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SPECIAL FEATURE: EDITORIAL

Socio-technological transitions

Understanding energy transitions

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Transitions to cleaner, renewable energy are at the heart of policies in many countries. The focus on renewables has, if anything, become greater recently as uncertainty grows about the viability and acceptability of alternatives to achieve low-carbon growth, including nuclear power and carbon capture and storage (REN21 2010). The Fukushima accident has forced many governments to rethink their nuclear energy plans—Japan has just shutdown their last nuclear power plant, and Germany announced last year it will be nuclear free by 2022. But transitions away from fossil fuel-based energy systems have proven slow despite the potential of renewable energy sources and advancing technologies to utilize them.

Recent research in ‘Transitions Studies’ argues that transitions will not be a technological fix but will require some combination of economic, political, institutional and socio-cultural changes (Berkhout et al. 2009; Cohen et al. 2010; Stephens et al. 2008). Without doubt, these transitions must be guided by an ethics that brings together technology and sustainability. In the introductory message to this special issue, Jean-Louis Armand calls for such an ethic of long-range responsibility—one that is properly embedded in sustainability science as a guide for our future.

In response to this complex issue, *Sustainability Science* has organized a special issue on two related themes—the costs of mitigating greenhouse gas (GHG) emissions and the diffusion of clean energy technologies. The first four papers model abatement costs for world regions and sectors with a focus on medium term GHG emission targets (2020 and 2030)—a key step in stabilizing long-term climate change under the United Nations Framework Convention on Climate Change (UNFCCC). These studies find that transitions toward a low-carbon society are not an extension of the current trends, and far greater GHG reductions—both on national and global scales—are required in the mid-term. A further five papers explore the barriers and opportunities of energy transitions on the ground, using transition management theories to explain empirical cases in India, Japan, Malaysia and the United States.

Hanaoka and Kainuma conduct a comparison of GHG marginal abatement cost (MAC) curves from 0 to 200 US $/t$CO_{2eq}$ in 2020 and 2030 with engineering-based ‘bottom up’ models covering major countries. The study finds that there are great differences in the technological feasibility of GHG mitigation between world regions and models, giving a wide spread of results. Future portfolios of advanced technologies and energy resources, especially nuclear and renewable energies, are the most prominent reasons for these differences.

Akashi and Hanaoka use a bottom-up model named AIM/Enduse[Global]—part of the Asia-Pacific Integrated model (AIM)—to investigate the technological feasibility and costs of global 50 % emissions reductions by 2050 relative to 1990 levels. They find that such a major reduction is feasible with marginal costs of US $150/t$CO_{2eq}$ in 2020 and up to US $600/t$CO_{2eq}$ in 2050. Renewables, fuel switching and efficiency improvements in power generation account for 45 % of the total emissions reductions in 2020, while carbon dioxide capture and

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storage (CCS) and renewables account for a full 64 % of reduction potential by 2050.

Akimoto and colleagues then explore GHG emissions reduction potentials across world regions and sectors using the Dynamic New Earth 21 (DNE21+) model for energy-related emissions and a non-CO_2 assessment model for other emissions. Taking fossil fuel prices based on the International Energy Agency World Energy Outlook 2010 reference scenario as a baseline and considering a short payback time, the analysis finds that, with relatively low carbon costs below US \$50/tCO_{2eq}, the reduction potentials in UNFCCC non-Annex 1 countries, including India and China, are large. This holds even if the baseline emissions of China and India increase drastically due to rapid economic growth, and is due primarily to their greater potential for rapid large-scale introduction of highly efficient technologies.

The final paper in this first section by Wagner et al. reports MAC curves for mitigation options in Annex 1 countries to 2030 using the Greenhouse Gas–Air Pollution Interactions and Synergies (GAINS) model and World Energy Outlook (2007–2009) reference scenarios as baselines. They are concerned with identifying no-regret mitigation options and in identifying the value of local co-benefits through reduced air pollutants. They find that 25 % abatement of GHG in UNFCCC Annex I countries in 2020 (relative to 1990) is achievable at costs below €50/tCO_2 at an aggregate cost of less the 0.1 % of GDP. GHG mitigation potentials are greatest in the power and building sectors.

These modeling studies are extremely useful in showing that transformation of the global energy sector is fundamental to achieving deep emissions reductions; in demonstrating that the technological options to achieve reductions exist; and in providing a sense of the scale of the costs involved. One of the shortcomings of these models is their assumption that costs and prices alone will determine the structure of energy generation, future energy use, and innovation and diffusion of new technologies, including renewable energy technologies.

We know that price alone does not fully explain the uptake of new technologies. Instead, a series of institutional, behavioral and cultural factors also play an important role in technology development and diffusion. There are two main reasons for this. The first is that energy markets are not open and free, but highly influenced by national and international policies, including climate policies. The second is that governments play an important role in creating the enabling conditions for new technologies to emerge (through funding of science) and to diffuse (through creating markets for new technologies). Therefore this Special Issue includes a second set of papers that investigate institutional factors that play a role in the diffusion of new energy technologies.

Suwa and Jupesta (2012) offer a study on Japan's support for renewable energy deployment. Comparative studies between renewable portfolio standard (RPS) and feed-in tariff (FIT) schemes in the country identified barriers to policy transfer and innovation; technology 'lock in' and reluctance to experiment are found to be obstacles faced by policy makers. Innovative policy is deemed necessary to stimulate transition, but faces obstacles from established industrial and political interests.

Jolly et al. report how innovative business models have evolved for the five most visible and established initiatives in the area of off-grid PV solar energy in India. Up-scaling of these business models is found to be quite successful, though deep up-scaling (reaching the poorest) and institutional up-scaling (changes in the policy environment) remain difficult to resolve for entrepreneurs seeking to develop and diffuse highly-innovative new energy technologies.

The potential role of 'technology clusters' has been investigated widely in the context of the growth of high-tech enterprises in the biotechnology and other sectors. A series of agglomeration economies, including the availability of skilled people and information networks is thought to explain the persistence of clusters in global industries. The role of technology clusters in sustainable energy technologies, however, has not been dealt with in the sustainability transition literature. Stephens and McCauley explore the development of one such initiative in Massachusetts to consider its contribution in a regional socio-technical transition in the energy system. They find a set of positive roles in this regard, potentially accelerating change in the energy regime by promoting institutional thickness, generating activity at the regional level around sustainable energy and building trust between multiple and diverse stakeholders in the region.

The next two papers explore what can be learned by looking at case studies through the analytical lens of transition management theories. In India, despite numerous initiatives, rural cooking practices in many areas are still based on traditional uses of wood and biomass that when combusted in mud stoves cause health problems on top of GHG emissions. Rehman and colleagues use the principles of 'strategic niche management' (SNM) to analyze the deployment of cook-stoves and cooking fuel in India in an effort to understand the issues related to scaling up alternative cooking technology. Cost reduction of cook-stoves to address affordability is an important concern, which can be achieved with effective financing schemes by fostering public-private partnerships. The results show that sustainability, entrepreneurial rents and end user convenience are important for the success of transition experiments.

Finally, Zeeda et al. examine the potential role of religious communities in socio-technical transitions through the provision of localized resources in experiments for more sustainable municipal solid waste management in Malaysia. The "transition experiment" framework is used as a theoretical basis supported by empirical evidence from an exploratory case study of recycling programs conducted by four religious communities. The paper provides theoretically informed empirical insights on how the religious communities are creating these successful recycling experiments in urban communities in Malaysia. They argue that these communities are able to give voice to and shape visions of more sustainable waste management practices and build social networks in which innovation and improvement is continuously fostered.

This special issue of *Sustainability Science* details the results of a number of modeling studies on the feasibility and costs of achieving deep GHG emissions reductions through the diffusion of existing technologies, and reports several extended case studies of transition experiments, linking theory and practice. In observing and analyzing ongoing energy transitions, researchers need to maintain a balance between large-scale studies of macro-trends with a detailed understanding of the processes of technical and social change on the ground.

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