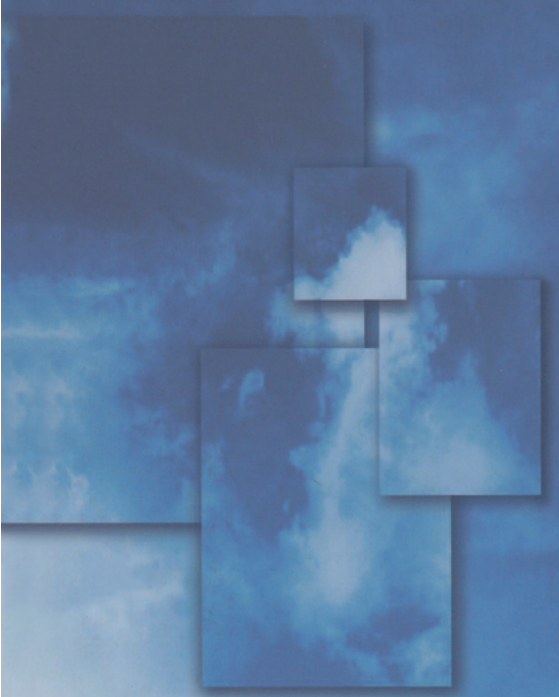
modelling long-term scenarios for low-carbon societies



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modelling long-term scenarios for low-carbon societies

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Aims and scope

Climate Policy presents the highest quality refereed research and analysis on the policy issues raised by climate change, and provides a fomm for commentary and debate. It addresses both the mitigation of, and adaptation to, climate change, within and between the different regions of the world. It encourages a trans-disciplinary approach to these issues at international, regional, national and sectoral levels.

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9 research and the commissioning of policy-relevant research
II policy and strategy formulation/implementation by local and national governments;
f1 the interactions and impacts of climate policies and strategies on business and society, and their responses, in different nations and sectors;
f1 international negotiations including, but not limited to, the UN Framework Convention on Climate Change, the Kyoto Protocol, other processes.

Climate Policy thus aims to build on its academic base so as to inject new insights and facilitate informed debate within and between, these diverse constituencies.

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Peer reviewed articles present academic, evidence-based research on climate policy issues:

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- §§ **Synthesis articles** (6-8000 words) present a survey and syntheses of the state of knowledge and keyissues in a particular area of relevance to climate policy, including scientific, economic, environmental, institutional, political, social or ethical issues.
- **Policy analysis articles** (1-3000 words) present evidence-based objective analysis of policy that is embedded within an existing literature and context.

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The Outlook section presents timely, relevant analysis and commentary, for a wide climate policy community, and includes:

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- **Records** of important new agreements, legislation and other developments including analysis of key events
- **f1 Feedback** on earlier material published in *Climate Policy*

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B Sectoral options and strategies for meeting policy targets
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m Policy and economic aspects of intergenerational and intragenerational equity
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HK Policy and quantitative aspects of land-use and forestry
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- Analysis of corporate strategies for climate change
- Socio-political analysis of prospects for the UNFCCC system

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This journal is committed to maintain the highest editorial Standards and continuous improvement. As part of moving to an online Submission system, we are implementing an Authors' Charter (see www.climatepolicy.com) to make our procedures and policies explicit and to help authors understand the editorial process and what to expect. As part of maintaining the highest Standards, *Climate Policy* asks all authors, editors and reviewers to disclose any relationship (e.g. financial, economic or institutional) that could be perceived as affecting the integrity of the scientific process.

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■ preface

Low-Carbon Society (LCS) modelling

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What are plausible visions of a low-carbon society, what options exist to achieve the transition to a low-carbon society, and what are the implications of those different options? This *Climate Policy* supplement reports the research findings and policy implications from an international comparative exercise to model scenarios of long-term low-carbon societies. This was undertaken within the framework and with the support of the Japan–UK research project 'Low-Carbon Society (LCS) Scenarios Towards 2050'. This project was jointly promoted by the Ministry of Environment Japan (MoEJ) and the Department for Environment, Food and Rural Affairs in the UK (DEFRA) with the aim of informing the Gleneagles Dialogue on Climate Change, Clean Energy and Sustainable Development, which was established during the UK's 2005 presidency of the G8, with progress to be reported and discussed during Japan's presidency in 2008. Following the first LCS workshop in Tokyo, it was agreed to bring together an international group of climate–economy modellers, including representatives from developing countries, to a meeting at the UK Energy Research Centre in December 2006 to plan a model comparison exercise. The results of that exercise, involving researchers from the UK, Japan, Germany, the USA, Canada, Thailand and India, are reported in this supplement. There are two introductory papers – first, the LCS workshop co-chairs, Jim Skea and Shuzo Nishioka, discuss the broader policy context of the LCS project, and second, we discuss the common themes for policymakers arising from the results.

The LCS modelling exercise described here takes its lead from the declaration issued during the 2007 G8 summit in Heiligendamm supporting a global target of a 50% reduction in GHGs by 2050. This corresponds to the more stringent stabilization pathways envisioned under the IPCC Fourth Assessment Report, but which, so far, have been subject to relatively little scenario analysis. The exercise used a range of global and national energy models; macroeconomic, technology-focused and hybrid approaches. Each modelling team investigated at least three scenarios: a *Base case*, a *Carbon price* case (rising to \$100/tCO_2 by 2050), and one or more *Carbon-plus* cases to analyse what additional measures may be needed to achieve a LCS scenario consistent with a 50% reduction in global CO_2 emissions by 2050. Individual modelling assessments focused on independently chosen core drivers and utilized the models' particular strengths.

We believe that the results of this exercise will be valuable to national and international policy makers and can usefully inform the discussions on the Gleneagles Dialogue during Japan's G8 presidency. The papers address the levels of technological progress and complementary behavioural change needed to achieve a low-carbon society; issues relating to timing of actions and the role of emissions targets; the economic costs and benefits of different pathways to a low-carbon society;

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the particular challenges facing developing countries to achieve LCS in light of their projected economic growth and energy use requirements; and the consequent need for international cooperation, notably in flexible burden sharing under international emissions trading regimes.

Many have contributed to the success of this research project, including the modelling teams, the editors and referees of *Climate Policy*, and the UKERC Meeting Place for organizing the LCS meeting within the Annual Energy Modelling Conference in Oxford, UK, in December 2006. In addition, we are particularly grateful for funding of this special issue from the UK Energy Research Centre (UKERC), the UK Department of Environment, Food and Rural Affairs (DEFRA), and the Japanese National Institute for Environmental Studies (NIES).

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editorial

Policies and practices for a low-carbon society

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Introduction

In February 2006, the Ministry of Environment (MOE) Japan and the Department of Environment, Food and Rural Affairs (DEFRA) in the UK set in motion an ambitious research project aimed at informing the Gleneagles Dialogue on Climate Change, Clean Energy and Sustainable Development established during the UK's 2005 G8 Presidency (DEFRA, 2005). The Dialogue has engaged G8 and other interested countries with significant energy needs. It has focused on:

- the strategic challenge of transforming our energy systems to create a more secure and sustainable future
- monitoring implementation of the commitments made in the associated Gleneagles Plan of Action
- sharing best practice between participating governments.

The Japan–UK Low-Carbon Society project has contributed to the first and third of these objectives. It took as its starting point the need to stabilize greenhouse gas concentrations at a level that would avoid dangerous climate change. It then went on to create visions of low-carbon societies, identifying the concrete steps required to achieve the necessary transitions.

The two governments have worked with three of the top climate and energy research centres in Japan and the UK – the National Institute for Environmental Studies (NIES), the Tyndall Centre on Climate Change, and the UK Energy Research Centre (UKERC). The Centres undertook a sequence of three workshops and symposia, involving both researchers and stakeholders from a diverse group of some 20 developed and developing countries.

A major component of the project was an international modelling comparison exercise, 'Low-Carbon Society (LCS) Scenarios Towards 2050', undertaken by nine national teams, with a strong developing-country focus. Core model runs were a *Base case*, a *Carbon price* case (rising to \$100/tCO_2 by 2050), and a '*Carbon-plus*' case to investigate an LCS with a 50% reduction in global CO_2 emissions by 2050. This was the level of global emissions reduction referred to in the outcomes of the Heiligendamm G8 Summit in June 2007 (Federal Government of Germany, 2007). The comparison focused on individual model strengths (notably technological change, international emissions trading, non-price mechanisms relating to sustainable development, and behavioural change) rather than a common integrated assumption set. The bulk of this *Climate Policy* supplement is devoted to reporting the outcomes of the international modelling comparison exercise. Strachan et al. (2008) present an overview of the exercise and synthesize the key conclusions. Other papers describe in more detail the conclusions for individual countries.

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The purpose of this editorial is to set the international modelling comparison exercise in the context of the wider Japan-UK Low-Carbon Society project and to describe the conclusions arrived at during the course of the two-year project. This article covers: a working definition of the low-carbon society concept; the need for, and feasibility of, achieving low-carbon societies; establishing and developing low-carbon society visions; evidence of the scope for action offered by existing initiatives at the country, city and sectoral level; the roles of business, the investment community, technology, city authorities and consumers; aligning low-carbon societies with wider sustainable development needs; and policy recommendations.

What is a low-carbon society?

At the first project workshop in June 2006, the Steering Committee was challenged to set out its views on what, in concrete terms, would constitute a low-carbon society. The following working definition was proposed. This was not intended as a scientific Statement but rather as a flexible framework which would allow fruitful discussions, leading to practical actions. The definition was intended to capture the perspectives and needs of countries at all stages of development. A consensus was reached at the first workshop that this definition did indeed provide a basis for research and action (National Institute for Environmental Studies, 2006, pp. ii-iii).

A low-carbon society should:

- take actions that are compatible with the principles of sustainable development, ensuring that the development needs of all groups within society are met
- make an equitable contribution towards the global effort to stabilize the atmospheric concentration of COz and other greenhouse gases at a level that will avoid dangerous climate change, through deep cuts in global emissions
- *m* demonstrate a high level of energy efficiency and use low-carbon energy sources and production technologies
- adopt patterns of consumption and behaviour that are consistent with low levels of greenhouse gas emissions.

Although the definition is intended to cover all national circumstances, the implications are different for countries at different stages of development. For developed countries, achieving a low-carbon society would involve making deep cuts in C02 emissions by the middle of the 2Ist Century. It would involve the development and deployment of low-carbon technologies and changes to lifestyles and institutions. For developing countries, the achievement of a low-carbon society must go hand in hand with the achievement of wider development goals. This would be with a view to ultimately achieving an advanced state of development, with C02 intensity commensurate with that achieved by low-carbon societies in developed countries.

Another key feature is that the definition, while not neglecting the role of technology in any way, also emphasizes the importance of lifestyle and social change. This, along with the close link between the low-carbon society concept and that of sustainable development more broadly, was to become a defining feature of the project as it progressed.

Methods

The project was launched by the then Japanese Environment Minister, Yuriko Koike, and the British Ambassador to Japan, Graham Fry, in Tokyo on 16 February 2006.1 This was followed by three major

international events in Tokyo, London, and then once again Tokyo in June 2006, June 2007 and February 2008, respectively. In each case a one-day symposium open to a wide ränge of stakeholders was linked to an intense two-day workshop involving low-carbon society researchers from a ränge of countries.

The goals of the first workshop in June 2006 were to:

a) identify and understand the need for deep cuts in greenhouse gas (GHG) emissions towards 2050 based on scientific findings
b) review country-level GHG emissions scenario studies in developed and developing countries
c) align sustainable development and climate objectives
d) study methodologies to achieve low-carbon societies
e) identify the gaps between our goals for developing country-level low-carbon society scenarios and the current reality
f) identify opportunities for Cooperation and how best to cooperate in estimating country, regional and global-level, low-carbon society scenarios (National Institute for Environmental Studies, 2006).

Out of objectives (b) and (d) came the idea for the international modelling comparison exercise which was discussed in greater depth at a technical workshop in Oxford in December 2006.

The second workshop, in June 2007, adopted two broad goals:

1. to demonstrate and raise awareness of the benefits of transitioning to a low-carbon society through sustainable development
2. to develop recommendations on how to close the gap between the business-as-usual and low-carbon society scenarios.

The first goal was addressed by: demonstrating that a low-carbon society could be consistent with policies relating to the environment, economy, development, access to energy and energy security; involving a wider ränge of stakeholders (including business leaders, policymakers, academics and NGOs) to assist with raising awareness of the low-carbon society concept and disseminating low-carbon society information; to provide expert input on the practicalities of transitioning to a low-carbon society; and sharing expertise and further building analytical capacity relating to low-carbon society visions and modelling.

The second goal was addressed by: identifying feasible contributions that large sectors could make in achieving a low-carbon society; exploring what low-carbon cities might look like and showcasing existing examples; and drafting policy options to achieve a low-carbon society with reference to timeframes and the need for swift action.

A third and final workshop was held in Tokyo in February 2008. This developed key findings and recommendations in four areas: behaviour change and its impact on delivering low-carbon societies; delivering low-carbon societies through sustainable development; enabling low-carbon societies through investment; and addressing opportunities and barriers to a low-carbon society, especially in economically sensitive sectors. The workshop was followed by an open symposium where the conclusions of the workshop series were presented to a wider stakeholder audience including government, business and NGOs.

The feasibility of achieving a low-carbon society

The first workshop included a comprehensive set of presentations and papers describing emissions scenario exercises both globally and for a ränge of developed and developing countries (National

Institute for Environmental Studies, 2006). The countries included Japan, the UK, France, Germany, the European Union, Canada, Russia, China, Mexico, India, Brazil, South Africa and Thailand. A key focus for the discussions was the various methodological approaches used by the modelling teams. These discussions led directly to the establishment of the international modelling comparisons project described in this *Climate Policy* supplement.

The key message from both the workshop presentations and the subsequent modelling activity was that the achievement of low-carbon societies, in the context of global CO_2 emission reduction of 50% by 2050, is indeed feasible in technological and economic terms. Energy efficiency, demand-side responses and the choice of technologies for electricity generation were among the most important contributors to emissions reduction. Novel transport technologies such as fuel-cell hydrogen vehicles and plug-in hybrids also played an important role in some model runs.

For such a 50% global CO_2 emission reduction, most models in this LCS project comparison showed an associated GDP loss in the range 0.35–1.35% annually by 2050, though one model showed an increase in GDP due to the stimulus provided by higher levels of investment in low-carbon technologies.[2] However, the required carbon price signal or marginal cost of abatement was found to be in the range \$100–330/tCO_2. This greatly exceeds the current price of carbon in the EU Emissions Trading Scheme, which was trading at just over \$30/tCO_2 in early March 2008 (Point Carbon, 2008). There is a serious question about the political viability of establishing a market signal, through taxation or otherwise, at these higher levels right across the economy. There is also a set of issues regarding international cooperation in emissions reductions, including flexible and equitable linking of emissions markets. So although modelling activity has demonstrated that low-carbon societies are technically and economically feasible, there is a major challenge in putting in place policies that will secure the technological and behavioural changes required.

Visions of a low-carbon society

A key element of turning the possibility of a low-carbon society into a reality is to develop visions that will be credible and attractive to the general public. A good example of this is the Japan Low-Carbon Society project. This envisages a world in which global temperature rise is held below 2°C, global CO_2 emissions are cut by 50% by 2050, and Japanese emissions are cut by 70%. The results of this project were presented at Workshop 2 in London (Matsuoka, 2007; National Institute for Environmental Studies et al., 2007).

However, a key conclusion is that more than one path of social development is consistent with this outcome. The research team constructed two contrasting visions of a Japanese low-carbon society.[3] Vision A (*'Doraemon'*)[4] is technology-driven, with citizens placing great emphasis on comfort and convenience. They live urban lifestyles with centralized production systems and GDP per capita growing at about 2% per annum. Vision B (*'Satsuki and Mei'*)[5] is of a slower-paced, nature-oriented society. People tend to live in decentralized communities that are self-sufficient in that both production and consumption are locally based. This society emphasizes social and cultural values rather than individual ambition.

In both cases a 70% reduction in CO_2 emissions is achieved by 2050. However, the mix of technologies employed is different (Table 1). In both cases, energy efficiency improves considerably – both in industry and in the home. The big differences are in: transport needs relating to the very different patterns of settlement; and in the structure of electricity production. The technology-driven society relies heavily on nuclear power and fossil-fuel use coupled with carbon capture and storage. Hydrogen is produced for use in fuel-cell vehicles. The nature-oriented society instead relies heavily on biomass, both for electricity generation and for biofuel production for use in hybrid vehicles.

TABLE 1 Comparison of CO_2 emission reduction drivers

	Vision A (*'Doraemon'*)	Vision B (*'Satsuki and Mei'*)
Society	High economic growth Decrease in population and number of households	Reduction of final demand by material saturation Reduction in raw material production Decrease in population and number of households
Industrial	Energy-efficient improvement of furnaces and motors etc.	Energy-efficient improvement of furnaces and motors etc.
	Fuel-switching from coal/oil to natural gas	Increase in fuel-switching from coal and oil to natural gas and biomass
Residential and commercial	High-insulation dwellings and buildings Home/building energy management system	High-insulation dwellings and buildings Eco-life navigation system
	Efficient air-conditioners	Efficient air-conditioners
	Efficient water heaters	Efficient water heaters
	Efficient lighting systems	Efficient lighting systems
	Fuel-cell systems	Photovoltaics on the roof
	Photovoltaics on the roof	Expanding biomass energy use in home Diffusion of solar water heating
Transportation	Intensive land use Concentrated urban function Public transportation system	Shortening trip distances for commuting through intensive land use Infrastructure for pedestrians and bicycle riders (sidewalk, bikeway, cycle parking)
	Electric battery vehicles Fuel cell battery vehicles	Biomass–hybrid engine vehicle
Energy Transformation	Nuclear energy Effective use of electricity in night time with storage Hydrogen supply with low-carbon energy sources	
	Advanced fossil-fuelled plants + carbon capture and storage Hydrogen supply using fossil fuel + carbon capture and storage	Expanding share of both advanced gas combined cycle and biomass generation

Source: Matsuoka (2007).

Both paths of social development will lead towards a low-carbon society. More realistically, a variety of development paths that combine elements of these more extreme visions would also be compatible with deep reductions in CO_2 emissions, demonstrating the robustness of the low-carbon society goal.

Practical actions for a low-carbon society

While low-carbon societies are a long-term goal, there are practical steps that can be taken today to put ourselves on the right trajectory. The second low-carbon society workshop focused on a number of case studies where concrete steps were already under way, mainly at the city level, to realize the low-carbon vision.

Watson (2007) described how Arup, the global design and Consulting firm, is collaborating with the Shanghai Industrial Investment Corporation to plan the new city of Dongtan in China, covering an area three-quarters the size of Manhattan at the mouth of the Yangtze River. Dongtan will have low energy consumption and will be as close to carbon-neutral as is possible. The development will include electricity generation from wind, solar, biofuel and recycled city waste, with hydrogen fuel cells being used to power public transport. A network of cycle and footpaths will help the city achieve close to zero vehicle emissions. A key part of the initiative will be ongoing research and evaluation activity which will ensure that lessons are learned and can be applied in subsequent developments.

Shimada (2007) focused on the sustainability challenge in Shiga prefecture, Japan. Here, the challenge is to restore water quality in Lake Biwa, reduce the volume of waste going to landfill by 75% and reduce CO_2 emissions by 50% by 2030. The plan involves a three-way partnership between citizens, business and local government. The goal is that the partners will share economic benefits as well as environmental gains through 'sustainable taxation' and 'sustainable finance'. Specific measures would include environmental regulations, regulations on land use and construction, subsidies for advanced technologies, voluntary environmental action plans, and awareness/education programmes. This case study highlighted the central role that governments must play in taking forward the low-carbon society concept.

Deacon (2007) outlined the comprehensive actions being taken by the Mayor of London to cut CO_2 emissions across the city. The Action Plan sets targets for 2025 and comprises four main programmes: Green Homes, Green Organizations, Green Energy and Green Transport. The Green Homes programme could cut CO_2 emissions in this sector by almost half, helped by subsidies for house insulation and energy-efficient devices. The Green Organizations programme aims to encourage businesses to cut their energy use through simple managerial approaches - turning off lights and IT equipment - and improving building energy efficiency. The ambitious goal of the Green Energy programme is to take one-quarter of London's electricity supply off the National Grid and meet it through more efficient local energy systems. The Green Transport programme will encourage people on to public transport, using methods such as congestion charging, and will incentivize more fuel-efficient vehicles, for example by exempting them from congestion and parking charges. Altogether, London's CO_2 emissions should fall by 60% by 2025 compared with 1990 levels.

The role of stakeholder groups

The second workshop also squarely addressed the role that different stakeholders' groups could play in developing low-carbon societies. The workshop addressed the roles of the investment community, business and consumers. However, a key message from the associated stakeholder symposium was that government had the primary responsibility to initiate low-carbon development (DEFRA, 2007, p.34). Businesses, for example, can deliver results, but governments must provide the frameworks and incentives to direct business activities in the right direction.

The world will be *investing* around US$20 trillion between 2005 and 2030 in energy infrastructure, with developing countries making up on slightly more than half of this spending. China alone

will make up almost one-third of the total from developing countries (Garibaldi, 2007). An alternative scenario modelled by the IEA (IEA, 2006) shows that emissions reductions of 16% or 6.3 billion tCO_2 by 2030 can be achieved without incurring additional investment relative to the IEA reference scenario.

Delivering these potential emission reductions requires shifting part of the total energy sector investment from supply expansion to energy efficiency and the demand side. In addition, public and private energy technology R&D investment has been decreasing over the past decades, due partly to liberalization in the energy sector, the lack of clear long-term signals, and an inappropriate regulatory environment. This trend needs to be reversed.

Current mechanisms that leverage financing play an important, but so far insufficient, role in promoting low-carbon investment. Clean Development Mechanism (CDM) projects in the pipeline to 2012 are expected to generate 2 billion tCO_2e of certified emissions reductions worth perhaps $4 billion p.a. (Acquatella, 2007). However, this is only a fraction of the estimated $20–30 billion p.a. of low-carbon investment required in developing countries. The removal of barriers, such as high transaction costs, technology risk and policy uncertainty, could enable an increase in the scale of investment through CDM. The Global Environment Facility (GEF) has provided US$6.2 billion in grants and has generated over US$20 billion in co-financing from other sources since 1991. According to the World Bank, a tenfold increase would be needed to finance a strategic global programme to support cost reduction of pre-commercial low-carbon technologies. Trading on the EU Emissions Trading Scheme (EU ETS) is now worth US$8 billion per year. The global carbon market shows a very large growth potential, especially if the largest global emitters join in carbon trading and if emerging regional carbon trading schemes merge into a single market.

Expanding capacity for demand-side investment will require innovation and structural change within the finance sector. Most energy finance facilities are ill prepared to handle barriers associated with energy efficiency programmes. These include financial constraints on individual consumers, high implicit discount rates, partial information on energy performance of end-use appliances, the need to organize a large number of individual actions, and partial information on the potential savings to demand-side investment.

To support the further expansion of financing mechanisms for low-carbon investment, clear, stable, long-term signals are needed, particularly in terms of a global price for carbon. Market mechanisms, such as carbon taxation and emissions trading, are key. Energy subsidies and tariff barriers need to be dismantled.

Business is now increasingly of the view that there is no inherent conflict between having a healthy, competitive economy and a cleaner environment. Access to mobility, illustrated for example by the '*Doraemon*' vision cited above, can be reconciled with a low-carbon society through the continuous application of innovation and creativity (Smith, 2007).

The transport arena serves as a good example of a sector in which business has a big role to play. But there are no 'silver bullets' to reduce greenhouse gas emissions. In transport, there are three broad levels at which steps can be taken to reduce greenhouse gas emissions. The first is simply through human behaviour. Sticking to speed limits would help, as would the adoption of smarter driving techniques which can improve vehicle efficiency by close to 10%. With nearly one-third of car journeys involving a distance of less than 2 miles, there is ample opportunity to use alternative modes of transport such as walking, cycling and public transport. Good infrastructure and planning policies designed to reduce the need to travel can also have a longer-term effect. The UK Low-Carbon Vehicle Partnership (LowCVP) has argued strongly for information and education campaigns to encourage low-carbon vehicle purchase and smarter driving.

The second level is the development of cleaner vehicle technologies and fuels. Hybrid petrol–electric vehicles are already beginning to have an impact on the market. These can enable a pathway to more radically advanced vehicle designs based on alternative fuels (such as hydrogen), alternative means of propulsion (fuel cells), and electric vehicles. Vehicle fuels with a lower carbon footprint, including sustainably produced hydrogen and biofuels will also play their part.

The final level is through changes to the transport system itself. As well as modal switching, it is possible to imagine that information and communication technologies can be used to inform drivers so that congestion is avoided and CO_2 emissions are consequently reduced. Taking these three levels together – human behaviour, vehicle technology and traffic systems – it is possible to envisage the provision of a given level of mobility service with 70% less CO_2 emissions than at present (Yamashita, 2008).

There has been a growing acknowledgment that the way *consumers* approach energy must change if rapid decreases in greenhouse gas emissions are to be achieved. Economics and psychology have dominated consumption research. However, a purely economic perspective is not enough, as individuals do not operate in a social vacuum. Equally, psychology focuses on the individual and downplays the importance of the social and cultural contexts in which energy is used. In fact, energy consumption is structured by the range of choices available (Jackson, 2007; Wilhite, 2007). Energy demand can be conceptualized as a product of both choosers and the set of choices available. No amount of taxes or price increases on automobiles or fuel will affect mobility practices unless the consumer has an alternative. Air conditioning is growing rapidly around the world, not because people have elevated their demands for thermal comfort, but because the constructed world that they inhabit no longer allows for comfortable natural cooling. Energy policy needs to broaden its focus from technical and market efficiency to an examination of how energy service needs can be achieved in the least energy-intensive way. Policies aiming at deep reductions in CO_2 must take a holistic and long-term approach to change.

Low-carbon societies and sustainable development

It is often assumed that there must be trade-offs between environmental quality and socio-economic development. However, an important conclusion of the Low-Carbon Society project was that pathways to achieve developmental goals can be climate-friendly and that sustainable development can be a driving force for addressing climate challenges. Rather than thinking in terms of trade-offs, the development/climate 'frontier' can be pushed back through technological and institutional innovation, international and regional cooperation, targeted technology and investment flows, and working to align stakeholder interests (National Institute for Environmental Studies, 2006, p. 39).

Given both the growth and greenhouse gas mitigation potential in developing countries, it is more efficient to focus on the co-benefits between sustainable development and the pursuit of a low-carbon society. One approach is for developing countries to make pledges to implement sustainable development policies and measures (SD-PAMS). Starting from development objectives, countries would map out the implementation of policies and measures in a manner that would take cognizance of the need to mitigate or adapt to climate change.

Each individual country will take its development path on the basis of its local resource endowments. It is therefore important to focus on the potential barriers and incentives that can help developing countries in moving towards a lower carbon future. The workshops showcased efforts by various developing countries which have created good examples of win–win strategies associated with emission reduction efforts.

An ***Indian*** case study (Shukla, 2006) showed that energy policies framed on India's sustainable development vision could well align energy security and a low-carbon future.[6] Under most scenarios, per capita CO_2 emissions would remain low, compared to global averages, throughout the 21st century while, at the same time, India can further contribute to cost-effective greenhouse gas stabilization, offering low-cost mitigation opportunities, given the appropriate incentives. There would be substantial co-benefits associated with the joint reduction of SO_2 and CO_2 emissions, although realizing this would require modifications to international instruments such as the CDM and greater alignment between national and global environmental regimes in general. Again, in India, electricity reforms have reduced the carbon content of electricity compared with the baseline.

In ***Brazil***, measures relating to land-use change and energy have a large potential to reconcile greenhouse gas mitigation and sustainable development (La Rovere, 2006). The major challenge is to limit deforestation, which has drivers that go far beyond the purely economic domain. Improved governance may increase the enforcement of existing laws and regulations to avoid illegal deforestation in the Amazon region, and thus reduce emissions. However, in the medium and long term, CO_2 emissions from fossil fuel combustion will be the most important factor. The main opportunities to align climate change and sustainable development objectives in Brazil include: energy efficiency in industry and transport; the greater use of natural gas in the industrial, residential and commercial sectors; greater exploitation of hydropower potential; the production of ethanol from sugar cane for use as a vehicle fuel; blending biodiesel with diesel oil to fuel buses and trucks; and renewable power generation to promote wider access to electricity among the rural population.

South Africa's development objectives focus on growth, job creation, and access to key services including energy and housing (Mwakasonda, 2006). Increasing the percentage of renewable energy in the electricity generation mix is a specific goal. The government strategy aims to generate 5% of the national grid-supplied power from renewable technologies, such as micro-hydro, biomass-fuelled turbines, solar thermal, wind turbines and PV. A national target for renewable energy sources can lead to local environmental benefits, and GHG reductions. At least 50% of all new houses built in communities incorporate climate-conscious solar passive design principles in their construction, thereby eliminating the need for space heating and cooling, resulting in lower CO_2 emissions.

Efforts at the national level must be supported by international action. Making low-carbon technologies and finance available to developing countries is a key measure. It is also necessary to spell out the incentives for sustainable development and climate policies in formulating support programmes.

Conclusions and recommendations

The Low-Carbon Society project has shown that low-carbon societies are achievable, but also that it will require a major coordinated effort, nationally and internationally, to achieve this vision. Although advancing the technological frontier will be vital, changes must go to a deeper social level if climate change and development goals are to be reconciled.

The key conclusions emerging from the workshop series were that:

- Achieving the transition to a low-carbon society is essential if greenhouse gas concentrations in the atmosphere are to be stabilized at a safe level. Modelling and scenario work has shown that this transition is possible.

- It will be less costly to move towards a low-carbon society than it will be to delay climate change mitigation efforts and experience the more extreme impacts of climate change.
- Long-term certainty is needed to create the market conditions for investment in low-carbon solutions - a comprehensive approach to RD&D for low-carbon technology as well as emerging markets, products and services is required to underpin this investment.
- Some of the more substantial changes will be required in the built environment, transport, and power sectors.
- There are major synergies between policies that promote sustainable development objectives and those that encourage the transition to a low-carbon society. Pursuing these policies can deliver significant economic, social and environmental co-benefits, especially in developing countries.
- The role of government is critical and top-level political leadership will be essential. Governments must establish the enabling conditions under which individuals, business and organizations can benefit from the opportunities offered by new low-carbon markets, technologies, products and services. A portfolio of policies will be required to achieve this.
- The building of trust within and between nations is essential to reinforce the credibility of long-term goals and policies.
- Consumer choice and individual action, in the context of clear policies that enable low-carbon options and lifestyles, can be powerful drivers in delivering the level of behaviour change required to enable the transition to low-carbon societies.

There are clear inferences to be drawn from these conclusions in terms of policy. If low-carbon societies are to be achieved, action is needed in the following areas:

- Long-term goals to reduce global greenhouse gas emissions by at least 50% of 1990 levels by 2050 are required.
- Long-term policy signals to strengthen carbon pricing, e.g. through taxation and enhanced international emissions trading, should be established to create appropriate incentives for business.
- It would help if tax burdens were shifted away from income and employment towards environmental pollution in order to internalize the cost of CO_2 emissions and encourage businesses and individuals to reduce emissions.
- The focus of development investment in developing countries should be shifted towards lower-carbon approaches.
- There needs to be a step change in the transfer of low-carbon technologies to developing countries. This can be achieved by expanding financial flows and developing new financing mechanisms.
- Trade regimes should be adjusted to encourage rapid deployment of technologies and products that enhance sustainable development while lowering CO_2 emissions.
- Energy efficiency improvement should be accelerated, using incentives that encourage institutional and behavioural change.
- The demonstration and deployment of near commercial technologies, such as carbon capture and storage, is required, as is significantly increased investment in R&D for technologies with greater promise in the long term.
- Policies and frameworks should be implemented which enable a change in human behaviour and lifestyle, by removing high-carbon choices and providing consumers with the opportunity to benefit from low-carbon approaches.

- The required level of trust can only be built by continuing and enhancing dialogue between stakeholder groups within countries and between countries with diverse national circumstances. International cooperation should be enhanced, as should the sharing of expertise and best practice between national, regional and international stakeholders.

None of this will be easy. Much further work will be required to articulate policy measures in the necessary detail. But the Low-Carbon Society project has demonstrated that this task is both necessary and possible. It will also bring benefits in terms of human development that go beyond the climate arena.

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Notes

1. This was the first anniversary of the Kyoto Protocol having come into effect.
2. See Strachan et al. (2008) for a discussion of the broad uncertainties in drivers of this cost range.
3. These visions are discussed and quantified in Fujino et al. (2008).
4. *Doraemon* is a Japanese comic series about a robotic cat who travels back in time from the 22nd century.
5. Satsuki and Mei are the daughters in the film '*My Neighbor Totoro*'. They live an old house in rural Japan, near which many curious and magical creatures live.
6. This is also discussed and quantified in Shukla et al. (2008).

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