Low-Carbon Innovation and Development

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Editors • Rasmus Lema, Björn Johnson, Allan Dahl Andersen, Bengt-Åke Lundvall, and Ankur Chaudhary

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Preface

Globelics is a worldwide community of scholars who place learning, innovation, and competence-building systems at the heart of the development process. Over the years, Globelics has been a forum for bringing together the two rather different traditions of innovation studies and development studies. The community incorporates a range of social science disciplines and approaches in the analysis of learning, innovation, and competence building.

The objective of the annual Globelics Thematic Review is to communicate insights from the community to policy circles and development donor organisations. Each review focuses on a separate theme, in a format relevant and accessible to users outside academic circles. It gives an overview of research outcomes as well as reflections on policy implications.

Rasmus Lema, Björn Johnson, Allan Dahl Andersen, Bengt-Åke Lundvall, and Ankur Chaudhary edited this Thematic Review. The report reflects the insights from papers on low-carbon development presented at Globelics conferences and meetings. However, responsibility for the final report lies with the editorial team and the Globelics Secretariat.

The editors drew substantial input from the Globelics seminar on learning, innovation, and low-carbon development held in Copenhagen 2-4 April 2013. The round table discussion on innovation, learning, and low-carbon development, held on 11 September at the Globelics Annual Conference 2013 in Ankara, was also a key source. We thank all of the participants for their valuable inputs and comments.

The editors are also thankful to Nina Kotschenreuther and Shagufta Haneef for editorial support and to Leticia Nogueira and Tadeo Fernando for the identification of Globelics Conference papers within the field of low-carbon development.

The purpose of the Thematic Review is to inspire future Globelics research and to influence policy. It is not intended to give detailed and specific advice to donor and development organisations in the field of low-carbon development. Instead, the intention is to offer practitioners insight into some of the general principles for policy formulation that follow from an innovation perspective on low-carbon development. We hope that the analysis will inspire the design and development of new and more effective strategies for low-carbon development.

Bengt-Åke Lundvall
Secretary General, Globelics

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Executive summary

1. In this review we use the concept of **learning, innovation, and competence-building systems** (LICS) as an analytical tool and as a framework for defining low-carbon policies and development strategies. Improved systems of innovation and competence building are essential to low-carbon development. The concept is a dynamic and interactive perspective in which technologies and institutions co-evolve and it indicates that policies need to operate on both the demand and the supply side.
2. The learning, innovation, and competence-building system (LICS) perspective adapts the **systems of innovation** notion to a development perspective. In developed economies the low-carbon challenge means re-orientation of the management of innovation system. In less developed economies, the attention shifts from system management toward system building and strengthening and from the development of new technology to competence building and absorption of technologies developed abroad.
3. In this Thematic Review we communicate relevant insights from the Globelics research community to **policy circles and development donor organisations**. The key issues addressed are, firstly, how the notion of LICS can help us understand the challenges of low-carbon development (LCD), and secondly, a discussion of the design of support structures for the building of LICS that contribute to low-carbon development.

Low-Carbon Development

4. Climate change is just one of several threats to **sustainable development**. However, it is the most urgent since the boundaries for a safe operating space for humanity have already been crossed when it comes to climate change. Emphasis is on what kinds of action are required at different levels (global, regional, national, and local) and by different types of actors (gov-

ernments, transnational corporations, NGOs, and organisations).

5. **Low-carbon development** is defined as strategies that mitigate emissions to avoid dangerous climate change while at the same time achieving social and economic development. In this report we point to patterns of **structural change** that would reduce the consequences of economic growth upon climate change or even support a positive climate effect.

Globally differentiated problems and responsibilities

6. Different regions and countries play **different roles** – not only when the causes and effects of the climate change problem are discussed – but also when contributing to their solution. While the wealthy countries are major contributors to the problem, the poorest countries are those that will suffer most from the consequences.
7. The processes of innovation, diffusion, and building production capacity in the South and in the North must take place in **interaction between North and South**. These processes should be interconnected and take place in parallel, rather than in sequence. Countries at different levels of development will play different roles when it comes to the development, dissemination, and use of low-carbon technologies. As new competences are built in the South, the international division of labour change over time.
8. The **advanced economies** are in a strong position to invest further in research and development of new green industries and infrastructures necessary to make low-carbon technologies competitive with fossil fuel. **Emerging economies** are increasingly engaging in competition with the advanced economies when it comes to the production of the new technologies. As consequence there is large scope not only for the emerging economies own reduction in contribution to global warming, but also for innovation that reduces the price of low-carbon solutions and for the development of technologies that are particularly relevant in poor countries.
9. **Low and middle income economies** will need to build both adaptive and innovative capacity in the enterprise sector in combination with upgrading the skills of end users. Capabilities should be directed toward low-carbon which combines energy poverty support reduction, economic development and climate change motivation and adaptation. Technological needs in those countries typically have an emphasis on affordable access to energy and to small-scale decentralised energy sources, particularly in rural areas.

Learning, innovation, and low-carbon technology

10. The term **low-carbon technology** refers to technologies that exploit renewable resources such as wind, solar, and water as well as tech-

nologies that help to reduce the climate impact of fossil fuel technologies. The development, dissemination, and use of low-carbon technologies are important prerequisites for tackling climate change.

11. It is not feasible to limit the discussion to the technical aspects of learning, innovation, and competence building. It is necessary **to rethink substantial parts of the development process as a learning process**. There are numerous sources of learning spanning from outcomes of scientific research to the development of new skills among end-users. Shifting the attention toward learning and innovation capabilities is a way to increase the effectiveness of deployment and use of low-carbon technologies.
12. Low-carbon development requires **organisational and institutional change** as well as changes in the realms, instruments, and techniques of policy making. Low-carbon development requires a radical and complex process of change. Innovation systems at different levels will be involved (including the regional, national, and even global levels), and many sectors and technologies will be affected. Rapid structural change is needed, as are high and continually increasing rates of investments and, not least, accelerated rates of learning among individuals and within organisations.
13. The future demand for low-carbon technologies will reflect **values** as well as policy interventions. Both the consumerism in wealthy countries and its role as a model of aspiration for the growing middle classes in the emerging economies need to be changed. Strategies that foster such a change need to combine regulation with public information and with citizen involvement. Key issues include the linking of collective responsibility to private self-preservation, and the interaction between more strict regulation and the formation of new routines and norms.
14. A realistic assessment of **barriers** to the development and diffusion of low-carbon technologies is required. Some barriers reflect governance problems with national and vested interests obstructing change. Others reflect path dependency and the fact that the existing energy infrastructure is streamlined to fit the use of carbon-based technologies. The introduction of innovative solutions to overcome these barriers are necessary for progress in the struggle against global warming.
15. It is equally important to understand the **drivers** that may help accelerate the development and use of low-carbon technologies. First-mover advantages in the production of low-carbon technologies may stimulate private initiative as well as national policies building production capacity. Critical consumers and citizens may force the business sector actors to engage in the promotion and use of low carbon technologies. In the current situation with 'free resources' in terms of unemployment and big corporate savings in search of profitable new investment opportunities, a new green model

of economic development may open a path out of a threatening global stagnation.

16. Inspiration for new strategies in development, such as those outlined in this review, ultimately depends on a change in perceptions of the nature of low-carbon innovation. Partners and stakeholders need to be convinced that **innovation is a comprehensive and interactive process** – which is not only, or even primarily, about breakthrough 'high tech' equipment emerging from R&D labs. Innovation is stepwise improvement and depends on change in values, policies, institutional frameworks, cultures, and economies.

Innovation policy and low-carbon development

17. **Innovation policies** must address both specific low-carbon technologies and the infrastructures within which they are deployed. Developing and disseminating renewable energy systems may prove ineffective, even impossible, for energy sector transformation, if it is not complemented by appropriate **infrastructure transformation**.
18. There is need for **differentiated policy intervention**. The distinction between different types of innovation – incremental innovation, disruptive innovation, and radical innovation – allows us to see the need for different types of policy intervention. Innovation may take different forms depending on the renewable technology in question.
19. **Market-based instruments** such as carbon taxes and renewable energy quotas can induce incremental innovation. Disruptive innovations and their dissemination require technology-specific policies, market formation, and public procurement to stimulate competence-building and nascent markets.
20. Internationally coordinated and **government-driven mission-oriented programs** are required to initiate radical change in the supply of low-carbon energy. Radical low-carbon energy innovation calls for investments in a range of diverse and experimental avenues of research. To give new direction to development in the direction of low-carbon development, the individual initiatives by private actors are insufficient due to market failure; in these cases there is a need for an 'entrepreneurial state'.

Building low-carbon energy systems

21. The transformations of **energy systems** are critical to low-carbon development. Transformation involves innovation and innovation policy measures along at least four broad lines: i) the energy supply side and energy access, ii) energy demand, energy efficiency and social legitimacy, iii) development and dissemination of low-carbon infrastructures to facilitate changes in the supply and demand sides of energy, and iv) the dismantling of high-carbon energy systems.
22. On the **supply side**, policy makers need to understand the long run interplay between

carbon-based technologies and renewable energy technologies. The current cost structure does not reflect externalities, such as global warming, and therefore it serves as an important incentive for the use of inexpensive carbon-based technologies. Investments made today will reduce the long-run cost of tackling climate change. Over time, innovation and technological learning combined with the deployment and use of renewable energy technology will make renewable alternatives more competitive and will reduce externalities.

23. On the **demand side**, increased energy efficiency is crucial for tackling global warming. A large potential for energy efficiency remains untapped, not least in emerging and developing countries where energy efficiency is low. Given their vast current and future consumption levels, not least in emerging economies such as China, India, Brazil and South Africa, the potential for energy-saving innovation is enormous. For instance, energy performance standards for buildings will become a central policy instrument. This may be combined with transferring good lessons from developed economies and from international technological knowledge sharing.
24. Changes toward a low-carbon economy will necessarily involve the transformation of **infrastructures**. Electricity transmission is particularly relevant for the development and large-scale deployment of renewable energy technologies. Sources of renewable energy are generally concentrated in areas located far from areas of electricity consumption, making efficient infrastructural connections between sources and users a crucial challenge. The absence of transmission grids (and credible plans for their establishment) blocks investments in energy transformation systems. This contributes further to the uneven competition between low- and high-carbon technologies.
25. Governments should lead **infrastructure transformations** due to the public good nature and immense upfront investment costs. Transforming and building infrastructures are central to low-carbon development. Incremental innovation is possible within existing infrastructures, while disruptive innovation requires significant transformation of infrastructures. Radical innovation will require completely new infrastructures, not the least those for decentralised energy systems.
26. It is necessary to address not only the development of renewable energy technologies but also the '**dismantling**' of systems for fossil energy technology. The destructive aspect of a green energy system transformation is just as important as the creative aspect. Fossil and renewable energy sources are in direct but uneven and unfair competition.

General recommendations

27. Development policy should seek to combine the human development and environmental sustainability objectives through promotion

of processes of learning, innovation, and development. Few organisations have started to **bring innovation and low-carbon development together** in policies for system development**.** This is what this review seeks to do.

28. Some of the recommendations require a higher level of **governance capacity** in public organisations. To enhance governance capacity may thus be a prerequisite for low-carbon development.
29. Policy is about **taking manageable steps in the right direction and to engage in policy learning** rather than seeking to design optimal policies upfront. Furthermore, unpopular but necessary policies for sustainability transitions must be introduced in a strategic, stepwise manner. Governments and other actors should continue to develop new instruments and adjust existing instruments to new technologies and local circumstances.
30. Building and **strengthening national local LICS** is necessary for achieving a self-directed and wide-scale adaptation, dissemination, and use of new low-carbon technologies. Creating local demand for technology requires market-formation policies, but without local LICS, this will not translate into a demand for new knowledge.
31. **Linkage formation** is crucial to the formation of local LICS. Experience shows, that while it has been possible to build LICS components (e.g. universities, research institutes, R&D regulations, etc.) in the South, it has been much more difficult to stimulate the interactions between components, mainly because of lacking demand for knowledge. New connections can centre on direct creation of sustainable energy access and on indirect creation of industrial and economic development.
32. At the local level, securing **energy access** is about building new energy LICS in rural areas and transforming the existing urban ones. Building new rural energy systems requires new energy routines, new institutions, and competence building for the application of new energy sources. Policies should focus on making new energy technology available, supporting market formation via microcredit financing and thus creating socially inclusive learning spaces to facilitate the shift in energy technology.
33. The **industrial and economic development** dimension of low-carbon development is crucial to ensure the production capacity for dissemination as well as the economic development of countries in the South. A central element of low-carbon development is that countries can develop green jobs and build their competence base. A range of jobs and tasks are involved in the various stages of energy provision, from component manufacturing to operation and maintenance. **Innovation-oriented local content requirement** policy in combination with **directed public procurement** schemes are key instruments that may help stimulate this process at the national level.

34. Policies for supporting local innovation capabilities are not an alternative to global diffusion, but a necessary complement. **Global diffusion and local innovation goes hand in hand**. International 'technology transfer' tends to be ineffective without complementary investments in local capability to creative engagement in the absorption and further development of knowledge and equipment from abroad. Countries in the South must build renewable energy technology-specific LICS in order to successfully receive new technology and subsequently adapt it to local conditions and ensure large-scale dissemination and use.
35. Low-carbon development involves building low-carbon LICS in both the North and the South, and stimulating their interaction. There is a growing consensus that international action to harness technology for climate change mitigation and general development in the South must go beyond a debate of technology transfer to focus instead on **innovation cooperation**, i.e., joint action to accelerate the development, adaptation, and deployment of suitable technologies. Innovation cooperation needs to extend beyond the technological aspect and encompass other facets of the innovation system that support the deployment of technology and builds capabilities. A better understanding of the role of local innovation in developing countries for achieving and sustaining low-carbon development is urgently needed.

Recommendations to donor organisations

36. Donor organisations should seek to **support experimentation with new business models** for decentralised energy provision, bringing together system actors such as energy service providers, financial institutions, equipment manufacturers, and suppliers of operation and maintenance services. This support may combine policies for renewable energy with funding for infrastructure such as microgrids. It will also involve consultations that bring together local community government and service providers to combine service-level standards and social standards for democratising technology choices and enhancing job generation.
37. Engaging with and **supporting system operators** with the capacity for oversight in particular technology fields are crucial to provide advice and connect stakeholders. System operator organisation can facilitate project replication and up scaling. A key task for donors is to engage with local administrations to build the 'meta-capabilities' necessary for bringing together and orchestrating the various actors. Bringing experiences and capabilities to the system level should be a key priority area.
38. Support mechanisms to enhance **South-South technology transfer** by organising matchmaking events for buyers and suppliers of appropriate sustainable technologies in the global South. South-South collaboration is likely to be particularly important in this regard. The emerging economies of BRICS are in a strong

position to advance relevant and affordable technologies because their conditions are similar to those in poor countries. Donors should actively work to bring together the relevant actors in the global South and provide platforms for collaboration. Some Northern donors have started working with 'triangular cooperation methods' in low-carbon fields where the donors actively facilitate technology collaboration and exchange between Southern partners

39. Support **awareness raising and curriculum development** for low-carbon and sustainable development. Educational systems are crucial elements of low-carbon LICS because they are central to influencing the values that form aspirations, consumptions choices, and capabilities for 'low-carbon behaviour' – from the recycling of existing products to the development of new innovative products and processes. Many donors are in a strong position to influence policies in favour of a commitment to education. Donor organisations and policy makers leverage existing educational initiatives to develop low-carbon development campaigns at different levels of the school system.
40. One key role of donors is to create **new alliances for financing**. Introduce initiatives that connect institutional investors in developed countries with green energy investors in the developing world. One particularly important task in this respect is to help set up channels connecting finance in the OECD countries with low-carbon investment needs in the developing world.
41. Donor organisations may need to find ways of making **long term commitments** to low carbon development. It may be necessary to pool donor support into funds to be able to finance parts of the energy transformations in low income countries. For example, donors may help finance feed-in tariffs so that the costs is shifted away from poor consumers in the South to large-scale donor funds to ensure that transformation does not adversely affect existing energy consumers.
42. International organisations also have a key role to play in **shaping perceptions** and discourses of low-carbon development. Efforts focused on climate change mitigation sometimes overlook the developing world's energy access imperatives, with the result that those policies are often allowed to gravitate towards cheaper, high-carbon solutions. More comprehensive efforts directed at low carbon development sometimes overlook the crucial role of learning and innovation.
43. A **change of values** is needed in the global community. International policy debates are not yet driven by the proposed new notion of low-carbon development. The policy agenda is often driven by the more narrow notions of climate change and is heavily influenced by economic interest. Those engaged in international assistance can help to spearhead this process – in recipient countries as well as at home.

1. Innovation for low-carbon development
Stating the problem

Among climate researchers, there is increasing agreement that the rise in the global mean temperature is due to a human-induced atmospheric concentration of greenhouse gases. If climate change is to remain within acceptable bounds, both in terms of pace and magnitude, the current systems for producing energy-based fossil fuels must be changed gradually into systems based on renewable energy; the direct as well as the indirect consumption of energy must be reduced. In this thematic review, we define and describe *low-carbon development* as an important element of such a reduction in greenhouse gas emissions.

To be effective in curbing climate change, low-carbon development must be implemented globally, i.e., in the North as well as in the South. Such a dramatic change in development paths will probably be unfeasible without a globally negotiated distribution of the burdens and benefits in accordance with accepted principles of fairness. The necessity of shifting toward low-carbon development in international agreements is obvious when considering both the global character of climate change and the greatly unequal distribution of technical and institutional capabilities and living standards between the North and South. It becomes even more obvious when one considers the importance to this process of knowledge development and knowledge destruction.

Various kinds of technical and institutional innovation are necessary in order to restructure production and consumption toward more sustainable socio-economic systems. The recognition that innovation is interactive is essential; hence, the innovative path and performance of an economy – whether a country, region, or sector – is a result not only of the innovation performance of individual firms, but also their interaction with each other and with other systems, not least the financial, political, and research systems.

Within the context of structural change toward sustainability, the focus of this review is on the role of increased reliance on renewable energy sources. More specifically, we explore how an internationally coordinated development of low-carbon learning, innovation, and competence building systems can contribute to climate change mitigation.

Learning, innovation, and competence building systems (LICS) are at the heart of this report. A basic assumption is that a 'systems perspectives' can contribute to the design and implementation of better development strategies. The notion of LICS implies that economic and social development depends on innovation. Successful innovation requires multiple layers of interaction and learning among a wide range of individuals, organisations, and institutions.

The key issues addressed in this review are, firstly, how the notion of LICS can help us understand the challenges of low-carbon development (LCD), and secondly, how the design of support structures for the building of LICS contributes to the strengthening of LCD.

Supporting low-carbon LICS rests on the development of knowledge infrastructures, institutions, and learning capabilities. The building of such systems is usually a long process, which, given the nature and urgency of the climate challenge, presents a problem of its own. Therefore, it is essential to identify the key leverage points for stimulating the process.

The building of low-carbon LICS is only part of the restructuring toward LCD. In addition to its urgency, the process involves complex issues not only of infrastructure, industrial capacity, investments, technology, and energy efficiency, but also the influence of institutional/cultural factors, social inclusion, and energy access. Low-carbon development will not, however, be implemented unless these problems are tackled.

It is becoming increasingly clear that low-carbon development will not be a smooth and harmonious process in which countries and companies work together in order to achieve their common interest in climate change mitigation. The challenges posed by a number of tensions will much more likely lead to conflict. Tension exists between the interests of the North and the South, between a broad push for socially and environmentally sustainable development and a narrower agenda of climate change mitigation. Other tensions exist among established and new technologies. The tensions will affect policy making, which will have to deal with conflicts about the distribution of income, wealth, and power in the sharing of costs and the benefits of structural change.

This review draws on research within the Globelics community in order to demonstrate key insights into the process of supporting LICS for low-carbon development. It seeks to bring together the development, climate change, and innovation agendas. This is important because, as the global climate change regime moves ahead, the need for investment in innovation related to climate change mitigation and adaptation in poor countries and communities will increase. The funds available for the introduction of new technologies, not the least in Africa, are also likely to increase. Substantial opportunities for the funding of low-carbon innovations and related systems will arise. Ensuring that system-building initiatives are appropriate to local contexts is crucially important to national policy makers and donor organisations seeking to integrate climate change mitigation with a development agenda.

1.1 Planetary boundaries and climate crisis

Climate change is only one major environmental problem facing humanity. Since the publication of *Limits to Growth* (Meadows et al., 1972), it has become increasingly clear that the consequences of human economic activity are challenging the 'carrying capacity' of the planet.[1] In the 1980s, the Brundtland Commission epitomized this as the notion of sustainable development, defined as development that meets the needs of the present without compromising the ability of future generations to meet their needs (WCED, 1987). In order to adhere to this principle, it is necessary to stay within the biophysical thresholds for the carrying capacity of the planet. If this is ignored, future generations will be faced with dire consequences. In the run-up to the 2009 United Nations Climate Change Conference in Copenhagen, Rockstrom et al. (2009) identified nine planetary boundaries that define a safe operating space for humanity. The transgression of these boundaries is likely to cause unacceptable and irreversible environmental damage. The boundaries reflect nine interlinked processes:

1. Climate change;
2. Biodiversity loss (terrestrial and marine);
3. Bio-geochemical change (interference with the nitrogen cycle);
4. Change in land use;
5. Global freshwater use;
6. Ocean acidification;
7. Stratospheric ozone depletion;
8. Chemical pollution; and
9. Atmospheric aerosol loading.

With respect to the first three processes, we have already exceeded the safe boundaries while we are close to overstepping them for processes 4-6. With respect to the remaining boundaries, we are still within safe operating limits (land use and stratospheric ozone depletion), or we do not yet know the extent of the problem (chemical pollution and atmospheric aerosol loading).

The highest priority should be to address the problems created by the transgressions already made. However, although the processes can often be addressed individually with specific measures, the interdependent nature of the problems should be recognised. In the words of Rockstrom et al.: 'Because many of the boundaries are linked, exceeding one will have implications for others in ways that we do not as yet completely understand' (2009, p. 475). However, some of the interlinking processes have already been mapped. For example, the rise in sea levels caused by climate change may accelerate diversity loss and change conditions for freshwater use through the intrusion of saltwater. The fact that addressing one problem may come at expense of others is another aspect of the interdependency. For example, concentrated solar power (CSP) is a promising technology that addresses climate change, but the vast quantity of freshwater required presents a problem; CSP systems are typically located in places with scarce water resources (Bucknall, 2013). Although hydropower is another promising technology, it often has major negative consequences for the communities affected by construction of dams, and freshwater withdrawal is a serious threat (Wales, 2013).[2] There are countless such trade-offs and unintended consequences effects.

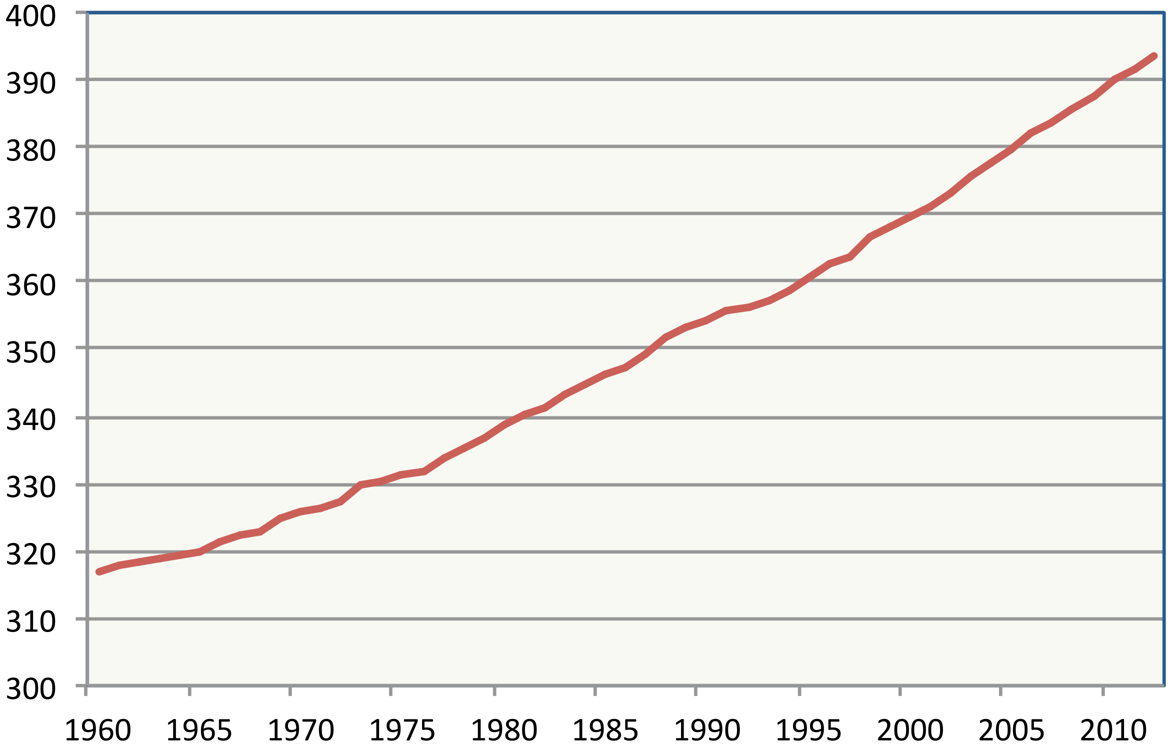
It is clear that addressing human-induced climate change in itself will not lead to environmentally sustainable development. Climate change mitigation is a necessary, although insufficient, step toward this goal. Such development requires that all the planetary boundaries be respected. At present, climate change is the most urgent issue, but an overly narrow focus on low-carbon innovation may mean not only that the other boundaries receive inadequate attention, but also that their interdependencies are overlooked (Altenburg & Pegels, 2012, p. 8; Mulugetta & Urban, 2010, p. 7549). Any solution involved in climate change mitigation needs to be considered in relation to the broader perspective of sustainable development.

Although three of the planetary boundaries have already been overstepped and they all pose a threat to human existence, the most immediate danger, i.e., of climate change, has become one of the most pressing issues of our time. There is now almost universal agreement that the global mean temperature is rising due to the human-induced increase in carbon dioxide (CO_2) and other greenhouse gases in the atmosphere.[3] In 2013, for the first time in 4.5 million years, the atmospheric level of CO_2 exceeded 400 parts per million (EIA, 2013). Since the mid-1900s we have rapidly been moving beyond the planetary boundary for atmospheric carbon dioxide concentration, which Rockstrom et al. (2009) calculated at 350 ppm (see fig. 1).

As a result, the climate on earth is changing – on average getting warmer – with rising sea levels and 'climate chaoses' characterised by more frequent and stronger weather phenomena such as droughts, floods, storms, and heat waves. According to the EIA, the goal of limiting the global long-term average temperature rise to 2 °C above preindustrial levels 'remains technically feasible, though extremely challenging' (EIA, 2013, p. 9). Without action, rises are more likely to be between 3.6 °C and 5.3 °C, with the bulk of the changes occurring before 2100.

Keeping within the 2°C threshold is possible only with very rapid 'decarbonisation', i.e., a reduction of carbon emissions in the energy sector and in the whole economy (Schmitz & Becker, 2013). The Intergovernmental Panel on Climate Change suggested in its *Fourth Assessment Report* that, by 2050, carbon emissions needed to be reduced 50 percent from 1990 levels, starting in 2015 (IPCC, 2007). To have a realistic chance of limiting the probability of a global temperature increase to less than 2°C during this century, GHG emissions

Fig. 1. Accumulation of atmospheric CO_2 concentration



Source: NOAA/ESRL (2013). Parts per million (yearly averages) measured at Mauna Loa, Hawaii.

must be reduced by approximately 80 percent before 2050.

There is widespread agreement, however, that this schedule for reducing carbon emissions will not be met: 'The world is not on track to meet the target agreed by governments to limit the long-term rise in the average global temperature to 2 degrees Celsius' (OECD/IEA, 2013, p. 9). A new climate change agreement within the United Nations Framework Convention on Climate Change (UNFCCC) should be in place by 2020, but major changes are required to maintain any chance of reaching the 2 °C target. As emphasised below, the necessary changes are massive and it seems unrealistic that major changes would be implemented in the short run. However, problems are growing as we approach an environmental tipping point; at that point, the costs of tackling climate change will rise and the urgency of changing from finite resources will increase:

> The question is thus not whether the global economy will adopt resource-efficient (and particularly low-carbon) production or not: it will have to. The question is whether this transition will be organised before major environmental and economic crises occur or whether abatement action will be taken only under the pressure of acute crises and at a far higher cost (Altenburg & Pegels, 2012, p. 8).

Therefore, the world is faced with a deadline. At the core of the challenge is the global economic system's dependence on fossil fuel-based energy sources. The energy sources currently being exploited emit greenhouse gases that lead to climate change. Since the current economic systems are predominantly based on fossil fuels, a drastic change is necessary and hinges on the creation of CO_2 neutral systems.[4]

This would help to mitigate climate change by reducing and phasing out fossil fuels and changing the energy consumption patterns. The global economy will need to adopt resource-efficient modes of production. In the short run, the most efficient techniques currently available need to be adopted, but in the longer run entirely new techniques need to be developed (to be discussed in the next section). Very drastic reductions in the degree of dependence on fossil fuels are necessary within a relatively short time. A rapid implementation of such drastic reductions is difficult to undertake because of the magnitude of the changes involved. The vastness of a low-carbon transition is equal to earlier large-scale societal transformations such as the industrial revolution. As the United Nations Department of Economic and Social Affairs has put it, a 'global green technological transformation, greater in scale and achievable within a much shorter time-frame than the first industrial revolution' is required (UNDESA, 2011, p. 1).

Revolutions entail broad interlocking societal changes, but even single components of change present major challenges. For example, the electricity sector is a key component in this respect. Decarbonising the global electricity sector by 2050 would require an added low-carbon capacity of about 32,000 terawatt hours per year, five times the capacity of the whole power sector in 1973 (Jacobsson & Bergek, 2004). A total replacement of hydrocarbons in energy production by 2050 would imply that the renewable energy industry must double its capacity every seven years for 70 years. Conversely, after two centuries of increase in carbon-based energy at the magnitude of 3.5 percent annually, the world must learn to reduce its dependence on carbon at the same rate for decades ahead (Laestadius, 2013). Reducing the energy use and greenhouse gas emissions associated with growing and increasingly urban populations will require drastic changes in consumption patterns, transportation and industry systems, residential and building infrastructures, and water and sanitation systems.

History offers many examples of major environmental crises that have severely reduced populations or forced them to move away from their habitats. However, the global scale of the climate change makes it a different challenge. Moreover, its causes and effects are distributed unequally across the globe. Climate change affects continents and regions very differently, with the least developed regions most negatively affected. These countries, in turn, have comparatively low per capita emission rates. Hence, those least responsible for climate change are those that are most vulnerable to it. The global problems of poverty and climate change are therefore closely interrelated. Any effort to tackle poverty on a global scale – to lift poor sections of societies into the middle classes – through the stimulation of income growth created and sustained by existing energy-related technologies will lead to gross overstepping of the planetary boundaries. The next section will elaborate on the interlocking nature of this complex of problems.

1.2 Development, fairness, and limits to growth

From an historical perspective, economic growth has been concentrated in the established economic powers, i.e., the OECD countries, which have also accounted for the majority of carbon emissions. More recently, global economic growth has been fuelled by new economic powers, i.e., large developing countries such as Brazil, China, India, and South Africa. Critically, the energy-intensive lifestyle of current advanced economies are now being emulated globally (Wolf, 2012). This increases the environmental pressure as it aggravates the problems of the unequal distribution of income between countries, which are in turn connected with powerful 'demonstration effects'.[5]

To remedy this situation, values that induce more environment-friendly lifestyles and consumption patterns must be developed first in wealthy countries, as these have been in the forefront of defining aspirations for the global middle classes. Although the concept of low-carbon development was championed by donor agencies (pioneered by DFID in the United Kingdom, in particular), the process does not depend primarily on mitigation and adaptation strategies in and for the developing world. The United States and Europe, which have led the development of consumerism that inflicted heavy damage on the climate, now have to take the lead in developing new environmental values. The attention of both producers and consumers must be directed toward conserving environmental resources through a combination of regulations and incentives. Furthermore, a shift in values and ethics is necessary. The current imperatives of 'more is better', combined with the observation that human needs are relative – they are defined in relation to what people have, they are not absolute – makes it impossible to procure enough goods and services, regardless of the scale of economic growth. Without changes in values and ethics, development will remain locked into growth-dominated modes with poor outlooks for sustainability.

Although 'frugal innovations' from the developing world may show the world how to reduce materials and waste, it seems that the core changes in value have to come from the top of the income distribution hierarchy where aspiration level's tend to defined; in this sense a bottom-up approach starting in the developing world will not work. Urging the rapidly growing emerging economies to take their 'fair' share of the responsibility for the global environment – as seems to be the view of most high-income countries – does not convince developing countries, because it is unfair. Moreover, it will not increase the sustainability of consumer values. The implication is not that the wealthy world should take responsibility for low-carbon development while the developing world should do the 'development' part. On the contrary, the implication is that low-carbon development should be a global, albeit a globally differentiated, process that promotes much more than just 'green growth'. The process fosters economic growth while making growth processes sustainable (Hallegatte et al., 2012).

Green growth will not be capable of overcoming the long-term limits on growth (Jackson, 2009). It is useful to see the problem in an evolutionary perspective: we understand production as energy and that materials are made into goods and services for consumption in a process directed and controlled by knowledge. If we expect production to grow exponentially, the production process will eventually meet material and energy limits because exponential decrease in the material and energy requirements of production is difficult to imagine. This is also the case when we take recycling into account. The total decoupling of materials and energy from production growth is probably unattainable.

However, if we assume (as we often do) that the growth of knowledge will not meet with comparable limits on materials and energy, we may postpone putting limits on the growth of the creation, distribution, and use of new knowledge. In fact, any serious move toward a new development path radically less wasteful of energy and materials has to rely on the development and implementation of new knowledge. In other words, it will hinge on innovation. We may call this 'dynamic economising' with materials and energy. This means that we should use not only the existing resources in the most efficient way within the possibilities offered by existing technologies, but constantly develop new knowledge and resources that enable us to economise even further.

It is important to observe that a discussion of the economic growth process under the restraint of the material and energy side covers only one aspect of the problem. We may refer to this as the 'source side', where the transformation of materials and energy creates unwanted by-products. However, there is also another side, the 'sink side' of the problem, which concerns the storage and concentration of those by-products. This side is closely linked to the limited 'carrying capacity' of the earth that was mentioned earlier.[6] Even allowing for a permeable boundary between sinks and sources, the planetary boundaries are all predominantly the result of the earth's limited carrying capacity on the sink side.

1.3 Green path creation as a solution to carbon lock-in

It is widely agreed that countries in the North are often deeply locked into fossil fuel-based energy systems (Smith, 2009; Unruh, 2000) and that most developing countries are following a similar path of carbon-intensive energy systems (Unruh & Carrillo-Hermosilla, 2006). The factors driving 'carbon lock-in' are multiple, but four factors seem essential.

- Energy technologies typically feed into larger technological systems that are central to the functioning of society; they are not individual artefacts that can be changed independently. This feature of energy technology and the weight of other sectors' dependency on energy make energy technological systems difficult to change.
- Like other technological systems, energy technologies are subject to path dependency. When understanding technology as a socio-technical system consisting of interlinked artefacts, path dependency is created by the interaction of factors such as economies of scale, network externalities, adaptive expectations, and knowledge accumulation. These mechanisms are enforced where interindustrial dependencies are present.
- At the organisational level, the difficulties that firms encounter in reorienting their core competences impede the shift to low-carbon development. Incumbent technologies have demonstrated the capacity for radical performance improvement when threatened by emerging technologies. For example, the ongoing 'shale gas revolution' indicates that fossil energy is fighting back rather than going green.
- Incumbent actors are often vastly superior to new 'green' actors in terms not only of financial and human resources, but also of political influence; these factors may amount to powerful resistance to change. This is further aggravated by the fact that many of the organisations in need of transformation hold powerful positions, such as public companies, ministries, and energy agencies with strong political influence (Walz, 2007).

The mechanisms leading to lock-in are often supported by formal as well as informal institutions in terms of consumption routines, energy use, and infrastructure operation (Unruh, 2000). This makes the shift to LCD difficult in general but there are additional factors underlying the carbon lock-in that is taking place in the developing world.

Although developing countries have multiple opportunities to move along distinct innovation paths and reduce the carbon intensity of development trajectories, strong forces are working against this. A case in point is the relative immaturity of most green technologies. For example, even though the number and scale of renewable energy technologies (RETs) are increasing in the South, most countries will remain largely fossil-dependent for the near future. RETs cannot yet be considered ‘plug and play’ commodities because they tend to disrupt electric systems (or fuel systems) or depend upon costly system-level changes.

Secondly, local capacity for mastering the direction of technological development is often insufficient. Energy technologies are mainly in the hands of large multinational enterprises (MNEs). Due to the logic of capital intensity and increasing returns to scale in energy technology, the international market is oligopolistic. It favours actors that can deliver complete packages of capital, competence, and finance. MNEs specialise mainly in standardised fossil energy packages. For the reasons mentioned above, such companies cannot be expected to facilitate technological leapfrogging.[7]

Thirdly, the expansion of renewable energy sources is costly, and most developing countries are likely to depend on international sources of finance. Three sources finance energy system investments: public, private, and multilateral organisations. Most developing countries depend on the international capital markets, whose importance in energy finance has increased over the last two decades, and on multilateral organisations. Multilateral lending organisations are essentially banks that must respond to market signals and repay debts although they might have the influence to distort prices temporarily.[8]

Fourthly, production subsidies for petroleum products, electricity, natural gas, and coal are significant. In 2011, such subsidies amounted to USD 480 billion, equivalent to 0.7 percent of global GDP, or 2 percent of total government revenue (IMF). Energy subsidisation of this kind is seen typically in the South, particularly in oil-producing economies in the Middle East and Northern Africa. The subsidies mean that renewable energy is not competing on a level playing field, but their removal is hampered by the vested interests of the beneficiaries of the system.

The notion of carbon lock-in is useful for identifying the barriers to a low carbon energy transformation, but it also tends to portray the challenge of breaking those barriers as insurmountable. Path dependency is not destiny. History is rich in examples of intentional path creation or shifting (Garud & Karnøe, 2001). Carbon lock-in is not a static state but a dynamic process in which coalitions of actors with different interests compete over the direction of change, often by exerting influence on institutional change. Lock-in and shifting paths can be overcome if ‘low carbon’ coalitions become sufficiently strong locally and internationally (Schmitz, 2013). Moreover, we observe that the carbon lock-in described above is increasingly being challenged: International think tanks, multilateral organisations, and donor agencies are stressing the need for low carbon transformation. Important financial actors are responding to the inability of financial markets to internalise the long-term cost of carbon lock-in. For example: the European Investment Bank recently restricted lending to carbon energy projects; the World Bank cut financing to coal; the UN Green Climate Fund opened in December 2013. Additionally, the Association of Chartered Certified Accountants began to develop new accountancy guidelines that clarify the cost of carbon activities. A group of 70 global investors managing more than USD 3 trillion in assets launched the first coordinated effort to spur the world's 45 top oil and gas, coal, and electric power companies to assess the financial risks emerging from continued carbon lock-in.

1.4 Low-carbon development and innovation

There are broad and narrow views of low-carbon development. In the narrow view, low-carbon development is the process of transforming the current fossil fuel-based economic system, particularly the energy system, toward CO_2 neutrality. This view closely resembles notions of low-carbon growth (Ellis et al., 2009; DFID, 2009) and is confined essentially to elements of the environmental dimension of sustainability (in particular, greenhouse gas). It is rooted in the goal of sustainable development (Mulugetta & Urban, 2010) while not necessarily addressing the multiple planetary boundaries, and especially their inter-linkages.

The broad view differs in two respects. First, in contrast to growth-focused concepts (low-carbon growth and sustainable growth), it explicitly brings together two objectives: climate change mitigation and the sustained development of low- and middle-income countries. It thus includes the social and political dimensions of sustainability. In the words of Urban and Nordensvärd:

> Low-carbon development is a recently emerged concept that aims to mitigate emissions to avoid dangerous climate change, while at the same time achieving social and economic development in a carbon constrained world (Urban & Nordensvärd, 2013, p. 7).

Low-carbon development in its broadest sense involves more than just reduced levels of carbon growth as it aims to promote international development, particularly inclusive development (see Box 1, next page). The low-carbon development concept is a projection not only of the co-existence of climate change mitigation and international development. It is also inherent in the notion that synergies between the two can be developed. For example, the push to create green energy systems before brown energy systems take hold in low-income countries may help to create energy access for the poor. However, as will be shown, there are many questions about synergies vs. conflicts between mitigation and various types of development.

The second way in which the broad view differs from the narrow is in the linkages between the transformation of the fossil fuel-based system and the planetary boundaries, i.e., between low-carbon development and environmental sustainability.

Box 1. Climate change and inclusive development

Inclusive development is a process of social and structural change, which gives voice and power to the concerns and aspirations of otherwise excluded groups. It redistributes the income generated in both the formal and informal sectors in favour of such groups, allowing them to shape the future of society in interaction with other stakeholder groups.

In the context of low-carbon development, it is important to focus on development as driven by interactive learning and innovation. Inclusive development may then be conceptualised as a process that includes otherwise marginalised groups in the process of driving structural change and economic growth toward reduced dependence on fossil fuel-based energy systems. It also gives them a fair share of both the substantial values connected to learning and the results of learning in terms of income and wealth.

Because of the sheer scale and urgency of the climate change challenge, low-carbon development needs to be inclusive. There is a need for institutions, values, and policies that are capable of including and mobilising many companies, organisations and other actors. Most importantly, large segments of the populations must be mobilised in order to break the power of interests vested in fossil-based energy. Creative destruction is a necessary part of low-carbon development and, without broad inclusion, powerful groups with carbon-based interests will be able to retard or even prevent it.

Successful low-carbon development depends on inclusive institutions and values in two ways. First, inclusion is a way to mobilise the human and natural resources and the financial powers required to increase the use of renewable energy from its current 5 percent of global energy use to nearly 100 percent. Inclusive institutions are also instrumental in the structural transformation and the connected redistribution of income and power that will necessarily accompany low-carbon development.

Secondly, inclusion has substantive intrinsic value in development. The broad inclusion of all groups in the discourse about low-carbon development as well as in the implementation process will stimulate capability building in the population as they are drawn into learning and innovation activities. It may be argued that this is the true meaning of development. It is also reasonable to assume that the instrumental and substantive values of low-carbon development will be mutually supportive and strengthening. If inclusion is valued for its own sake, it is more likely that people will engage in the process of low-carbon development despite the costs involved.

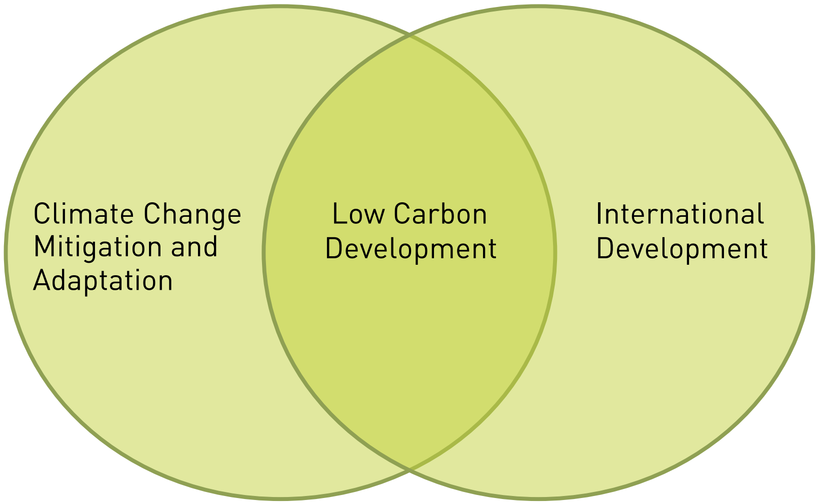
Sources: Johnson and Andersen (2012) and Section 2.5 of this report.

Low-carbon development is defined occasionally in ways that fall short of the notion of sustainable development. Under the definition provided by Urban and Nordensvärd above (2013, p. 7), low-carbon development is – strictly speaking – consistent with transgressing all the planetary boundaries except climate change. However, for the reasons outlined in this chapter, the interdependencies between related environmental problems should be acknowledged explicitly. The notion of low-carbon development works primarily as a focusing device, directing the attention toward what is probably the most immediate and serious environmental threat, but it should not replace the notion of sustainable development.

We define low-carbon development as structural change that simultaneously improves living conditions in low- and middle-income countries and helps to mitigate climate change without adverse effects for other planetary boundaries (fig. 2).

Engaging in low-carbon development means that innovation needs to take a new course that supports the shift to a 'green techno-economic paradigm' (Freeman, 1996, p. 38). It is more about the direction of innovation than about the rate of innovation. The green transformation will require

Fig. 2. Defining low-carbon development – an illustration



Source: Modified from Urban and Nordensvärd (2013).

major changes in production and consumption across a range of technological spheres, not the least energy, transport, and construction. It will be a process of 'creative destruction' (Schumpeter, 2010 [1942]; Bergek et al., 2013) in the original sense of the term: existing economic systems have to be destructed while new and more environmentally sound ones are created in their place.

This report uses a systems perspective to the transformational challenges. The innovation system concept was developed in the late 1980s by scholars in Europe (Freeman & Lundvall, 1988; Lundvall, 1992) and the United States (Nelson, 1993). These scholars agreed that in order to understand how learning and innovation take place, it is crucial to understand the interaction between organisations at the level of the national 'system'. Since the 1980s, our understanding of the systemic nature of innovation has progressed dramatically. Over the last ten years, the systems concept has become used widely in studies of learning and innovation in developing countries (Lundvall, 2009; Lundvall et al., 2006; Malerba & Mani, 2009; Kraemer-Mbula & Wamae, 2010).

Since the emergence of the innovation system concept, research into systems has taken two different perspectives; the first adopted a narrow focus, linking innovation to science and technology. The second, and broader, perspective encompasses learning, innovation, and competence building at different levels of aggregation; it includes experience-based as well as science-based innovation. Narrow definitions of the innovation system are of limited relevance when it comes to understanding the problems of developing economies. In fact, narrow innovation system concepts may be misleading for innovation policies in advanced countries, too.

Competence building and innovation stem not only from science-based, but also from experience-based, learning, which unfolds among many systems actors; these include business enterprises and intermediaries such as applied research institutes. Learning based on experience may complement science-based learning through all phases of development, but the former is very important in the early stages of development, where the science system is somewhat disconnected from the needs of the productive economy (Arnold & Bell, 2001).

Scholars in the Globelics network have explicitly sought to capture a broad systems approach by referring to LICS rather than solely to innovation systems, but the theoretical heritage from innovation system research (Lundvall, 1992; Nelson 1993) is explicitly acknowledged. At the core of the concept is the importance of tacit knowledge and interactive learning for innovation and growth. Contrary to the view that knowledge is a pure public good, a range of research in the field of innovation studies has demonstrated that important components of knowledge are tacit and difficult to understand out of context (Nelson and Winter, 1982; von Hippel, 1994; Johnson et al., 2002). This contextually rich knowledge may prove costly or even impossible to transfer through the use of codified supports or instruments such as manuals or journals.

Another core idea is that generating novelty depends on interaction among actors with related but different knowledge. Without this variety or difference there is a risk of myopia and of missing out on the perception of new opportunities (Nooteboom, 2000, pp. 72-73). For firms, one way to foster the exploitation of variety in knowledge is interactive learning within them, both among teams and between services and divisions. Another way is through interaction with other firms and organisations in order to draw on outside sources of related but different knowledge. This idea is developed in Lundvall's (1985) work on the role of user-producer interactions in national innovation systems.

Box 2. What are LICS?

The concept of learning, innovation, and competence building systems (LICS) is a further development of the innovation system concept. It refers both to the system components (such as firms, universities, research organisations, vocational training institutes, and so forth) as well as to the institutions that influence their interactions. It is the nature and frequency of interactions in the systems that determine the rate and direction of learning, innovation, and competence building. The LICS approach to development research is based on the premises that learning, innovation, and competence building are interdependent processes:

- *Learning* may refer to attainment and deepening of skills and know-how as well as to increasingly more adequate information about the world. Learning may take place when pursuing routine economic activities or as result of search processes, including research.
- *Innovation* refers to both productive practices that are new to the context and to the capacity to develop new technologies for the world. It requires a mix of experience-based learning and learning from research and development (R&D) activities.
- *Competence building* is the upgrading of skills and capabilities through organisational learning or through investments in educations and training, both in firms and society as a whole.

The concept of LICS puts the mutually reinforcing processes of learning, innovation, and competence building at the heart of the development process. It is fundamental to the notion of LICS that local context matters: highly abstract systems analysis or policy that ignore the specificities of particular environments can be of only limited use in understanding and promoting innovation and development.

Note: See Section 2.1 for a more detailed discussion of the LICS concept.

Box 2 introduces the LICS concept and a more complete discussion is provided in the next chapter. The notion of LICS is built on many years of innovation systems research, but it is devised for analyses in the context of developing countries. As Cozzens and Sutz emphasise, the notion of LICS 'opened the road to acknowledging that definitively one size does not fit all in terms of an innovation systems approach, and the specific characteristics of innovation systems in developing countries started to be analysed' (Cozzens & Sutz, 2012, p. 10).

Recently, a number of studies have tried explicitly to apply a learning and innovation perspective to the low-carbon challenge. This literature has focused mainly on the North (Kemp & Soete, 1992; Geels, 2002; Jacobsson & Bergek, 2004), but a growing body of research focuses specifically on developing countries (Altenburg & Pegels, 2012; Ockwell et al., 2008; Berkhout et al., 2010; UN-DESA, 2011). In this report the notion of low-carbon LICS is defined as the system of knowledge institutions, business, policy makers, and users who are involved in developing, using, and evaluating solutions for low-carbon development.

The focus of this report is on the climate change mitigation aspects of low-carbon development, although we acknowledge that adaptation is a necessary and important element of low-carbon development. We also acknowledge that a 'huge diversity of innovation-related adaptation issues will arise in poor countries' due to climate change (Bell, 2009, p. 54).

The UNFCC defines climate change adaptation as adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. This implies that communities anticipate adverse effects and take action to reduce the damage caused by, e.g., flooding, sporadic seasonal change, storms, and draughts. For local communities, policies at the global and national levels are often less relevant because the effects of climate change tend to vary locally. Policies at the local level are more important in this respect and the efforts to support learning initiatives seem particularly important. For example, for users of agricultural land, climate change adaptation must be enhanced by user-driven innovation. The climate change research community has often used the notion of climate change resilience, but this term seems to emphasise resistance to externally created pressures. Emphasis should be placed on the capacity to create new processes and organisational arrangements, rather than particular products. As is true of the mitigation side, the most important element at the adaptation side may reside in the strengthening of local innovation capabilities.

2. LICS and low-carbon development

This chapter introduces the notion of learning, innovation, and competence-building systems (LICS) for a discussion of the requirements of low-carbon development. This development aims at strengthening LICS so that they are reoriented toward contributing to the goals inherent to this development. Since low-carbon development is a process of radical change, it involves LICS on the regional, national, and global levels. Many sectors and technologies are also involved.

We argue that economic growth and structural change are crucial aspects of low-carbon development and that to grasp its possibilities and difficulties, focus has to be on knowledge creation and utilisation, i.e., on learning and innovation. We identify a number of areas in which innovation (technical as well as organisational and institutional) would be helpful for low-carbon development. To implement this, innovation policy has to be reoriented from general innovation support to directed innovation support, which should be reflected in any effort to build or support LICS.

We proceed to discuss the necessity of new or changed values, institutions and policies in the implementation of low-carbon development. A particularly important aspect is the role of social inclusion in such changes.

Finally, we address the critically important issue of connecting the necessary institutional changes to the process of globalisation and to the regulative powers of nation states. The problem is that there is not a functional regulatory framework. If international cooperation and regulation are not strengthened and made more efficient, environmental destruction may continue in spite of the political readiness for increased environmental protection.

2.1 Learning, innovation, and competence building systems

The LICS concept is an adaptation of the innovation system concept to a development perspective. The notion of innovation systems (national, regional, local, sectoral) was first applied to high-income countries as studies of 'observed phenomena'. In this situation, innovation systems have often been studied in a positive rather than normative framework, i.e., as actually existing systems. The IS concept is often used as a device for focusing on resource creation through learning and innovation, rather than on the allocation of already existing, but scarce, resources. The concept is applied also to the selection and study of the entities driving the innovation processes (various routines, firms, government agencies, networks, markets, etc.).

The perspective changes when developing countries are studied. Innovation capabilities and innovation systems tend to be fragmented, with innovation being an activity in specific and sometimes isolated parts of the economy. Innovation processes are typically imitative and take the form of adaptation rather than introducing new-to-the-world elements. This situation tends to shift the IS perspective from systems description toward systems building.

Innovation systems in high-income countries often emerge and evolve, if not entirely by themselves, then to some extent behind the backs of private and public decision makers. In low-income countries, however, waiting for innovation systems to evolve may not be feasible. We want to shape, build, and nurture them through many different kinds of policy making. Building innovation systems becomes part of a development strategy.

In developing countries, there is a strong focus on the formation of innovation capabilities that are clearly needed at various levels (the individual, the firm, the government, the community, etc.) and in many sectors (agriculture, industry, service, government, etc.). Furthermore, there are many kinds of capabilities that are important in this context: technical, organisational, social, political, etc. It is obvious that such capability building requires that learning is organised and supported on a broad scale, at every level in the formal education system as well as in firms, communities, and families. To succeed in shifting attention toward innovation capabilities, it is necessary to view substantial parts of the development process as a learning process. We need to regard the process as broadly based since there are numerous sources of learning. While in high-income countries with well-performing innovation systems it may be useful to focus the analysis on R&D systems and high tech-based innovation, this makes little sense in developing countries. There we need to use broadly based innovation system analysis.

In a Globelics context, the use of the LICS concept signals that learning, innovation, and competence building are considered core processes in development; additionally, building LICS may be a central part of a development strategy. To build LICS means to support the establishment of infrastructures, institutions, and organisations that stimulate learning, innovation, and competence building processes on different levels of aggregation. The LICS notion applies, however, not only to developing countries. It implies a partial rather than a total change of focus. Development is constituted by similar processes across the globe. It is an ongoing process with sources in learning although the role and performance of innovation is different in the North and the South. The way we use the IS notion also has to be different.

On a global scale, the implications of low-carbon development are very different for individual countries due to their different conditions and resources, e.g., in areas such as technological competence, financial resources, and the presence of wind, biomass or hydropower. In the South, LICS are generally weaker in scale, scope, and investment, and system components are neither well connected nor coordinated, with the result that these countries are rarely well prepared for developing new energy technology (Sagar, Bremner & Grubb, 2009). Moreover, the majority of competences underpinning renewable energy technologies are concentrated in the North. Even though innovation competences are undergoing a global redistribution, further improvement of existing, and the development of new, renewable energy technologies are expected to happen mostly in the North. As a consequence, international technology transfer and collaboration in the field of renewable energy technology must be a central dimension of low-carbon development.

For many developing countries, the key process for addressing energy needs can be summarised thus: expand affordable energy supplies and services, improve energy efficiency, transform traditional renewable energy systems into modern ones, and simultaneously improve and gradually dismantle fossil energy systems.[9] In contrast, the technology needs emerging from the energy needs are to: accelerate technology transfers, adapt the latter technologies to local ecological, cultural, and economic conditions and to unaddressed local needs, and, in turn, stimulate broad dissemination. Large competence gaps between local needs and local capabilities are frequent (Sagar, 2013). The implications of supporting low-carbon development are thus quite different for LICS in the North and in the South. However, this is not merely a process of diffusion and adaptation initiated from the North. It is primarily a process of strengthening LICS in the South so that energy systems can gradually become more innovative and capable of meeting local needs (section 4.4).

2.2 LICS and low-carbon development

A discussion of the specific case of low-carbon development presupposes an analysis of the role of learning, innovation, and competence building. This involves much more than R&D, R&D-based innovation, and innovation in high-tech activities, which seem to be the most common focus areas. It requires a much broader approach, one that includes an analysis of the structure and change of a number of systems of learning, innovation, and competence building, which support, or may be induced to support, low-carbon development. Since such development must be seen as a process of radical change, it is clear that it involves innovation systems on several levels (for example local, national, and even global levels) and many sectors and technologies.

Furthermore, it would be counterproductive to limit the discussion to technical aspects of learning, innovation, and competence building. Effective low-carbon development also needs to include organisational and institutional change as well as changes in the realms, instruments, and techniques of policy making. We do not yet know precisely which technologies need to be developed, nor do we know what organisational changes may be required. One country will be different from the next. The ways in which institutions and policy making need to be changed are also unclear. We do know, however, that some of the necessary technical, organisational, and institutional changes will be quite radical and that they will interact with each other. Unless we take into account these linkages and interactions, we will be unable to understand the requirements of low-carbon development. This is why we should use a systems approach to deal with the challenge and why we should assume that LICS are relevant and important to our understanding of, and policy making in, low-carbon development.

Based on this background, it is clear that a discussion of low-carbon development should rest on a broad and flexible notion of LICS. The broad scope enables us to embrace many kinds of innovation, minor as well as major, technical as well as organisational and institutional. Flexibility is required, as the innovation capabilities that need to be developed differ among countries.

Providing equal opportunities, especially in education and health care, has been crucially important in most recent examples of successful development (Johnson & Andersen, 2012). It is thus reasonable to assume that the impact on the livelihood of marginalised and poor people will be important also to the building and performance of innovation systems that can support low-carbon development. Moreover, if large segments of the population are deprived of participation in the process of low-carbon development, and if its potentially great economic, social, and political costs (i.e., the costs of structural change accompanying all development processes) are distributed unequally and unjustly, the result may be not only weak support, but also protests and resistance from the negatively affected groups.

We conclude that a LICS approach to low-carbon development has to be broad, flexible, and inclusive.

This conclusion is strengthened further by the vast quantity of resources required for dismantling carbon-based energy systems and building new systems based on renewable energy; this is a major problem on its own. It involves not only the costs of developing new knowledge, new organisations, and new institutions; it involves compensating people who stand to lose income and wealth from structural change. Massive investments of physical capital – equipment, materials, buildings, energy, transport systems, etc. – are also needed. We are unable to offer a realistic estimation of the investments required, but it takes little imagination to see that a major mobilisation of economic resources will be required, especially when seen in the short-term perspective.

As mentioned at the beginning of this chapter, low-carbon development is concerned with strengthening national LICS so that they are reoriented toward contributing to the goals inherent in low-carbon development. For some countries, this may imply the building of low-carbon energy technology systems of innovation. For other countries, it implies a strengthening of dissemination and adaptation capabilities for low-carbon energy and for LICS in general, but without engaging in the construction of low-carbon energy technology systems.

With regard to energy transformations (the topic of Chapter 3), it may be worthwhile to focus on technology levels. In a given country, LICS with a focus on particular low-carbon technologies (e.g., solar photovoltaic (PV) technology) do not necessarily exist. In such cases, the support of sectoral or technology-specific LICS are important. To do so we must understand LICS as social organisms that, as flowers in a garden, must be nurtured.

However, the observation of practical technology-specific LICS building often shows that these processes ultimately hinge on the strength and efficiency of existing national LICS and industry structures. A case in point is Bangladesh, where a local manufacturing industry in the field of solar energy was successfully developed. In contrast, Kenya's failure in this regard provided a strong demonstration of the influence of differences in existing competences when industry-promoting policies were enacted (UN, 2011, p. 141). See Box 3 for further details on systems competence building in Kenya. The box shows that although Solar PV has had considerable success in Kenya, it has been concentrated in solar PV deployment; on the other hand, manufacturing has been confined to 'experimentations' and these have been adversely affected by national instability.

Box 3. Solar home systems in Kenya

Photovoltaic (PV) technology already gained a foothold in Kenya in the late 1970s and early 1980s. It was used to power commercial and community applications such as telecommunications facilities and health centres. The first recorded experience with Solar Home Systems (SHS) stems from the mid-1980s, when an ex-Peace Corps volunteer, Harold Burris, used PV technology for his home. In 1985, Burris teamed up with another Peace Corps volunteer, Mark Hankins, to install PV lighting in a rural Kenyan school. Following this installation, the headmaster and teachers wanted PV for their homes. From this point, Burris began to market his solar home systems locally, in a relatively wealthy part of Kenya. Within a few years, Burris and his technicians were busy installing SHS, and the PV suppliers in Nairobi entered this growing market once they received news of the success enjoyed by Burris.

Hankins also began to exploit this opportunity but focused initially on solar training. Through his own company, Energy Alternatives Africa (EAA), he won project funding to support experimentation with ideas for further developing the SHS market. Over the next decades, EAA became an important player in Kenya, implementing many donor-funded projects. These projects included installing PV systems in community buildings, such as schools and hospitals, along with the training of local technicians. Other projects involved developing and testing various products or balance-of-system components, such as solar lanterns or charge regulators. Some projects experimented with building local manufacturing capacity for solar batteries, while others tested various financing mechanisms, such as microcredit through local savings and credit cooperatives.

EAA can be seen as an innovation system operator in the Kenyan SHS domain. The worth of this market is now about USD 6 million annually and more than 320,000 SHS are installed in homes across the country (Byrne, 2011; Ondraczek, 2013). Further advances have been observed subsequently. For example, the Kenyan government – for many years hostile to PV (and other renewable energy technologies) – recently implemented a large project to install PV systems in schools, a project worth about a third of the annual SHS market. Kenya now has a feed-in tariff for PV. A recent development is the start of solar module assembly through a Dutch-Kenyan joint venture (see http://www.ubbink.co.ke/). Earlier, a Chinese company had shown an interest in manufacturing modules in Kenya (Disenyana, 2009) but the deal fell apart following the postelection violence in 2008. It is also worth noting that, contrary to widely disseminated rhetoric, development of the Kenyan SHS market was not led by the private sector. Instead, it depended crucially on donor interventions to create spaces for experimentation and learning, interventions that often involved private sector actors who then used the learning to further develop their market activities.

Source: Byrne and Ockwell (2013).

The multilevel interdependency between national and technology-specific LICS implies that, as new technologies and knowledge are developed, adapted, disseminated, or used in the national LICS, this knowledge is itself transformed. One implication is that building technology-specific LICS (at lower levels of aggregation) constitutes a diversification and transformation of the national LICS (at higher aggregation levels) because LICS are open and recursive systems. Hence, the process of building technology-specific LICS is necessarily embedded in and co-evolves with the national LICS. In this perspective, a low-carbon transformation of the energy sector (from black and brown to green) becomes a matter of building renewable energy LICS in a process where national LICS are made more low carbon.

The successful development, adaptation, dissemination, and use of new energy technology depend on a number of interrelated and interacting factors. In the early phases, the focus is primarily on technical aspects. Once acceptable technical solutions are found, the focus moves to developing a viable product of interest to users. They should therefore be involved in the product design processes. At the same time, companies need to change focus from R&D to enhancing manufacturing capacity and building supply chains and relevant infrastructures. Design alterations and up-scaling processes tend to have strong feedback mechanisms connected to the original technical configuration. Hence, these steps would ideally happen partly in parallel rather than sequentially. Various forms of finance are necessary in the process – venture and seed capital for initial search and debt financing for up scaling. Any kind of expansion of production capacity rests on a demand for the product. Typically, there is a need for public authorities to engage in market formation by establishing technical standards, public procurement, financial incentives, and/or use required by law. Such initiatives help reduce user uncertainty and secure initial demand, which can facilitate learning by doing and the effect on economies of scale. Such a process of technology development/adaptation depends additionally on a number of factors. Are there clear financial incentives for companies to enter this particular low-carbon industry? Are the technical competences in place, and are they sufficiently entrepreneurial to face the risks involved? Governments are often required to incentivise companies by creating 'green rents', e.g., by protecting and encouraging them (Altenburg, 2012); they also invest in collective complementary assets such as technology-specific knowledge development (education, training, and research) and infrastructures. All the elements are systemically interrelated. Hence, developing, importing and adapting, disseminating and using low-carbon technology is essentially about building low-carbon LICS.

Due to the differences in competence and knowledge between North and South, and the role of absorptive capacity in technology transfer activities, countries in the South must build renewable energy technology-specific LICS. This will enable them to receive new technology and successfully adapt it to local conditions, ensuring large-scale dissemination and use. Low-carbon development thus involves building low-carbon LICS in both the North and the South and stimulating their interaction.

2.3 Knowledge, growth, and change

Inventions and innovations enabling more intensive and extensive uses of both renewable and nonrenewable natural resources have been prerequisites for population growth and for the unsustainability of the present world economy. Still, if technical change has the power to increase negative environmental impacts, it may also have the power to do the opposite. In any case, a radical change of direction toward low-carbon development is impossible without developing and widely utilising new knowledge and innovation.

In a LICS perspective, low-carbon development is seen generally as an interactive process involving institutional and technical change. In many respects, it must also encompass and utilise economic growth in the traditional sense of increased production of goods and services. In many regions of the world, economic growth is still exceedingly important as a means to a better life, even if growth must be combined with the allocation of resources to reduce illiteracy, illness, malnutrition, and other deprivations. In fact, as experienced by Japan, China, Korea, Singapore, and many other countries, economic growth and structural change were fostered by early public support for the education and health of the people.

Growth is also necessary as a means of building new infrastructures, technologies, constructions, houses, and machineries on which low-carbon development depends. As has already been emphasised, low-carbon development requires a massive investment of resources not only in the form of manual and intellectual work but also of physical capital and natural resources. Without economic growth, the required massive investments cannot be realised. At the same time, however, the aim of economic growth must undergo a radical change and be directed toward the requirements of low-carbon development. While economic growth has always been accompanied by structural change, this coupling becomes more than usually important to low-carbon development.

In summary: Low-carbon development is a process of structural change and economic growth driven by the interaction between technical and institutional change. The process depends on several kinds of learning and knowledge creation. However, the low-carbon development discourse has thus far focused on technical aspects rather than on institutional aspects of the challenge. This is not surprising since it is quite obvious that radical technical change is necessary, but perhaps not equally obvious that institutions also need to change in radical ways. It is also easier to visualise the various technical possibilities than to pinpoint the institutional changes (in property rights, social inclusion, incentives, education, financing, etc.) that need to accompany them.

2.4 Innovation for low-carbon development

It should not be difficult to identify a number of areas in which innovation, technical as well as organisational and institutional, would support low-carbon development. Energy production and consumption need to move away from fossil fuels; final demand should consist increasingly of goods and services with low climate impact; and technological and organisational knowledge should be directed systematically toward the same goal. Progress in any of the following, partly overlapping dimensions, would be moves in the right direction:

- Substituting nonrenewable with renewable energy and resources;
- New processes (production, transport, and logistics) requiring less energy and resource input per unit of production;
- New, longer-lasting, and more recyclable products;
- A move toward less energy- and resource-intensive production activities;
- Change of location in economic activities to reduce resource use for transport;
- New principles for construction and housing and new forms of agglomerations; and (i.e., city planning and development that reduce resource transport and heating).

Referring to these types of changes, we may think of ways in which innovation can contribute to low-carbon development. Innovation should, however, not be viewed as a panacea for any problem connected with climate change. Significant parts of current innovation efforts work to undermine sustainability; for example, some consumer product innovations are designed only to stimulate consumers' appetite for a new product model. Another example is process innovations that increase the use of resources per unit of value produced. In a market economy, process innovations that reduce the price of resource-intensive products will move the production structure in the wrong direction. It is therefore necessary to redefine innovation policy from general innovation support toward directed innovation support, and this should also be reflected in efforts to build or support LICS. Because of the aforementioned differences between LICS in the South and the North, this may also imply different policies in each region.

A detailed direction of learning and innovation processes is unfeasible. However, history gives many examples of how such processes can be guided by governments, in order to lead eventually to a new technological trajectory in the economy. Market forces are obviously incapable of solving the problem without guidance, nor can the state take on the role of entrepreneur. The so-called effective demand of future generations is currently zero, which indicates a need for strong intervention by forces outside the marketplace. This does not exclude the use of market mechanisms; neither does it imply central planning and total loss of autonomy for agents in the private sector. Rather, it calls for intelligent management of the interaction between government interventions, market forces, and other actors. The need for creativity and entrepreneurship in individuals as well as in organisations may actually be stronger than ever.

The discussed guidance may take many forms: taxation, subsidies, public research, public production and procurement, standardisation, and regulation. Such policy tools can be selected and designed according to their effect on innovation and learning. Measures that make procedures inflexible should be avoided. They should give freedom in the choice of method as long as the desired outcome of specific low-carbon objectives is reached.

The implementation of this kind of guided capitalist development will doubtlessly meet with fundamental institutional obstacles. One of the most severe problems is that nation-states dominate political governance while climate change is preeminently a global phenomenon. However, positive responses to this problem are possible, one of which is to point to a green competitiveness strategy. Another is to point to the need for international or even global agreements.

Were it possible to convince policy makers that taking the lead in low-carbon development would give them an advantage in international competition, we might expect governments to do so. This has taken place at a modest scale, for example, with windmills in Denmark, electric cars in California, and wind and solar power in China.

However, for various reasons, this argument has met with resistance. One is that a low-carbon strategy will be unfavourable to some industries with a long historical legacy and with strong political power. Organisations that represent the enterprise sector as well as the financial-industrial complex tend to oppose government intervention if some of their members will be affected negatively. Governments therefore need to establish alliances with those parts of the enterprise sector that have a direct interest in a low-carbon strategy.

Another factor reducing national efforts in the North is the general resistance in the establishment, often fed by mainstream macroeconomists, to selective policies that give the state a steering role. It is a widespread assumption that the market can and should do the job of allocating resources, and that governments should become involved only when there are obvious cases of market failure. This market dogmatism in the North may be contrasted with the extreme degree of pragmatism that characterises the Chinese leadership; it seems that as long as a policy works, their leaders have no problem with any kind of mixing of markets, management, and planning. A change toward a low-carbon innovation strategy will require a battle with market dogmatism.

Without international coordination, some of the necessary initiatives may be difficult to implement at the national level. If industries are footloose, new burdens may result in outsourcing to other countries, which may have a net negative impact on global warming (Wang & Watson, 2007). This could be the case if activities are moved to a country without green ambitions. The need to design global cooperation in parallel with national efforts is thus evident, and we can safely say that radical changes in economic systems should be anticipated.

With these general reflections in mind, we now return briefly to the different areas in which innovation is important.

2.4.1 Substituting nonrenewable with renewable energy and resources

The process of substitution will involve the production, distribution, and use of energy. While major technical progress has been observed in the production of renewable energy, some of the most serious bottlenecks concern storage, distribution nets (grids), and the linking of production to distribution nets. Where, for instance, electric vehicles are concerned, both battery technology and insufficient infrastructure have proved to be obstacles.

The general picture seems to show a clear agenda for research, development, and experimentation. But a mobilisation of resources is needed to tackle the existing problems and create incentives for a rapid diffusion of feasible solutions. Polices will need to combine market creations such as feed-in tariffs with polices for technological experimentation. (See Box 4 for the case of solar PV policies in China.)

Major problem-based collaborative projects, whether national or transnational, need to be established in order to overcome bottlenecks. The lo-

Box 4. Solar PV policies in China

In 2011, the share of installed capacity of solar PV in China increased to almost 5 percent of world solar capacity. This was an increase from only 1 percent of world capacity in 2008 (REN21, 2011). This increase had much to do with the change in national policy that focused primarily on promoting the domestic market (Liu & Goldstein, 2012). The policies introduced were The Rooftop Subsidy Program and Golden Sun Demonstration Program.

The Rooftop Subsidy Program was formulated by the Ministry of Finance and Ministry of Housing and Urban Rural Development of China in March 2009. This provided subsidies for rooftop systems (upfront RMB 15/W) and for BIPV systems (upfront RMB 20/W) and subsidised 50 percent of the cost of supplying critical components for on-grid PV systems. The Golden Sun Demonstration Program was formulated by the Ministry of Science and Technology and National Energy Administration in July 2009. This program supported the large (more than 500Mw) solar PV projects over a period of 2-3 years.

Both programs are ongoing. In addition to the above, two rounds of public tender for solar powered projects were implemented in 2009. In 2011, to encourage development further, a National Feed in Tariff (FIT) scheme was announced by the National Development and Reform Commission (NDRC). In 2012, the National Energy Administration (NEA) issued the twelfth Five-Year Plan for Renewable Energy Development, demonstrating clearly their plan to invest in renewable energy. This includes especially the use of solar energy in establishing the grid system and mobilising local government, consumers, and other important actors.

Sources: Iizuka (2013); Zhang and He (2013).

cation of strategic missing links is one of the tasks facing an intelligent innovation strategy. While many cases with great potential for the interlinking of knowledge fields present themselves, there is no existing mechanism to couple the fields.

2.4.2 More energy-efficient processes

One of the reasons for the growing labour productivity over past centuries is the constant increase in the cost of labour. We would argue that a similar effect on energy and resource productivity could result from an ongoing increase in green taxes. While a steep increase would have the strongest immediate impact on behaviour, it would need to be combined with a long-term incremental increase in order to shape a new trajectory where focus is moved from labour to energy and resource productivity. However, because of the need for improved energy access in large segments of the population in many low-income countries, lower green taxes may have to be implemented in these countries.

The development of new capital goods for less energy-intensive production will require a combination of innovation efforts. An important part of the strategy will be to locate and offer special attention and support to lead users. Learning to produce and use low-energy equipment will require major effort. In many developing countries, there is a large scope for developing more energy efficient production, not just for environmental reasons but also to reduce production costs. Energy efficiency technologies may be promoted earmarked low interest loans to producers but larger systemic issues will also need to be addressed. Box 5 discusses this for the cases of Energy Efficiency technologies in cassava processing in Nigeria and maize processing in Kenya.

2.4.3 New longer-lasting and recyclable consumer products

A challenge for public policy lies in interventions that can realise the objective of introducing more sustainable consumer products. Superficial forms of intervention could aim at sales efforts for the stimulation of consumers' demand for the most recent model of a particular consumer product. An alternative would be to establish collaboration between the enterprise sector and regulatory authorities, in which the producer is recognised as a green standard setter.

A third possible avenue of action would involve consumers. Consumer organisations may be given a clearer mandate to rank products according to their energy requirements and environmental impact; governments may likewise set a threshold for acceptable minimum standards and exclude non-acceptable models from the national market.

These innovation processes will require research and development as well as stronger interaction with users. In some fields, users may actually already be engaged in the innovation process, through either user panels or membership in consumer organisations. Where recycling and durability are concerned, upgrading consumers' skills and insights through training and information may go hand in hand with producer certification.

Box 5. Energy efficiency in cassava and maize processing, Nigeria and Kenya

A recent scoping study examines the status of energy efficiency technology in Nigeria and Kenya. The study has focus on adoption of energy efficiency technologies in micro, small and medium-sized enterprises in two agro-industry subsectors: cassava processing in Nigeria and maize processing in Kenya.

The evidence from this study also shows the notion that energy efficiency technologies are relatively underdeveloped and government poli¬cies are important since they create an enabling environment for the diffusion of green technologies. This is so especially through mobilisation of critical resources, encouragement/incentive for private sector involvement, and facilitation of development cooperation activities. Some of the key specific findings of the study include:

- The most influential drivers of energy efficiency technology adoption were similar in both countries. Key drivers and facilitating factors for adoption of energy efficiency measures by cassava and maize processors were in-house knowledge about energy man¬agement, availability of technical expertise, and the desire and need to save costs.
- Energy costs are a significant cost item for many agro-industrial sectors but few companies have adopted sophisticated energy efficiency measures. The main reason for this is that the system of innovation for energy efficiency is weakly developed.
- High initial setup costs and high cost of finance are the most important barriers to the adoption of energy efficiency measures among the cassava processors and maize millers.
- The foreign components of both renewable energy and energy efficiency technologies are mainly from China, and to a lesser extent from India. There is a need for foreign technology to be more adaptable to African contexts and a need to upgrade African technology. Technical cooperation should be based on this insight

The study establishes that there is a great interest among companies to engage in technical cooperation with foreign companies and research institutes. Such cooperation can take various forms such as schol-arships for African students and training of workers, joint research programmes and exchange programmes, technological transfer based on African solutions which are upgraded and non-African technologies which are adapted to the African context. Technical cooperation should however go beyond the transfer of technology and include issues of creating an enabling environment for technological acquisition, finance, education and training.

Source: Ndichu et al. (2013)

2.4.4 A change toward less energy intensive production

It is unclear whether a low-carbon innovation strategy would impede change, including structural change. Some forms of innovations will need to be slowed down, e.g., innovations that exploit consumers' urge for the new or that lead to growth in energy- and resource-intensive production. However, at the same time, other types of innovation will need to be stimulated. We would expect the restructuring of the overall economy to be accelerated in the process of low-carbon development – or at least until a low-carbon development path has become firmly established.

This has implications for the financing of innovation and investment. To channel finance into low-carbon energy systems and low-carbon production and consumption, 'low-carbon development banks' must be established. Government will play an important role in determining the direction of investment, not to select specific projects, but to promote specific new industries in order to build low-carbon LICS.

The fundamental enabling mechanism behind economic growth – structural change – needs to be strengthened rather than weakened. The restructuring will be reflected in shifts in the demand for labour. There will be sectors where specific jobs disappear while new jobs in other sectors are created. Many existing jobs will require new skills and new perspectives. There will be a need for new kinds of education and for the retraining of engineers, designers, skilled workers, and managers.

2.4.5 Transport-reducing location of economic activities

As great resources are required for the transport of resources from one part of the world to another, green movements have made proposals aiming at the co-localization of production and consumption. The conventional economic wisdom is that any trade that actually takes place is rational because the specialisation that it reflects contributes to higher efficiency.

The efficiency of the current pattern of global trade and the resulting volume of transport of people and goods is difficult to judge because the transnational corporations that undertake it manage a substantial part of the trade. Much company trade, particularly intracompany trade is guided by a financial, rather than resource, logic. A useful tool for reducing 'excessive trade' lies in levying taxes on international transport and trade in proportion to their energy consumption or, more generally, their impact on the environment.

Ongoing innovation processes aiming at more efficient methods of transport are taking place in areas where a combination of national and global problem-based projects could result in major breakthroughs. The high degree of concentration in the sector may require that third parties, for instance at the United Nations level, help the major business groups join forces in order to develop more sustainable modes of transport.

2.4.6 Low-carbon principles for construction, housing and urban planning

For various reasons the construction sector is among the most conservative in terms of innovation and organisational change. This is to some degree a reflection of a special division of labour, in which project design is separated from implementation. Another factor that slows innovation is that construction teams working on a new building are put together *ad hoc* so that cumulative learning is limited.

When it comes to the construction of green buildings, some of the weaknesses of the innovation process will need to be overcome. New combinations of technologies and disciplines may likewise help develop new forms of housing that are comfortable and aesthetic as well as sustainable. Governments are already setting new standards to ensure that more ambitious plans are prepared in collaboration with experts and citizens. Rather than being prescriptive, standards should aid a goal-oriented approach while leaving room for creativity.

Urbanisation and city growth are major processes of economic change, both in the South and the North. With regard to urban planning and development, there are large untapped possibilities for saving energy by improving housing, transport, and waste management and, more generally, the improvement of urban infrastructure and urban order. Urbanisation can become a major road to energy saving in which city-based LICS may have a crucial role to play. Conversely,

Box 6. International cooperation on sustainable waste management in Dhaka

Bangladesh is one of the least developed economies of the world. Under normal circumstances, the country holds little attraction for waste management projects. The Waste Concern Group, a Bangladeshi social business enterprise, has established a successful partnership with World Wide Recycling (WWR) BV of the Netherlands, a subsidiary of a medium-sized integrated firm with diverse waste management expertise. The partners run their activities under two joint ventures operating waste recycling and waste-to-energy projects.

WWR and Waste Concern Group became pioneers by registering the first Clean Development Mechanism (CDM) project focusing on organic waste composting. The CDM project has resulted in an organic waste handling practice based on composting. The compost plant obtains organic waste from the population of Dhaka through direct collection from vegetable markets. The resulting higher-yield, lower-cost compost is sold to farmers, and the carbon credits obtained are sold on the international market. The fact that city authorities bear no costs is a critical aspect of this model. Waste collection is done free of cost; processing takes place on land owned by Waste Concern Group.

Sources: Waste Concern Group (2004); Doranova (2013).

under-investment in low-carbon solutions in the development of new (mega) cities will come at a high cost, both financially and in terms of environment and climate change. As described in Box 6, there are international collaboration projects in this field under the auspices of the clean development mechanism (CDM).

This brief discussion of the potential role of various kinds of innovation in low-carbon development has indicated the need for new kinds of LICS. Stronger attention should be given to the ways in which innovation affect the amount and type of energy used. Performance indicators for measuring progress would have to be changed, and consumers would have to find new ways to satisfy their need for stimulation and newness.

We see few technical barriers for moving the innovation system in this direction; however, the political and institutional barriers are huge. Vested interests, nationalism, finance capital interests, economic market dogmatism, and political short-termism constitute key barriers for the needed change.

2.5 Values, institutions, and policies

We have described low-carbon development as a process of interaction between institutional and technical change. However, the few examples already mentioned indicate that the notion of institutions must be broadened for use in this context. In fact, values and policies also have to be included in any discussion of nontechnical barriers to low-carbon development.

The implementation of environmental protection policies is aided by the presence of a popular feeling of commitment to the environment and its protection. This will facilitate the shaping of more energy-saving consumer habits and increase the acceptance of rising costs in connection with introducing low-carbon energy systems. Malleable values and expectations about the future may work for change in more modest expectations of future increases in material living standards.

The question is from where such values will come. Values are shaped in complex processes over time and there is no guarantee that new 'good values' will automatically emerge to protect the social fabric when needed. Environmental destruction will not necessarily lead to support for environmental protection as soon as people realise that serious threats are looming. It is true that the increasing focus of public debate on the environment and growing scientific knowledge of the character of the threats have resulted in broadened environmental awareness. The Euro Barometer questionnaires document that people tend to place environmental problems as some of the most important questions for the future.

Lately, however, broad environment problems have lost some of their urgency in people's minds, for example where climate change is concerned. The financial crisis seems to retard the development of stronger environmental values. The current tendency toward strongly individualist sentiment in Western cultures and a dissemination of such values among rapidly growing developing countries are also working against a 'green' shift in values. Concern for the environment is essentially a concern for humankind. This does not sit well with the current surge in individualism although a contrary cultural and consumer trend can be observed in trends in ecology, fair trade, and sustainably produced products.

We should not expect any major impact from isolated moral campaigns in favour of green behaviour on the part of consumers, workers, farmers, managers, and capitalists. The global ecological crisis is faced with the problem that, as individual actors, we tend to see our own share of responsibility marginal: even those of us who accept that the problem is important are reluctant to change our behaviour. However, substantial changes in the most widely accepted norms are still possible. Such changes will be based more upon new institutional frameworks and regulations than upon moral preaching.

New values need to go beyond 'green' shopping and practicing low-energy lifestyles because the changes required for low-carbon transition must, to some extent, be initiated top-down by a strong (entrepreneurial) state. This will in turn require democratic legitimacy in populations – on a global scale – that acknowledge the importance and implications of the climate crisis and consciously vote for the low-carbon path, even if, or when, it decreases their material standard of living. This is an extremely serious and complex challenge. The legitimacy of low-carbon policies is nevertheless a premise for achieving anything of significance on the supply side; otherwise, manoeuvring space for policy changes is very limited.

Thorough ongoing change in economic behaviour (i.e., changes in the ways research organisations prioritise among different tracks to pursue, the ways firms develop and choose product and process technologies, how consumers distribute their purchases, and how politicians gain power) requires a fundamental change in institutional frameworks. The decisive institutions are the ones connected to the learning society, and special attention should be given to policy learning and the institutions that support it. New policy instruments and new ways of using them must be increased in terms of low-carbon development. Deeper environmental awareness and new visions about the relationships between environment and society, foresight, data collection, theory development, new environmental bureaucracies, new forms of cooperation between the research system and the political system, new legal and regulatory frameworks – these are only some of the factors that must be developed.

It is impossible to describe in detail the depth and breadth of the necessary changes. They will depend on the context, which shows great variation from one country to the other. The development of institutions and policies should be mutually supportive, partly by design and partly by evolution. Because of the magnitude of the challenge, inclusive political and economic institutions are necessary (Acemoglu & Robinson, 2012). By definition, inclusive institutions distribute power and economic influence widely, establish legally binding restraints on the people in power (the rule of law), secure property rights and create incentives for large parts of the population to invest in learning. These institutions also secure the population's participation, not only in production, but also in the management of it. If institutions are not sufficiently inclusive, they will obstruct the creative destruction of vested interests, which typically block necessary new policies. The structural change needed for sustainable growth and development will be too slow.

It would be difficult to exaggerate the importance of social inclusion by institutions and policy-making processes for the successful implementation of low-carbon development. To move the development and implementation of technologies in directions that can significantly reduce the present accumulation of environmental problems and the dependence on fossil fuels may require development, not only of a wide range of new institutions, but also of institutions that include broad majorities of the population in political and economic decision making. This may be called deep institutional change.

Social inclusion is an important aspect of the 'Nordic model'. The Nordic countries are small, have high taxes, strong trade unions and generous unemployment support. While some economists would highlight these elements as being detrimental to economic performance, the Nordic countries are among the most successful economies worldwide, both in terms of GNP and in terms of well-being and happiness indexes. Much of their success can be explained by the investment of social capital. This is reflected in the high level of trust that makes business transactions as well as interactive learning across organisational borders more effective than in comparable societies. At the level of the national political systems, cooperation among classes has historically played a fundamental role in the way the countries have responded to critical crises. Lastly, such cooperation is reflected in wider active participation in organisational change processes and learning in the workplace. The importance of inclusive institutions is not confined to high-income countries. Their development has been crucial throughout the history of civilization and they should therefore not be regarded as a high-income luxury that countries in the South cannot afford now.

A critically important issue is how many necessary institutional changes are connected to the process of globalisation and to the regulative powers of nation-states. In a situation where nation-states are in mutual political and economic competition, they are unlikely to pioneer policies and institutional changes that risk damaging their competitiveness. If international cooperation and regulation cannot be established, environmental destruction will continue in spite of the political will to prioritise environmental protection. Nation-states in Europe and elsewhere have historically served as frameworks for uniquely high rates of economic growth, rates that have enabled the establishment of welfare states and the creation of class compromise. The current global governance system is strongly rooted in this history and new emerging economies such as China and India have started to use national political institutions to foster rapid economic growth. There is a strong connection between the nation-state as an institution and current economic growth trajectories.

This becomes especially clear when governments focus on increasing international competitiveness. Welfare, employment, and growth require that domestic firms and experts enjoy conditions that are at least as attractive as those found in other countries. In its crudest form, competitiveness is reduced to the level of wages or wage costs per unit of production. Business lobbyists are particularly active when it comes to using the argument for competition to promote self-interest, e.g., in calling for lower wages and lower taxes. Government efforts to respond to ecological challenges by taxes on pollution, resource use, and energy have come under attack increasingly at the national level because they undermine the competitiveness of domestic firms or make it less attractive for foreign investment. The focus on national competitiveness may have a negative impact on the use of resources. It slows down the increase in energy and resource productivity. Polluting industries with energy and resource intensive activities are sheltered in order to avoid job loss.

One way to overcome the trap of competition is to enter into global or multilateral agreements on environmental regulation. Many years of discussion about how to improve international environmental regulation have produced only meagre results. However, the ability to engage effectively in such transnational agreements will be of decisive importance for moving toward sustainable development. This requires a major change in perspective. Today, the nation-state remains a 'natural' arena for discourse and action, but the solutions need to be global.

This chapter has attempted to clarify the role of innovations in low-carbon development and discuss how this process may be affected by changes in institutions, values, and policies. In the next chapter we turn to the support of the development of low-carbon LICS.

3. Building low-carbon energy LICS

This chapter considers more specifically the transformation of energy systems involved in low-carbon development. The key message is that the core of any national policy for low-carbon development must be the building of LICS; this process must be coordinated with international activities. The chapter explores the issues involved at the national level focusing on energy sector transformations. Energy sectors are based on a number of different energy technologies. The low-carbon perspective seeks to change the mix of energy technologies so that overall, the sector becomes 'lower carbon'. We thus apply the notion of technology-specific LICS (see Chapter 2). At the sector level, this challenge presupposes the creation of LICS for low-carbon energy technology, typically renewable energy technologies, and the phasing out of high-carbon energy technologies. At the national level, the latter is equivalent to changing national LICS into more low-carbon LICS.

To structure this analytical task, the issues are presented separately as important dimensions of low-carbon development that will be linked together in the process. Global low-carbon development involves innovation policy measures along at least four broad lines:

i the energy supply side and energy access;
ii energy demand, efficiency, and social legitimacy;
iii development and dissemination of low-carbon infrastructures to facilitate changes on the supply and demand sides of energy;
iv dismantling high-carbon energy systems.

These are interdependent dimensions of building successful low-carbon LICS. The policy issues are addressed primarily in Chapter 5.

3.1 Energy production

The transformation of energy systems toward low-carbon development entails innovation along at least four dimensions. The first concerns significant improvements of existing energy technologies. The second concerns simultaneous improvement and large-scale diffusion of renewable energy technologies to replace fossil energy and satisfy the growing global energy demand. Thirdly, we discuss the development of radically new sources of energy (for the longer term). This translates into investments in a range of diverse and experimental paths of research to increase the likelihood of radical technological energy innovations. Fourth, we discuss improvements in energy access in the South.

3.1.1 More efficient fossil energy technologies

Despite the current strong emphasis on renewable energy technologies, fossil energy made up 78.2 percent of Global Final Energy Consumption in 2011 (RE 21, 2013). The International Energy Outlook 2013 (EIA, 2013a) estimates that global energy consumption will increase by 56 percent between 2010 and 2040. The report further projects that the global use of petroleum[10] will rise from 87 million barrels per day (MBD) in 2010, to 97 MBD in 2020, to 115 MBD in 2040. The growth will be concentrated in the transport sector and in the South, particularly China and India, while it will decrease in the North. The world's use of coal is projected to grow at an annual average rate of 1.3 percent between 2010 and 2040, to peak in 2025. Consumption will be dominated by China (47 percent), the United States (14 percent), and India (9 percent). Consumption of natural gas is expected to increase by 64 percent in the period 2010-2040. Gas is an attractive option for many countries as it is less capital-intensive than most energy sources and has a much lower carbon intensity than oil and coal, which makes it more compatible with low-carbon policies (EIA, 2013a). The implication of the likely continued presence and economic importance of fossil energy in the coming decades is that strategies for low-carbon development need to include initiatives to limit their CO_2 emissions (see Section 1.4). Ignoring this would undermine constructive low-carbon strategies. Three areas of fossil energy where innovation can contribute to a low-carbon development are: the efficiency of coal-fired power plants, carbon capture and storage technology, and the development of shale gas.

In 2009, coal-fired power generation alone contributed 30 percent of total global CO_2 emissions. The efficiency of plants varies enormously due to differences in their age, steam conditions, local climatic conditions, coal quality, operating and maintenance skills, and adopted technology. Even though high-efficiency, low-emission technologies for coal plants are becoming more widespread (50 percent of new plants in 2011), approximately 75 percent of all operating plants used low-efficiency technology in 2011 (OECD/IEA, 2012). From a global perspective, efficiency improvement is therefore one of the most cost-effective and shortest lead-time strategies for reducing emissions from energy production. This is especially true for countries in the South, where plant efficiency is generally lower and coal use for electricity generation is increasing (World Coal Institute, 2012). In China, coal is used for an estimated 77 percent of total electricity generation in 2010 (in the United States, it is 44 percent), which represented 40 percent of total world coal-fired electric generating capacity. Although China has been closing its older, inefficient coal-fired power plants, the country continues its rapid increase in coal-fired generating capacity (OECD/IEA, 2013). Further improvement and dissemination of highly efficient low-emission technology can be part of a global low-carbon development strategy in which innovation plays a key role (OECD/IEA, 2012).

Carbon capture and storage technology removes CO_2 from fossil energy in power plants or industrial use and stores the carbon underground. Carbon capture and storage have so far only few, small-scale applications and is struggling to improve. The reasons for this are:

- The absence of a dominant technological design;
- Continued uncertainties about the liabilities of long-term underground storage;
- Uncertainty about sufficient possibility of improving carbon capture and storage and developing the vast supply chains for carbon capture and storage within the required time, i.e., the next two or three decades;
- Uncertainty about the financial viability of developing large-scale CCS systems and supply chains; and
- Strong public resistance due to NIMBYism[11], fear of crowding out renewable energy technologies, fear of rebound effects and of legitimising continued fossil-energy use (Markusson et al., 2012).

Carbon capture and storage is thus largely unproven on the scale required for a serious impact. However, assuming that fossil energy retains its role in the world's energy matrix for the medium term, the technology has the potential to form part of a lower-carbon process. Carbon capture and storage is thus an immature low-carbon technology, promoted mostly in oil and coal producing nations such as Norway, Canada, China, and the United States. In principle, however, it would have greater potential in the South if improved and diffused through LICS-building processes.

The rapid growth of shale gas production in the United States has led to a decline in CO_2 emissions and increased competitiveness of natural gas versus coal. Estimates of shale gas resources outside the United States are relatively uncertain, and estimates will continue to change as exploration continues. In the short run, however, major production is expected in the United States, China, and Canada, while Mexico, Chile, and the Middle East (OECD/IEA, 2013) are expected to join the list. Even though the size of life-cycle emission from shale gas remains disputed, the fuel is significantly more low-carbon than both coal and oil. Hence, if gas replaces coal and oil, the further improvement and diffusion of the technological competences underlying the North American shale revolution could be a strong contributor to 'low-carbon development' in a narrow sense, but due to other environmentally negative consequences, it may strain other planetary boundaries.

Innovation in these fossil energy technologies can contribute to low-carbon development. The latter implies improving and disseminating energy technology LICS. Improvement involves strengthening existing LICS by mobilising resources and supporting new learning spaces. Diffusion requires LICS-building via the support of learning spaces to adapt and disseminate technology from abroad. A key point in this is to overcome the potential tensions between fossil and renewable energy technologies in terms of competition for resources. The guiding principle must be to lower carbon use and foster development. This may lead to a process where fossil energy technology needs to be improved at the same time as it is phased out.

3.1.2 Diffusion of renewable energy technologies

By 2011 renewable energy sources accounted for 19 percent of global final energy consumption (up from 16.7 percent in 2010); nuclear energy supplied 2.8 percent and fossil energy 78.2 percent. Among renewable energy sources, traditional biomass (wood, charcoal, etc.) made up 9.3 percent of energy consumption, with modern renewables at 9.7 percent. The latter consists of hydropower (3.7 percent), biofuels (0.8 percent), biomass/solar geothermal heat and hot water (4.1 percent), and wind/solar/biomass/geothermal power generation (1.1 percent) (RE 21, 2013).

Hence, 6 percent of world energy consumption currently comes from modern renewable energy technologies (minus hydro). Even though overall capacity is still fairly low, the global capacity to produce renewable energy is growing quickly (RE 21, 2012). This growth is concentrated in the wind energy and solar PV sectors, with India, Brazil and, in particular, China as strong participants. China is the world leader in wind and solar thermal energy (RE 21, 2007, 2011). In 2008, Brazil generated 2 percent of global renewable electricity (including hydropower), China 2.8 percent, India 0.7 percent, while Germany generated 0.5 percent and the United States, 2.1

The picture is significantly different for Africa, where investment in renewable energy remains low compared to other regions. The renewable energy markets are underdeveloped and energy demand is satisfied mainly by traditional biomass and fossil energy (RE 21, 2013). The continent, sub-Saharan Africa in particular, is facing extraordinary challenges due to its predominantly rural population, large parts of which are without access to electricity. In consequence, biomass and organic waste combustion are the main energy sources (covering 95-99 percent) in residential energy use. The unsustainable ways that local biomass and organic waste sources are often used create environmental and health problems. Despite the bleak overall picture, there are notable exceptions, with large-scale hydropower plants (Mozambique, Zambia, Namibia, Kenya, Ghana, and Cameroon) and geothermal and solar PV in Kenya (Belward et al., 2011; Byrne & Ockwell, 2013).

Despite the growing use of renewable energy technologies, it is far from reaching the scale required (cf. Chapter 1). The inadequate dissemi-

Table 1. Estimated cost of electricity according to source in 2018

Plant Type			
	Minimum	Average	Maximum
Conventional coal	89.5	100.1	118.3
Advanced coal	112.6	123.0	137.9
Advanced coal with carbon capture and storage	123.9	135.5	152.7
Natural gas fired			
- Conventional combined cycle	62.5	67.1	78.2
- Advanced combined cycle	60.0	65.6	76.1
- Advanced CC with carbon capture and storage	87.4	93.4	107.5
- Conventional combustion turbine	104.0	130.3	149.8
- Advanced combustion turbine	90.3	104.6	119.0
Advanced nuclear	104.4	108.4	115.3
Wind	73.5	86.6	99.8
Wind — offshore	183.0	221.5	294.7
Solar PV	112.5	144.3	224.4
Solar thermal	190.2	261.5	417.6
Geothermal	81.4	89.6	100.3
Biomass	98.0	111.0	130.8
Hydro	58.4	90.3	149.2

Source: EIA (2013b). Note: the table shows the total system levelised cost (2011 USD/MWh) for plants entering service in 2018.

nation appears in a context where the dangers of climate change are becoming physically visible, where policies exist to stimulate dissemination, and where a range of renewable energy technologies are in place. This apparent paradox finds an explanation in innovation studies. New technologies are typically economically inferior to established technologies and therefore face two serious obstacles. First, in spite of their vast potential, the new technologies may be inferior in terms of performance characteristics and cost. The technological potential is normally released only after a series of post introduction improvements (learning curves) have taken place. Secondly, due to the systemic nature of technology, their new forms are relatively disadvantaged *vis-à-vis* established technologies that have established infrastructures, institutions, and enjoy broad social and cultural acceptance. For these reasons there are no clear or strong market signals for the delivery of new technologies to the world even though they have the potential to afford large benefits to the public (Sagar, Bremner & Grubb, 2009). Accordingly the challenge of dissemination should be seen as a process of building LICS specifically adapted to renewable energy technologies, in which systemic barriers are gradually removed (Jacobsson & Bergek, 2004).

The establishment of a clear cost hierarchy for renewable energy technologies is complicated by the great variability among countries, and even regions, of technology- and location-specific supply chains, cost structures, and resource availability (IRENA, 2012). As discussed, there are nevertheless significant cost differences between fossil and renewable energy technologies, as well as among different forms of renewable energy technologies. It appears from table 1 that for renewable energy technologies to be able to compete with fossil energy, productivity-enhancing innovation needs to take place. This must happen at the same time it is established. Such a simultaneous innovation and dissemination process is an obstacle, because a technology under rapid improvement tends to stall the implementation process.

The diffusion challenge can be clarified further when seen as involving three different types of innovation. Smith (2009) distinguishes between incremental innovation, disruptive innovation, and radical innovation.[12] Incremental innovation concerns improvements in and the diffusion of relatively mature and established technologies such as heat pumping technologies for cooling/heating in buildings, and hydropower. Disruptive innovation involves technologies with significant unexploited technological potential, such as geothermal energy, solar panels, and wind energy (particularly offshore). Radical innovation concerns relatively immature technologies such as fusion power, hydrogen, ocean energy, advanced fuel cells, space-based solar power, and similarly advanced energy storage technologies, e.g., batteries, capacitors, and compressed gas storage. These distinctions allow us to see the need for different types of learning spaces ranging from basic science to market creation. Incremental innovation and dissemination possibly may be achieved with market-based instruments such as carbon taxes and renewable energy quotas. Disruptive innovations and their dissemination require technology-specific policies, further market formation, and public procurement to stimulate competence building. Furthermore, nascent markets are needed to support learning spaces in which performance characteristics can be improved.

Access to finance and further market creation will be crucial. Relevant policies include technology-specific feed-in tariffs and low-carbon financing. More radical forms of low-carbon energy innovation are necessary for the longer term, thus calling for basic research. Here learning spaces have a stronger orientation toward such research, R&D, and experimentation. The investments needed are not only highly uncertain, but also large-scale and capital-intensive, and must be expected to take a long time; coordination problems are also foreseeable. These features are augmented as we move from incremental through disruptive to radical innovations; it is therefore to be expected that private actors will play a rather minor role (Ghosh & Nanda, 2010; Mazzucato, 2013), and that internationally coordinated and government-driven mission-oriented programmes will be necessary.

Although such a process may be expected to be coordinated from the North, countries in the South must participate in order to develop critical absorptive LICS for further dissemination. All three types of innovation and dissemination are necessary, and must be coordinated across technologies (including fossil energy), time, and space to further low-carbon development. Each type will demand different policy instruments.

Another aspect of the dissemination challenge in low-carbon development is to create the necessary production capacity for the large-scale production of renewable energy technologies. The building of technology-specific LICS is a necessary but insufficient step toward establishing a supplier industry for renewable energy technologies. The industrial dimension of low-carbon development is crucial to ensure not only the production capacity for dissemination, but also for the economic development of countries in the South. It is often posited as a central element of low-carbon development that countries can develop green jobs, build competences, and export capital goods. Experience tells us that building a rudimentary industrial supply capacity for a single new technology takes at least a couple of decades. Further decades are required for moving along learning curves and reaching sufficient scale for export demand (Jacobsson, Bergek, Finon & Lauber, 2009). Whether a global effort can speed up the process of establishing such industries remains to be seen. However, it is clear that most countries in the South do not presently have the required LICS capacity, and it must therefore be a longer-term goal to initiate the industrialization of renewable energy technologies. In the short term, the goal will be to import, adapt, disseminate, and use low-carbon technologies.

Industrial capacity may follow suit but in any case, this issue should be considered from the beginning. The knowledge gap between North and

South may mean that global inequality is reproduced in low-carbon development: countries in the South might continue their neoperipheral insertion into the global economy with dependence on innovation from abroad (Arocena & Sutz, 2010). This would undermine the development dimension of low-carbon development. To avoid this, the planning of local LICS-building should start immediately. Some form of international division of labour is, however, to be expected although this may change over time. Hence, the processes of innovation, diffusion, and building production capacity in the South and in the North must interact and take place in parallel, rather than in sequence. An innovation-oriented local content requirement policy is one of the instruments that might help stimulate this process at the national level (Johnson, 2013).

One interesting renewable energy technology is modern biomass. Modern biomass can be defined as biomass produced in a sustainable way, which excludes the traditional use of biomass as fuel wood and includes electricity generation and heat production, as well as transportation fuels (Goldemberg and Coelho, 2004)[13] Modern biomass supposes that biomass can be produced and consumed in a sustainable way. However, presently this kind of biomass is mainly produced and used in developed countries, although Brazil is a leader in this technology in the developing world, particularly in Bioethanol (see Box 7). Raw materials for modern biomass can be all sort of agricultural and forest crops or residues, animal residues and urban solid waste. The main advantage of biomass products alongside being renewable and low carbon emission is that they can be provided as solid, liquid or gas fuels. Thus, they can be easily stored and compete with fossil fuels in several niche markets, like in transportation technologies. The main uses for bioenergy are heat, electricity and biofuels.

Solar thermal technologies are also important RE technologies, particularly for residential water heating. The main technologies for domestic water heating are unglazed and glazed water collector and evacuated tube collector. Technology dominance is not at the hands of a few manufactures, on the opposite, there are plenty of manufacturers and product suppliers worldwide.

The leading use of evacuated tube collector is mainly due to the Chinese market which has installed 152,180 MWth (Mauthner & Weiss, 2013). China provides a unique experience since its accelerated solar water heater industry development and high market growth rate occurred without any incentive policy at national level, no fiscal, taxation, regular subsidy and financing policies for the market and manufacturers. Only a combination of long-term R&D and innovation which led to low-cost products and high performance-cost ratio and a few demand pull initiatives (provincial and municipal mandatory installation in new buildings and an appliance program for rural areas).

3.1.3 Energy access

Access to modern energy sources is considered an integral part of development. Access to lower

Box 7. Modern biomass in Brazil

Brazil has demonstrated strong capacity to increase bioenergy supply and demand. Brazil was for a long time the world leader in liquid biofuels with its ethanol program. However since the middle of last decade, Brazilian sugarcane ethanol lagged behind the American corn ethanol. In 2011, United States and Brazil accounted for 63 percent and 24 percent of the world bioethanol production. In the other kinds of biomass, developed countries are still the world leaders, for instance in biomass for power markets, where European Union and United States are the world leaders. Biomass responds for 28 percent of Brazil total energy demand, but unlike many others developing countries the greatest share (20 percent) is modern biomass that is deeply inserted into the agro-industrial production system. Brazil is the second in the world ranking of electricity biomass generation only after United States, and almost 4.6 percent of all domestic electricity supply is generated by biomass conversion, mostly of sugarcane bagasse.

Ethanol and biodiesel are already important biofuels substitutes for gasoline and diesel oil in some countries. They can be consumed mixed or pure with the adaptation of the engines. Bioethanol is produced from food crops, as corn or sugarcane, and biodiesel is obtained from palm, soya, or any vegetable oil. In the case of first generation biofuels where the bioenergy raw material is not a crop residue, energy use can compete with food production or with other important agriculture raw materials. Second generation technologies like hydrolysis, pyrolysis, and even gasification, can use agricultural cellulose rich residues in the production of ethanol and other fuels, like diesel, kerosene, and synthetic gas. Second generation technologies are expected to reduce the challenge energy-food competition.

Source: Furtado (2013); Ren 21 (2013)

carbon energy is crucial. A state of energy poverty refers to the unavailability of cooking facilities with modern fuels and the absence of electrical lighting for reading or other household and productive activities after sunset. As of 2009, 1.4 billion people lacked access to electricity, 85 percent of them in rural areas. Almost 2.7 billion people rely on woody biomass fuels for cooking. Across the South, the energy-poor are faced with the perverse situation that even though they consume less energy than the majority of the world's population, they pay the highest price per unit of energy. The poorest in the developing countries, typically in rural areas, thus spend a higher share of their resources (income and time) on providing energy to the household than the prevailingly urban higher-income groups (Sova-

Box 8. Energy hubs in Kasese, Uganda

Only 10 percent of the population in the district of Kasese, Uganda, have access to the power grid. People are restricted to the use of kerosene or *tadooba,* a paraffin product, in order to enjoy after-sunset lighting in their homes. Providing access to safer and cleaner energy sources is thus a priority, but alternatives must be affordable so they do not exceed current energy expenses, which correspond to roughly one dollar per day.

The Access2Innovation initiative gathers interested stakeholders from various backgrounds (companies, public authorities, universities, etc.) to develop a solution that addresses energy needs in Kasese. The framework discussed for this solution is the creation of energy hubs, which would be centrally located close to schools and commerce, offering the recharge of batteries that need to be light enough for a child to carry home for use at night. Local energy consumption is low. The level of energy consumption needs to provide domestic lighting, mobile phone and radio charging. The generation of energy in the hubs will rely on the abundant sunlight photovoltaic panels. The potential of this opportunity relies on the partnerships and funding possibilities offered by the facilitators.

Access2Innovation offers access to locally based NGOs with a deep understanding of the local community, its needs, and culture. The project enjoys government support. In addition to access to energy, the hub format will help raise school attendance, since the children's trip to school would also provide for the daily energy supply. The potentials of the project include the opportunity to inspire similar projects elsewhere in Uganda itself and Africa.

Another possible result of the project relates to the provision of energy to small businesses, which can foster entrepreneurship and economic activity in the region. Some of the challenges facing this case concern the transport of the material for the construction and installation of the energy hub, as well as recruiting and training people for its maintenance. Further challenges include protection from theft, pricing limitations, developing cash-free payment systems to avoid corruption, and the provision and safe discard of used batteries.

Source: Remmen (2013).

cool, 2012). Because of their modest contribution to global pollution, energy-poor people are overlooked by climate change policies (Sagar, 2005).

Energy poverty is associated with a number of other deprivations that hit women in particular. The hours needed to collect traditional fuels in the form of wood, charcoal, agricultural residues, or dung comprise a large part of the day. This work is often done by women. Moreover, there are health issues in relation to the use of energy sources such as the burning of fuels for cooking, heating, and reading (kerosene). The domestic roles of women and girls expose them to extremely dangerous indoor contamination, so that the latter are more often sick than boys are. The socialisation of girls further means that their schooling is likely to suffer. Moreover, the energy efficiency of energy-poor households is very low. Their high-carbon energy use is prone to lead to deforestation, desertification, and land degradation that in turn exacerbate the problems of paying for and spending the time needed for collection. Due to their low absolute level, scant attention is given to these routines (Sovacool, 2012).

Most research on providing access to energy has found that 'technological fixes' are insufficient for the transformation of rural energy systems. Cultural patterns, lack of finance/credit, low user competence, low awareness, market regulations, and high prices are some of the factors that militate against local energy transformation (Sovacool, 2012). Transforming traditional rural energy systems thus requires new energy routines, new institutions, and competence building for the application of new sources energy. Policies should focus on making new energy technology available, supporting market formation via microcredit financing and thus creating socially inclusive learning spaces to facilitate the shift in energy technology. At the local level, securing energy access involves building new energy LICS in rural areas and replacing the existing urban ones.

The challenges for energy access depend on the specific characteristics of energy systems and their context, but there are trade-offs related to the design of the energy system and access. A contentious issue concerns off-grid *versus* on-grid energy access, the former often referring to small-scale, decentralized energy production, and the latter to a large-scale centralized production, typically with a costly transmission infrastructure. Where the main goal is to satisfy the low-level energy needs of poor households, access to off-grid solutions, even if unstable, may suffice. As an example, see Box 8 on solar energy hubs in Kasese, Uganda. However, such solutions may not work in all settings. If power is needed for energy-intensive natural resource-based industries, the stability and backup power of the grid is probably necessary.

The question of energy access for low-carbon development strategies thus involves a multitemporal perspective. Off-grid energy access is a reasonable short-term goal while on-grid development could be a longer-term goal, as energy consumption will grow with the economic development in the South. On the other hand, if energy storage technologies improve significantly, off-grid low-carbon development may as well become feasible over time. In addition to local energy transformation, innovation in storage technology should be a political priority. Despite the rhetoric about the need to increase access to energy – for a number of developing countries it would make most sense via decentralized options – investment and activity are still skewed toward centralized options (Mallett, 2013).

3.2 Demand side

The demand side of low-carbon transformation of energy systems refers to efficiency in energy use, the importance of users, social legitimacy for building LICS, and the importance of market creation for the dissemination of low-carbon technology.

3.2.1 Energy use efficiency

Increases are expected in the world's demand for energy, in particular for electricity as transport and heating become increasingly electrified (in the North). Despite expected energy efficiency efforts, demand is thus expected to rise from 3250 TWh/yr to 4900 TWh/yr in 2050 (for EU27 and Norway and Switzerland) (EC, 2010). Globally, energy efficiency has been improving, particularly in the South, although the 2000s have seen an abatement in this development, partly due to increased economic activity in the South (RE 21, 2013). Still, a large untapped potential for energy efficiency remains, especially in emerging and developing countries (UNIDO, 2011). Box 9 outlines some of the key barriers for industrial energy efficiency in developing countries and sets options for their adoption.

In general terms, increasing energy efficiency requires improvements in existing LICS rather than building new ones. According to Walz (2013), the energy efficiency in the industrial sector of developing countries is on average 2-4 times lower but the picture is rather diverse; given their vast consumption levels, the BRICS-countries with very low energy efficiency have enormous potential for energy saving innovation. These countries' aggressive pursuit of development in renewable energy technology is paradoxical, given their failure to emphasise the low hanging fruits of energy efficiency.

Although the situation must be addressed by all countries, the large emerging economies in the South in particular could reap large benefits. This is an important element of global energy transformation because their demand exercises a strain on energy resources. Energy performance standards for the building sector and others should be a central policy instrument, as an estimated 60 percent of potential global savings in emissions can be gained in that sector (OECD/IEA, 2013). Such standards could serve to reorient the direction of innovation and stimulate dissemination and uptake in existing LICS. Where such policies exist, they should to be strengthened; where they are absent, they should to be implemented. It is important to avoid rebound effects, which may be mitigated in the South where, in all fairness, room for growth in per capita energy use should be allowed.

Box 9. Industrial energy efficiency in developing countries: barriers and options

Barriers to develop and use energy efficient technologies are pronounced in the developing world. These barriers include energy subsidies creating an artificially low price for energy, a lack of information and skills, difficulty in accessing capital, and concern regarding production disruption. Addressing energy use in industry as a means to realise low-carbon transitions is important, as industry is a key contributor to carbon emissions, especially in emerging economies. Research regarding the experiences of policies aimed at increasing industrial energy efficiency in developing countries yielded the following policy implications:

1. The need for a systematic / sector-wide yet targeted approach;
2. The need for a long-term time horizon and clarity on roles and responsibilities;
3. The need to tailor policies to specific needs of a country and sector; and
4. International energy efficiency programs do make a difference.

Industrial energy efficiency policies were more effective when they focused on sectors (e.g., government, industry associations, firms, academia) versus individual firms and through a series of policy instruments (e.g., informational instruments coupled with incentives and / or regulations) versus one policy tool. One example comes from the cement industry where in the 1980s the sector consolidated at a global scale offering opportunities for firms to learn. While important to focus on the sector as a whole, it was crucial to target policies appropriately to increase effectiveness – for instance, to distinguish policy levers between small and medium-sized enterprises and large-scale firms. Furthermore, and juxtaposed against the urgency that addressing climate change requires, was the need for long-term time horizons (in contrast to the common structure of development programs with 3-5 year cycles) and clarity on roles and responsibilities to elicit success. This rationale is in line with how decisions on capital investment and infrastructure are made in addition to timelines where behaviour changes / paradigm shifts happen systematically. Having a long timeline for a project is distinct from unsuccessful projects whose lifecycles were 'long' but laid dormant for much of the project life. For example, a project by the Global Environment Facility (GEF) on efficiency boilers with China was plagued by delays, and thus had subsequent changes in personnel and responsible agencies. Here, a key cause of delay occurred when potential suppliers were reluctant to provide technology licences due to Intellectual Property (IP) concerns.

Source: Sorrell, Mallett, and Nye (2011); Mallett, Sorrell, and Nye (2011).

3.2.2 Social legitimacy and inclusion

The issues of social legitimacy and inclusion were mentioned in the previous chapter. The impact of such factors for building learning spaces and LICS is discussed briefly here. As was seen in Section 2.5, not only the price, but also users' energy consumption routines, have strong implications for the dissemination of new energy technology.

Many low-carbon development initiatives take the form of rapidly implemented, centralized, large-scale energy solutions that require grid connections. This may lead to conflict between the priorities of policy makers and communities (Ockwell & Mallett, 2013, p. 122). In the context of strong technological competences, the engagement of local stakeholders is critical to adoption and dissemination. In many cases, the barriers to uptake of low-carbon technology are not finance or access to technology, but rather an absence of proactive local users and actors. One successful and documented form of local engagement is cross-sector and multistakeholder partnerships (Ockwell & Mallett, 2013). Hence, if LICS-building is to ensure the dissemination and use of low-carbon technology, the process must be socially inclusive, involve users, and give them voice and ownership. Inclusion and user learning are thus central aspects of low-carbon development at the local level.

As argued in the previous chapter, low-carbon development necessarily involves a vast redistribution of resources, power, and competences, something that the potential, probably powerful, losers are likely to resist. The distribution of green rents must therefore be socially acceptable (Jacobsson & Bergek, 2011), and those who stand to lose in the process must be compensated. These issues concern the entire legitimacy of low-carbon development, which, under non-dictatorship rule, effectively decides on the arena for policy manoeuvring on the supply side. Hence, at the national level, the process of low-carbon development needs to be inclusive and enjoy broad social legitimacy to overcome barriers. Moreover, social inclusion on a global level is also needed to enable low-carbon development and mitigate its inherent tensions. It is necessary for the strong to include the weak, for example, through new forms of international collaboration.

In sum, it seems that low-carbon development is predicated on the creation of inclusive institutions at local, national, and global levels.[14]

3.2.3 Market formation and demand for knowledge

It is a unique characteristic of climate actions that their realisation will benefit mostly future generations.[15] As the market demand of future unborn or infant generations is currently zero, forces outside the marketplace need to intervene. A central goal of policy is thus to construct markets for low-carbon technologies by creating and managing green rents (Altenburg, 2012).

Private investors tend to be hesitant because, under current circumstances, most renewable energy technologies are not price-competitive. Distortion of prices arises partly from externalities. In general, the market price mechanism does not automatically internalise the cost of the environmental damage caused by the use of fossil energy, nor does it internalise the benefits of the use of renewable energy. Attempts have been made to address this type of market failure with technology-neutral market-based instruments, e.g., carbon taxes and cap-and-trade. These instruments tend to increase the price of energy, at least initially, which is unfortunate for developing countries; higher energy prices may harm economic growth in energy-importing countries (UN, 2011). The latter is another issue of low-carbon development that must be addressed.

Private investors are deterred further because, as markets are politically driven, it is very difficult to know how the future market and demand will act in the absence of international binding agreements. Governments may have a sudden change of heart. This creates uncertainty, which implies that governments must engage in large-scale mobilisation of resources to finance investments in and stimulate demand for low-carbon technologies.[16] Public procurement may be a relevant policy to aid market formation by supplying crucial early demand and reducing consumer uncertainty with demonstration projects. Market formation also involves reducing uncertainty by establishing technical and quality standards. Early niche markets will in turn create a demand for new competences in the labour market and education and training systems. In sum, for learning spaces to emerge around low-carbon technologies, governments must create 'green' rents to stimulate private company investment. Microfinance may be another appropriate instrument for supporting demand the demand of the rural poor for low-carbon technologies.

Nevertheless, the creation of domestic demand for low-carbon technology does not guarantee that this demand translates into an effective domestic call for new low-carbon competences and knowledge. Experience shows that, while it has been possible to build LICS components (e.g., universities, research institutes, R&D regulations, etc.) in the South, it has been much more difficult to stimulate the interactions between components, mainly because the demand for knowledge is lacking (Arocena & Sutz, 2000; Cimoli, Ferraz & Primi, 2009; Rodrik, 2007). In some countries in Latin America, the demand for knowledge has weakened because of the economic transformation in recent decades. Some causes are the replacement of local capital goods for imports, the weakening of in-house engineering firms, the post-privatization dismantling of R&D capabilities in public enterprises, and reduced incentives for regional R&D investments stemming from the dominance of multinational enterprises. Weak interaction between knowledge producers and potential users generates a type of insertion into the global economy which may be labelled as neoperipheral, this is characteristic of countries that are dependent on innovation from abroad (Arocena & Sutz, 2002, 2010).

Weak demand for knowledge has also been attributed to institutional factors such as a 'passive learning culture' (Juma, Fang, Honca, & Huete-Perez, 2001; Viotti, 2002) world leaders adopted the United Nations Millennium Declaration in which they pledged to halve, by 2015, the proportion of the world's people earning less than a dollar a day, suffering from hunger and unable to obtain safe drinking water. This paper argues that meeting these targets will entail concerted efforts to raise economic productivity in the developing world and to redirect industrialized countries to address research and development (R&D. Technology imports by passive learners typically lead to few technically demanding alterations. Only the most essential capabilities of technology use in the production system are acquired, i.e., those necessary to solve basic production problems. Active learners, on the other hand, intentionally pursue mastery of the imported technology, usually leading to improvements. Such learning is a necessary, although insufficient, precondition for the development of LICS.

Local LICS are necessary for achieving a self-directed and wide-scale adaptation, dissemination, and use of new low-carbon technologies. According to this perspective, creating local demand for technology requires market-formation policies, but without local LICS, this will not translate into a demand for new knowledge. Developing countries will likely become dependent on low-carbon innovation from abroad. Avoiding this requires the encouragement of active learning cultures; the problems and concerns of local stakeholders must be represented in the process. In other words, without local, socially inclusive learning spaces, little can be achieved. The fact that inclusion and local market formation are inseparable issues means that policy must thus address both market demand and knowledge demand.

3.3 Low-carbon infrastructures Transmission

Infrastructures are central to the functioning of our high-carbon economies (Jonsson, 2000), and any change toward a low-carbon economy involves their transformation.[17] The infrastructure of the electrical system is particularly relevant for the development and large-scale deployment of renewable energy technologies. Sources of renewable energy are widely dispersed across countries but are found generally in areas far from the core areas of electricity consumption. The intermittency of renewable energy generation implies that renewable energy sources must be connected (and their power eventually stored) across very large territories to constitute a reliable source of energy (Boyle, 2012; Tawney, Bell & Ziegle, 2011)[18] (Ideally, the sun is shining and the wind blowing somewhere in the system at all times.) In this situation, the absence of transmission grids (and credible plans for their establishment) can block investments in a transformation of energy systems. Moreover, the cost of installing renewable energy technologies is affected adversely since the cost of grid connections is born by operators. This contributes further to the uneven competition between low- and high-carbon technologies. According to Tawney et al. (2011), the International Energy Agency estimates that a global replacement of fossil energy with renewable energy in the period 2010 to 2050, in order to halve the energy-related CO_2 emissions, would require transmission investments of USD 4.2 trillion, equivalent to USD 100 billion per year.

To put these figures into perspective, the United States invested USD 9 billion in transmission infrastructure in 2009. There is reason to believe that resource mobilisation is lacking. According to the American Wind Energy Association, the key issue in grid developments is that 'transmission developers are hesitant to build transmission in a region without certainty that a power plant will be built to use the line, just as wind and solar developers are hesitant to build a power plant without certainty that a transmission line will be built' (Tawney et al., 2011, p. 8). Contemplating the necessary co-evolution of renewable energy dissemination and transmission expansion, whether in the short or long run, one is reminded of the chicken and egg problem.

It has often been argued that infrastructure is a crucial element, which influences the 'direction' of innovation. Infrastructure is a key element within the selection environment pertaining to technological choices. New technologies and technological systems (notably 'radical' and 'disruptive' ones) require specific infrastructures for their emergence and dissemination (Freeman, 2001). In the case of low-carbon development, it is necessary, therefore, to change infrastructures in significant ways. Incremental innovations can thrive within existing infrastructures, while disruptive innovation requires significant transformation of infrastructures. Radical innovation, in turn, is likely to require completely new infrastructures. We must thus move from a static to a dynamic understanding of infrastructures.

On the one hand, some of the techno-economic properties that characterise infrastructures lend them an aura of permanence. Those properties are their scale, indivisibility, capital-intensity, externalities, asset durability, and 'systemness' (Markard, 2011). Moreover, the centrality of infrastructure to the functioning of society means that its stability is often a goal in itself. The implication of the above-mentioned properties is that, when and if infrastructure change takes place, it is mostly incremental. The ability of governments to mobilise large resources and absorb the risks involved leads to the expectation that they will undertake the needed infrastructure transformations (Mazzucato, 2013; Smith, 2005).[19] However, any true understanding of infrastructural change rests on the fact that infrastructures are socio-technical systems that are continuously maintained, reproduced, and transformed. While in the short run infrastructures may be conceived as static systems, the long-run view must see them as dynamic systems. This constitutes the essential duality in the infrastructure term.

In consequence, innovation policy should address both specific low-carbon technologies and the infrastructures within which they are deployed. There is no necessary connection between changes in these domains, technologically or temporally. They are nevertheless interacting factors, and private-sector innovation decisions may be closely linked to public sector infrastructure strategies (Andersen & Wicken, 2013). In conclusion, developing and disseminating renewable energy technologies may prove ineffective, and even impossible, for energy sector transformation unless it is complemented by appropriate infrastructure transformation. Countries in both the North and the South thus need to develop LICS that can simultaneously enable the building of low-carbon infrastructure and the technological mastery of renewable energy technologies.

3.4 Dismantling high-carbon LICS

The comparatively low price of fossil energy, which due partly to state subsidies, means that green leapfrogging in the South will not be a straightforward process, and that high-carbon energy is likely to remain part of the world's energy matrix for some time. Because these energy sources are in direct but uneven competition, we must address not only the development of renewable energy technologies but also the dismantling of LICS for fossil energy technology. This destructive aspect of a green energy system transformation is just as important as the creative aspect.

The dismantling of high-carbon LICS is further complicated by the enormous value to the stock market of fossil fuels in the ground. According to Carbon Tracker (2013), to avoid global warming above 2 °C in comparison to preindustrial levels, the world can tolerate only the burning of approximately 20 percent of known fossil energy reserves (totalling 2,860 $GtCO_{2)}$. This creates a number of challenges for low-carbon development. The 200 largest fossil fuel companies globally (listed on stock exchanges) have a combined value of USD 4 trillion and debts worth USD 1.5 trillion. Equity valuations may have to be reduced by 40-60 percent to correspond to the 2-degree scenario. This would lead to credit rating downgrades for these companies, with potential debt servicing problems, in turn creating carbon vulnerability in global markets.[20] This is problematic as current evaluations of companies are based on the full exploitation of proven reserves at a consistent production rate and price. If climate goals are to be met, it is not a matter of if but when these fossil fuel assets are frozen. With the downgrading of fossil energy company bonds, debt default could lead to an international financial crisis.

This report urges policy makers to initiate reforms that can deal with such systemic uncertainty rather than assuming that everything will conform to the models of the past. Meanwhile, companies are still rewarded for finding and developing new fossil energy reserves, and market risks are accessed as if global warming were not an issue (Carbon Tracker, 2013). This situation is a symptom of carbon lock-in where markets, despite compelling evidence, are not convinced that governments are serious about climate change policy. These views are gaining wider acceptance (recently the carbon budget notion was embraced by the IPCC). However, proven reserves are rising quickly as the global fossil energy industry is highly active in parts of the South such as South America, East Africa, and Eurasia, with the OPEC countries still controlling two-thirds of known oil reserves (BP, 2013; Mitchell, Marcel & Mitchell, 2012). Developing countries that have recently discovered fossil fuel energy reserves see them as a means for development by serving as a source of state income; these reserves supply domestic industry with cheap energy, and local policies are directed toward building new fossil energy-related industries. In these regions, tensions between low-carbon targets and economic development are obvious.

From a global perspective, interactions between brown and green energy are becoming increasingly complex. The data indicate that it may be naïve to believe that fossil energy can be totally discarded in the short run. Still, the process of moving away from fossil energy needs to start now. Each country should make strategic roadmaps with milestones for short-, medium-, and long-term goals for the total decarbonisation of energy production with a gradually decreasing share of fossil energy whose efficiency is simultaneously improved. Still, it is unclear whether and how these dynamic trade-offs can be managed at both national and international levels. Research has hitherto mainly focused on the creation of new low-carbon technology and policies rather than studying 'the governance of termination' (Stegmaier & Kuhlmann, 2013), 'policy dismantling' (Jordan, Bauer & Green-Pedersen, 2013), or 'regime destabilization' (Turnheim & Geels, 2012). It is clear, however, that such processes would involve policies of delegitimising high-carbon technology, of immobilising associated resources (keeping them in the ground), and of 'unlearning' or destruction of competences and institutions for supporting the existing energy regime.

4. Managing the tensions

New technologies and innovations will play a vital role in achieving low-carbon development. However, given the large differences in financial and technological capacity across countries, unresolved questions of roles and responsibilities remain. Major tensions are already slowing international negotiations in various arenas, e.g., climate and trade, and impeding the low-carbon transition. This chapter reviews key areas of tension concerning low-carbon innovation policy and strategy at the global level. We concentrate on four major tensions impeding the transformation to a low-carbon world:

1 Climate versus development? Climate change presents a major challenge to humanity. However, there are other challenges, the solutions to which depend on furthering economic and social development, most importantly within poor, developing countries. The real and perceived trade-off between these different priorities has tended to stifle progress in policy making, but recent discourse has emphasised the creation of 'co-benefits'. Such benefits are most likely to materialize within coherent low-carbon innovation systems.

2 Advanced versus developing economies? Which countries are responsible for the low-carbon transition, how is it done, and within what timeframe? These issues relate to not only the financing of the transformation process; the development of enabling technologies, as well as capacity-building for the adoption of such technologies worldwide, are becoming increasingly important in global policy deliberations, especially for developing countries with weaker capabilities.

3 Incumbents versus newcomers? The world of technology has witnessed a constant competition between incumbents and newcomers. But where climate change transformation is concerned, this competition takes place against the backdrop of an emerging climate regime and a potential global power shift. Thus, we see a

competition between incumbent and newcomer players at multiple levels: technology, corporate, and national.

4 Technology transfer versus innovation cooperation? The low-carbon development agenda raises important issues about global technology collaboration. The urgency of rapid diffusion often leads to policies for deployment of low-carbon technology through technology transfer. However, the relatively slow process of raising capability levels and establishing collaborative relationships between LICS (as opposed to technology transfer) is likely to lead to more sustainable outcomes.

In the next section, we present and analyse these tensions in order to uncover the underlying issues, the understanding of which is essential for a discussion of possible pathways to circumvent the tensions in low-carbon development policies.

4.1 Climate versus development

As emphasised in Chapter 1, the notion of low-carbon development brings together the climate change and development policy agendas, but they are often discussed separately. Table 2 shows a number of challenges that connect directly or indirectly to climate change mitigation and adaptive action. For universal energy access to be realised by 2030, an investment of approximately USD 1 trillion will be required, mostly in developing countries (IEA, 2012). Yet, these numbers – and the scale of activity required to ensure success – pale in comparison to the efforts and resources that will be required for addressing the climate problem. However, resources for both of these activities remain limited and far below what are needed.

Policy makers in developing countries must address poverty alleviation, industrialization, job creation, and S&T capacity building. Given the precarious energy availability in several developing countries, energy security objectives are also a concern.

The challenges of reducing poverty and expanding access to energy services combined with stimulating low-carbon development are particularly thorny issues for developing countries. The focus on increased energy access competes with other poverty reduction goals for financial and institutional support from policy makers, donors, and multilateral agencies operating in developing countries. The challenges are increased by the need to ensure that energy is affordable for poor populations; expensive low-carbon technologies are unattractive from a (short-term) cost perspective.

In a world of finite resources many such trade-offs pose real dilemmas.[21] Accompanying the tensions in low-carbon development, the climate change question also has a strong bearing on other development goals.

As noted in Chapter 1, very large segments of the population in developing countries depend on agriculture for sustenance; a large portion are minor landholders for whom climate-induced weather shifts could lead to significant setbacks. The development of large communities across the globe

Table 2. Global developmental challenges

Indicator	Number (millions)
People without access to electricity	1,300
People without access to clean cooking facilities	2,600
Undernourished people	870
People without access to safe drinking water	783
People without access to basic sanitation	2,500

Sources: WEO (2012); SOFI (2012); JMP (2012); WWDR (2012).

could also be jeopardised by the impact of climate change. Although the goals of development and low-carbon growth are perceived as conflicting, they are in reality closely interrelated.

Co-benefits are the additional benefits of policies implemented to mitigate climate change. Most policies designed to reduce greenhouse gas emissions or to adapt to climate change entail important additional benefits for human development. The case of rural electrification is a clear example of a contingent initiative, but also one that requires innovation and capacity building at multiple levels, from viable business models, to training local operation and maintenance staff in problem solving.

4.2 Advanced versus developing countries

The tension between advanced and developing countries with regard to the development of enabling technologies and capacity building for their global diffusion is particularly challenging. Discussion of this question is part of much broader issues in the climate change policy debate. The discussion of emission reductions and associated technology initiatives at the global level has been paralysed for more than a decade. Since the establishment of the UNFCCC in 1992, many developed countries have instituted programmes to reduce their GHG emissions, although a political consensus for adequate action on low-carbon technology development and deployment is still lacking.[22] While developing countries have also started taking tentative steps to manage their GHG emissions, they continue to rise, especially given the economic growth of these countries in recent years.[23] Consequently, as highlighted in Chapter 1, we are far from the mitigating action needed to avoid dangerous climate change (Kartha & Erickson, 2011; UNEP, 2010). Tackling the climate problem will require a significant reorientation of human and economic activities. Transforming the present energy system and technology paradigms will incur enormous costs. According to IEA estimates, achieving the 2 °C scenario would require a further investment of USD 36 trillion between 2012 and 2050 as compared to a business-as-usual scenario (see IEA ETP, 2012).

Table 3 highlights the enormous disparity between developed and developing countries in terms of per capita emissions and access to electricity (as indicated by per capita electricity generation). Not only are the developing countries much poorer, their per capita emissions are substantially lower than those of developed countries.[24]

Notwithstanding the recent rise of BRICS countries as major emitters, the resistance of advanced economies to technology transfer derives from concerns over competitiveness. This sentiment is compounded by the growth in BRIC countries' rising technology competence (albeit still lagging far behind) and investments in their own R&D.

Increasing the capacity for the development of low-carbon infrastructure and technology in developing countries is an important part of climate change mitigation. The current expansion of infrastructure in developing countries is a process that is likely to continue in the coming decades. Because of the desirability of minimising high-carbon infrastructure, the building up of such capacity is an urgent matter. However, real efforts have been meagre despite the urgency of the climate problem, the limited capacity of developing countries, and the presence of capital and technology capacity in the developed world. The delay will increase the overall cost of future efforts to achieve the needed mitigation.

The current economic crisis has further aggravated the existing tensions concerning the responsibility to support the needed low-carbon transformation. Tight capital availability, growing account deficits, and increased focus on national competitiveness have had at least two effects. The first is a slowing of developed countries' investment in low-carbon technology development (though investments by risk capital have increased during this period) (Frankfurt School-UNEP Centre/BNEF, 2013). The second effect is the stimulation of co-operation toward capacity building within developing countries, several of which are now perceived as competitors.

At the national level, a number of countries are engaged in supporting and developing low-carbon sectors in very different ways, as they attempt to manage the tensions of national competitiveness, energy security, and climate change. The developed countries, with their current technology leadership and much higher R&D investments, seek to further their innovation lead in low-carbon technology over developing countries. At the same time, countries such as China, Brazil, South Africa, and India seek to become players by looking toward their large emerging markets for low-carbon technologies coupled with their low-cost manufacturing and perhaps frugal innovation capabilities.[25]

Table 3. Key indicators in selected developed and developing countries

Countries	Per capita emissions (a)	Carbon-intensity of the economy (b)	Per capita electricity generation (c)	Total emissions (d)
United States	17.31	0.41	14.04	5,415.00
Germany	9.32	0.26	7.61	769.98
Japan	8.97	0.25	8.72	1,168.49
United Kingdom	7.78	0,21	6.08	493.21
South Africa	6.94	1.20	5.13	441.28
France	5.52	0.16	8.7	360.89
China	5.40	1.79	3.13	7,711.38
Brazil	1.99	0.35	2.65	398.19
Gabon	1.80	0.27	0.13	2.70
Indonesia	1.71	1.09	0.71	400.91
India	1.39	1.30	0.82	1,665.38
Sudan	0.33	0.35	0.14	14.40
Nigeria	0.30	0.30	0.97	47.50

Notes : The table shows 2010 data on:
(a) CO_2 emission s per capita (tonnes CO_2/capita)
(b) CO_2 emissions/GDP (kg CO_2/US dollar (2005 prices)
(c) Generation in KWh, thousands
(d) CO_2 emissions in million tonnes of CO_2: reference approach.

Sources: a, b, d: CO_2 Emissions from Fuel Combustion (2012 Edition), IEA, Paris; c: World Bank Development Indicators dataset for Per Capita GNI (market exchange rate) (2012).

Box 10. Technological trajectories in the car industry

Currently, the car industry relies on fossil fuel-based internal combustion engines (ICEs) and is one of the major contributors to global greenhouse gas emissions. Driven by policy action and indications toward future action, the sector is witnessing efforts toward low-carbon innovation, with several more sustainable alternative approaches for the replacement of the present ICE ecosystem. Meanwhile, as developing countries see increased industrialisation through a burgeoning automobile industry, the sector remains an industrial keystone of several major developed economies.

Against this backdrop, we observe two evolutionary trends within the global industry. First, firms from developing countries (primarily China and India), having established themselves in their domestic market, have begun strategising for the global markets. Secondly, we see an increasing proliferation of efforts at decarbonisation within the car industry, primarily through the adoption of electric propulsion systems rather than existing ICE systems. Thus, overall, within the automobile sector the tension between the incumbents and newcomers is being played out at three levels: countries, firms, and technologies. Of course, the approaches to decarbonisation are different across firms. While Toyota has taken a hybrid electric route, Nissan and others have chosen a pure electrical vehicle route. Others are hedging their bets with investments in a range of hybrid and pure EV solutions (e.g., GM, Ford, Daimler, etc.). Concurrently, the incumbent ICE technologies are also improving their efficiency, thereby posing a serious challenge to the emerging technology paradigm.

At the same time, emerging firms in developing countries are hoping to use this transition within the global car industry to catch up with their established peers in the developed countries. National champions in China and (to some extent) India are investing in the overall innovation chain for electric mobility, hoping to leverage these technologies to catapult them into the global markets. At the country level, the transformation toward low-carbon mobility is supported through various policies with the aim of gaining (in developing countries) or preserving (in developed countries) industrial competitiveness in the automobile sector. Other motivations are energy security and climate change mitigation. Interestingly, these efforts, while positioned as investments toward climate change mitigation, are being created by nations, both developing and developed, to support the domestic car industry in transitioning toward the new technology landscape.

Source: Chaudhary (2012).

Low-carbon technologies are strategically important as the cornerstone of future industrialization in developing countries. However, these technologies are also an instrument for furthering the competitive edge in developed countries. This leads to a strong interest in supporting domestic low-carbon technology-related industries in both developed and developing countries.

This conflict between the need for global climate change mitigation and the respective national imperatives of competitiveness and job creation is threatening the global trade in low-carbon technologies and associated products. A framework to address such tensions is currently lacking. Without a directed effort to move toward responsible liberalisation of such trade, efforts toward climate change mitigation could easily devolve into new trade wars. A recent example of this tension is within the solar power sector. The tensions lead to protectionist rhetoric and policies in China, the European Union, and the United States. The result has been market uncertainty within the still-nascent renewable technology sectors.

From a low-carbon development perspective, while developing countries require access to low-carbon technologies, assistance in their contextualization, and financing for their deployment, the imperatives discussed above necessitate a multiple-objectives policy approach. In summary, although competitiveness is a pressing issue for both developed and developing countries, the two groups differ on the starting point and the urgency of action. The resulting tension is a major impediment to global low-carbon development.

4.3 Incumbents versus newcomers

At the company level, examples of responses to a changed business environment include the emergence of new firms and the transformation of existing ones, as players jostle to gain the competitive advantage (and mitigate risk) in a shifting landscape. For instance, the present fossil fuel-powered global economy consists of greatly different types of players: from fossil fuel producers (mining, oil companies, etc.), to operators that convert fossil fuels into usable forms of energy (power plants, engine manufacturers, etc.) to end users. Different low-carbon technology paradigms will necessarily disrupt existing value chains, affording opportunities for new players to emerge and take their place.

As low-carbon technologies are adopted globally, firms with strong capabilities in such technologies are poised to gain a large market in developed as well as developing countries. The uncertainty of the situation is illustrated by the nascent nature of low-carbon technologies; disruptive changes to existing models and the emergence of new models toward low-carbon development are likely to continue. However, different technologies present dissimilar deployment propositions depending on the complexity of technology, the extent of impact on the incumbent system, and the cost of deployment. For instance, it is easier to deploy nondisruptive low-cost and low-complexity measures to improve energy efficiency by boosting component performance than to use complex, disruptive, and expensive technologies such as electric vehicles.

A significant portion of the global innovation capability is vested in transnational companies (TNCs). Innovation for low-carbon development is no exception. As a recent UNCTAD report contends:

> Although international climate-change negotiations are proceeding slowly, the main issues of concern for developing countries – finance and technology – can be addressed partly through better harnessing of TNC resources (2010).

Through their global networks and experimental expertise, TNCs have access to knowledge, capital, and deployment expertise, which are in their interest to deploy as they secure their own place in the future low-carbon economy through technology leadership. Further, the slow pace of international climate change negotiations means that these firms are actively looking for policy-driven deployment markets for their technologies (which, for socio-economic reasons, are not ready for the market). This initial deployment is critical, both to secure expertise of the market and technology as well as to build a scale that lowers the cost of low-carbon technologies.

The sectors of developing countries that are likely to require low-carbon technologies, such as transport, power, and industry, are generally latecomers to the global scene. The result is a lag in the technology capability and expertise of such firms compared to global cutting-edge firms. Furthermore, the weak capabilities of the national innovation systems in which these firms are embedded are a major challenge to rapid improvement. While countries such as Brazil, China, and India have made significant progress in recent years, they continue to lag well behind industrialised countries in indicators of technological/innovation capabilities and performance.[26]

From a low-carbon transformation perspective, the firms, in their respective sectors, seek to leverage any deployment of technology within their home markets to build capacity for future exports to foreign markets. At the same time, in some sectors such as electromobility, low-carbon technologies offer an opportunity for developing country firms to take a major leap toward becoming global leaders in the emerging low-carbon ecosystem (Box 10). To compensate for their relatively low technology competence, these firms have started to leverage their local linkages and build international knowledge linkages while at the same time lobbying their policy makers for local industry support mechanisms, both regulatory and incentive driven.[27]

4.4 Technology transfer versus innovation cooperation

As highlighted in the previous sections, the broad development, dissemination, and deployment of a variety of less GHG-intensive technologies are key prerequisites for global low-carbon develop-

Box 11. Climate technology and innovation centres

The Climate Innovation Centres (CICs) and Climate Technology Centre and Network (CTCN) seek to encourage cross-border technology flows, foster interfirm linkages, and strengthen the absorptive capacity of the developing countries. While these measures to support capability-building and deployment are essential, such institutional linkages should be synergetic with national policy frameworks in order to efficiently and effectively further low-carbon development in the developing countries.

From an implementation standpoint, the 2010 Cancun meeting of the United Nations Framework Convention on Climate Change (UNFCCC) agreed to create a new technology mechanism to facilitate the transfer of climate-friendly technologies in the broader sense, i.e., a mechanism that emphasises the development of endogenous capabilities in absorption, adaptation, and innovation. The creation of a technology executive committee (TEC) and a climate technology centre and network (CTCN) to implement the technology transfer provisions of the UNFCCC indicates a move from traditional technology transfer to technology cooperation between the advanced and developing countries. The aim is to enhance the efficacy and scale of climate-friendly technology deployment. This new technology mechanism spans all the key stages of the technology cycle from information acquisition to assimilation, adaptation, and local contextualization of technological aspects. Further, in a departure from the past, cooperation among the advanced and the developing countries is envisaged to tackle the complexities of this issue.

While the CTCN is expected to become operational by late 2013, a CIC is already operative in Nairobi, Kenya (with other CICs in Ethiopia, Vietnam, South Africa, India, Morocco, Ghana, and the Caribbean about to become operational soon). The Kenya CIC, launched in September 2012 with World Bank's support (as part of the infoDev's Climate Technology Program) and aid support from Danida and UKaid, was expected to support over 70 sustainability-oriented ventures within the first five years, generating 4,600 jobs directly and 24,000 jobs in total within the next 10 years. To tailor the design of the CIC specifically to Kenya's needs, an extensive stakeholder process involving over 100 private, government, academic, and NGOs was conducted to chart the specific CIC offerings.

As of December 2013, the Kenya CIC has already supported 70 new clean technology ventures in areas of water, agribusinesses and renewable energy by providing matchmaking (between the technology requirement of the solution and the technologies available for transfer), incubation, capacity-building, market development, and financing support services.

Sources: Sager, A.D., Bremmer, C., and Grubb, M. (2009); Sampath and Roffe (2012); UNEP RISØ (2013) ment. However, mechanisms for technology transfer must be built into low-carbon development paradigms, because technology ownership and its development capacity are still skewed toward the advanced economies. The deployment of such technologies in developing countries is crucial to mitigating dangerous climate change.[28]

Debates about technology transfer and ways to achieve it have traditionally considered the problem as one of simply providing access to hardware technologies, with no regard for the facilitation of knowledge exchange and development of local technological capabilities (Lema & Lema, 2012). This paradigm characterised trade and IPR-related discussions for several decades of the twentieth century; the aim was to increase international commitments to technology transfer rather than to structure institutional arrangements that fit local circumstances in order to ensure the absorption, contextualization, and deployment of technology (Sampatha & Roffe, 2012; Lema & Lema, 2012). Notwithstanding the limited economic and human development benefits achieved through technology transfer in conventional sectors, the initial structuring of discussions within the UNFCCC took a traditional, limited viewpoint of technology transfer. This led to efforts to stimulate climate-friendly technology transfer limited to hardware and financing assistance, a strategy widely deemed unsuccessful (Ockwell & Mallett, 2013). However, there has been an evolution in this approach: recognition of the centrality of GHG-reduction technology deployment in developing countries addresses the public good in terms of climate change challenge, along with the recognition of the limitations of the traditional position on technology transfer.

There is a growing consensus that international action to harness technology for climate change mitigation and general development in the South must go beyond a debate of technology transfer to focus instead on innovation cooperation, i.e., joint action to accelerate the development, adaptation, and deployment of suitable technologies (Sagar, Bremner & Grubb, 2009). This innovation cum cooperation needs to extend beyond the technological aspect to encompass other facets of the innovation system that support the deployment of technology. A better understanding of the role of local innovation in developing countries to achieve and sustain low-carbon development is also needed (Ockwell et al., 2009).

Despite progress in the approach and institutional framework for technology transfer, several issues remain. The issue of technology transfer is deeply integrated with the trade- and IPR-related issues discussed earlier in this chapter, and a successful technology transfer mechanism would need to consider these complex issues as well. While new technology mechanisms such as the Technology Executive Committee (TEC) and Climate Technology Centre and Network (CTCN) have been established, any evaluation of results will have to await their implementation (Box 11).

5. Moving forward: Policy dimensions

Low-carbon development is only one among many objectives pursued by governments and donor organisations in the developing world. Nevertheless, the low-carbon imperative has become an integral element of the development agenda. A large number of development organisations have included low-carbon development in their policies and portfolios of programmes and projects. While many of these organisations have begun to implement innovation programmes, few have started to bring innovation and low-carbon development together in a systemic perspective. This is what the current report has sought to do. This implies that development policy should seek to combine the objectives of human development and environmental sustainability through the promotion of processes of learning, innovation, and development. This concluding chapter discusses policy implications.

5.1 Actors

The transformation of innovation systems toward low-carbon development will reflect the outcome of decisions made by public and private actors at different levels. At one extreme, the global agreements made in international organisations such as the United Nations will change the incentive structure for public and private actors at the international, national, and local levels. International cooperation on standards and regulations at the regional level, for example, the European Union, may set more ambitious goals and develop more effective tools to reach them than what can be agreed upon at the global level.

At the other extreme, changes in the everyday behaviour of individuals and households would have a major impact upon the transformation toward low-carbon societies. If people demand and consume fewer energy-intensive products and support (for example, as voters) policies for low-carbon development, climate change mitigation would be easier.

Between those two levels there are other important actors. In particular, local municipalities are becoming more influential. There are several reasons for this. One is that it is becoming increasingly clear that cities will be the main vehicles for growth and development in the future. The greater part of the world's economic activity and more than 50 percent of its population are concentrated in urban areas; virtually all population growth over the next 30 years is projected to be concentrated in these areas. Consequently, cities have far-reaching effects upon the world's economies: they will play a vital role in the realisation of sustainable development (UN-HABITAT, 2011).

Cities constitute environments for interactive learning and innovation. Cities have always been locations for the main producers of new knowledge and vehicles for economic growth and development. They are engines of innovation: they make people connect and interact, and knowledge is best produced by people who are close to each other. The hallmarks of city life – density, diversity, and interaction – feed innovation (Botero, 1988; Jacobs, 1969; Hall, 1998; Glaeser, 2011).

There are several ways in which cities may help economic growth to become cleaner. Large groups of people living and working close together put strains on natural resources and energy and create different kinds of pollution. But in creative periods and environments, city development has also been characterised by sharp recognition of such problems and by the mobilisation of efforts to solve them. Cities contribute to a more sustainable development by, on the one hand detecting and experiencing problems that need to be solved and, on the other, by providing creative environments for the solution to these problems. Additionally, dense populations use far less energy and materials per capita for living, heating, and transport than more dispersed populations. Increased and improved public transport has, especially in cities, great potential to reduce carbon emission. Furthermore, waste management and waste treatment are much more efficient in cities than in less urbanised areas; many cities in developing countries have made substantial progress in this area. (See Box 12) In the past few decades, many cities have gone from net emission to net reduction of greenhouse gases in waste management mainly as result of enhanced energy and material recovery. Waste prevention systems may add to the benefits already achieved (Johnson et al., 2011).

Globally, several cities have recognised their specific role in experiencing and solving environmental problems and have been pioneers in advance and independently of the national political agenda and government. In some areas they have also participated in development of international networks, helping each other to solve environmental problems. This is exemplified by waste management, where politicians, civil servants, consultants, and researchers meet each other at international conferences organised by waste management societies.

Even if cities are becoming more important, national governments are still expected to be the main actors that move between global and individual action. However, in many less developed countries, the effectiveness of government is low and in such cases, donor organisations may become important actors and engage in attempts to increase the effectiveness of government action. Public-private partnerships may be seen as another attempt to make public policy more effective.

There are many actors at several levels in the policy arena for low-carbon development, but in what follows we point to national public policies that need to be implemented in order to move developing countries toward low-carbon development. We refer also to the role of donor organisations and of public-private partnerships. We recognise that the implementation of some of the recommendations requires a higher level of governance capacity in public organisations than the ones actually at work. To enhance governance capacity may thus be a prerequisite for low-carbon development.

5.2 Policies for low-carbon LICS formation

There is now a growing body of knowledge of how to create LICS in developing countries (e.g., Lundvall et al., 2010). However, little advice is available when it comes to policies for the formation of low-carbon LICS.[29] They aim at increasing prosperity and welfare while ensuring climate change alleviation. Due to considerations of the public good concerning low-carbon LICS, governments and international development agencies play a key role in creating such systems. Government policies are important for any LICS, but they are imperative for low-carbon LICS because of the seriousness and urgency of the climate change problems; other factors include the many market and system failures inhibiting low-carbon transitions.

The appropriate policy measures will depend on context, particularly the level of existing innovation capabilities and system attributes. In the following sections, we summarise some key policy challenges for countries seeking to leverage innovation systems for low-carbon development.

5.2.1 Energy and industrial policy

Public policies have a particularly important role to play in the development of low-carbon LICS. We must consider the high external and social costs arising from carbon emissions and other unsustainable outcomes of economic activities in the 'business as usual' scenario. Different kinds of economic policies, particularly industrial policies, are needed in order to encourage the processes described in Section 2.5; these include substituting nonrenewable with renewable energy and resources, introducing new environment-friendly processes of production, etc.

Policies for the development and, in particular, the diffusion of green technologies has been implemented across a wide range of developed countries with considerable success. A number of policy instruments have worked, and governments and other actors should continue to develop new instruments and adjust existing ones to new technologies and local circumstances. From this perspective, policy is about taking steps in the right direction rather than designing optimal policies. Furthermore, unpopular but necessary policies for sustainability transitions must be introduced in a strategic, step-by-step way.

As argued in Chapter 3, market formation to ensure demand is an important policy requirement. In terms of key policy options, instruments such as feed-in tariffs, public procurement policies, and subsidies can be used. Feed-in tariffs have been introduced in many countries to guarantee return on investments in green technologies. Tariffs have been instrumental for the success of electricity generation from renewable energy such as wind, solar, and hydropower in China, India, and South Africa, and other large developing countries. However, in the majority of developing countries, such tariffs cannot stand alone.

A systemic perspective is required as tariffs in themselves are unlikely to promote access to energy in poor countries because only a small fraction of the households are connected to the national grid. In sub-Saharan Africa, the proportion is typically less than 25 percent. Therefore, subsidies should not be linked only to renewable energy generation, but also aim at supporting new infrastructures, such as minigrids. Decentralized models of energy provision are likely to be economically viable in many developing countries where long distances between population centres make connections to centralized grids very costly. Most importantly, donors are needed to fund experiments toward developing grid technology solutions as well as business models for feed-in tariffs and service provision in decentralized energy models.[30]

While measures such as feed-in tariffs and low interest finance for the promotion of carbon reduction technologies are essential, they are also expensive. The tariff structures in developing countries may need to differ from those in wealthier countries. Funding from donors and centralized national funds may thus have to compensate for costs that normally would be transferred to consumers. As households and businesses are likely to spend a larger share of their income on energy, prohibitive increases should be avoided. Donor funds may similarly support public procurement initiatives such as hybrid and electric public transport by bringing together consortia including government agencies, finance, and technology providers.

In combination with market creation initiatives and business model designs, a number of measures supported the technological capabilities of domestic green technology firms, including government support for R&D. More broadly, domestic industries in countries such as China and India have been treated as strategic. The Chinese government has used policy measures, e.g., import duties on certain components, local content requirements and preferential financing (Lema et al., 2011, 2013) while in India similar measures have been taken to support its national solar mission (Sahoo, 2013).[31]

Standards are also an important part of the policy mix.[32] The use of standards to induce low-carbon development is spreading in developing countries. China has introduced fuel standards to reduce local and atmospheric pollution and stimulate higher fuel efficiency in transportation,[33] and Malaysia has introduced process standards in waste management (Box 12). Standards are applicable to a wide number of areas, including construction, water, energy

Box 12. Waste management policy in Malaysia

Waste management goals differ among countries. Human health protection is of the utmost importance in developing countries, whereas in most developed countries the conservation of resources and the environment is the main concern. However, with increasing internal and external pressure for environmental protection, developing economies are facing a dual challenge of tackling both the basic goal of human health protection (high collection rates and the control of illegal dumping) and environmental conservation (high recycling rate, reduced reliance on landfills, and low-carbon footprint). With the increasing severity of global climate change, it is inevitable that the second goal of energy and resource conservation for waste management is addressed, thus forcing newly industrialising countries to develop more sustainable low-carbon waste management systems.

In order to achieve these multiple goals, the Malaysian government introduced the Solid Waste and Public Cleansing Management Act 2007 to strengthen the institutionalisation of waste management by centralising and standardising regulations at the federal level. Prior to the Act, local authorities had defined and practiced waste collection and disposal in very different ways, and more than 90 percent of municipal solid waste was disposed at open sites. The federal intervention ensured the safe closure of 120 open dumpsites and the introduction of ten sanitary landfills. The development and introduction of the act also led to a number of socio-technical experiments to fulfill its dual objectives.

The goals of the Act are firstly to establish a solid waste management system which is holistic, integrated, cost effective, sustainable, and acceptable to the community. The system emphasises the conservation of the environment, selection of affordable technology, and works to ensure public health. Secondly, the Act mandates the implementation of solid waste management based on the waste hierarchy that emphasises waste minimisation through 3R (recycle, reduce and reuse) intermediate treatment, and final disposal.

The transition from conventional, unsustainable land filling practices to an integrated system with waste minimisation, recycling and treatment as integrated priorities requires interaction and networking by multiple stakeholders. The transition also has to continue for at least 20-30 years, and thus exceeds the traditional perspective of short-term elected government. Instead it must subscribe to a governance structure enabling the incorporation of bottom-up stakeholders as front runners in transition innovation. As in most developing economies, this remains an institutional challenge in Malaysia and requires more creativity in governance and public policy reforms.

Source: Mohamad and Keng (2013).

generation, and waste management. It is a major challenge for donors and policy makers to combine such technical standards with social standards for democratizing technology choices and enhancing employment generation.

5.2.2 International technology collaboration and knowledge sharing

Global interactive learning plays an important role in low-carbon development. It can take place within both the public and the private sectors. Collaboration between government agencies, universities, standard-setting institutions, etc., should be a key goal of technology transfer policy. Governments and donor agencies may support the creation of platforms for interactive learning, for instance, through arrangements for secondment in relevant institutions abroad to exchange experiences and inspiration. [34]

In the private sector, equipment imports and licensing are key vehicles for the international dissemination of knowledge. These international connections tend to provide the focus in discussions of technology transfer in the climate change debate. However, scholars within the field of innovation have amply demonstrated that such vehicles tend to be ineffective without complementary investments in local capability building for the creative engagement in, and absorption and further development of, knowledge and equipment from abroad (Fu, Petriobelli & Soete, 2010; Lema & Lema, 2012). Relevant capabilities are found not only in R&D labs, but also among those concerned with design, engineering, and organisational processes, often obtained by 'doing using and interacting' modes of learning (Lundvall et al., 2007).[35]

The key challenge to policy is to identify ways to leverage global linkages for more sustainable and inclusive processes. This may hinge much less on importing low-carbon equipment than on the identification of business and organisational arrangements for the advancement of appropriate solutions. These solutions depend less on the technology or the hardware than on deployment, maintenance, and consumption, i.e., on their use. The processes and models for cooperation should be the key foci of technology transfer. Ensuring that the most adequate technologies are selected and that they are disseminated and used in a way that improves living conditions should be the key objectives for global technology arrangements.

South-South collaboration is likely to be particularly important in this regard. Actors originating from the BRICS countries may have the potential to provide particularly relevant low-carbon technologies that benefit the poor in LDCs. The emerging economies of BRICS are in a strong position to advance relevant and affordable technologies because their conditions are similar to those in poor countries. Donors should actively work to bring together the relevant actors in the global South and provide platforms for collaboration. Some Northern donors have started working with 'triangular cooperation methods' in low-carbon fields where these actively engage in facilitating technology collaboration and exchange between Southern partners (Nishimoto & Nuttall, 2013).[36]

5.2.3 Educational and labour market policy

Building the innovation capacities required for low-carbon development depends on learning processes in formal settings as well as on organisational learning in the economy. Educational systems are crucial elements of low-carbon LICS because they are central to influencing the values that form aspirations, consumption choices, and capabilities for 'low-carbon behaviour'. These range from the recycling of existing products to the development of new innovative products and processes. Many donors are in a strong position to influence price policy in favour of a commitment to education. Donor organisations and policy makers may exploit the experience gained from the relatively successful HIV/AIDS campaigns to develop new low-carbon campaigns at different levels of the school system.

The key tasks for policy makers and international agencies is thus to position sustainability in the mainstream of the national curricula. However, at the same time they should help to develop sector-specific vocational training that promotes green solutions in energy, transport, resource extraction, etc. The vocational and higher education sectors should also play a key role in low-carbon development as they can help build the links to relevant productive and service sectors. In Bangladesh and China, the presence of a skilled workforce gained through vocational training was key to the development of extensive solar PV industries (UNDESA, 2011, p. 146).

We thus see an opportunity to connect human resource development to low-carbon innovation priority areas, for example, in rural electrification missions that depend on extensive training for operation and maintenance. In China, the extensive wind power industry is significantly constrained by shortages in operation and maintenance personnel (Lema, 2013).

The transformation from high-carbon systems is associated with a reorientation of educational systems, as the labour force needs to be upgraded and reskilled. This task calls for policy cooperation among the educational sector, the enterprise sector, and the labour market. Ultimately, workers will need transitional support in the process of sector labour mobility as unemployment may rise in, for example, fossil fuel provision. Retraining is key to the success of the process.

5.2.4 Access to finance

This report has focused mainly on the innovation aspects of low-carbon development. It has not dealt at length with financing, which is a major issue in climate change, not the least in the context of poor countries with limited economic resources for financing investment in green innovation capabilities. However, the mobilisation of finance for innovation in and through appropriate programmes is a prerequisite for a transformation toward low-carbon LICS. The funds commanded by governments in developing countries and donor organisations are very limited compared to the investment required for green transformation. Therefore, while direct financial contributions may be important, the indirect role played by these organisations is most important. This is true particularly for the role of convenor when seeking to match funds from the private sector or development banks with national initiatives and programmes.

There are a range of private financial sources, such as venture capital and green funds, but due to the uncertainty involved, their actual investments in developing countries have been modest (UNDSESA, p. 154). There is a need for public-private partnership initiatives for co-financing. This might encompass the involvement of pension funds in the wealthy world and the establishment of dedicated funds, such as the rural renewable energy funds in Tanzania, Senegal, and Mali, among other places. It is not only a question of making funds more accessible. The weak and fragmented financial systems in Africa must be upgraded through capacity building and the creation of new institutions.

One key role of donors is, thus, to create alliances for financing. One particularly important task in this respect is to help set up channels connecting finance in the OECD countries with low-carbon investment needs in the developing world. Inspiration may be found in Denmark, where a national consortium of pension funds has recently helped to secure a rapid expansion of offshore wind energy generation. Donors could work to create such initiatives, which connect institutional investors with green energy investments at the international level. This may be a promising avenue, because the total amount of funding required to address climate change in the developing world is enormous when compared to the capacity of ODA finance.

5.2.5 Making the connections

In the preceding sections, we have discussed a number of policy options for the individual components of low-carbon LICS. Each of these is important in its own right, but at this juncture the most pressing policy task is to create linkages between subsystems and actors. The innovation process hinges on interactive learning across the system components to enable coordination and information exchange among users, service providers, finance, education, research, etc. As the fragmentation of innovation systems is a key impediment to progress, it is important to combine support for innovation system components (actors and subsystems) with support for system building. This should become the top priority for aid policy.

5.3 Strategies for development aid

Assuming that innovation – green innovation is no exception – is a systemic and interactive learning process, development organisations may be inspired to pursue new strategies. This final section seeks to give a brief overview of key suggestions for the design of donor strategies. Initially, it should be recognised that the scale of action required is immense, the uncertainties many and serious, and the process costly and demanding. Few donor organisations have the mandate to engage in processes with these characteristics. Political backers in home countries are risk averse and have little tolerance for uncertainty and failure. Due to vested interests and alternative priorities, low-carbon development is moreover a contentious issue in many recipient countries. The construction of policies and strategies in this field therefore needs to combine boldness of vision with careful alignment of priorities.

5.3.1 Supporting learning and capability-building

Low-carbon development pathways should be based on locally nested capabilities for devising appropriate and sustainable solutions and systems. The capabilities should not be limited strictly to the development and shaping of technologies, but should be relevant also to the end users of sustainable products and services. The specific nature and type of the required capabilities will depend on the specific settings, existing transport systems, energy infrastructures, recycling practices, etc. They will also depend on the availability of local resources, human as well as natural. In an ideal world, context-specific capability building for low-carbon in-

Box 13. Building low-carbon LICS
What can donor organisations do?

- Combine policies for renewable energy with funding for appropriate supporting infrastructure such as microgrids.
- Support awareness raising and curriculum development for low-carbon and sustainable development.
- Facilitate consultation that brings together local community government and service providers to combine service-level standards with social standards for democratising technology choices and enhancing job generation.
- Support experimentation with business models for decentralised energy provision, bringing together system actors such as energy service providers, financial institutions, equipment manufacturers, and suppliers of operation and maintenance services.
- Pool donor support into funds for financing feed-in tariffs that do not adversely affect existing energy consumers.
- Support international experience exchange through international secondment of personnel in government agencies, public advisory organisations, standard-setting institutions, etc.
- Support mechanisms to enhance South-South technology transfer by organising matchmaking events for buyers and suppliers of appropriate sustainable technologies in the global South.
- Support vocational training for low-carbon innovation priority areas.
- Introduce initiatives that connect institutional investors in developed countries with green energy investors in the developing world.

novation would be the overriding objective of the international community.

The combination of context sensitivity and the learning perspective implies the critical need for policy learning and dynamic goal setting. It also implies a need for developing local capacity for anticipating risks, learning about barriers, formulating policies to address these barriers, and revising policies in the light of experience. The international community should strengthen local capabilities for determining what kinds of strategies and policies are feasible in the specific setting. In developed and developing countries alike, this capability is underemphasised.

International donor organisations are in an advantageous position to work with national policy makers in two broad areas. The first is strategic intelligence on the available kinds of innovation capacity and capability in the given setting. The second is how to make appropriate choices about the types of projects to be funded. As every technology actor will argue from self-interest, conflicting claims often make this process difficult; sometimes, advanced technology projects tend to be more successful than projects based on more basic technologies. In principle, a learning approach would lead to more successful programme creation as the involvement of stakeholders should in itself lead to more appropriate and dynamically guided processes.

5.3.2 Supporting systems

Low-carbon innovation is a deeply systemic process that involves a range of interconnected actors such as consumers, service providers, and technology suppliers as well as advisory, research, and government organisations. The nature and direction of innovation is susceptible to influence from several interfaces. Policies that provide direction for concerted efforts are particularly important, as are policies for supporting actors who take responsibility for coordinating systematically interrelated activities.

Development aid was directed traditionally at individual projects rather than system building, particularly before the 1990s. Since then, the approach has been increasingly 'programmatic' and focused on institutional change through budget support and sector-wide programs.[37] However, the main point of the new direction proposed in this report is that local stakeholders are supported through links established with a broader set of systemic capabilities; these would not necessarily have been developed in individual and unconnected projects or through general sectoral strengthening. This can happen only when attention is given to 'systems integration' and to initiatives that bring together actors and competences in ways that can be replicated in new projects and on a larger scale.

Major donor-funded development projects exist alongside small NGO-run projects. Bringing experiences and capabilities to the system level should be a key priority. This process will typically have to be organised according to the specific field of technology concerned. Engaging with system operators who can oversee individual fields is crucial to establish them in the role of 'spiders in the web' so they may provide advice and connect stakeholders. This type of organisation would facilitate project replication and upscaling. A key task for donors is thus to engage with local administrations to build the 'meta-capabilities' necessary for coordination.

5.3.2 Shaping perceptions and discourses

Inspiration for new strategies in development such as those outlined here ultimately depends on a change in perceptions about low-carbon innovation. Partners and stakeholders need to be

Box 14. The Bureau of Energy Efficiency, India

In the Indian case, one of the major success stories in climate change mitigation has been the experience within the energy efficiency sector. To a large extent, this has been driven by the Bureau of Energy Efficiency (BEE). It takes a strategic approach to identifying areas and designing policy interventions that incorporate learning from global experiences but also considers the local economic, political, and institutional context.

In its role as the 'system operator' for the energy efficiency sector, BEE helped to identify and prioritise high-potential areas within the energy efficiency umbrella, identify the innovation gaps that exist, and help design programs to address them. Of course, fulfillment of this role requires a sophisticated understanding of local needs, the market and institutional context, and the suite of available relevant technologies' performance and cost envelopes. Moreover, since a system operator cannot hope to be the fulfilling agency for the actions within an intervention area, it also requires consultation with a range of stakeholders to ensure that a broad group of actors buy into the process. These actors eventually become key players in the innovation process.

In the case of developing countries, as evidenced by the BEE experience in India, there might be important gaps in the innovation chain marked by the absence of existing actors. In such cases, the system operator needs to support the formation of new actors to fill these gaps. Furthermore, given the very different innovation needs of different geographies and for different technologies, the system operator needs to take a bird's-eye view of the full innovation process and existing activities; in this way, programs, policies, and partnerships can be structured to most effectively bridge the innovation gaps. Interestingly, while the BEE case highlights the role of system operators who are focused on specific areas within specific geographies, models such as the Climate Innovation Centres are suggestive of system operators that span multiple areas and multiple geographies.

Source: Sagar (2013)

convinced that innovation is a comprehensive and interactive process. It is not only, or even primarily, about breakthrough 'high tech' equipment emerging from R&D labs. Innovation is centred on stepwise improvement and depends on changes in values, policies, institutional frameworks, cultures, and economies.

International organisations also have a key role to play in shaping perceptions and discourses about low-carbon development. Low-carbon technologies can act as catalysts for the improvement of welfare and broader economic development. Moreover, it cannot be assumed that there is a comprehensive view of the diverse objectives of development. For example, efforts focused on low-carbon development tend to overlook the developing world's energy access imperatives, with the result that those policies are often allowed to gravitate toward cheaper, high-carbon solutions.

International policy debates are not yet driven by the proposed new notion of low-carbon development. Climate change mitigation tends to be the driver in the policy agenda and is heavily influenced by economic interest. True change will ultimately depend on real compromises and a change in values. A change in values is needed in the global community. Those engaged in international assistance will need to engage in and spearhead this process, in recipient countries and at home.

Appendix: Low-carbon development in Globelics

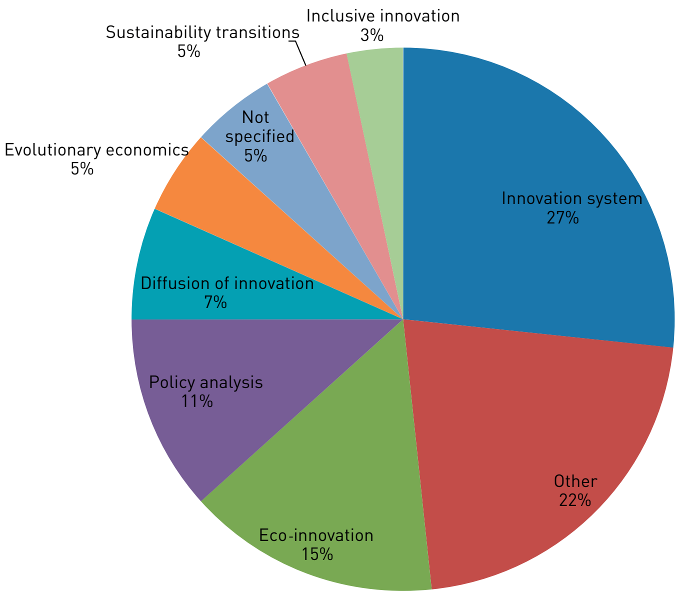
Papers on low carbon from Globelics Conferences

The following presents an analysis of papers presented at the Globelics Conferences in 2010-2013:

- The 8th Globelics Conference in Kuala Lumpur, Malaysia 2010
- The 9th Globelics Conference in Buenos Aires, Argentina 2011
- The 10th Globelics Conference in Hangzhou, China 2012
- The 11th Globelics Conference in Ankara, Turkey 2013

Papers from these conferences were examined for themes relevant to low-carbon development, such as sustainable development, green transformation, green growth, climate change, eco-innovation, energy, environmental innovation, etc. The examination and analysis are based on information from titles, keywords, and abstracts.

Fig. 3. Approaches used in low-carbon papers at Globelics conferences



A total of 873 papers were presented at Globelics conferences for the period 2010-2013. Of these, 59 papers are on low-carbon issues. This is equal to 7 percent of all papers presented at the four conferences.

Figure 3 shows the concepts and approaches in low-carbon papers. Innovation systems approaches amount to 27 percent. This category includes:

- Innovation system
- Technological innovation system
- National innovation system
- Regional innovation system
- Sectorial innovation system
- Sustainability-oriented innovation system

The category 'other' amounts to 22 percent and includes:

- Base-of-pyramid innovations
- Co-construction of technologies
- Global innovation networks
- Global value chains
- Governance of innovation
- Innovative and productive systems
- International technology collaboration
- Lead markets
- Management of green rents
- Socio-technical regimes
- Sustainable livelihoods
- System dynamics-based modelling
- Technology life cycle

Fig. 4. Sectors analysed in low-carbon papers at Globelics conferences

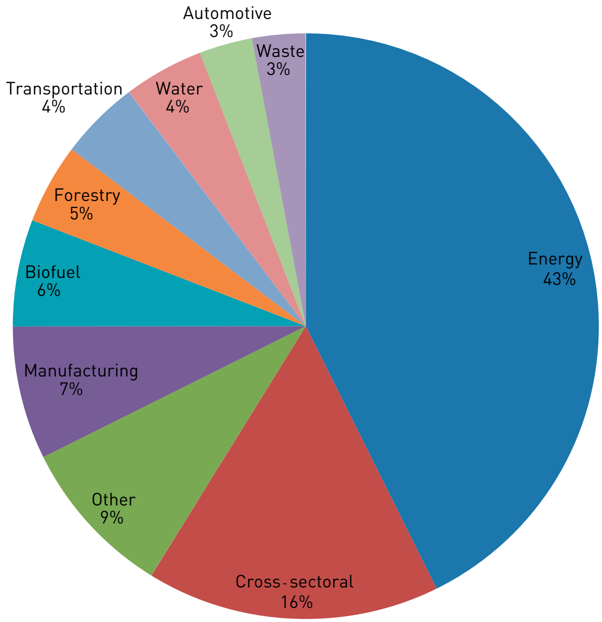


Figure 4 shows the sectors studied in the 59 low-carbon papers. Energy sectors amount to 43 percent while 16 percent are cross-sectorial papers. Nine percent of the papers are in the category 'others', which includes agriculture, biodiversity, construction, and infrastructure. The energy sectors can be subdivided into wind energy (35 percent), general (28 percent), renewables (17 percent), solar (17 percent) and carbon capture and storage (3 percent).

The complete list of papers is listed below in alphabetical order

Absar, M. (2010). The impact of climate change on the glaciers, water resources and livelihood of Pakistan. Paper presented at the 8th Globelics Conference, Kuala Lumpur, Malaysia.

Aguayo, F. (2011). Watching the blades go round: Adoption of wind energy technology in Mexico. Paper presented at the 9th Globelics Conference, Buenos Aires, Argentina.

Aladesanmi, O., Oladipo, O. G., & Siyanbola, W. O. (2011): Environmental policy as a drive for environmental innovation in Nigeria. Paper presented at the 9th Globelics Conference, Buenos Aires, Argentina.

Almeida, M. F. de L., & Melo, M. A. (2012). Sustainability-oriented innovations in energy sector. Paper presented at the 10th Globelics Conference, Hangzhou, China.

Altenburg, T. & Engelmeier, T. (2012). Rent management and policy learning in green technology development: The case of solar energy in India. Paper presented at the 10th Globelics Conference, Hangzhou, China.

Andersen, A. D. (2013). The role of infrastructure in innovation-system building and transformation in the context of a pending low-carbon transition. Paper presented at the 11th Globelics Conference, Ankara, Turkey.

Andersen, M. M. (2010). Eco-innovation in the globalizing learning economy: The greening of national innovation systems. Paper presented at the 8th Globelics Conference, Kuala Lumpur, Malaysia.

Baark, E., Kemp, R., & Turkeli, S. (2012). The political economy of eco-innovation governance in China and Europe: A comparative perspective. Paper presented at the 10th Globelics Conference, Hangzhou, China.

Bastos, V., Maia, G., & Conti, B. (2012). Global trends in cleaner technologies and challenges to the Brazilian sugarcane system of innovation. Paper presented at the 10th Globelics Conference, Hangzhou, China.

Berkhout, F., Verbong, G., Wieczorek, A., & Raven, R. (2010). Sustainability experiments in Asia: Green innovations shaping alternative development pathways? Paper presented at the 8th Globelics Conference, Kuala Lumpur, Malaysia.

Binz, C., Truffer, B., & Coenen, L. (2012). Systemic anchoring of global knowledge dynamics and the location of clean-tech industry: The formation of on-site water recycling in China. Paper presented at 10th Globelics Conference, Hangzhou, China.

Cabezas, S.R., Laría, P.I., & Rama, V. (2011). Wind energy in Río Negro - A new industrial district at Patagonia (Argentina). Paper presented at the 9th Globelics Conference, Buenos Aires, Argentina.

Carvalho, F. (2013). A portrait of eco-innovative activities in Brazilian firms: Their main determinants, processes and results. Paper presented at the 11th Globelics Conference, Ankara, Turkey.

Carvalho, F., Arruda, C., Ferreira, G. G., & Dutra, H. (2012). What triggers eco-innovations in Brazilian firms? Evidence from the Brazilian Innovation Survey. Paper presented at the 10th Globelics Conference, Hangzhou, China.

Ching, S. C. Y. (2010). Leveraging social and environmental responsibility through the changing role of government: The relational state perspective. Paper presented at the 8th Globelics Conference, Kuala Lumpur, Malaysia.

Cozzens, S., Cortes, R., Soumonni, O., & Woodson, T. (2011). Nanotechnology and the millennium development goals: Water, energy, and agri-food. Paper presented at the 9th Globelics Conference, Buenos Aires, Argentina.

Babalola, F. D., Borokini T. I., Onefeli, A. O., Muchie, M. (2012). Innovative responses to climate change mitigation: Exploring the contributions of indigenous trees in urban areas of southwest Nigeria. Paper presented at the 10th Globelics Conference, Hangzhou, China.

Delaportas, K. (2012). The time varying nature of diffusion determinants: Empirical evidence from the wind industry. Paper presented at the 10th Globelics Conference, Hangzhou, China.

Demirel, P. (2013). Environmental protection and innovation in developing countries: Evidence from Turkey. Paper presented at the 11th Globelics Conference, Ankara, Turkey.

Djezou, W. B. (2010). What fiscal policy for a sustainable management of forest resource in Côte d'Ivoire? Paper presented at the 8th Globelics Conference, Kuala Lumpur, Malaysia 2010.

Djezou, W.B. (2011). Agriculture and deforestation: What optimal conversion of forest land to agriculture in Côte d'Ivoire? Paper presented at the 9th Globelics Conference, Buenos Aires, Argentina.

Erden, Y. (2013). Can renewable energy solve the problem? Preliminary remarks on basic problems in Turkish energy sector and suggestions for solution. Paper presented at the 11th Globelics Conference, Ankara, Turkey.

Freire, C. (2013). Is there a path to inclusive and low carbon growth? Paper presented at the 11th Globelics Conference, Ankara, Turkey.

Freitas, I.B, Dantas, E., & Iizuka, M. (2013). Catching up in using and producing renewable energy technologies in the BRICS. Paper presented at the 11th Globelics Conference, Ankara, Turkey.

Freitas, I.B, Dantas, E., & Iizuka, M. (2010). The global institutional frameworks and the diffusion of renewable energy technologies in the BRICS countries. Paper presented at 8th Globelics Conference, Kuala Lumpur, Malaysia.

Furtado, A. (2013). Low carbon energy innovations systems in natural resource rich developing countries: The case of Brazil. Paper presented at the 11th Globelics Conference, Ankara, Turkey.

Garrido, S., & Lalouf, A. (2011). Before the law: The process of co-construction of technologies, regulations and local development in the WCO biodiesel production (Southern Buenos Aires, 2001-2010). Paper presented at the 9th Globelics Conference, Buenos Aires, Argentina.

Kabiraj, S. (2012). Innovating the green way: Natural considerations for sustainable consumption. Paper presented at the 10th Globelics Conference, Hangzhou, China.

Lazaric, N., Douai, A., Jin, J., & Ayerbe, C. (2012). Bandwagons or snobbish effects: Two paths for developing eco-innovations in France and China. Paper presented at the 10th Globelics Conference, Hangzhou, China.

Lema, R., & Lema, A. (2010). Whither technology transfer? The rise of China and India in green technology sectors. Paper presented at the 8th Globelics Conference, Kuala Lumpur, Malaysia.

Lema, R., Berger, A., Schmitz, H., & Song, H. (2011). Competition and cooperation between Europe and China in the wind power sector. Paper presented at the 9th Globelics Conference, Buenos Aires, Argentina.

Lema, R. (2012). The decomposition of innovation and China's catch-up in wind power technology. Paper presented at the 10th Globelics Conference, Hangzhou, China.

Li, C. (2012). Industrial policy and supply chain of the new energy vehicle industry in China. Paper presented at the 10th Globelics Conference, Hangzhou, China.

Matos, M.G. de P., Paiva, B., & de Nogueira, J. (2011). Innovation, preservation and sustainability in cultural activities: An exploratory analysis based on the local innovative and productive systems framework. Paper presented at the 9th Globelics Conference, Buenos Aires, Argentina.

Mohamad, Z.F., & Idris, N. (2011). Role of religious communities in enhancing transition experiments: A localised strategy for sustainable solid waste management in Malaysia. Paper at the 9th Globelics Conference, Buenos Aires, Argentina.

Nurse, K. (2011). Innovation governance for sustainability and social inclusion in the Caribbean. Paper presented at the 9th Globelics Conference, Buenos Aires, Argentina.

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Seminar on Learning, Innovation and Low-Carbon Development

A seminar entitled Learning, Innovation and Low-Carbon Development was organized by the Globelics Secretariat and held in Copenhagen on 4-5 April 2013. The purpose of the seminar was to gather insights from the Globelics network on the topic of low-carbon development. Twenty-six noted academics participated.

The following papers were presented[38]

Altenburg, T. (2013, April). Sustainability-oriented innovation systems (SOIS): Managing the green transformation. Paper presented at the Globelics Seminar on Learning, Innovation and Low-Carbon Development, Copenhagen, Denmark.

Bartels, F. (2013, April), Low carbon development: The challenges of 'green' innovation. Paper presented at the Globelics Seminar on Learning, Innovation and Low-Carbon Development, Copenhagen, Denmark.

Bertelsen, C. (2013, April). Low carbon innovation and development: A perspective from Danida. Paper presented at the Globelics Seminar on Learning, Innovation and Low-Carbon Development, Copenhagen, Denmark.

Byrne, R. (2013, April). Low carbon development, poverty reduction and innovation system building. Paper presented at the Globelics Seminar on Learning, Innovation and Low-Carbon Development, Copenhagen, Denmark.

Doranova, A. (2013, April). EU-South cooperation perspectives in eco-innovation. Paper presented at the Globelics Seminar on Learning, Innovation and Low-Carbon Development, Copenhagen, Denmark.

Furtado, A. (2013, April). Low carbon energy innovations systems in resource rich developing countries: The case of Brazil. Paper presented at the Globelics Seminar on Learning, Innovation and Low-Carbon Development, Copenhagen, Denmark.

Iizuka, M. (2013, April). Diverse and uneven pathways toward low carbon society in emerging economies. Paper presented at the Globelics Seminar on Learning, Innovation and Low-Carbon Development, Copenhagen, Denmark.

Lema, R., & Andersen, A. D. (2013, April). Learning and low carbon development: Key questions. Paper presented at the Globelics Seminar on Learning, Innovation and Low-Carbon Development, Copenhagen, Denmark.

Maharajh, R. (2013, April). The political economy of low carbon innovation. Paper presented at the Globelics Seminar on Learning, Innovation and Low-Carbon Development, Copenhagen, Denmark.

Mallett, A. (2013, April). International technology collaboration. Paper presented at the Globelics Seminar on Learning, Innovation and Low-Carbon Development, Copenhagen, Denmark.

Mohamad, Z.F., & and Keng, J. (2013, April). Opportunities and challenges in sustainable waste management transition in Malaysia: A multi-level socio-technical perspective. Paper presented at the Globelics Seminar on Learning, Innovation and Low-Carbon Development, Copenhagen, Denmark.

Muok, B. (2013, April). Case study on East Africa. Paper presented at the Globelics Seminar on Learning, Innovation and Low-Carbon Development, Copenhagen, Denmark.

Perrot, R. (2013, April). Emergence of low carbon industries in South Africa: Wind energy and hydrogen. Paper presented at the Globelics Seminar on Learning, Innovation and Low-Carbon Development, Copenhagen, Denmark.

Remmen, A. (2013, April). Access2Innovation. Paper presented at the Globelics Seminar on Learning, Innovation and Low-Carbon Development, Copenhagen, Denmark.

Sagar, A. (2013, April). Organizing for low-carbon innovation in developing countries. Paper presented at the Globelics Seminar on Learning, Innovation and Low-Carbon Development, Copenhagen, Denmark.

Sampath, P.G. (2013, April). Promoting international and regional incentives for low carbon development in LDCs. Paper presented at the Globelics Seminar on Learning, Innovation and Low-Carbon Development, Copenhagen, Denmark.

Smith, K. (2013, April). Transitions to renewable energy systems: The innovation and policy issues. Paper presented at the Globelics Seminar on Learning, Innovation and Low-Carbon Development, Copenhagen, Denmark.

Walz, R. (2013, April). How does LCD innovation differ: Specificities of low carbon technologies and energy systems. Paper presented at the Globelics Seminar on Learning, Innovation and Low-Carbon Development, Copenhagen, Denmark.

Special session at Globelics 11th Annual Conference

At the 11th Globelics Conference in Ankara, Turkey, 11-13 September 2013, the Globelics Secretariat organized a special session featuring a round table discussion on innovation, learning, and low-carbon development. This session was designed to give additional input to the report. Rainer Walz chaired the session.

The following presentations were given

Erbaş, B.C. (2013, September). Round table discussion on innovation, learning and low carbon development, Globelics 13. Invited presentation at the ¸11th Globelics Conference, Ankara, Turkey.

Kemp, R. (2013, September). Low-carbon development as a challenge for government. Invited presentation at the 11th Globelics Conference, Ankara, Turkey.

Lema, R. (2013). Innovation systems and strategies for low carbon development. Invited presentation at the 11th Globelics Conference, Ankara, Turkey.

Maharajh, R. (2013). Innovation, learning and low carbon development session. Invited presentation at the 11th Globelics Conference, Ankara, Turkey.

Sampath, P.G. (2013). Innovation, learning and renewable energy technologies. Invited presentation at the 11th Globelics Conference, Ankara, Turkey.

Notes

1 This book was a flagship publication of the 'environmental decade' of the 1960s and early 1970s, based on seminal works such as Boulding's *The Economics of the Coming Spaceship Earth* (1966) and Ehrlich's *The population bomb (1968)*. Both of these books addressed the threshold level of humans on earth that the environment can sustain in the long run (i.e. the 'carrying capacity').

2 Large hydropower dams often have serious ecological and social consequences (Singh, 2009; Linaweaver, 2003).

3 Carbon dioxide (CO_2) is the most important greenhouse gas and biggest contributor to climate change. However, there are a range of GHGs, including CO_2, methane (CH_4), and ozone (O_3). These gases are emitted during the combustion of carbon-based fuels, mainly coal, oil, natural gas, and wood, which takes place in connection with conventional energy production, industrial production, transport, and household consumption.

4 While CO_2 neutral energy systems are the key immediate goal, the longer-term and more ambitious goal should be to reduce atmospheric carbon dioxide concentrations to preindustrial levels.

5 The notion of 'demonstration effects' refers to effects on the behavior of individuals caused by observation of the actions of others and their consequences, typically the idea that people expect or want to buy or have things because they see that other people are able to have them.

6 The increased general awareness of environmental problems (in the West) started on the sink side, mainly as a result of the 1962 publication of Rachel Carson's *Silent Spring*. This book documented the serious detrimental effects of pesticides on wildlife, particularly birds. Since then, discussion of environmental problems has focused predominantly on the sink rather than the source side.

7 The concept of leapfrogging is based on the work of Schumpeter (2010/1942). The hy-

pothesis proposes that companies holding incumbent technologies have less incentive to innovate than potential rivals. When innovations by newcomers eventually become the technological paradigm, the newcomer companies leapfrog ahead of former leading firms. In the context of sustainable development, leapfrogging may accelerate the process by skipping polluting technologies.

8 This implies that their policies incorporate the climate myopia of financial markets and lean toward fossil energy projects. This high-carbon distortion is intensified by domestic policies in developing countries where financial policies tend to pursue a similar logic. The fear of power shortages that would be critical for industry, and risks associated with 'unproven' renewable energy, contribute to make fossil energy systems appear as a low-risk and cost-efficient path to create wealth (Unruh & Carrillo-Hermosilla, 2006, pp. 1188-89).

9 As indicated by Smith (2002), a strong policy case can be made for energy access expansion among the world's poor with fossil fuel energy, considering the disproportionately small emission impact of such an expansion.

10 Including other liquid fuels as crude oil and lease condensate, natural gas plant liquids, bitumen, extra-heavy oil, and refinery gains. Other liquids include gas-to-liquids, coal-to-liquids, kerogen, and biofuels.

11 NIMBY stands for 'Not-In-My-Back-Yard'.

12 Incremental innovation means gradual changes within established trajectories in the high-carbon paradigm. Disruptive innovation is the establishing of new trajectories within a high-carbon paradigm without dismantling it. Examples are the change from manual to electrical typewriters to personal computers with text software. This often involves creative destruction and the emergence of new industries (modelled in the industry life cycle thinking), but this can take place perfectly well within the carbon-intensive paradigm. Arguably, the diffusion of renewables can take place to some extent as part of the carbon-intensive paradigm. Radical innovation refers to a change of techno-economic paradigm by the introduction of energy sources that are able to completely replace carbon energy; it also refers to the use of the most unsustainable renewable energy sources. Historically, this type of innovation has been realised only after decades of intensive state support.

13 Biomass is already the most important renewable source of energy, 91% of total renewables in 2011 and 10% world energy demand (IEA, 2013). The most important share of biomass energy consumption is concentrated in traditional biomass (57% of bioenergy in 2011) and in the developing countries building sector. Much of this production leads to deforestation, and the use of biomass for cooking and heating is done in inefficient equipment making traditional biomass a major source of indoor pollution.

14 As argued in last year's thematic report, innovation system foresight may be one instrument for setting in motion inclusive, medium- to long-term vision-building processes aimed at present-day decisions. Innovation system foresight may also work to ensure joint action in order to build and strengthen LICS with the ultimate goal of promoting global low-carbon development (Johnson & Andersen, 2012).

15 Although as the costs of, e.g., storms and inundations increase realisation of benefits from actions aimed at reducing climate change, the results will also benefit the current generation.

16 Investment funds, venture capital, long-term institutional investors, and foreign direct investment can function as channels of finance for production of RET.

17 We use the term infrastructure to refer tangible/physical systems such as transport and logistics (including air and space), telecommunication, water provision and water management, housing, waste management, and recycling.

18 The need for a new era of transmission technology and planning is recognised also by promoters of decentralized energy solutions (Scheer, 2012).

19 This may be in stark contrast to recent decades of deregulation and liberalization of power markets (Battaglini, A., Lilliestam, J., Haas, A., & Patt, A., 2009; Hammons, 2008).

20 Fossil fuel trade is concentrated in, e.g., the New York, Moscow, London, and combined Chinese exchanges.

21 The tradeoffs among mitigation objectives and development objectives is a key shaping force within the political economy of low-carbon sectors in developing countries, not the least renewables. For the case of India, see Dubash (2012).

22 Under the UNFCCC convention of 1992, the parties aimed at 'the stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system' in accordance with 'their common but differentiated responsibility and respective capabilities. Accordingly, developed countries should take the lead in combating climate change and the adverse effects thereof'. Further, the developed countries were tasked with taking the lead on the development of appropriate technologies and cooperating in the improvement of the endogenous capacities and capabilities of the developing countries to participate in the efforts.

23 In the context of UNFCCC, the advanced economies are considered under the annex-1 countries category, i.e., the industrialised countries that were members of the OECD in 1992, in addition to countries with economies in transition (the EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States. (See: http://unfccc.int/parties_and_observers/items/2704.php)

24 Moreover, for export-oriented developing countries such as China, a large fraction of GHG

emissions are incurred in order to satisfy the final demand of consumers in other countries. These considerations add another layer of complexity to the responsibility debate concerning end use outside the producer countries (where emissions occur). See Ackerman, F. (2009). Carbon embedded in China's trade. Unpublished draft report. Stockholm: Stockholm Environment Institute.

25 See Wooldridge (2010) for a discussion of frugal innovation; see also the story of the Boy Who Harnessed the Wind in Malawi (Kamkwamba & Mealer, 2009) for an example from a low-carbon area.

26 See www.globalinnovationindex.org/content.aspx?page=GII-Home

27 For more tangible examples of tactics firms and other actors are undertaking, see Mallett et al. (2009) and Lema and Lema (2012).

28 In a broad sense, technology transfer is 'systemic knowledge for the application of a process'. It includes tacit know-how and the product as well as service- or process-related aspects of the technology (Sampatha & Roffe, 2012).

29 ltenburg and Pegels (2011) is an important exception.

30 A key problem is to ensure an element of competition in the minigrids to green energy technologies to compete with brown energy technologies (Haslip, 2011).

31 Sahoo, A., & Shrimali, G. (2013). The effectiveness of domestic content criteria in India's Solar Mission. *Energy Policy, 62, 1470-1480.*

32 Although standards are often perceived to restrict the behaviour of firms and thereby affect competiveness negatively, research has shown that the imposition of standards may also raise efficiency and quality, and ultimately reduce costs. In the developed world, high standards have often enhanced the competitive advantage of firms and economies (Porter & van der Linde, 1995).

33 Oliver, H. H., Gallagher, K.S., Tian, D., & Jinhua, Z. China's fuel economy standards for passenger vehicles: Rationale, policy process, and impacts. *Energy Policy, 37, 4720-4729.*

34 Secondment refers to the temporary relocation of a person from their regular organisation for assignment elsewhere, often made for the purpose of interactive learning.

35 Private enterprises in BRIC countries are also using increasingly active forms of technology acquisition and collaboration. These include insertion into GVCs to obtain knowledge and technology transferred within the trade and investment-centred linkages. Involved are joint R&D with international firms and outward foreign direct investment (OFDI), both brownfield (acquisition of firms) and greenfield (establishment of firms) in knowledge-intensive activities (Lema & Lema, 2012).

36 This emerging concept of Triangular Cooperation can be seen as response to global power shifts toward the South and East (Ashoff, 2010).

37 The distinction between projects and programmes is important. Projects tend to be

more standalone activities, while programmes are often broader, more inclusive and holistic in nature, e.g., tackling a sector and including activities both on the ground and capacity development efforts.

38 Please contact the Globelics Secretariat at secretariat@globelics.org for copies of papers.

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