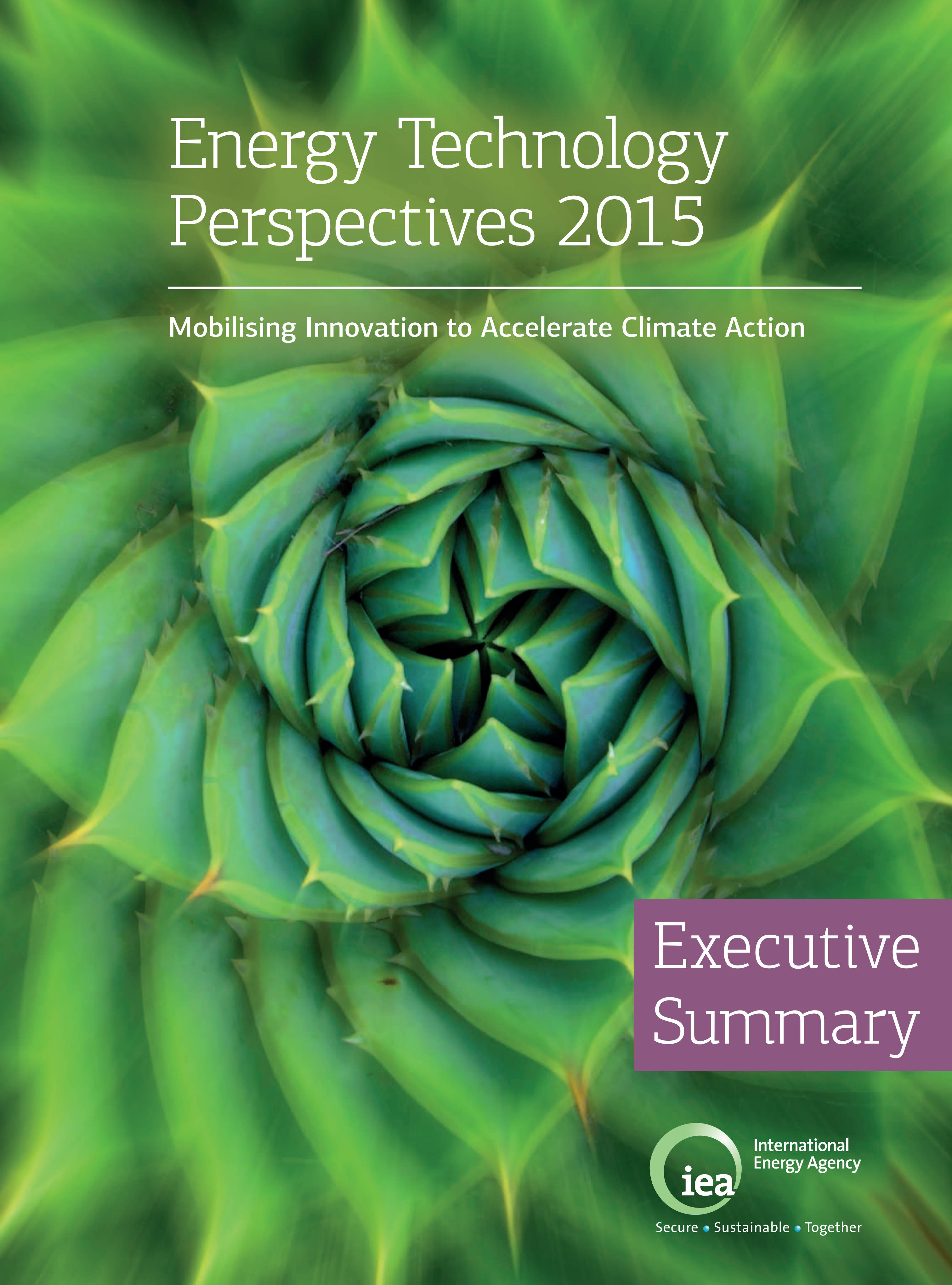
Energy Technology Perspectives 2015

Mobilising Innovation to Accelerate Climate Action



Executive Summary

International Energy Agency

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Energy technology innovation is central to meeting climate mitigation goals while also supporting economic and energy security objectives. Ultimately, deploying proven, cost-effective technologies is what will make the energy system transformation possible. Continued dependence on fossil fuels and recent trends such as unexpected energy market fluctuations reinforce the role of governments, individually and collectively, to stimulate targeted action to ensure that resources are optimally aligned to accelerate progress. Establishing policy and market frameworks that support innovation and build investor confidence over the long term is a first-order task to deliver.

Energy decarbonisation is under way, but needs to be boosted

The year 2015 should mark a turning point in global climate change action. As leaders from around the world strive to reach agreement on the need to move quickly on multiple fronts, capturing the benefits of an energy transition should be a top priority. As the world prepares for assertive decisions at the UN Framework Convention on Climate Change (UNFCCC) negotiations, decision makers should focus on the wide range of benefits that can be delivered to society by transforming the energy system. International Energy Agency (IEA) analysis shows that it is realistic and economically sensible to pursue a clean energy agenda, and that tools and mechanisms exist to support innovative and transformative changes that lead to an affordable, secure and environmentally sustainable energy future. But recent trends reaffirm the need to accelerate energy technology innovation, including through policy support and new market frameworks.

Decoupling of energy use from gross domestic product (GDP) and population growth continues, but the current rate needs to double to achieve the 2°C Scenario (2DS). On the global level, the energy intensity of GDP and the carbon intensity of primary energy both have to be reduced by around 60% by 2050 compared with today. This implies that the annual rate of reduction in global energy intensity needs to more than double – from 1.1% per year today to 2.6% by 2050. Recent progress towards the 2DS is encouraging but remains insufficient; it is troubling that advances in those areas that were showing strong promise – such as electric vehicles and all but solar photovoltaics (PV) in renewable power technologies – are no longer on track to meet 2DS targets.

The unexpected decline in fossil fuel prices creates challenges and opportunities for decarbonising the energy system. While the recent drop in fossil fuel prices changes the short-term economic outlook of energy markets, using it to justify a delay in energy system transformation would be misguided in the long term. Short-term economic gains and delaying investment in clean energy technologies will be outweighed by longer-term costs. In fact, shifting to clean energy and achieving more efficient energy production and consumption can provide an energy security hedge against future market uncertainty. Deployment of innovative technologies that exploit clean domestic sources would reduce dependence on resources exposed to market price fluctuations.

Lower fossil fuel prices should also be considered as an opportunity to better align pricing with the true costs of energy production, in part by phasing out fossil fuel subsidies and introducing carbon pricing. Such an approach would substantially boost the perceived market viability of low-carbon technologies, driving investments in research, development, demonstration and deployment (RDD&D). In the case of carbon capture and storage (CCS), for example, lower fossil fuel prices reduce costs associated with the energy penalty inherent in adding CCS to energy generation or industrial processes. In turn, this reduces the level of support needed from governments to promote private investment in reducing the carbon impact of continued fossil fuel use in these sectors.

Among energy end uses, heating and cooling systems offer substantial potential for decarbonisation that so far has been largely untapped. Today, heating and cooling in buildings and industry accounts for approximately 40% of final energy consumption – a larger share than transportation (27%). With 70% of heating and cooling demand relying on fossil energy sources, these end uses are estimated to have been responsible for 30% of global carbon dioxide (CO_2) emissions in 2012. Broad application of energy efficiency and switching to low-carbon final energy carriers (including decarbonised electricity) can push the fossil share to below 50% by 2050 with renewables (including renewable electricity) covering more than 40% of heating and cooling needs. Direct and indirect CO_2 emissions linked to heating and cooling would fall by more than one-third by 2050.

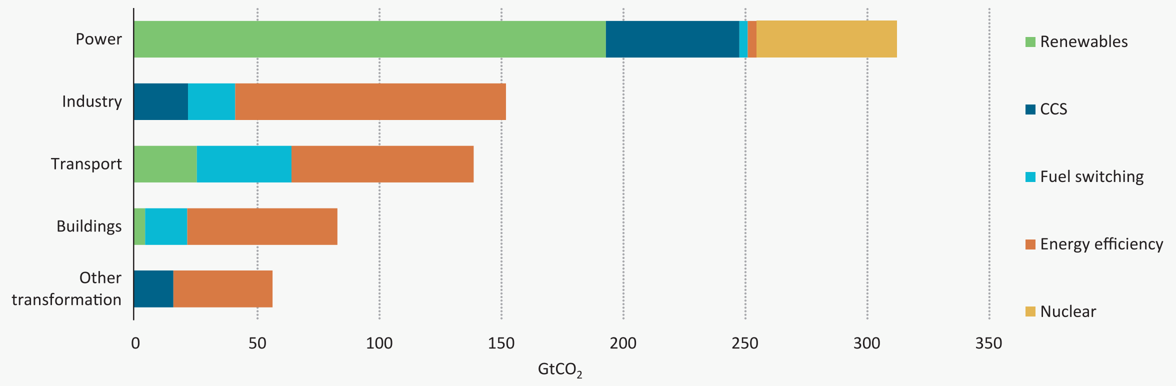
Decarbonising electricity supply and increasing electricity end-use efficiency remain two key components of the 2DS, as highlighted in *Energy Technology Perspectives 2014* (*ETP 2014*). With a share of 26% in total final energy consumption, electricity becomes the largest final energy carrier by 2050, slightly ahead of oil products. The biggest challenge by far lies in making a massive shift towards clean electricity production. Meeting the 2DS under such an increase requires reducing the global average carbon intensity of electricity production by more than 90%. Improving the efficiency of electricity use provides 12% of the cumulative emissions reduction, and also enables cost savings through reduced capacity and investment needs in the power sector. Electrified end-use options can also provide flexibility opportunities that support higher penetration of variable renewable electricity sources.

Accelerated uptake of low-carbon electricity supply options is needed to displace the continued deployment of new unabated fossil-based power plants. Utility-scale solar PV and onshore wind are now competitive with electricity generated by new conventional power plants in an increasing number of locations. While the cost gap between electricity from renewables and that from fossil fuels is narrowing, fossil plants still dominate recent capacity additions. Together with a slowdown in deployment rates of PV and wind, this undermines the trajectory needed to decarbonise energy supply and meet the 2DS renewable power targets. On a more positive note, the 2014 opening of the first commercial-scale coal-fired power plant with CO_2 capture marked a significant milestone for CCS, demonstrating that fossil fuels can be part of a sustainable energy system.

The promise of energy technology innovation can mobilise climate action

The energy sector accounts for around two-thirds of global CO_2 emissions in 2012, highlighting the benefits of innovation across a portfolio of clean energy technologies across all relevant sectors essential for decarbonisation. The technology mix that can deliver the emissions reduction will evolve over time as technologies move from research and development to market readiness. Support for technologies across all energy sectors provides the greatest potential to ensure uptake of immediately available solutions that keep climate goals achievable while also stimulating the initial development of more complex solutions needed for long-term deep decarbonisation. It also helps smooth the uncertainty inherent in individual technology development and increases the opportunity to align climate change mitigation goals with other energy policy objectives.

Figure I.1 Cumulative CO_2 reductions by sector and technology in the 2DS to 2050



Key point *A portfolio of low-carbon technologies is needed to reach the 2DS; some solutions will be broadly applicable, while others will need to target specific sectors.*

Wind and solar PV have the potential to provide 22% of annual electricity sector emissions reduction in 2050 under the 2DS; to fully exploit the performance improvements achieved through technology innovation over the past two decades, innovation is now needed at the system level. Experience shows that the main challenges to deployment – and thus the requirements that framework conditions need to meet – change as these technologies progress along the deployment curve. Thanks to innovations that improved their efficiency and reliability, onshore wind and solar PV are ready to be mainstreamed in many energy systems. Efforts to move in this direction should draw on the wealth of experience gained as various countries have passed through the earlier stages of inception and scale-up. Continued technology innovation will need to expand beyond wind and PV systems to encompass enabling technologies that reduce the variability of wind and solar PV or increase the flexibility of power systems. For very high deployment levels of wind and PV, innovation is needed in demand-side integration, energy storage and smart grid infrastructure. Widespread deployment of wind and PV technologies, consistent with the 2DS, now requires an integrated and well-designed policy and market regulatory framework.

The ability of CCS to enable fossil resources use while still contributing to CO_2 emissions reduction goals requires governments to shape markets that stimulate private investment in CCS and provide vital early commercial experience. Measures that raise the costs and risks of using fossil fuels without CCS, such as carbon pricing or emissions standards, will play important roles. But more targeted, market-based instruments are also needed to manage the investment risks and market failures in early stages of technology scale-up. This includes activities to develop CO_2 storage resources as national, regional or private assets. Given the importance of CCS for emissions reduction in industrial sectors and for enabling CO_2 removal options, the value of CCS – which will rise over time – needs to be appropriately rewarded. Governments can also leverage the political value of CCS to avoid early retirement of fossil-based generation plants and manage the pace of capital turnover, maintain diversified fuel sources and prices, and create jobs in low-carbon manufacturing.

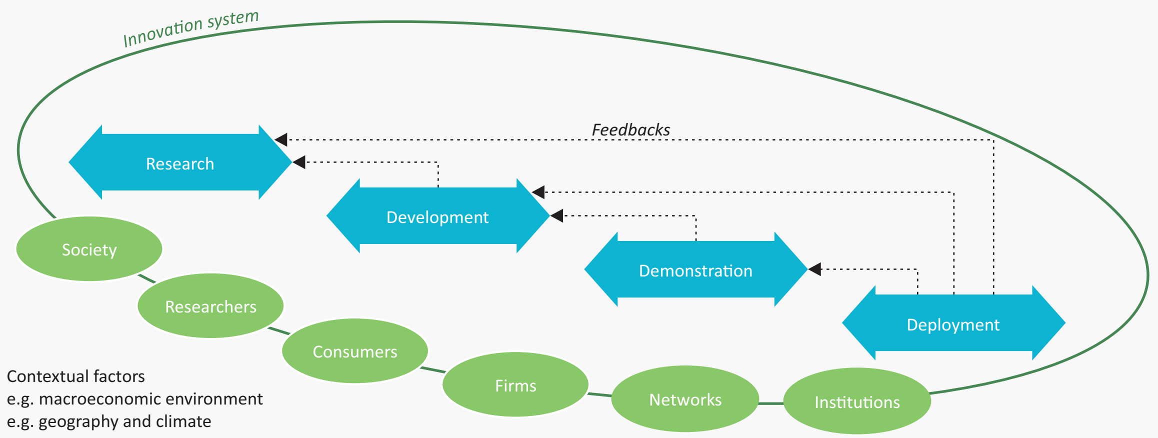
Aligning innovation goals on a global basis will enable the industry sector to reap the benefits of meeting the multifaceted challenge of decarbonisation. Almost 30% of direct industrial CO_2 emissions reduction in 2050 in the 2DS hinges on processes that are in development or demonstration today. In the medium term, the most effective measures for reducing industrial emissions include implementing best available technologies and energy efficiency measures, switching to low-carbon fuel mixes, and recycling materials. Deploying innovative, sustainable processes will be crucial in the long run, with CCS playing a key role. Integrating carbon capture, improving resource efficiency, reusing waste process streams and identifying alternative applications for diversified products should be cross-sectoral goals. To ensure the timely roll-out of innovative industrial processes, governments should seek to address barriers that are preventing progress such as economic and policy uncertainty, inadequate risk management, unbalanced collaboration and knowledge protection. Lack of clarity on when climate policies might make low-carbon production globally competitive, coupled with volatile energy prices, makes it difficult for industry to justify investments in low-carbon technologies and sustainable products.

Innovation support is crucial across the low-carbon technology spectrum

Both incremental and radical innovations are needed to decarbonise the global energy system; government support across all phases of RDD&D can facilitate both. Governments can play a critical role for promising technologies by ensuring stable, long-term support in all stages of innovation – i.e. from basic and applied research through to development, demonstration and deployment phases. An interactive and iterative innovation process, involving multiple stakeholders, captures feedback at various steps to support both "learning by research" and "learning by doing". Learning to date emphasises the need to support technology innovation with strategically aligned policy and market frameworks that reflect the level of technology maturity.

Understanding which of the available policy tools are effective for different technologies – and at different stages of their maturity – is key to success. Allocation of resources towards different technologies must consider both short- and long-term opportunities and challenges for innovation. Market-ready (or near market-ready) solutions, including many energy efficiency technologies and several renewable energy technologies, can deliver emissions reduction in the short term. At this stage, the responsibility of policy makers is to ensure efficient use of support resources (which are often scarce), prioritising support for the most promising technologies while still maintaining a portfolio of solutions. Ongoing RDD&D support is needed for technologies that show long-term potential but still require efforts to reduce costs, carry out large-scale demonstrations or achieve performance improvements for market entry.

Figure I.2 Systems-based interactive innovation



Sources: GEA (2012), *Global Energy Assessment: Toward a Sustainable Future*, Cambridge University Press, Cambridge, United Kingdom and New York; the International Institute for Applied Systems Analysis, Laxenburg, Austria.

Key point *Interactions across the entire innovation system will enable actors to develop necessary incremental improvements and breakthroughs in technologies needed to meet climate goals.*

The challenges associated with deployment warrant special attention: successful development and demonstration do not guarantee commercial success of a given technology. The innovation path exposes technologies to many challenges, breeding both successes and failures. Experience shows that even when low-carbon technologies prove cost-effective under prevailing market conditions, other (non-cost) barriers can stall their uptake and limit private sector engagement. Instruments such as minimum efficiency standards and information campaigns (designed to address risk aversion to new technologies or promote behavioural change) can help to create the favourable market environment needed to make the leap to large-scale deployment. New policies or regulatory approaches (e.g. standards and codes for buildings or vehicles or market rules in power systems) and public-private cross-sectoral frameworks along industrial product value chains are also needed. Creative approaches, such as capturing and valuing the multiple benefits of technology innovation, leveraging research on consumer behaviour, and bundling policy packages to address multiple barriers can also boost deployment.

Achieving widespread deployment of the needed technologies in the pipeline requires strategic, parallel action in technology development and market creation to close the cost gap inherent in their application. For example, CCS deployment has begun in specific regions and sectors where policies are well-aligned with strategic local and commercial interests. Meeting industrial demand for CO_2, such as in enhanced oil recovery operations, is one non-climate benefit that is driving CCS technological development and reducing the cost gap. Other important drivers that support early deployment include climate policy and public investment in innovation. Research and development (R&D) alone will not deliver the necessary performance improvements and cost reductions, however;

it must be leveraged through learning by doing in demonstration and deployment efforts, which can benefit from non-climate drivers for early stage projects.

Multi-stakeholder co-operation in support of international climate initiatives can greatly accelerate low-carbon technology innovation in alignment with global climate goals. Ambitious goals set within the framework of initiatives such as the UNFCCC can create consensus on shared objectives and build confidence in ongoing development of both established technologies and emerging low-carbon solutions. As the 2015 UNFCCC agreement is expected to be based on nationally determined climate goals, an important element is to provide signals that support scale-up of technology innovation to put the world on a 2DS trajectory. To build greater confidence in the feasibility and increase ambition of mitigation goals, the agreement could also strengthen mechanisms to inform parties on technology innovation trends. In general, multilateral collaboration on energy technology innovation could provide greater confidence that international aggregate action is aligned with global climate goals.

Innovation in emerging economies could deliver greatest, fastest advances towards climate change goals

Growing demand for energy – and the infrastructure needed to provide it – creates a unique opportunity for emerging economies to reduce CO_2 emissions by deploying low-carbon technologies. Energy demand growth, linked to increasing global population, economic development and the objective of achieving universal energy access, is a major driver for energy system expansion. During infrastructure build-out, emerging economies can be early movers in applying a systems approach to the roll-out of advanced low-carbon technologies. For example, "dynamic" power systems – that is, systems characterised by high growth rates in demand and/or facing significant investment requirements – may offer better opportunity to balance supply and demand in more efficient ways, in contrast to more "stable" systems where the transition puts incumbent generators under high levels of economic stress. Planning and building dynamic systems taking into account variable renewable energy targets would avoid the need for costly retrofits at later stages.

Non-member economies of the Organisation for Economic Co-operation and Development (OECD) are particularly important to long-term decarbonisation of the global industrial sector. As material demand rises along with their share of global markets, these economies hold significant potential to deploy new, low-carbon industrial processes. Ultimately, their uptake of innovative processes accounts for almost three-quarters of worldwide direct industrial CO_2 emissions reduction in 2050 in the 2DS. Two key prerequisites are needed to realise this potential: first, international co-operation to support technology and knowledge transfer, as well as the buildup of domestic skills and capacity for innovation, and second, the establishment of market environments that are conducive to commercially viable and innovative energy technologies.

While both OECD countries and OECD non-members will need to alter their energy systems, innovation pathways, as well as policy and market frameworks, will vary across regions. Decisions about the appropriate mix of technology solutions will have to take into account specific circumstances at national and regional levels (Figure I.3). Open and transparent communication among stakeholders can support the adoption of solutions most suited to local needs, thereby securing early buy-in and long-term sustainability of the transition. Multilateral collaboration can help identify commonalities or differences in local circumstances and challenges, and increase the relevance of shared lessons learned and best practices.

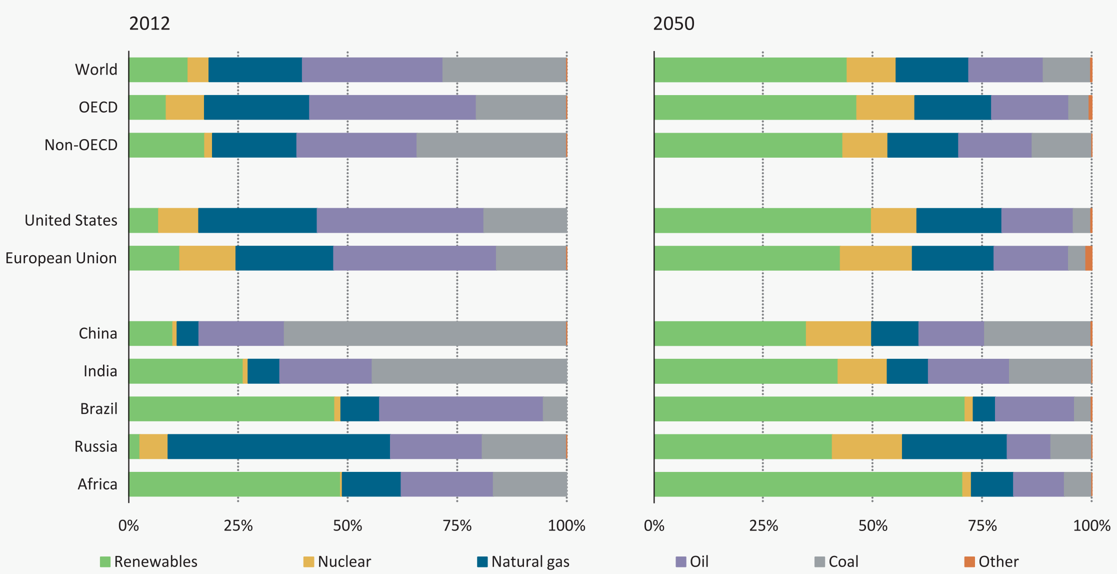
Box I.1 The importance of international collaboration

Understanding circumstances in various regions of the world allows better-informed decisions on which solutions could be best suited to local requirements (see Figure I.3). International dialogue can help share best practices and provide insights in decision rationales that can effectively support domestic transition plans.

Since its inception, the IEA has been actively engaged in multi-lateral energy technology collaboration to support the development and deployment of clean energy technologies through its core institutional activities. Among them:

- the Energy Technology Initiatives, enabling innovation through 39 co-operative agreements involving more than 6000 experts from over 50 countries that work together to accelerate advances in energy technologies
- the whole range of IEA publications, which analyses the wealth of information provided by IEA multilateral energy technology initiatives to inform more effective decision-making. Notably, IEA Technology Roadmaps allow stakeholders to agree on the necessary milestones to achieve the sustainable energy transition
- the International Low-Carbon Technology Platform, which is the chief IEA tool for multilateral engagement on clean technologies between its member and partner countries, the business community and international organisations
- training and capacity-building activities to spread best practices in energy policy and energy statistics.

Figure I.3 Regional primary energy demand profiles in the 2DS



Key point *Different national circumstances, including availability of resources, will require tailor-made solutions and pathways for deep decarbonisation by 2050 that initially leverage available solutions before developing home-grown solutions.*

Domestic innovation of low-carbon technologies in emerging economies is increasing, an important complement to their current reliance on absorbing and/or adapting technologies developed elsewhere. The People's Republic of China (hereafter "China"), India and Brazil (among other countries where a vibrant manufacturing sector underpins innovation) are advancing deployment of a number of low-carbon technologies. But the status of innovation across a broader range of emerging economies is mixed. Their overall share of global research, development and demonstration (RD&D) is rising and some countries (particularly China) are closing the gap in key areas, but patent data indicate that innovation remains concentrated in a few OECD countries. A strong domestic market, coupled with industrial capacity and an export-oriented economy, are important factors for developing and deploying more innovative technologies and systems improvements. At the regional level, growing innovation capacity and technology transfer, along with increasing investment flows, both within and among emerging economies are creating new reciprocal opportunities.

An important role for OECD countries is to engage actively in low-carbon initiatives in emerging economies; sharing lessons learned to accelerate their progress along the innovation pathway will be mutually beneficial and support global climate goals. Recognising that actions in emerging economies will play a vital role in achieving global emissions reduction targets, OECD countries can both support actions in emerging economies and design their own RDD&D strategies to address the needs of emerging economies. This approach would benefit both the supplier and recipient of technologies, while contributing to decarbonisation of global energy systems. Policy and market experience acquired in OECD countries may be beneficial as emerging economies seek to strengthen their innovation systems, particularly in the areas of allocation and management of RD&D funds or effective system and policy architecture for deploying renewable energy across key regions.

Box I.2 *ETP 2015* country case study: Energy technology innovation in China

To achieve its aim of being a global leader in low-carbon technology markets, China will need to further strengthen its ability to innovate. Over the past decade, China has used its energy and science and technology policies to advance technology development and deployment in closer alignment with economic and climate objectives.

China has demonstrated its capacity to deliver original, integrated and optimised innovation. Continued success will increasingly rely on joining and expanding international innovation networks and harnessing their power to collaboratively transform domestic and global energy systems. As China continues to move up the value chain in advanced technology and innovative systems, challenges and opportunities inherent in the global technology transfer landscape will affect both the import and export of Chinese technologies.

Recent adoption of more stringent air pollution and environmental policies in China, along with measures to improve coal quality and the efficiency of coal-fired electricity generation, provide additional incentives for clean energy innovation. Through these energy policy and technology reforms, China seeks to capture opportunities for economic advantage from the transition to a cleaner, more sustainable and increasingly market-oriented system.

Ultimately, the increasing capacity of Chinese industry to accelerate innovation in low-carbon technologies can boost the confidence of policy makers to pursue even more ambitious climate mitigation goals, knowing they can be achieved with positive trade-offs for energy security and economic development.

Current RDD&D investment falls short of long-term climate goals, misses opportunity for dividends

Substantial financial resources are needed to achieve the energy transformation: public financing models and RD&D funds need to be mobilised to leverage private-sector capital in new ways. Public expenditures on energy RD&D have been growing in absolute terms since the late 1990s; their share of total R&D, however, has fallen dramatically from a peak of 11% in 1981 and has remained flat between 3% and 4% since 2000. Governments alone will not be able to deliver the clean energy investment consistent with the 2DS objectives; unlocking private-sector capital is essential. To leverage and direct private-sector capital flows, governments need to implement policy tools that will help address investor concerns about the inherent high financial and policy risks associated with large energy investments.

Examples of effective action exist in OECD countries, with some models being adopted or developed in emerging economy contexts. Specifically, China and Brazil have used subsidised, low-cost debt to finance low-carbon technologies in domestic markets, with creative models for venture capital, private equity and state-owned enterprise financing. China and Brazil have taken the lead in using national development banks for climate financing in developing countries; India and other countries are considering similar opportunities and seeking ways to foster South-South transfers of technology, skills and knowledge. But proper governance structures remain essential to reduce risks to investors and decrease the cost of capital in emerging economies.

Economic analysis shows that fuel cost savings more than offset the additional investment costs of the 2DS, creating a compelling case for investing in the transition to a low-carbon global energy system. About USD 40 trillion additional investment (relative to the USD 318 trillion expected to be invested anyway in the business-as-usual 6°C Scenario [6DS]) is needed to transition to a global low-carbon energy system in the 2DS. This represents less than 1% of the cumulative global GDP over the period from 2016-50 and sets the stage for fuel cost savings of USD 115 trillion – i.e. almost triple the additional investment.

Setting long-term technology goals – and tracking progress towards them – can build the confidence needed to mobilise private investment in RDD&D. The effectiveness of efforts to stimulate RDD&D should be demonstrated, particularly on the part of policy makers who are accountable for appropriate use of resources. Collective efforts should be taken to identify short- and long-term technology needs at the global level, and to develop tools to track progress in technology development against defined benchmarks. Technology benchmarks can be based on indicators such as technical performance (e.g. efficiency or capacity factor), capital cost, cost of energy generated, life cycle assessments, etc. Ongoing evaluation of innovation efforts is needed to assess success, accumulate learning experiences and determine how to best support specific technologies. The ability to assess the potential of low-carbon technologies and track progress towards larger goals through a rich set of metrics is essential to ensure that policies implemented are effectively aligned and deliver on stated objectives. Such a process would need built-in flexibility to account for faster or slower progress, as well as the influence of external conditions (e.g. energy prices or macroeconomic conditions).

Multilateral collaboration can improve the cost-effectiveness of energy technology innovation and build confidence that progress is being achieved at global scale. Globalisation of the economy is sparking a move towards more open innovation frameworks that help pool resources to accelerate R&D, underwrite demonstration and stimulate faster deployment of proven technologies. Multilateral initiatives have grown significantly since 2005, covering areas such as technology and knowledge transfer, regulatory and market analysis, and policy dialogue and co-ordination. These initiatives increase the capacity of local innovation and successful deployment of innovative energy technologies (in the context of local policies and environments) to cumulatively contribute to global climate change mitigation efforts.

Box I.3 Recommendations to energy ministers

Each chapter of *ETP 2015* provides policy recommendations specific to individual sectors or challenge areas. Five high-level recommendations emerge to set the stage for a low-carbon future:

Governments should develop a vision for a clean energy future, especially in the context of the 2015 UNFCCC climate agreement. Sector- and technology-specific actions and targets should be identified to accelerate the decarbonisation of the energy sector. Governments should ensure that support continues beyond technology development to address policy and market barriers.

National policy-makers should enact stable policies to ease access to finance by reducing the risks for investors. Financing costs for low-carbon technologies can be a major hurdle for projects. Policy frameworks that support new business models (such as energy contracting or green bonds) can help attract investors to areas that face financing challenges.

International negotiators should base future emissions reduction ambitions on a vision that includes the expected progress on clean energy technologies. Governments should give full consideration to future technologies that will be deployed through continued innovation, as well as to the anticipated improved performance and reduced costs of today's best available technologies.

Private and public support should be measurable and should target all phases of RDD&D to facilitate both incremental and radical innovation. Technology-specific indicators to track progress on development and deployment should be complemented by sector-specific metrics in the power, buildings, industry and transport sectors.

OECD countries should support actions in emerging economies and design their own RDD&D strategies to address the needs of emerging economies. This approach would benefit both suppliers and recipients of technologies while contributing to decarbonisation of global energy systems.

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Energy Technology Perspectives 2015

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The IEA is expanding the availability of data used to create the *Energy Technology Perspectives* publication. Interactive data visualisations are available on the IEA website for free. After buying the book, extensive additional data, interactive visuals and other tools will be made available on a restricted area of the website.

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As climate negotiators work towards a deal that would limit the increase in global temperatures, interest is growing in the essential role technology innovation can and must play in enabling the transition to a low-carbon energy system. Indeed, recent success stories clearly indicate that there is significant and untapped potential for accelerating innovation in clean technologies if proper policy frameworks are in place.

In an especially timely analysis, the 2015 edition of *Energy Technology Perspectives* (*ETP 2015*) examines innovation in the energy technology sector and seeks to increase confidence in the feasibility of achieving short- and long-term climate change mitigation targets through effective research, development, demonstration and deployment (RDD&D). *ETP 2015* identifies regulatory strategies and co-operative frameworks to advance innovation in areas like variable renewables, carbon capture and storage, and energy-intensive industrial sectors. The report also shows how emerging economies, and China in particular, can foster a low-carbon transition through innovation in energy technologies and policy. Finally, *ETP 2015* features the IEA annual *Tracking Clean Energy Progress* report, which this year shows that efforts to decarbonise the global energy sector are lagging further behind.

By setting out pathways to a sustainable energy future and by incorporating detailed and transparent quantitative modelling analysis and well-rounded commentary, *ETP 2015* and its series of related publications are required reading for experts in the energy field, policy makers and heads of governments, as well as business leaders and investors.

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