade.

Current evidence

The main applications envisaged for synthetic biology are related to energy, health and monitoring. Energy applications include improved biofuels, cleaner hydrocarbons, waste water-driven biological fuel cells, and fuel from captured CO_2. Although the bioremediation of contaminated land and water and the removal of carbon dioxide from the atmosphere are both oft-proposed uses for man-made organisms, there is as yet little published evidence to suggest that these environmental applications are being fully investigated.

Current research is dominated by the US where both private and academic groups are competing to make the world's first engineered biological part, system and, eventually, organism. One of the more widely-known groups resides at the J Craig Venter Institute (JCVI) which, since early 2007, has made significant advances including apply-

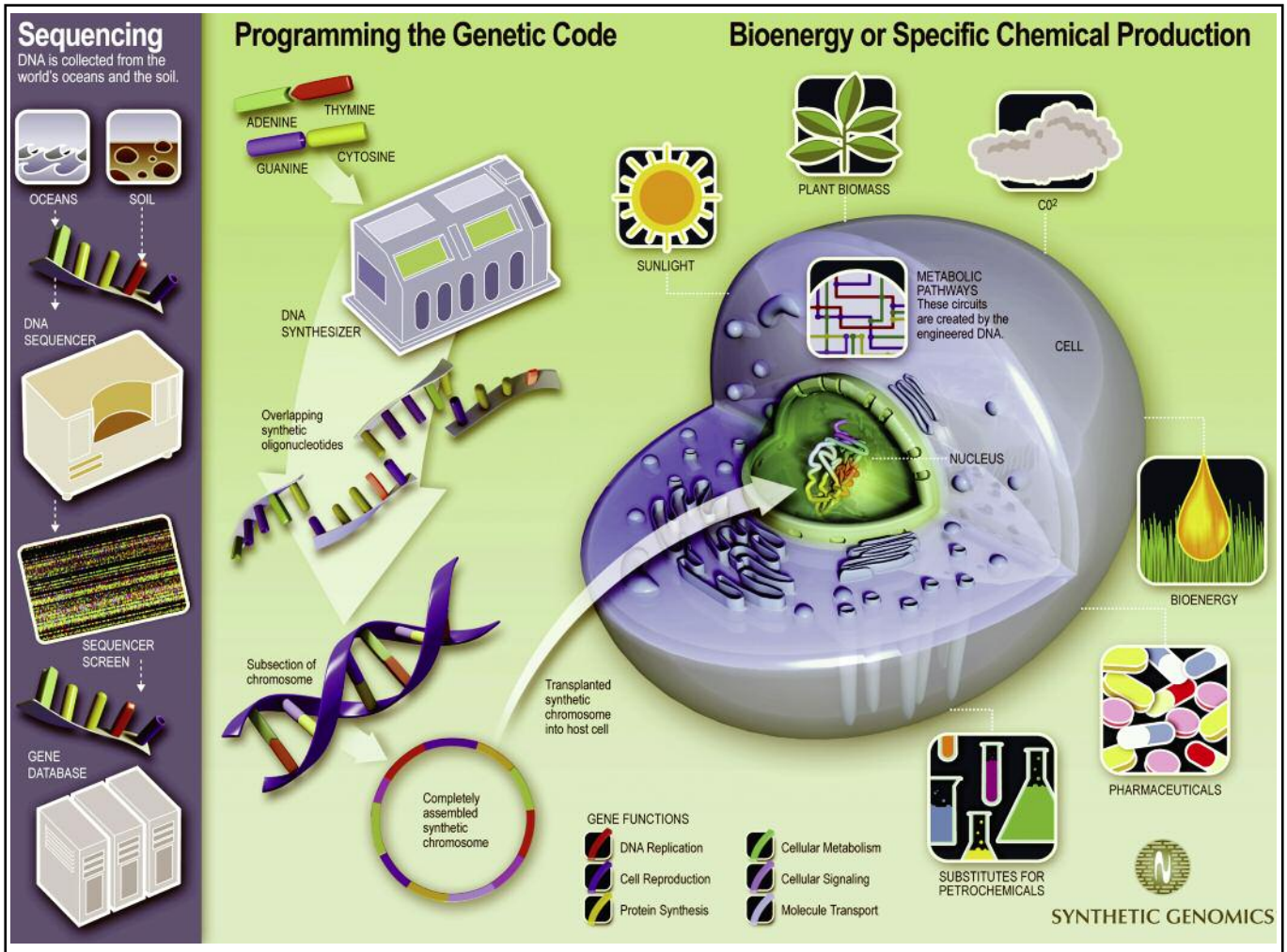

Figure 1. Diagram representing how synthetic DNA is made and possible jobs it could perform. Reprinted by permission of Synthetic Genomics, Inc *(www.syntheticgenomics.com/science.htm)*

ing for a patent on the first synthetic life form and building a genome. Other teams, including scientists at the Massachusetts Institute of Technology (MIT), are focusing on the construction of workable genetic 'parts' that can then be joined together.

In Europe, 18 research projects investigating synthetic biology have received funding. These projects cover a broad range of synthetic biology applications, including the development of a European strategy and analysis of safety and ethical impacts. UK-based synthetic biologists are being co-ordinated by the Research Councils.

Responses

Biosafety concerns revolve around the deliberate or accidental release of synthetic organisms or manufactured biological parts into the environment, which could have significant consequences beyond their intended benefits. Some scientists argue this carries little risk because the man-made organisms will not survive outside of highly-controlled laboratory conditions or could be deliberately designed to ensure this is the case. However, some applications, such as cleaning up contamination, will require organisms to survive in the natural environment. Genetic complexity means that predicting the properties and behaviour of these synthetic biological parts and entities will never be completely accurate. Whilst these negative consequences have not yet been identified, 'the notion is that, as we engineer more complex systems, our ability to predict their behaviour diminishes', according to James Collins, a Boston University microbiologist.

Biosecurity issues, including the deliberate use of synthetic biology to make and release dangerous viruses and bacteria, have been the main focus of debates on the risks of synthetic biology. As DNA sequencing and synthesising costs fall, more people will be able to access this technology. Indeed, a biohacker culture could soon emerge, reminiscent of the computer hacker culture of the 1970s where people can, in theory, build biological parts in their garages.

These discussions echo discussions on genetic modification safeguards in the 1970s and through to the 1990s.

However, equipped with this hindsight, scientists and engineers in synthetic biology are keen to avoid the problems and public relation issues that plagued earlier genetic engineering, leading to a more open debate within the scientific community and a real drive to engage stakeholders in the discussions. Despite this, a consensus on how to proceed has not been reached and views remain mixed. Some of the options thus far proposed include:

- **New governance:** Specific regulations to protect the environment and human health through government monitoring of the products ordered from companies, raw material regulation or regulation combined with monitoring compliance and licences.
- **Self governance:** Mandatory safety and ethical training plus the development of a comprehensively-adopted set of ethics and standards.
- **Business as usual:** The synthesis of biological parts poses no different threat than genetic engineering and, therefore, the issues have already been addressed.

Only a few published reports have tackled the issue and no proposal has received universal support. Self governance appears to be favoured by many scientists in the synthetic biology field. However, many NGOs and civil society groups argue that self governance is not the right approach when its only proponents are the scientists involved, calling instead for a large-scale public debate about the likely environmental, societal, security and health impacts of synthetic biology.

In late 2007, the Center for Strategic and International Studies (CSIS), MIT and JCVI released a report entitled 'Synthetic Genomics: Options for Governance' that focused on self governance for bioterrorism, worker safety and protection of communities and the environment in the vicinity of legitimate research laboratories (Garfinkel *et al*, 2007). Environmental risks were not addressed. Indeed, the authors argue that 'a policy framework to address the development and use of synthetic genomes for contained use must precede any analysis of the intentional release of engineered micro-organisms into the environment'. This shortcoming highlights the need for proactivity by environmental regulators.

In 2008, the Hybrid Vigor Institute called for four recommendations (Caruso, 2008) to be completed at quickly as possible to establish governance for synthetic biology:

'
- Research and report the current regulatory situation for synthetic biology across agencies and sectors. Because of the *déjà vu* argument being presented by proponents, this research should include a reassessment of the viability and utility of regulations for the products of traditional genetic engineering.
- Conduct a comprehensive critique of the synthetic biology reports that have been published so far, and assess their impact on decision makers.
- Using (and challenging the assumptions of) the data and scenarios in the above-mentioned reports, conduct a comprehensive risk characterization of synthetic biology.
- Convene cross-sector stakeholder working groups on elements in the assessment that were deemed most important to address.'

The regulatory challenge that synthetic biology presents is significant, but has not yet progressed beyond studies. The range of potential applications for synthetic biology will likely demand a range of regulatory responses, mirroring the situation for nanomaterials. How these regulatory approaches may look is uncertain. What is more certain is that waiting until commercialised products enter the

Box 2: 'Twelve late lessons from early warnings' (European Environment Agency, 2001)

1. Acknowledge and respond to ignorance, as well as uncertainty and risk, in technology appraisal and public policymaking.
2. Provide adequate long-term environmental and health monitoring and research into early warnings.
3. Identify and work to reduce 'blind spots' and gaps in scientific knowledge.
4. Identify and reduce interdisciplinary obstacles to learning.
5. Ensure that real world conditions are adequately accounted for in regulatory appraisal.
6. Systematically scrutinise the claimed justifications and benefits alongside the potential risks.
7. Evaluate a range of alternative options for meeting needs alongside the option under appraisal, and promote more robust, diverse and adaptable technologies so as to minimise the costs of surprises and maximise the benefits of innovation.
8. Ensure use of 'lay' and local knowledge, as well as relevant specialist expertise in the appraisal.
9. Take full account of the assumptions and values of different social groups.
10. Maintain the regulatory independence of interested parties while retaining an inclusive approach to information and opinion gathering.
11. Identify and reduce institutional obstacles to learning and action.
12. Avoid 'paralysis by analysis' by acting to reduce potential harm when there are reasonable grounds for concern.

market will result in hurried and 'catch-up' regulatory action; a more proactive approach is essential.

Key messages emerging from this review include:

- Synthetic biology research and development is receiving huge investment as groups rush to develop applications and get them to market.
- Genetic complexity is so great that scientists cannot accurately predict long-term consequences.
- Synthetic organisms may present unique risks unforeseen by current regulations.
- The challenge of regulating synthetic biology mirrors the complexity now being experienced with nanomaterials.
- Action needs to be taken now to improve synthetic biology governance, not only to protect human health and the environment but also to facilitate reaching the potential of the science.

Discussion and recommendations

If we are to address, or at least minimise, the lag between commercialisation and regulation, we must learn from the lessons of the past. The European Environment Agency (EEA, 2001) report *Late Lessons from Early Warnings* distilled 12 key lessons about how society may better protect itself from the unintended consequences of emerging technologies (see Box 2). These lessons have already been applied to assess nanomaterials (Hansen *et al*, 2008) and serve as a useful framework to assess our preparation for the emergence of synthetic biology.

Lessons 1-3: Heed the warnings

There have been upwards of 20 government and scientific reviews on nanotechnology since the Royal Society report in 2004, all reaching broadly the same conclusions and none resulting in action. The priority now is to heed the warnings, assessing the options now and acting on the best choices before widespread application.

Lessons 4 and 11: Facilitate learning

In 2003, the UK Government called for horizon scanning and futures programmes across all departments and agencies in recognition of the lack of time available in day-to-day work to address emerging issues. These programmes are good first steps towards instilling a culture of learning. Early awareness may prepare us better, but requires a proportionate regulatory response not only within existing regulatory remits but through integration across the regulatory community.

Lesson 5 and 8: Stay in the real world

Like the proponents of nearly every new substance, synthetic biologists proclaim safety due to use in secure settings and engineered precautions. However, history shows that most eventually end up in the environment following actual use (asbestos, PCBs, GMOs) and risk assessments in the lab often miss the potential synergistic or unexpected behaviour of substances (such as the ozone-depleting consequences of CFCs). While the world changes, regulatory frameworks remain defined by past events; we need to shift this paradigm.

Lesson 6 and 9: Consider wider issues

Synthetic biologists are focusing on societal and ethical issues at an earlier stage than nanotechnology. However, early talk is characterised by a focus on benefits and dismissal of potential environmental consequences. Environmental regulators need to influence these scientists by demonstrating that genetic systems are part of ecosystems, which make interactions of some sort an inevitability, whether good or bad.

Lesson 7: Evaluate alternative solutions

Synthetic biology and nanotechnology both claim to offer future solutions to existing environmental problems. These possibilities should be considered with an open mind while recognising that every problem needs the best solution, not just the most advanced. At the same time, the pursuit of environmental solutions based on any future emerging technology needs support because, while many are claiming environmental applications, few are actively being pursued.

Lesson 10: Retain regulatory independence

Trust and voluntary regulation agreements are claimed to be the cornerstones of better regulation. However, risk is inherent in obtaining the data needed for a risk assessment from those being assessed. Proponents of nanotechnology and synthetic biology are both advocating self regulation, but the experience of the US EPA and Defra shows that contributions are far from forthcoming.

Lesson 12: Avoid paralysis by analysis

Uncertainty exists for both producers and regulators, yet production marches on while regulation gets mired in review and the hopeless wait for definitive evidence. Fifteen years worth of published evidence for potential harm from nanomaterials has not yet produced a clear-cut answer. The current knowledge base in synthetic biology can be used now to design a regulatory protocol that assesses the different forms of synthetic organisms as they emerge, rather than facing evaluation *en masse* as we are now for nanomaterials.

Lesson 13: Monitor early

In addition to the above 12 lessons from the EEA, early monitoring can better inform the shape and scale of required regulation. New substances that pose environmental or health risks come on the market before regulation can control their use. If pervasive environmental monitoring were well established, we'd have a baseline for inventories that could be interrogated at the moment

potential risk is identified. Pervasive monitoring could potentially prevent a great deal of environmental harm; however, new processes for handling these warning signs will be needed.

Lesson 14: Stakeholder engagement

We also add stakeholder engagement to the list of lessons. We must seek to include and consult with a wide range of potentially affected parties to surface latent concerns before forming expert judgment on appropriate regulatory models. 'Citizen science' has featured heavily in recent nanotechnology studies. Stakeholder dialogue on the development of synthetic biology now, not after commercialisation, may yield more informed and proportionate responses.

Conclusion

Scientific knowledge and technological innovation increase at an astonishing speed while regulation moves at a snail's pace. There are some legitimate reasons for this disconnect, but regulators should act to narrow the lag between innovation and regulatory action. Tracking threats and opportunities as they emerge, having open discussions, monitoring for new substances as they are released rather than after there is harm, and acting on the best information and insight that current knowledge has to offer while allowing room to reshape regulations in future will help. The world evolves; regulation can too.

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'WIND TUNNELLING': THE RAPID SCENARIO-BASED TESTING OF EMERGING ISSUES

The future is uncertain, and planning for assumed certainties is therefore a dangerous practice. In 2006, the Environment Agency published a suite of four *Scenarios 2030* which serve to expand a linked set of plausible futures based on prioritised set of driving forces. In this article, **MARK EVERARD, MARTIN DUCKWORTH, JOE RAVETZ** and **JOHN REYNOLDS** outline how these scenarios have been applied as a rapid-assessment framework to 'wind tunnel' the likely trajectory of emerging issues and the resilience of suggested responses to them under a different set of possible futures.

'Everything is vague to a degree you do not realize till you have tried to make it precise.'

– Bertrand Russell,
The Philosophy of Logical Atomism

Introduction

The preceding chapters in this report have explored various emerging issues, and their potential implications for the response of society and the Environment Agency. It is important to consider uncertainties inherent in both the issues themselves and the future in which they will unfold. This will help us develop responses that are more robust against future changing demands. There is widespread consensus today, based upon observations from the past and also the daunting challenges facing the world today, that many aspects of the future will be qualitatively different to the current status quo. Scenarios are a helpful tool to assist thinking on uncertain futures and for reviewing their potential implications.

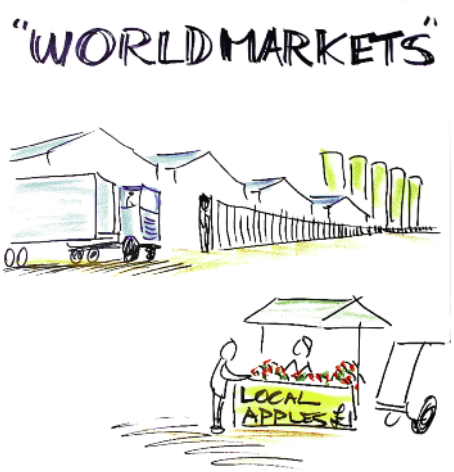
The 'wind tunnelling' process

The 'future-proofing' approach that we have taken to exploring the implications of the various issues addressed by the Environment Agency research project reported in this special edition of *Environmental Scientist* draws heavily upon scenarios. The scenarios that we are using are the generic set developed for the Environment Agency in 2003. These *Scenarios 2030* (Environment Agency, 2006) integrated a wide range of drivers likely to result in pressures on the environment, resolving through a prioritisation exercise into two principal axes relating primarily to governance and resource consumption. The resulting four scenarios are described and illustrated in the context of 'Citizen and

Figure 1: Graphic representation of the four *Scenarios 2030* (taking 'Citizen and community' as the subject matter)

'Restoration'. In this scenario, there is a coincidence of *sustainability-led governance* with patterns of *dematerialised consumption* across society by 2030, including a strong system of governance at the UK and global level which manages the impacts of consumption and climate change responses. Government expenditure on public infrastructure increases (e.g. housing, transport, energy generation), as does investment in emerging energy technologies. The UK economy becomes more service-oriented, with reductions in manufacturing and industrial sectors. There is a general high level of awareness of respect for the environment and the ecosystems that support all dimensions of human wellbeing, and this is reflected by an enlightened regulatory regime and integration of ecosystem considerations into the market. Because sustainability is such a prominent theme in society, people tend to collaborate around problems. Socially-driven environmental awareness increases, with a desire to use less resources, putting pressure on governments to deliver positive change.

In the **'Alchemy'** scenario, we still see *sustainability-led governance* but there is a high level of *material consumption* by 2030. Economic growth is stable, fuelled by investments in technology and infrastructure and expansion of high-tech and knowledge-based sectors. There is strong EU environmental regulation and rapid technological development in the western world, which encourage government investment in environmental technology and clean energy infrastructure. The government promotes supply-side investment in new technology and infrastructure as a response to resource-intensive consumption. There is a high dependence upon technology to solve societies' problems, with the market playing a key role in management of the environment and impacts upon it from lifestyles.



The **'Survivor'** describes the converse scenario to 'Alchemy', in other words where there is *growth-led governance* but there are *dematerialised consumption* patterns by 2030. This includes high energy and natural resource prices (e.g. oil at $200-250 per barrel) which stifle global trade and hit economic growth. This stimulates self-sufficiency efforts in sectors such as energy and agriculture. Inevitably, this results in a depletion of ecosystems and their associated ecosystem services. As such, there are significant inequities across society, and a focus of environmental policy is upon surviving the worst impacts and reconstruction of ecosystems with strong regulation. Government tends to avoid international action on energy and climate change, and favours economic growth at all costs. However, this is still an uphill task. Material consumption and resource-intensive consumer behaviour declines, with rising energy and commodity prices, and growing public environmental awareness.

The final scenario, **'Jeopardy',** is something of a dystopia with both *growth-led governance* and high levels of *material consumption* by 2030. It is an affluent world, arguably not grossly dissimilar to the lifestyles of the Western world today. By 2030, the 'consumption culture' dominates politics, economics and society. Consumer spending and low energy prices fuel high levels of stable economic growth, although benefits accrue principally to the wealthy as levels of inequality increase. People are consumers, tolerating the environmental impacts of their lifestyles and also relying on defensive anti-pollution measures. Regulation focuses on liability and enforcement, but also some level of resource protection, though there is limited government intervention and regulation. The free market reigns with the externalities associated with this model becoming more prominent. Climate change, water pollution and biodiversity loss all intensify. Citizens show little environmental or global awareness, despite catastrophic climate change impacts in developing countries.

community' issues in Figure 1.

The scenarios are not forecasts. Rather, they aim to provide a structured way to ask 'what if' questions about whether certain forces and events unfolded, and what would be the resulting challenges and opportunities. Each scenario clearly has very different implications for the environment and the needs of society, raising different challenges for the Environment Agency. Each has divergent implications for the issues addressed in this study and appropriate responses to them.

The process of 'wind tunnelling'

The term 'wind tunnelling' describes the use of the scenarios as a rapid test of policy responses to the likely trajectories of key issues. (The term is derived from the analogy of testing a physical model's response to different conditions in a wind tunnel.) This wind tunnelling process was applied as part of the analysis of the range of issues addressed in the preceding six chapters.

There are two commonly used wind tunnelling approaches. The first 'holistic' method tests the current strategy against each scenario and looks for common elements across the scenarios. This gives insights into the implications for current strategy and action plans for dealing with situations under each of the scenarios. This is demonstrated in Figure 2 below.

An alternative analytical approach is where policy options are tested against each scenario. These are then assessed to determine whether they are successful in each scenario. If an option is successful against all scenarios, it is likely to be a robust policy. If it is a failure in one or more scenarios, the policy could be reviewed or, if it is pursued, the risks associated with the failures will be better understood so that they can be monitored and managed. This approach is demonstrated in Figure 3 below.

Undertaking wind tunnelling does not remove uncertainty about the future. However, by testing options against appropriate scenarios, it help reduce and manage the associated future risks.

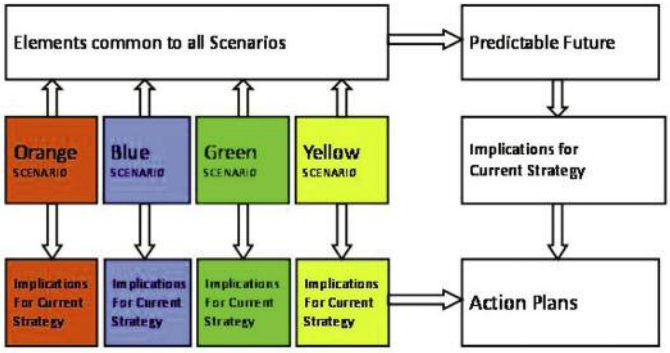


Figure 2: Wind tunnelling – holistic approach

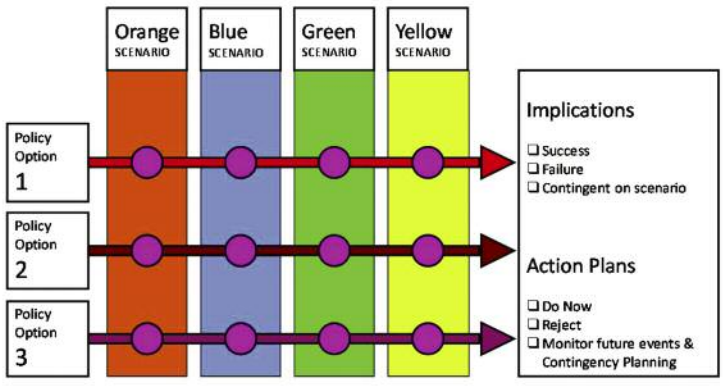


Figure 3: Wind tunnelling – analytical approach

The outcomes of wind tunnelling

Figure 1 contains a description of some of the implications for 'Citizen and communities' resulting from the wind tunnelling exercise. Rather more detailed study of implications of these different scenarios for the 'Citizen and community' agenda, addressed in the preceding chapter, came to the following conclusions:

'Restoration' (sustainability-led governance/dematerialised consumption)

The UK economy begins to shift towards dematerialised and decarbonised activities. Public attitude changes and local social enterprises each contribute to greater environmental responsibility.

The public begins to learn or re-learn a whole set of skills including: food cultivation and land management; energy efficiency; and low impact transport. These may be enabled and encouraged by future trends in Web 2.0-based social networking and training in the form of edu-tainment. It becomes the default for people to ask their neighbours or colleagues for lift sharing before driving anywhere, and to put unwanted goods on a community network before going into the waste stream.

This is aided and abetted by

ecosystems trading and price signals, both for carbon and for other goods. Cities and towns are surrounded by an eco-belt with high levels of biodiversity and food cultivation, where there used to be a rather sterile green belt.

The Environment Agency could have a central role to play in this citizen and community-centred future. However, the scenario is unlikely to be a panacea. There would remain challenges in mediating between national, regional and local competition for land and ecosystem services, and also addressing the demands of a still-growing population. Rapid development of new skills and services could be an opportunity for the Environment Agency, but this societal change would stretch the Agency's capacities and resources for outreach and engagement.

'Alchemy' (sustainability-led governance, material consumption)

Consumer demand, driven by rising material affluence and a reliance on technological fixes, is tempered by efficiency schemes driven by tighter regulation and resource shortages.

Many industrial supply chains increase the rate of technological innovations. There are potential side effects from advances in nanotechnology, cyber-technology, materials science, genomics and synthetic organisms. Each raises risks which are relatively unknown, difficult to assess, often irreversible and potentially catastrophic.

Citizens and communities are caught in a dilemma. On the one hand, fulfilment of their consumption expectations involves ever-growing technological systems but, on the other hand, fulfilment of their risk and security needs involves a slowing down of innovation with strong regulation and detailed analysis.

The Environment Agency will need to find new ways of managing these larger and more extended patterns of risk and hazard. It may need greater powers for regulation, and resources for precautionary scientific analysis, to minimise perverse incentives and hazards from a plethora of new and often untested technologies.

For the citizen and community agenda, there may be new skill sets emerging around various forms of sustainable technology. There will be new forms of global alliance and corporate responsibility to pursue, as lengthening supply chains and sophisticated technology spread the environmental burden on a global scale.

'Survivor' (growth-led governance, dematerialised consumption)

While the survivor mentality brings some conflicting pressures and benefits for the environment – a renewed 'dig for victory' culture, and so on – this takes place in a mood of social retrenchment and distrust. The failing economy creates many losers and some winners, with a slowing of investment and innovation and a perpetuation of dirty and inefficient industries. Environmental standards seem to be in direct conflict with growth and employment.

The self-sufficiency effort itself creates many new hazards. Local food cultivation can produce contamination and animal disease, and local biomass energy can produce intensive air pollution. Integrated catchment management becomes more difficult at a time of fragmentation of governance and social networks.

There could be greater use of market-based trading in carbon and other resources. However, following through this logic, this could lead to market corruption, speculation and market rigging. Environmental improvements themselves could also see growing social polarisation. For example, while the wealthy can afford Low/Zero Carbon (LZC) houses or cars, the poor are stuck with inefficient buildings, dirty vehicles and higher maintenance costs.

The Environment Agency will need to be constructive in a challenging situation. It may need to develop new skills for public engagement, not so much for an enlightened green-thinking community, but to counter the distrust and corruption which could come with the fragmentation of the economy and society.

The task of regulation may need to look again at the BATNEEC and BPEO approach, where investment cost and industrial vulnerability are priority concerns.

'Jeopardy' (growth-led governance, material consumption)

As 'citizens' emerge as consumers, and 'communities' emerge as 'interest groups', there is a fragmentation of society in a headlong rush for material growth.

As in the 'Alchemy' scenario, 'Jeopardy' contains its own contradictions between the need for material affluence and material security, with the balance stacked against the rational public management of risk. Instead, this scenario shows a world where technological risk and security is manipulated and commercialised by transnational corporations, and where governance itself is influenced or even bought out by corporate power.

The effects on the local environment may be quite direct. As the rest of the world catches up with UK levels of affluence, it is just as cheap to manufacture in the UK, and many industries return to their original homes. The resulting industrial enclaves are then not only pollution havens, but also natural locations for low-cost housing, particularly for the migrant workers who follow the more hazardous industrial jobs. Meanwhile, industrial pollution and extreme climate change events are screened out in affluent gated enclaves and enclosed all-weather housing complexes.

The Environment Agency will need all its powers and resources to respond to this material-intensive trajectory. It will need to track the UK and global effects of rising affluence, and re-invent the case for regulation to counter the effects of unrestricted frontier capitalism.

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IES: NEW MEMBERS

The Institution of Environmental Sciences is pleased to welcome the following new members and re-grades:

Duane Ager	Chief Scientific Officer	M
Robert Ainsworth	Geo-Environmental Engineer	A
Samia Alattar	Graduate	A
Karen Algate	Senior Project Manager	M
Richard Allard	Contaminated Land Officer	M
Gordon Allison	Principal Air Quality Consultant	M
Tommy Atkins	Environmental Assistant	A
Anna Badowska	Water Engineer	Af
Kate Barlow	Principal Consultant	M
Maria Batko	Senior Environmental Scientist	M
Michael Beeston	Research Assistant	A
Adam Bethell	Senior Environmental Consultant	A
Daniel Birkinshaw	Senior Air Quality Consultant	A
Natalie Bissell	Environmental Consultant	A
Edward Borsey	Environmental Manager	M
Jessica Bott	NAFIS Clerk	A
Warren Bowden	Environment Director	M
Yvonne Brown	Senior Principal Consultant	M
Michael Bull	Director	M
Lynda Caldwell	Environmental Technician	A
James Calow	Principal Biodiversity Consultant	M
Lesley Carr	Patnership Support Officer	A
Wen Chang	Environmental Scientist	M
Christopher Colwell	Senior Geo-environmental Engineer	M
Alan Cooke	Freelance Environmental Consultant	M
Warren Corns	Research & Development Manager	M
Jeremy De Valck	Commercial Project Manager	A
Curtis Dean	Pollution Control Officer	M
Marvin Devonish	Environmental Protection Officer	M
Alan Edwards	Director	M
Andrew Edwards	Senior Air Quality Consultant	M
Terry Ellis	Environmental Consultant (Air Quality & Climate Change)	A
Hazem El-Zanan	Senior Air Quality Specialist	M
David Evans	Principal Geo-environmental Specialist	M
Rupert Evans	Senior Hydrologist	M
Karen Eynon	Researcher	A
Alex Fairhead	Intern	A
Angela Flowers	Senior Policy Officer	M
Noelia Garcia-Martin	Graduate Environmental Engineer	A
Alison Geeves	Environmental Consultant	A
Ioanna Gegisian	Environmental Consultant	A
Shelley Goad	Graduate	A
Shweta Gopal	Environmental Consultant	M
Victoria Gouge	Senior Air Quality Consultant	M
Ana Grossinho	Principal Consultant	M
Scott Hamilton	Environmental Scientist	M
Simon Harlow	Geo-Environmental Engineer	A
Jonathan Harris	Environmental Scientist	A
Shaun Hartnell	Graduate	A
Edward Henshaw	Director & Principal Consultant	M
James Hopkinson	Environmental Consultant & Engineer	A
Richard Hunter	Health, Safety & Environmental Specialist	A
Emma James	Senior Air Quality Consultant	M
Gulnur Jasim	Environmental Consultant Middle East and India	M
Paul Johnson	Director Environmental Consulting	F
Hannah Jones	Environmental Scientist	M
William Keefer	Process Engineer II	M
Sarah Key	Graduate Environmental Geologist	A
Christopher Laver	Graduate Technician/ Engineering Assistant	A
Ruth Lawless	Environmental Consultant	A
Samantha Lawrence	PhD Student	A
Peter Lee	Consultant	M
Siu Lee	Assistant Environmental Consultant	M
Martin Lilley	Trainee Meteorologist	A
Gemma Lucas	Environmental Scientist	M
Kam Lui	Environmental Officer	M
Patricia Mackey	Sustainable Development Officer	M
James Massey	Senior Scientist	M
Greg McAlister	Environmental Consultant	M
James Milner	Energy Conservation Engineer	A
Emma Monk	Sustainable Development Specialist	A
Rhodri Morgan	Geo-Environmental Consultant	A
Howlan Mullally	Senior Sustainability Consultant	M
Raymond Murphy	Environmental Consultant	M
Keith O'Brien	Senior Environmental Scientist	M
Matthew O'Brien	Senior Environmental Scientist	A
Francis O'Donnell	Sea Fisheries Protection Officer	M
Babatunde Ojo	Director	A

KEY: **F = Fellow** **M = Member** **A = Associate** **Af = Affiliate**

NEW MEMBERS *continued*

Juliette O'Keeffe	Environmental Project Officer	M
Beatrice Olero	Materials Technician	A
Chris Onions	Tutor	Af
Kirsty Ormerod	Graduate	A
Emeka Osaji	Research Associate	M
Jennie Preen	Environmental Monitoring & Control Officer	M
Robert Price	Partner/Geo-Environmental Consultant	M
Andrew Ramand	Senior Environmental Consultant	M
Tomas Rideg	Environmental Scientist	A
Amy Roberts	Environmental Scientist	A
Peter Shaw	Senior Lecturer	M
Alan Smith	Environmental Consultant	A
Keisha Smith	Senior Engineer	A
Elizabeth Somervell	PhD Student	A
Thomas Stenhouse	Principal Environmental Scientist	M
Claire Toosey	Graduate	A
Andrew Tranter	Environmental Consultant	M
Sotiris Vardoulakis	Lecturer (Environmental Exposure Assessment)	F
Nicholas Walton	Programme Manager – Environmental Sciences	F
Joseph Waterhouse	Environmental Consultant	M
Jonathan Weston	Environmental Consultant – Grade 2	A
Matthew Williams	Research Scientist	A
Robert Willows	Environmental Risk & Forecasting Science Manager	M
Zaki Zainudin	Lecturer	M

KEY: **F = Fellow** **M = Member** **A = Associate** **Af = Affiliate**

NEW TECHNOLOGY APPLICATIONS

• continued from page 40

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'WIND TUNNELLING'

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The most topical challenge may be if Environment Agency regulatory functions become effectively franchised to the private sector in the interests of cost saving. As the organisation is basically 'bought out', environmental champions may need to regroup independently in order to continue their mission.

Implications arising from wind tunnelling

Each of the four scenarios clearly paints a dramatically different future. None of these futures are, of course, certain and each merely describes a plausible future based on the principal axes identified, at least from today's perspective, as likely to be major influences on the future. Using scenarios therefore does not give us certainties about the future but rather circumscribes the 'possibility space' opened up by these diverse drivers of change.

Exploring the ramifications of these scenarios for the ways in which these focal issues may unfold is itself instructive, informing us of the likely skills, policy responses and flexibility that we will need to build in order to prepare for the range of potential futures that may unfold. No scenario story is, of course, immune to the disruptive influence of unpredictable or less readily predicted factors as diverse as unforeseen thresholds being crossed in the environment, catastrophic collapse of economies, political structures or ecosystems, cosmic events and so forth. However, exposing ourselves to different likely futures in the form of scenarios equips us with a higher level of foresight and preparedness to adapt to different futures.

The wind tunnelling approach, applied as a rapid appraisal method, has proved helpful in exploring the implications of the focal issues in this study as well as how we might prepare for them.

Illustrations for this article were kindly provided by Joe Ravetz.