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ENERGY AND INNOVATION: STRUCTURAL CHANGE AND POLICY IMPLICATIONS

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International Series on Technology Policy and Innovation

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Foreword

ENERGY AND SUSTAINABILITY, STAVANGER 2007

Can greener and more sustainable development be combined with augmenting welfare and wealth? Since 1997 the *International Series on Technology Policy and Innovation* (ICTPI) has discussed important issues of critical importance for the use of science and technology to foster socioeconomic and shared prosperity. Indeed in 2007, the energy question was emerging at its fullest. Prosperity was increasing in the world as a whole, and countries such as China, India, and Russia were becoming stronger and more powerful economic participants within the international society. The pressure on resources had already begun to increase accordingly. A moral, social, and economic imperative is that the poorest people on earth must also have access to reliable energy: but must they, or shall they, follow the current models of consumption? The goal of the 2007 meetings in Stavanger was to discuss technology development and innovation within the boundaries of energy and sustainability. The Stavanger conference was the tenth International Conference on Technology Policy and Innovation. As such, the perspective of the meeting on issues of energy and sustainability emphasized the importance of technology and innovation and the need for meaningful and sustainable public policy in that regard. It is natural therefore that the conference theme *Energy and Sustainability* has given rise to the book presented here.

The concept of sustainability is a broad label that can be applied to almost every facet of life on earth, and may be described as the ability to persist. The Brundtland Report named after the Norwegian Prime Minister Gro H. Brundtland, who led the World Commission on Environment and Development, provides an often quoted definition of sustainable development: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." For the human race, sustainability is a promise for long term protection of human welfare, which in turn depends on the well-being of nature and the responsible use of natural resources. Human life on planet earth may, indeed, be unsustainable at the pace in which we are exploiting natural resources that we are not replacing. While human effort strives to make life on this planet less burdensome, the challenge of returning the use of natural resources within sustainable limits calls for a considerable collective effort, using science to develop new technologies such as green technologies and renewable energy.

Green energy refers especially to forms of energy that meet current needs without compromising the ability of future generations to meet their needs. However, a broader interpretation of energy and sustainability allows inclusion of fossil fuels as transitional sources while technology develops new energy sources for future generations.

The host city for the 10th ICTPI meetings, Stavanger, is the current headquarters of Norwegian oil activity with over 50 percent of all energy-based jobs[1] in Norway. A thousand years ago the inhabitants of Stavanger were wellknown for their innovative, exploratory—but destructive—activities as they went "in viking" to faraway countries. Sometimes they traveled on peaceful errands, but their worldwide reputation was earned from far less peaceful activities. The era of the Vikings was followed by several centuries of economic difficulty and subsistence living, centered on agriculture, fisheries and light industry, on the northern edge of Europe. Several centuries later, after World War II, Norway underwent rapid economic growth, based on energy industries in fossil fuel production and hydroelectricity.

Today the Norwegian experience in such aspects is among the world's most technologically advanced. While the petroleum industry worldwide is linked to considerable damage to the environment, the expertise and experience gained in oil and natural gas extraction has in recent years allowed the petroleum industry to extend across a vast array of sectors, and its skills can be transferred into more environmentally friendly energy sources, such as offshore renewable and carbon capture and storage. The region of Stavanger is at the forefront of research and development and was the first to utilize offshore technology.

Sustainable energy sources are most often regarded as including all renewable sources, such as biofuels, solar power, wind power, wave power, geothermal power, and tidal power. They usually also include technologies that improve energy efficiency. Another interpretation includes only energy sources which are not expected to be depleted in a time frame relevant to the human race, and can potentially include nuclear power. However, the largest challenge, as fossil fuels are still the main energy source, is to develop cleaner means of using and extracting this energy.

In 2007, the ICTPI was organized to have interesting discussions around the topic of energy and sustainability. This book contains the best and most relevant articles that were produced as a result. Lately the emerging consensus concerning the need for sustainable forms of energy has reached new heights as it gains increasing attention among important leading nations such as the United States, Russia, and China. Whether this stronger environmental rhetoric can be converted into substantial action remains to be seen. Creative and innovative policies can help ensure progress along the long and winding road from great thoughts to entrepreneurial action. As the world society reaches towards a consensus to use more sustainable means of energy, we offer this book as a contribution to the debate.

On behalf of the organizers of the Stavanger ICTPI-10 conference, I would like to thank all the authors and reviewers who have contributed to this book. Particular gratitude goes to lead editor Marina van Geenhuizen for her hard work in turning an idea to a reality, as well as to the Faculty of Technology, Policy, and Management of Delft University of Technology (the Netherlands) who granted her the budget to accomplish this task. Special acknowledgments go to David Gibson and William Nuttall for coediting this book. Finally, I express my thanks to Margaret Cotrofeld who prepared the manuscript's final layout.

On behalf of the Stavanger Committee,

Elin M. Oftedal,
Conference chair and coeditor

NOTES

1. Many of the world's leading energy companies are located in the Greater Stavanger region: Conoco Philips, Dong, ENI Norge, Gaz de France, Marathon, Norsk AECD, Revus Energy, Ruhrgas, Shell, Statoil, Talisman Energy, and Total make up part of Stavanger's thriving petroleum industry. The Norwegian Petroleum Directorate and The Petroleum Safety Authority are also located in the Stavanger Region.

Preface from the editorial team

Innovation is the driving force behind economic growth. It is also a major requirement in achieving structural and systemic changes in energy systems. In both cases, however, technological innovation alone is not sufficient. Policies need to be designed that most effectively and efficiently bring the goal of structural change nearer, and in so doing avoid adverse or perverse effects. Structural change requires innovation on a broader scale, including the organizational, infrastructural, and social domains. The recognition for the need of at least some structural change in the energy system and the parallels found in developments in other parts of society or the economy is one source of inspiration for this volume. Examples include increasing the innovation level of developing countries' economies. In Europe the transition processes for new members of the European Union have been especially helpful. The division of the book into three sections reflects this inspiration: 1) sustainable energy policies, including technology-based solutions; 2) challenges in building the knowledge-based economy in ways similar to sustainable energy development; and 3) energy sector innovation on the firm level, due to more stringent rules (energy/environmental pressure) and due to technology improvement.

A second source of inspiration for composing this volume is the broad reach and coherence of ideas that can be gained through publishing a book as opposed to disparate research articles. Contributions come from very different corners in the world (Northern Europe, Central Europe, Central America, Japan, United States) and all have messages and learning lessons to tell the rest of the world. It is the dissemination to a larger audience that makes working on a book such as this a very rewarding activity indeed.

Special thanks goes forward to the Electricity Policy Research Group at the University of Cambridge, and the Cambridge–MIT Institute Energy Security Initiative, for extraordinary assistance; and to the IC^2 Institute at

The Unversity of Texas at Austin for over ten years' help in initiating and promoting the ICTPI and the related publications series.

Last but not least, the perfect organization of the Conference in Stavanger, including enjoying Norway's rich culture (Stavanger was in 2007 a Cultural Capital of Europe) and the dramatic Norwegian fjord landscape, made the 10th *International Conference on Technology Policy and Innovation* an unforgettable event and another source of inspiration for us all.

Marina van Geenhuizen (Lead Editor),
William J. Nuttall, David V. Gibson, and Elin M. Oftedal

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Energy and environmental innovation in context

Marina van Geenhuizen, William J. Nuttall,
David V. Gibson, and Elin M. Oftedal

ENERGY SECURITY, CLIMATE CHANGE AND ENERGY COSTS

The themes of this book center on the need for sound energy policies responding to climate change, energy security, and the perspective of rising energy costs. The themes encompass the technological base for such policies, the way the concomitant policies could be more effective (particularly those requiring structural change), and the linkage of energy policies with innovation at universities and in the business world. In addition, some parallels between structural change of energy systems and structural change in innovation systems (in emerging economies) are studied.

Any discussion of energy policy deals with three related issues. The first is energy supply and security. This motivates the question: Are our sources of energy supply sufficiently diverse, robust, and sustainable? The second issue is climate change: Can the needed energy be provided in ways that do not cause harm to the environment, particularly through greenhouse gas emissions? Last but not least is the issue of cost or price: Can energy needs be met in affordable ways that will allow economies to continue to grow? Given these three issues, it is necessary to think about how best to achieve the related goals of protecting the climate and meeting energy needs affordably in the decades ahead. In this context, energy efficiency is an obvious attractive option. The benefits of reduced emissions in cost savings terms are clear. In the short to medium term we would also expect to see improved energy security, but we note that, in time, energy markets could be expected to re-equilibrate, and thus erode the energy security gains.

There is no silver bullet solution to the problem of climate change—in other words, it will require multiple solutions. Energy efficiency is just one essential component of any long-range effort to protect the climate. A wide-ranging portfolio of technologies and strategies is needed. Every technology that could potentially play a part in this structural change comes with challenges in terms of the three issues of security, climate, and cost. While emissions of greenhouse gases are reduced where combined cycle natural gas combustion replaces coal-fired generation, the associated challenges are real in terms of supply and cost. Continuing with coal combustion, by contrast, our concern should center on climate consequences rather than supply security or costs, except in the context to place carbon capture and sequestration within affordable prices. Cost, of course, is an important challenge for nuclear power (especially up-front capital costs), as are considerations of waste management and, if extended globally, possible nuclear weapons proliferation. Further, with oil, challenges can be seen in all three areas. The world may have ample supplies overall, but the security of those supplies is an obvious concern, as are the price and the climate. The cost of renewables presents a challenge that clearly influences the supply and use of these technologies. For example, solar photovoltaics have the largest global opportunity and produce electricity at every scale (from houses to large installed "farms"), but the technology is still relatively expensive. And finally, there are many challenges for the hydrogen economy, from infrastructure changes to the very important question of where the hydrogen comes from. To conclude, there is no technology without a challenge, and no technology can encompass "the" energy solution to meet society's needs. The full range of solutions available needs to be considered and analyzed (e.g. Wang et al., 2009), although particular regions in the world have better perspectives for specific combinations of technologies than other regions. As a consequence, a portfolio of technologies and policies is emerging. The separate elements of this portfolio share the aim to bring about structural change, which could be reached in a stepwise manner—as urged by signs of a quickly evolving climate change—through a comprehensive and pressing system change requiring the management of a transition.

STRUCTURAL CHANGE AND TRANSITION MANAGEMENT

As previously indicated, the energy sector faces serious problems related to oil dependency, security of supply, and climate change. Although the environmental performance of the energy sector has improved over the past 30 years, policymakers as well as other actors in society increasingly acknowledge the limitations of end-of-pipe solutions and the need for structural change and transitions. The need to shift from incremental innovation to system changes has facilitated the emergence of "transition thinking" among scientists, policymakers, and increasingly, industry stakeholders.

Transitions are major, long term (several decades) processes of change in sociotechnical systems, for example, systems of energy supply, transport and communication, and health care systems. Transitional change involves both the structure and the content of physical systems, their interrelations, and the body-of-rules and institutions that govern actor behavior and decision making. Accordingly, transitions imply not just technological change, but also change in (consumer) habits, knowledge, institutional organization, policies, cultural aspects, law, and other aspects of society. That is why transitions are labeled as coevolution of technology and society. Transitions not only occur in many different domains, but also involve different levels of change: the local, regional, national, and international level. In addition, according to specific views on how transitions occur, a distinction needs to be made between the micro level (where changes originate and begin to mature in niches), the patchwork of regimes at mid level, and the "landscape" of the macro level that is eventually transformed (Geels, 2005; Geels and Schot, 2007).

However, actors involved often tend to continue development along paths based on past success, which at best will optimize the existing energy system rather than realizing structural change. In other words, if the transition is not managed, new technologies and solutions will still be developed, but not necessarily towards a sustainable energy system. The transition, therefore, needs to be steered toward a more sustainable and desirable direction. Management of transitions needs to be designed in a way that the multi-actor, multi-level, and coevolutionary attributes of transitions are acknowledged in a complex and difficult steering process. At the same time, it is necessary to take a comprehensive and integrated view in policy making for a sustainable energy sector (Turnpenny et al., 2008), among others by considering the removal of existing measures that support persistence of fossil fuel use, mainly government subsidies (environmentally damaging subsidies). Examples are tax exemption and reduction of fossil fuel in aviation and in electricity generation. Such situations reinforce lock-in and block transition, calling for the policy-assisted management of transitions. The design of transition management strategies is one of the themes explored in this book.

A second field of transitions is also addressed pertaining to innovation systems, particularly those in emerging economies. The term transition economies has been familiar in economic policy making since the early 1990s. Transition in this context refers to a comprehensive set of changes in the economic system of previously communist countries in Central and

Eastern Europe, including the Russian Federation and former states of the Soviet Union. It deals with the transition to market economies exemplified by changes in the banking system, ways of price determination, ownership rights, etc. (EBRD, 2009). Twenty years after the fall of communism, some of these countries have gone through a true transition, while others are still in the process. In addition, it seems that these countries recognize the need for a "second" transition, to a globally oriented knowledge-based economy.

Transition to a knowledge-based economy is, however, not limited to former communist countries. There are many emerging countries eager to move to and reap the fruits of a knowledge-based economy, notably China, India, Brazil, and Mexico. The question here is whether policymakers conform their measures to change according to the flying geese model (or the like) or to others, such as a dual model that incorporates elements of the flying geese model with other elements such as attracting foreign direct investment by multinational corporations. Originally Akamatsu (1962) used the metaphor of flying geese to capture the nature of industrialization in Japan. After 1945, Japan decided to move away from comparative advantage based on labor intensity in favor of comparative advantage of progressively more sophisticated and value-added industries (Edgington and Hayter, 2000). Accordingly, each "lead" industry sector flies through various stages, i.e. import, domestic production (import substitution), and export, and is eventually replaced by another "lead" industry. In this case, local technical know-how, capital goods, and also absorptive capacity, all eventually evolve (van Geenhuizen et al., 2009). As such, progress according to the original model leans heavily on endogenous power in entrepreneurship and innovation. Currently, however, many governments follow a dual strategy to increase both learning and growth of domestic firms and the attraction of multinational corporations. This policy is illustrated in this book with the biotechnology sector in China.

To promote regional endogenous growth, an important role is assigned to domestic universities. As the source of new knowledge, albeit technical, organizational, or market knowledge, universities produce up-to-date and relatively inexpensive graduates for the (regional) labor market (Aghion and Howitt, 1998). In addition, knowledge spill-overs favor innovation in the region. Economic utilization of academic knowledge takes many forms, like contract research commissioned by companies, licensing of knowledge protected by university patents to companies, collaboration of universities and companies in research consortia, and spin-off processes from universities through which basic knowledge is translated into applied knowledge that lends itself to market introduction (e.g. van Geenhuizen and Soetanto, 2009). Linear models go along with nonlinear (interactive and cyclical) models. The processes involved are not self-understanding and need a policy push. The potential for universities to contribute more efficiently to boost the knowledge economy is subject to a large differentiation, with outcomes that can be uncertain (Di Gregorio and Shane, 2003; D'Este and Patel, 2007) due to different institutional (cultural) barriers between universities and companies, a diverse absorptive capacity of these actors, and a diverse availability of a supportive infrastructure, etc. At the same time, companies that are eager to collaborate with universities can follow different models of collaboration. This role of universities in the transition to a knowledge-based economy, and ways in which companies can (re)shape their relationships with universities, is one of the themes of this book.

INNOVATION IN ENERGY: THE FIRM PERSPECTIVE

If a micro (or firm) perspective is adopted for an analysis of energy sector innovation, two different lines of innovation need to be distinguished. First, there are innovations that respond to more stringent energy rules, such as reducing energy use, reducing carbon emissions, or using carbon constraints in production. These types of innovations form part of new production processes and routines in firms. Secondly, other innovations exist in the very core of new technologies and in new practical applications for both large established firms and small high technology firms (including academic spin-offs). We mention small firms that produce solar cells or solutions in drilling (exploration) in the oil sector, and larger firms that produce advanced wind turbines to produce energy in shallow seas, or smart meters used in homes to increase awareness of energy use and to enhance energy efficiency. Technical aspects of a set of new renewable energy sources, aside from chances for adoption in the market (mainly cost level), is another theme addressed in this book.

Both types of energy innovation—those responding to environmental pressure and to challenges of new technology solutions—require firms to adopt particular strategies to build the necessary capabilities. Firms need the essential capacity to scan the external world for new knowledge, as well as the capacity to transform this knowledge into viable strategies while reconfiguring, renewing, and extending their resource base; the first is named *absorptive capacity* (e.g., Zahra and George, 2002), the latter is named *dynamic capability* (Zahra et al., 2006; Helfat et al., 2007). Theory on dynamic capability is still under-developed due to a shortage of empirical insights, particularly how and why managers use dynamic capabilities, what these are in an organization, and how these are deployed (Ambrosini and Bowman, 2009).

The building of capabilities by firms to arrive at higher levels of innovation, or merely to survive and grow in the high technology arena is one of the themes of this book, and refers to both transition in the energy sector in developed countries as well as to transition to a knowledge-based economy in emerging economies.