Chapter 3

Unleash innovation to accelerate the transition

Innovation is critical for the economic transformation required to address climate change. The rate and direction of innovation will, to a large extent, determine the economic cost and therefore the likelihood of achieving the Paris Agreement's mitigation and adaptation goals. This chapter examines current trends in innovation. It highlights the barriers and opportunities for accelerating the deployment of technologies, business models and services that support the transition to a low-emission, resilient future. The chapter outlines four priority actions for scaling up climate solutions: deploy targeted innovation policies to create and shape markets for climate innovations, scale up public investment in research and development (R&D), overcome financial barriers to demonstration and early-stage commercialisation to bring existing technologies to scale, and promote international technology diffusion to ensure that innovation benefits all.

Key messages

To deliver the economic transformation required to address climate change, governments must accelerate the deployment of existing technologies, business models and services, and swiftly move the next generation of climate solutions from the lab to the market. To scale up climate solutions, governments should:

- Deploy targeted innovation policies to create and shape markets for climate innovations.
- Scale up public investment in research and development to create the next generation of climate solutions.
- Overcome the financial barriers to demonstration and early-stage commercialisation to bring existing technologies to scale.
- Promote international technology diffusion to ensure that innovation benefits all.

Why is innovation transformative?

Innovation – the creation and diffusion of new products, processes and methods – is fundamental to the economic transformation required to address climate change. The rate and direction of innovation will, to a large extent, determine the economic cost and therefore the likelihood of achieving the Paris Agreement's mitigation and adaptation goals.

The world requires a radical change in the mix of technologies that underpin the production and consumption of goods and services. The IPCC Special Report on the impacts of global warming of 1.5ºC finds that:

> *Pathways limiting global warming to 1.5°C with no or limited overshoot would require rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems […]. The systems transitions consistent with adapting to and limiting global warming to 1.5°C include the widespread adoption of new and possibly disruptive technologies and practices and enhanced climate-driven innovation* (IPCC, 2018[1]).

Opportunities for low-emission innovations are economy-wide, and include: technologies for renewable energy, energy storage and smart grids; energy-efficient lighting, heating and cooling in buildings; electric, hybrid and fuel-efficient vehicles; more efficient crop varieties, vaccines to inhibit methane production by ruminants and laboratory-grown meat; and carbon capture, storage and use technologies. New technologies such as permeable materials for pavements and roads, drought-resilient crops and improved irrigation schemes could also help populations adapt to climate impacts.

Innovation is not only about the development and diffusion of new and disruptive technologies. It is just as much about institutional and organisational changes, and new services and business models (e.g. energy-as-a-service platforms, electric car sharing, circular supply models), all of which can help drive the systemic changes needed in production and consumption for the transition towards a low-emission, resilient future. Technological and non-technological innovations can work in tandem to significantly reduce the demand for infrastructure services and open up new and more cost-effective pathways to achieve the goals of the Paris Agreement.

What is the state of play?

The development of technologies for climate change mitigation and adaptation has increased rapidly since the beginning of the century. Globally, the number of patented inventions related to climate change mitigation in buildings, transport and energy generation tripled between 2000 and 2010. However, inventive activity has been slowing across all major environment-related domains since 2011, both in absolute terms and as a share of total inventions (OECD, 2017[2]). This might partly be a result of the recent fall in energy prices, which makes the value of future energy savings smaller, as well as the continued uncertainty over national and global climate policies.

However, there has been some progress in the diffusion of low-emission technologies. Renewable energy sources such as solar and wind are now cost-competitive with conventional sources of electricity in some markets and are being quickly brought to scale (IEA, 2017[3]). Progress has also been made across other sectors such as transport, where there have been improvements in vehicle efficiency and a doubling of electric car sales between 2014 and 2017 (IEA, 2018[4]). In forestry and agriculture, satellite imagery has revolutionised data collection and monitoring of deforestation, helping to inform policy making and enhance enforcement efforts.

Many of the emerging innovations have their roots in the digital revolution. Digital technologies are facilitating investment and citizen engagement in renewable energy and other sustainable development projects enabling more decentralised and flexible energy systems, and increasing energy efficiency (see Box 3.1). For example, smart charging technologies for electric vehicles are helping address intermittency in renewable energy supply, while smart meters are changing energy consumption patterns in homes and businesses.

Despite pockets of progress, the current level of innovation falls short of what is needed to reach the 2°C goal, let alone move towards 1.5°C, with severe implications for human health and well-being, biodiversity and economic growth. Of 38 clean-energy technologies included in the IEA's Sustainable Development Scenario in their World Energy Outlook (which is consistent with the 2°C goal), only four are on track to penetrate markets sufficiently: solar photovoltaic, lighting, data centres and networks, and electric vehicles. The majority of technologies need more progress, and a quarter are classified as "not on track", including carbon capture and storage, concentrating solar power and geothermal and ocean technologies (IEA, 2018[4]).

What are the barriers and opportunities for change?

To increase the likelihood and reduce the cost of achieving and adapting to the 1.5°C or 2°C goals, the world must accelerate the deployment of existing innovations in technology, business models and services, and swiftly move the next generation of climate solutions from the lab to the market. These innovations need to be adopted as widely as possible to ensure shared prosperity and an inclusive transition to a low-emission and resilient future. As no single government has all the technological, scientific, financial and other resources needed to address climate change, it is important that strong national policies for innovation are accompanied by effective international co-operation in the development and diffusion of innovations.

Advanced, emerging and developing economies face different challenges and opportunities in delivering climate solutions. However, there are four principal barriers to innovation that they all must overcome. First, markets undersupply innovation because of

the positive externalities associated with the generation and diffusion of knowledge (i.e. firms do not capture all the benefits of their innovations). Second, when firms and households do not have to pay for environmental services or the costs of pollution, the demand for green innovation is limited and the incentives for companies to invest are lower. Third, financing of the more radical types of innovation that could potentially be introduced by new market participants is constrained by information asymmetries, which can be exacerbated if there is uncertainty concerning future policy settings. Fourth, the international dissemination of climate technologies can be undermined by trade barriers and a lack of country capacity to adopt, adapt and deploy new technologies.

Innovation is not only critical for addressing climate change; it lays the foundation for new businesses, new jobs and productivity growth and it can help drive progress towards other Sustainable Development Goals (SDGs). To reap the full benefits of innovation, governments need to have the foresight and flexibility to take advantage of new technologies and opportunities, such as the digital revolution, and be prepared to break dependencies on institutions and technologies with which they are familiar.

Box 3.1. **Harnessing digital finance to engage citizens in sustainable development**

Digital finance encompasses a broad range of new software, customer interaction tools, financial products and business models. It presents new opportunities for raising capital, enhancing transparency and access to information, and making market mechanisms more inclusive. For example, new online platforms can aggregate global data on isolated investment opportunities, cutting the number of intermediaries between investors and project holders. Blockchain technologies can serve to enhance market transparency by offering "smart contracts" and keeping an immutable record of transactions made (see Box 5.3). The examples below highlight how online platforms, mobile phone applications and other digital technologies are engaging and empowering citizen-consumers.

Leveraging mobile phone technology

M-Pesa is a mobile phone-based service that enables easy deposit, withdrawal and transfer of money. Since its launch in 2007 in Kenya and Tanzania, it has enjoyed great success and spread to other developing countries. It has also enabled further innovation in the form of the M-Kopa, through which customers pay a deposit for a solar kit through M-Pesa as well as a daily rent for 12 months, at which point they become the owner of the device. In 2014, just two years after its launch, M-Kopa secured a USD 10 million (860 million Kenyan shillings) commercial-grade syndicated debt facility fronted by the Commercial Bank of Africa (CBA), which enabled it to extend its operations. To date, M-Kopa has raised USD 45 million in total equity funding and debt financing, and has connected 600 000 customers to affordable solar power. Similar pay-as-you-go (PAYG) solar solutions have been deployed across Africa, Asia and Latin America, for example Simpa Networks in India and Quetsol in Guatemala. These companies have the potential to revolutionise the low-income energy sector.

The latest arrival on the scene is M-Akiba, a retail bond issued by the Government of Kenya through which citizens have the opportunity to invest directly in infrastructure development projects. A low minimum level of investment (approximately USD 30 or 3 000 Kenyan shillings) offers them an affordable savings product, with 10% per annum fixed returns over three years comparable to peer financial saving products. The government hopes to borrow approximately USD 50 million (5 billion Kenyan shillings) through the bond. To date, it has raised approximately USD 2.4 million (247.75 million Kenyan shillings), and while it is still small scale today, M-Akiba together with M-Kopa and M-Pesa have already shown the potential of digital finance to catalyse broader public participation in sustainable development projects and empower citizens to make informed and sustainable decisions.

Box 3.1. **Harnessing digital finance to engage citizens in sustainable development** *(cont.)*

Matchmaking

Motif Investing is an online platform that relies on algorithms to detect and offer investment products, including in sustainability and infrastructure (e.g. solar, wind, electrical vehicles and biofuels). It specifically targets younger investors interested in low-fee impactful investments that are aligned with their environmental values, but also engages in business-to-business activities, for example with Goldman Sachs and JP Morgan Chase. This means that these large banks can offer portfolios that include sustainability investments without having to build them in-house, or having to compete for the next generation of investors.

Another example is the Canadian platform Convergence Finance, which hosts an online database that enables a quick and easy search for credible deals in emerging economies. This simplifies and shortens screening processes and broadens the pool of potential investors. A dedicated programme, called 'Design Funding', also offers project proponents support to run feasibility studies and to access proof-of-concept funding. As of May 2018, Convergence Finance had awarded USD 5 million of grants to 15 projects, thereby mobilising USD 110 million. Convergence Finance has funded large projects such as the establishment of a Climate Finance Facility in partnership with the Development Bank of Southern Africa (DBSA), the Coalition for Green Capital (CGC) and ClimateWorks Foundation. The facility will focus climate-friendly infrastructure projects in countries of the Southern African Development Community.

Crowdfunding

LittleBigMoney is a Colombian crowdfunding platform for social and environmental projects. The platform offers a registry of available projects and an online tool to finance them. Interactive features, such as video presentations of the projects, provide a personalised experience to investors. To date, LittleBigMoney has facilitated over 4 000 projects, bringing together more than 1 600 stakeholders, and mobilised almost 500 million Colombian pesos (USD 170 000).

Digitalisation presents transformative opportunities to empower citizens and drive the low-emission transition, but its possible unintended consequences are still poorly understood. Digital technologies consume large amounts of electricity, which could offset the energy efficiency gains it can deliver. Digitalisation of the energy sector also renders systems more vulnerable to cyber attacks, raises concerns about data privacy, and can create significant changes in work patterns, tasks and skills. All of these potential issues need to be prepared for and addressed with tailored policies.

Nonetheless, there appears to be widespread consensus on the importance of further exploring the potential for digital finance to advance sustainable finance, as recognised by the G20 under Argentina's Presidency, and by the launch of a Task Force on Digital Financing for the Sustainable Development Goals by the UN Secretary-General in 2018.

Source: UN Environment (2018[5]), Digital Finance and Citizen Action in Financing the Future of Climate-Smart Infrastructure (forthcoming), *Financing Climate Futures Case Studies*.

3.1. Deploy targeted innovation policies to create and shape markets for climate innovations

Getting the basics right: the enabling environment for climate innovations

A sound enabling environment for innovation – e.g. well-aligned tax, competition, education, science, trade and investment policies – and a strong environmental policy framework must underpin efforts to scale up climate mitigation and adaptation innovation (OECD, 2015[6]; Ang, Röttgers and Burli, 2017[7]). Governments can help increase investor confidence and ensure that innovation activity supports rather than undermines the low-emission transition by setting a clear and stable policy signal through long-term low-emission development strategies (see Chapter 2) and carbon pricing. For example, the introduction of

the European Union emissions trading system induced regulated companies to file 30% more patents in low-carbon technologies (Calel and Dechezleprêtre, 2016[8]). However, the price of carbon emissions globally is still extremely low (OECD, 2018[9])(see Chapter 4). Increasing the price on carbon would help catalyse private sector innovation in a cost-efficient manner, without burdening (and possibly even replenishing) public budgets. It would also incentivise behavioural responses by consumers, triggering additional energy savings.

A strong enabling environment for innovation is a necessary but not a sufficient condition for the transformation. To deliver transformative change, governments must also adopt a suite of demand- and supply-side innovation policies and finance measures that are tailored to the climate challenge.

Moving to the next frontier: mission-oriented programmes

One way governments can set the direction of innovation is by adopting mission-oriented programmes. Mission-oriented programmes align policies, public R&D programmes and public-private collaboration to overcome a concrete problem. This in turn helps to address a broader societal challenge or "wicked problem" – one that is complex, systemic, interconnected and urgent – such as climate change, environmental degradation and public health challenges (Box 3.2). At the core of the mission-oriented approach is the understanding that governments must not only correct market failures, but also actively drive and direct innovation by co-creating and co-shaping markets (Foray, Mowery and Nelson, 2012[10]; Mazzucato, 2017[11]).

Strengthening the market pull for climate innovations: demand-side policies

In the last decade, increasing attention has been paid to the role of demand-side policies for innovation to supplement the more traditional supply-side policies (e.g. R&D support). Demand-side policies can help direct resources and capabilities by creating or strengthening the market pull for climate innovations. In general, governments should emphasise competition and technology neutrality, rather than supporting specific technologies and solutions. However, judicious use of more technology-specific measures may be required to overcome the barriers facing low-emission technologies and drive transformative rather than incremental innovation. Feed-in-tariffs (FITs), for example, were instrumental in bringing wind power in Denmark and Germany to full commercialisation at a time when the technology was not yet competitive (OECD, 2011[18]).

National and subnational regulations or performance standards have also demonstrated their effectiveness in encouraging more innovation. These include energy-efficient building codes or renewable portfolio standards that require electricity providers to include a minimum share of clean energy in their output mix (e.g. California Renewables Portfolio Standard) (Rozenberg, Vogt-Schilb and Hallegatte, 2014[19]). However, these instruments tend to benefit technologies that are closer to market. This points to the need for a broad policy mix that includes both technology-specific and technology-neutral measures, regulatory and economic instruments, and direct R&D funding for technologies that are further from the market.

National and subnational public procurement can also be used to create market pull for climate innovations. By introducing climate-related criteria in procurement decisions, public procurement can bring low-emission solutions to market and trigger industrial and business model innovation through the creation of lead markets (Baron, 2017[20]). A number of governments have adopted sustainable public procurement criteria and practices, such as tenders with lifecycle costing that incorporates the costs of emissions in

value-for-money assessments, and market dialogues to help procurers and potential suppliers to formulate innovative tenders (OECD, 2017[21]). Like regulations and standards, procurement can spur innovation without engaging new spending.

Box 3.2. **Mission-oriented innovation to drive a green, low-emission transition**

Germany – Energiewende (energy transition)

The German *Energiewende* is a mission-oriented programme aimed at creating a low-carbon energy system, while at the same time phasing out nuclear power by 2022. The programme is governed by the Federal Ministry for Economic Affairs and Energy, in close interaction with regional governments and private entities. Households and energy co-operatives own a large share of the renewable energy systems, which has increased flexibility and fostered public acceptance: 90% of citizens believe the programme to be vital (O'Donnell and Gruenig, 2016[12]; Kuittinen and Velte, 2018[13]). The *Energiewende* is supported by a combination of tax incentives (e.g. to incentivise the retro-fitting of buildings), government-funded research programmes and low-interest loans from the state investment bank (KfW Group), for renewable energy and energy efficiency investments (Kuittinen and Velte, 2018[13]). Public finance has leveraged significant private investments in energy retrofits and renewable energy installations, closing the gap between public-sector involvement and the real costs of the *Energiewende* (O'Donnell and Gruenig, 2016[12]).

China – New Electric Vehicles

China's first targeted policy to promote New Electric Vehicles (NEVs) was launched in 2001 by the Ministry of Science and Technology. In the years to follow, the policy was extended and a range of ministries – for example the National Development and Reform Commission, the Ministry of Industry and Information Technology and the Ministry of Finance – as well as regional governments were engaged. The aim is to have five million NEVs on the road by 2020, and at least one in every five cars sold in China to be a new energy model by 2025. Both demand- and supply-side policies are being deployed to reach these goals, including: R&D projects; support for commercialisation; tax credits and fiscal rewards for purchasing NEVs; tighter regulations on combustion engine cars; public procurement and setting standards. While China has become the largest electric car market in the world, it does not appear to be on track to reach its mission goals by 2020 and 2025 (OECD, 2014[14]; Pelkonen, 2018[15]).

Belgium – Circular Flanders

Circular Flanders is a multi-stakeholder platform consisting of authorities, companies, non-profit organisations, civil society and academics with the mission to create circular economies for materials, energy, water and food in the Belgian region of Flanders. A change of thinking in the beginning of the century led to the creation of a variety of initiatives related to the circular economy. *Circular Flanders* was launched in 2017, integrating three of these: Plan C, a circular economy hub; SuMMa, a policy research institute; and Agenda 2020, a list of 45 concrete projects. The programme links with the Flemish government's Vision 2050, which establishes the circular economy as one of seven "transition priorities". While the main governing body of *Circular Flanders* is the Public Waste Agency, the transition priority is under the joint responsibility of the Ministry of Environment and the Ministry for Economy and Innovation. The program has six core activities: creating a network; offering financial support; sharing knowledge; developing policies; stimulating directed innovation; and scaling up best practices. It has been estimated that investment in the circular economy could cut materials expenses by 2-3.5% of GDP, as well as create 27 000 new jobs in Flanders. However, it is difficult to quantify outputs and outcomes to date as no overall targets have been set and no indicators exist to monitor the initiative (Tuerk and Bird, 2018[16]; Circular Flanders, 2017[17]).

A less apparent demand-side policy that can promote innovation is standardisation. If standardisation occurs too early, it may shut out better technologies; if it occurs too late, the costs of transition may prevent diffusion of non-compliant innovations. However, if employed with care, standardisation can help create critical mass to benefit from economies of scale. An example of standardisation in practice is charging infrastructure for electric vehicles. Standards for physical plugs, as well as for payment and power supply could create a competitive market, while also ensuring consumer convenience. The EU standardised the electric plug used for normal alternating current (AC) charging in 2014, but competing systems exist for the more recent direct current (DC) fast charging and wireless charging technology. If standards are not designed with flexibility, they can be outpaced by technological developments.

Consumers can also catalyse and influence the direction of innovation. Governments can empower consumers by deploying policies that counter inertia and scepticism about new goods and services (OECD, 2011[22]). Monetary or price-based incentives such as demand subsidies or tax allowances can encourage risk-averse consumers to buy innovative new products. For example, Belgium's Walloon Social Credit Society (SWCS) offers advantageous loans to low-income households under its "Ecopack" scheme. These support the adoption of energy efficiency measures: installing heat pumps, photovoltaic panels, solar water-heaters and pellet stoves; or insulating roofs, walls and floors (Société Wallonne du Crédit Social[23]). Information and awareness campaigns can also be used to influence consumer preferences and behaviour, where there may be information failures.

3.2. Deliver and scale up support for research and development of climate solutions

Research is the foundation of future innovation, but tends to be under-supplied by the private sector due to its long time horizon and the uncertainties surrounding the future commercial viability of any resulting technologies. Governments can help scale up R&D from private firms and universities through direct funding in the form of loans and grants, or through fiscal incentives, such as tax credits. Aligning R&D subsidies for fossil fuel research with low- and net-zero emissions goals is equally important.

Realising the full potential of innovation to drive the transition to a low-emission economy will require much greater levels of public investment in R&D. While estimates of the funding gap vary, there is a broad consensus that public investment in low-emission R&D would have to at least double to reach the goals of the Paris Agreement (Dechezleprêtre, Martin and Bassi, 2016[24]). There are positive signs that governments are starting to respond to this need, at least for certain sectors. The IEA (2018[25])indicates that public innovation investment in clean energy technologies increased by 13% in 2017 to USD 22 billion, breaking a streak of declines and stagnation over several years. Furthermore, through the international initiative "Mission Innovation", 23 countries and the European Union have pledged to double their clean energy R&D spending by 2021 to address climate change, make clean energy affordable and create new jobs and commercial opportunities. If the pledge is achieved, the combined annual R&D investment from these countries will rise to approximately USD 30 billion per year (Mission Innovation, 2018[26]).

Public research through government research institutes and laboratories has an important role to play in linking basic and applied research. In addition to targeting technological progress, public research should explore socioeconomic and political aspects that could help deliver systemic changes in production and consumption practices, habits

and behaviour or that could influence the acceptance and adoption of new technologies. The French Environment and Energy Management Agency's Strategic Roadmap for Smart Electricity Systems, for instance, identifies research priorities concerning economic and regulatory conditions (e.g. developing innovative business models to support the integration of energy storage systems), and human and social sciences (e.g. identifying and analysing the governance processes needed for innovations to spread), in addition to technological research priorities.

Box 3.3. **Collaborative approaches to R&D**

National multi-stakeholder collaboration for R&D

The SunShot Initiative

The US Department of Energy's Sunshot Initiative strives to make solar energy cost competitive by the end of the decade. SunShot awards partial funding for R&D projects to the best bids from companies, universities, state and local governments, non-profit organisations and national laboratories. The programme met its 2020 target of decreasing utility-scale solar energy cost from USD 0.28/kWh to USD 0.06/kWh three years earlier than expected. Similarly, the price of residential solar power dropped from USD 0.52 in 2010 to USD 0.16 in 2017, and from USD 0.40 to USD 0.11 for commercial use (US Department of Energy[28]).

European Institute of Innovation and Technology's KIC

With more than 300 partners from education, research, business and government, the European Institute of Innovation and Technology's Climate-KIC is the EU's largest and most extensive public-private partnership to accelerate the transition to a net-zero emissions economy. Operating from 13 centres, the initiative takes a broad approach by offering educational programs, supporting research and development, as well as fostering entrepreneurship (Climate-KIC[29]).

International collaboration for R&D

US-China Clean Energy Research Center

The US-China Clean Energy Research Center aims to generate a diversified energy supply and accelerate the transition to an efficient and low-emission economy, while delivering economic and environmental benefits to both countries. It is supported by public and private funding of at least USD 250 million over five years (2016-2020) and focuses on five technical tracks, including energy efficiency, water and energy technologies and clean vehicles. Each research consortium has a joint work plan and technology management plan, as part of a broader intellectual property framework (Energetics Incorporated, 2018[30]).

Strengthening International Cooperation on Climate Change Research (SINCERE)

SINCERE is a project by the European Union running from 2018-2022 with a budget of EUR 2.2 million, which aims to strengthen international climate change research and innovation co-operation involving European countries. SINCERE will involve the business sector and global financial institutions, other key international research as well as policy and societal actors. A particular goal is expanding the existing EU Joint Programme Initiative (JPI) Climate to include Eastern European member countries; another is to set up two flagship actions with Africa and Latin America (European Commission, 2018[31]).

International Energy Agency (IEA) Technology Collaboration Programmes

The IEA's Technology Collaboration Programmes involve over 6 000 experts worldwide who represent nearly 300 public and private organisations located in 55 countries. To date, participants in the programmes have examined around 2 000 energy-related topics, and carried out projects on socioeconomic aspects of technology deployment, research to reduce greenhouse gas emissions, advancing demonstration of innovative energy technologies, contributing to benchmarks and international standards, and sharing information through hundreds of expert stakeholder events (IEA[32]).

Well-designed collaborations between the public and private sectors, across firms, and among academia and national laboratories can help match problem-owners with solution-providers, pool resources, bring together complementary skills and expertise, and lower technology risks and R&D costs (Box 3.3). International co-operation on R&D can also accelerate innovation by enabling larger-scale projects, avoiding duplication and bringing together different skills and expertise. Co-operation can take place in a multilateral context with open participation, in limited-member groups or bilaterally. To ensure that co-operation is successful, care must be taken to balance different mandates and restrictions, and clearly define and co-ordinate management and responsibilities (OECD, 2014[27]).

Bottom-up open innovation strategies can also facilitate the emergence of innovations not prioritised by strategic road-mapping or technology and innovation assessments, and hence help prevent potentially promising innovations from being overlooked. Open innovation strategies can be pursued through challenge-led calls, which utilise prize competitions, crowdsourcing, ideation or open dialogues.

3.3. Overcome the financial barriers to demonstration and early-stage commercialisation

Innovative technologies and solutions emerging from R&D must pass through several stages of validation and refinement before reaching full commercialisation, and will depend on different types of investors and investment instruments along the way. These include angel investors and venture capital funds, corporates and corporate venture capital funds, financial institutions, civil society (e.g. crowdfunding) and philanthropists. Due to information asymmetry and the fragmented nature of investor networks, projects may face a discontinuity of investment and fall into a so-called funding "valley of death". This tends to occur at the demonstration phase (the "technology valley of death") or at early-stage commercialisation (the "commercialisation valley of death") (In, Monk and Levitt, 2017[33]).

Clean energy technologies that require large-scale capital investment, have long development timelines and face high technology risks are particularly vulnerable to funding gaps (Gaddy, Sivaram and O'Sullivan, 2016[34]). Indeed, recent analyses have highlighted the limitations of traditional venture capital (VC) models for funding such innovations. Although VC has played an important role in accelerating the commercialisation of some clean energy technologies, recent investment in clean technology tends to focus on a narrow range of more mature technologies, with energy efficiency and transportation receiving the lion's share (IEA, 2017[35]). This may be due in part to the time and capital constraints of VC investors and the relatively poor risk-return profile of clean energy investments (Gaddy, Sivaram and O'Sullivan, 2016[34]).

While a strong enabling investment environment is fundamental for pulling innovations through the valley of death, there is also a need to diversify and better align the investment vehicles and actors involved at the different stages of innovation, and to improve the allocation of investment risk. Governments can help bridge the valley of death by supporting the expansion of public and private incubators (e.g. Israel's Incubators Centre for Technological Initiative) and accelerators (e.g. Start-Up Chile), and by using public money to fund risky, long-term projects that could have large social benefits but are too early for private-sector investment. The US Department of Energy's Advanced Research Project Agency, for instance, provides researchers with funding, technical assistance and support for market readiness to help them develop new ways to generate, store and use energy.

Low-interest loans, loan guarantees, tax incentives and quasi-equity financing can be deployed to reduce investment risk and attract private sector finance. The European Commission and the European Investment Bank have developed a EUR 150 million programme, InnovFin Energy Demonstration Project, to fill the funding gap for first-of-a-kind demonstration projects for innovative energy technologies in the EU. The programme will provide funding of between EUR 7.5 million and EUR 75 million to large-scale energy demonstration project developers.

Governments can promote and facilitate new partnerships and coalitions to help align investment vehicles and actors, thereby ensuring a continued stream of investment all along the innovation chain from basic research through to deployment of new technologies. For example, the global Breakthrough Energy Coalition and its Breakthrough Energy Ventures funding mechanism bring together patient and risk-tolerant private investors, global corporations and financial institutions with the capital necessary to finance large energy infrastructure projects that emerge under the Mission Innovation initiative.

3.4. Promote international technology diffusion at scale

The wide diffusion of low-emission and climate adaptation innovations is critical for achieving the goals of the Paris Agreement and broader environment and sustainable development objectives. The adoption of strong environmental policies can drive international technology diffusion, as it helps create markets for low-emission innovations and provides firms with incentives to acquire new technologies. However, because technology diffusion takes place primarily through trade, foreign direct investment (FDI) and other market channels, removing tariff and non-tariff barriers to trade in low-emission technologies and manufacturing equipment is fundamental (OECD, 2011[36]). Indeed, Chinese producers became world leaders in photovoltaic panel production through the purchase of manufacturing equipment on the global market (De La Tour, Glachant and Ménière, 2011[37]). The deployment of climate mitigation and adaptation technologies often depends on the availability of specialised services, including those imported from other countries, pointing to the importance of lowering barriers to trade in services.

The extent and effectiveness of technology diffusion are determined not only by markets, but also by the absorptive capacity of recipient countries. The higher the level of domestic human capital, the higher the level of technology transfer as well as the local spillovers from trade and FDI (OECD, 2011[36]). Investing in education, technical extension services, public technology diffusion programmes and demonstrators is therefore important to enhance the ability of the public and private sectors to adopt, adapt and employ the most appropriate technologies. It can also help to facilitate the transition of economies and workers dependent on energy-intensive industries (Box 3.4).

International transfers of low-emission technologies have been primarily between advanced countries. The diffusion of climate change mitigation technologies to and from developing countries – particularly emerging economies – has increased significantly since 1992. In 2016, emerging economies accounted for 29% of the global imports of low-emission equipment goods and 24% of global exports. While emerging economies are better integrated into international technology markets, less developed countries remain largely excluded due to their general isolation and lack of absorptive capacity (Glachant and Dechezleprêtre, 2017[38]). International technology transfer mechanisms and development co-operation have an important role to play in ensuring that innovation benefits a larger number of countries.

International mechanisms have been established to support North-South and South-South technology diffusion, such as the UNFCCC's Technology Mechanism, the South-South Knowledge Exchange under The Energy and Resources Institute, IEA's Collaborative Technology Agreements and the new Technology Facilitation Mechanism established under the 2030 Agenda.

Box 3.4. **Decarbonising energy-intensive industries will be a key challenge to meeting climate objectives**

The industry sector relies heavily on fossil fuels (e.g. iron, steel, cement and chemicals manufacture), which makes its decarbonisation particularly challenging. Between 1990 and 2014, global industrial greenhouse gas emissions rose by 69%, all sectors included, which is three times more than in buildings, power generation and transport. Deep decarbonisation will require simultaneous technology, policy and financing innovations, as well as sector-specific pathways to net-zero emissions in order to ensure businesses' competitiveness is maintained.

Existing technologies and processes can help support the sector's decarbonisation including in: material efficiency and recycling; energy efficiency and heat integration; fuel switching from coal to natural gas; or advanced control, optimisation and improved monitoring practices. However, such technologies and processes will not put energy-intensive industries on track with the 2050 Paris Agreement goals, and there is an urgent need for deploying new technologies that can achieve deep decarbonisation.

Some of these new technologies that can help deliver these changes include:

1. Electrification of heat and high-temperature processes;
2. Fuel switching to sustainable biomass;
3. Advanced waste-heat recovery;
4. Carbon Capture and Storage (CCS); and
5. Other sector-specific process modifications, such as solid-state synthesis for ammonia production, which can potentially fully eliminate CO_2 emissions.

However, such technologies are both capital and risk intensive, and their market uptake will require fostering new skills, knowledge and value chains to support long-term financial viability and competitiveness. Some policy and financing can help achieve this:

- International collaboration on decarbonisation policies and projects is necessary in order to stimulate co-operation among businesses. This can also help prevent relocation of investments from countries subject to environmental laws to less regulated areas of the world, which has been a concern for governments sometimes limiting their decarbonisation efforts.
- At the national level, stable and predictable regulatory frameworks are equally important, in order to maintain market confidence and limit investment risks and higher costs of capital.
- Encouraging companies to consider technologies with longer payback periods than usual is also essential to avoid locking in inefficient technologies.
- Collaborative initiatives with trade associations, peer-to-peer businesses or academia can be particularly effective platforms for sharing and fostering decarbonisation best practices.
- Other well-known policies such as removal of energy subsidies, emission reduction targets, carbon trading, environmental taxes, ear-marked grants, or public procurement tools can help drive decarbonisation further too. An example of such policies is the UK government Renewable Heat Incentive ('RHI'), introduced in 2011, which provides a payment for each unit of renewable high-grade heat generated (e.g. from biomass and biogas) to businesses in the iron, steel, cement, and chemicals sectors – which could cover three quarters of total industrial heat demand in the UK by 2030.

Box 3.4. **Decarbonising energy-intensive industries will be a key challenge to meeting climate objectives** *(cont.)*

If successful, the decarbonisation of energy-intensive industries may also generate a range of benefits such as new employment opportunities. It may, however, also lead to job destruction and stranded workers. The low-skilled workforce is likely to be the most affected by the transition to low-emission economies, as more qualified employees will capture new opportunities in green technology and innovation more easily. Entire communities of low-skilled workers could be affected by a rapid transition in particular regions where emissions-intensive industries are a dominant employer. In these areas, dedicated resources will need to help workers from declining fossil-fuel industries to ensure they are redeployed, re-skilled or compensated (see Chapter 4). Lessons from past transitions (e.g. UK coal mine closures of the 1980s, winding down of the shipbuilding industry in Japan) can be drawn upon to inform the development of such policies that will be required at the national, regional and local levels. Empowering local and city governments to plan and finance the transition will be an essential part of creating new jobs, industries, skills and opportunities for all in the low-emission economy (see Chapter 7) (Botta, 2018[39]).

Source: Oluleye, G., N. Shah and A. Hawkes (2018[40]), Emerging Strategies for Decarbonising Energy-Intensive Industries (forthcoming), *Financing Climate Futures Case Studies*, Imperial College London Consultants, London.

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