ROUND TABLE ON SUSTAINABLE DEVELOPMENT

Accelerating the development and diffusion of low-emissions innovations

Background Paper for the
37th Round Table on Sustainable Development
20-21 November 2018
OECD Headquarters, Paris

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This paper was prepared under the authority of the Chair of the Round Table on Sustainable Development at the Organisation for Economic Co-operation and Development (OECD). The reasoning and opinions expressed herein do not necessarily reflect the official views of the OECD or the governments of Member countries.

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ACKNOWLEDGEMENTS

This paper was authored by Mario Cervantes (Senior Economist, OECD Science and Technology Policy Division), Žiga Žarnic (Project Leader and Advisor, OECD Round Table on Sustainable Development), and Hannah Copeland (Young Associate, OECD Round Table on Sustainable Development).

The paper benefitted from consultations with experts in the areas of science and technology, climate change and related policies, notably Richard Baron and Adeline Rochet (European Climate Foundation) and Julia Reinaud (Gates Ventures). The authors are also grateful to the following for the input and materials they provided: Dimitris Diakosavvas, Nick Johnstone, Teru Koide, Catherine Moreddu, Analusa Primi, Jens Sedemund, Mariagrazia Squicciarini, Ivan Haščič and Antoine Dechezleprêtre (OECD); Simone Landolina (International Energy Agency); and Wei-Shiuen Ng and Mary Crass (International Transport Forum).

The authors would like to thank Connie Hedegaard (Chair, OECD Round Table on Sustainable Development) for her intellectual leadership and advice, and Amelia Smith for thorough editorial advice.

The 37th Round Table on Sustainable Development is supported by i24c, the European Climate Foundation initiative on Industrial Innovation for Competitiveness. Their contribution is gratefully acknowledged.

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EXECUTIVE SUMMARY

At the twenty-first session of the Conference of the Parties (COP21) in December 2015, countries agreed to "limit global warming to 2°C above pre-industrial levels" and "pursue efforts to limit the temperature increase even further to 1.5°C" (UNFCCC, 2015). They also invited the International Panel on Climate Change (IPCC) to produce, in 2018, a special report on global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways.

The IPCC report, just released in October 2018, warns that the impacts and costs of a 1.5°C increase could be greater than expected if global warming continues at the current pace. Avoiding this requires global net CO_2 emissions to fall by 45% from 2010 levels by 2030, reaching net zero around 2050. Rapid, far-reaching and unprecedented changes are necessary in all aspects of society (IPCC, 2018).

Science, technology and innovation policies must be an important component of national strategies to reduce overall carbon dependency. 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 for climate-driven innovation.

Both national innovation policies and international co-operation can contribute to the development, commercialisation and widespread adoption of mitigation and adaptation technologies. Innovation policies can be more effective when they combine public support for research and development (R&D) with policies that encourage technology diffusion.

Many of the technologies needed to limit the global temperature rise already exist. Solar PV has made significant progress, and battery storage technologies could follow a similar trend. For example, Li-ion battery cost reductions are predicted to continue: Bloomberg New Energy Finance's *New Energy Outlook 2018* anticipates that Li-ion battery systems for the grid will cost just USD 70 per kilowatt-hour in 2030, 67 percent less than in 2018.

Innovations such as artificial intelligence (AI) and nanomaterials promise to advance low-emissions technologies even further, provided there are sufficient incentives for public and private investment in R&D. There are positive signs in this direction: an additional USD 4 billion of public funding in clean-energy innovation has been invested since 2015, with over 40 international research and innovation partnerships initiated. The intergovernmental initiative Mission Innovation, for example, has committed to co-ordinating global efforts to scale up clean-energy R&D and double clean energy R&D investment over 2015-2020.

But more is needed to shift the *direction* and *pace* of innovation towards a net zero carbon economy. While the deployment of existing technologies (such as renewable energy and energy efficient lighting) must be accelerated, moving the next generation of technologies that can address climate change from the lab to the market needs to be prioritised. Even technologies that already exist are not scaling up and diffusing fast enough to shift towards a net zero-emissions trajectory. Many currently available low-cost and commercially applicable technologies are locked in specific sectors, countries or regions and are not being widely diffused within and across countries. The capacity to adopt low-emissions technologies remains out of reach for many less-advanced economies.

Business and society have a role to play in engaging with governments in defining priorities and helping to remove sector-specific barriers. Companies also need to work together across global value chains to deploy emissions-reducing technologies. In the transport sector, for example, this implies working with suppliers, providers of physical and digital infrastructure and consumers to ensure low-emissions solutions – from electric vehicles to new business models that contribute to overall emissions reductions.

Participants in the 37th Roundtable on Sustainable Development are invited to consider and discuss the following questions:

1) **Best practices and barriers: how can existing frameworks be improved to support low-emissions innovations**?
2) **How can we scale and speed up the development stage of low-emissions innovations without misallocating capital**?
3) **How can markets for low-emissions innovations be created without hindering competition**?
4) **Next steps and key takeaways: How can we ensure that low-emissions innovations achieve real transformation**?

1. AN INNOVATION ECOSYSTEM FOR A LOW-EMISSIONS ECONOMY

1.1. The R&D and patenting activity landscape

Global energy-related CO_2 emissions increased by 1.4% in 2017 after three flat years (IEA, 2018a). In order to reach long-term climate goals, emissions need to peak before 2020 and decline steeply thereafter. Solutions must be implemented quickly and simultaneously, and low-emissions innovations are vital if countries are going to be able to keep their Paris Agreement commitments.

Low-emissions innovations are new products, processes and methods that reduce the greenhouse gas (GHG) emissions of production and consumption systems. They can be technological (e.g. technologies for renewable energy, energy storage or smart grids) or non-technological (e.g. institutional and organisational changes that alter behaviour, such as electric car sharing and circular economy models). They can focus on supply (e.g. renewable energy, low-carbon cement) or demand (e.g. energy efficiency, material efficiency). They can be interdependent (i.e. uptake of a new technology may depend on a change in behaviour) and involve trade-offs (e.g. pollution resulting from the extraction of rare earth minerals).

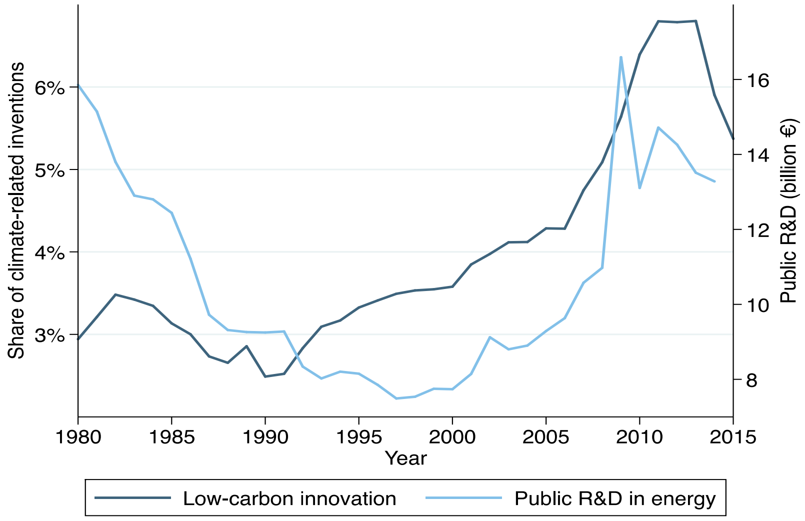
Low-emissions innovations can also provide improved access to cleaner sources of energy, water, or transport. Efforts to reduce emissions often go hand-in-hand with the objective of making economies more inclusive; for example, improved (and cleaner) public transport options particularly benefit disadvantaged segments of society.

A review of the 190 Nationally Determined Contributions (NDCs) submitted prior to the twenty-first session of the Conference of the Parties (COP21) found that nearly 140 developing countries highlighted the importance of low-emissions technologies for implementing their climate objectives, and 50% specifically referred to technological innovation or R&D (TEC, 2017).

Despite this, following two decades of strong growth, low-emissions innovation efforts have lost momentum. As a measure of innovation activity, patent filings and public R&D budgets in low-carbon innovation dropped after the crisis (Figure 1), though total public spending on low-emissions R&DD rose for the first time to over USD 20 billion in 2017 (IEA, 2018a).

Figure 1. Low-emissions innovation efforts have lost momentum

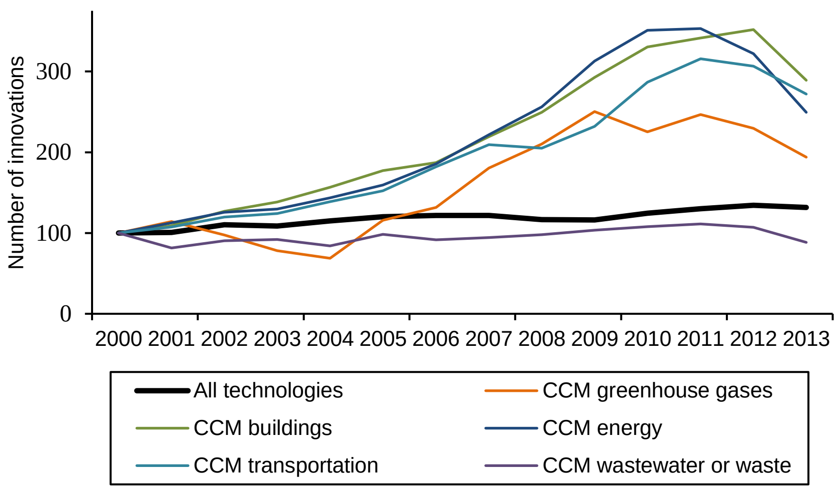
Worldwide patent filings and public R&D budgets in low-carbon innovation.



Notes: Official OECD statistics cover the period until 2015, but in 2017, total public spending on low-emissions R&DD rose for the first time in years – by 13% to over USD 20 billion (IEA, 2018a).
Source: OECD Green Growth Indicators database (OECD, 2017a).

Detailed data on low-emissions patenting show that the decline since 2011 has been across the board, from climate mitigation technologies in buildings to the energy sector (Figure 2).

Figure 2. Worldwide total patents by ENVTECH domain

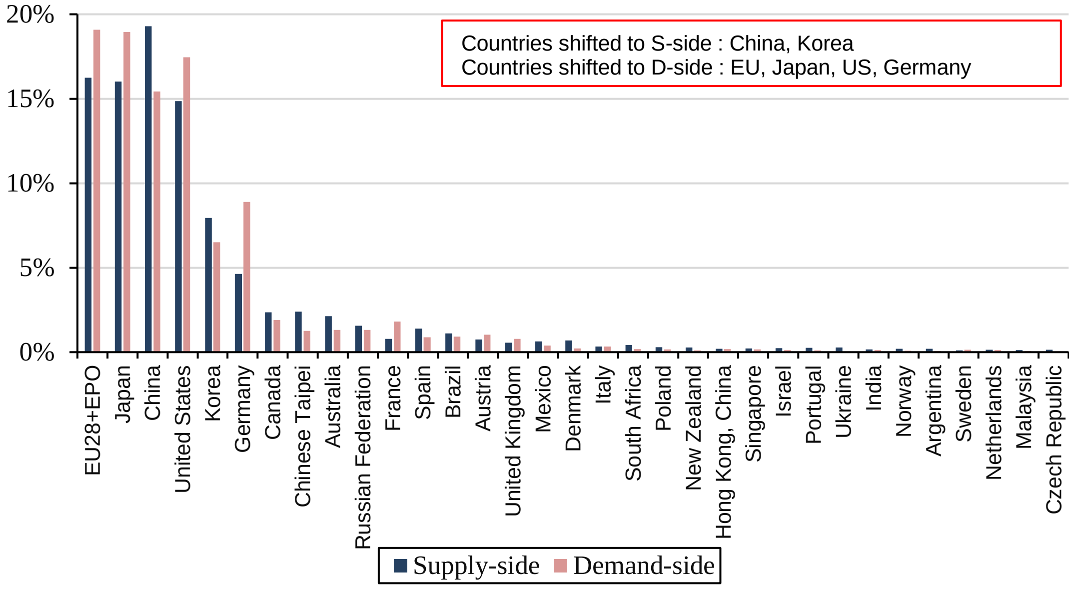


Note: Based on counts of priority patent applications (simple patent families), by inventor's country of residence, with patent family size of two or more (high-value inventions). CCM stands for climate change mitigation.
Source: OECD Green Growth Indicators database (OECD, 2017a).

The decline in patenting across low-emissions technologies can be attributed to several cross-cutting factors. Among these, the lack of carbon prices acts as a disincentive to R&D investment in emissions-reducing technologies. Changes in relative energy prices – notably the fall in the price of crude oil since 2013 – have also acted as a disincentive (Dechezleprêtre, 2016). Sector-specific dynamics, such as the collapse of prices for solar PV panels due to China's market dominance, may also have impacted on the R&D decisions of firms and thus on patenting activity.

In terms of the relative performance of developed and developing countries, 90% of low-emissions innovations still originate in OECD countries (especially in the US, Japan, Germany, Korea and France), but the contributions of China and India are increasing rapidly (OECD, 2017a). China has made great strides in patenting climate change mitigation technologies (CCMTs) on the supply-side, especially in solar PV patents (Figure 3).

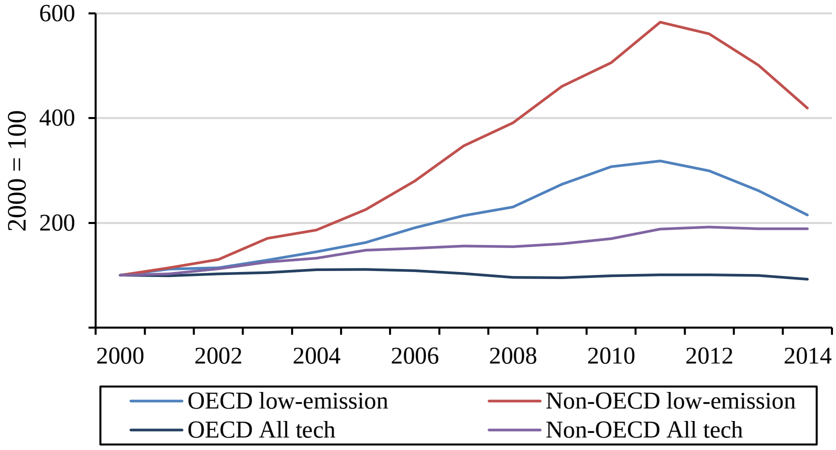
Figure 3. Shares of CCMTs by country or region (1999-2012)



Notes: Demand-side or supply-side patents as a share of total patents in each side. Patent counts are based on the priority date (first filing of the patent worldwide), by patent authority where patent applications were filed, using simple counts. . Demand-side technologies includes CCMTs related to energy generation. Supply-side technologies includes CCMTs related to transportation or building. The patents related to Energy are from CPC classes Y02E (CCMTs related to energy generation, transmission or distribution), Y02T (CCMTs related to transportation) and Y02B (CCMTs related to building).
Source: PATSTAT (2018).

At the same time, while OECD countries lead in the total number of patent applications, non-OECD countries have experienced higher patenting growth rates in recent years. This would make them potentially attractive partners for collaboration for firms in OECD countries that seek new growth markets (Figure 4).

Figure 4. Growth in the number of patent applications related to low-emissions in OECD and non-OECD countries, 2000-2014



Note: Patent counts are based on the priority date (first filing of the patent worldwide) by patent authority where patent applications were filed, with patent family size of two or more (high-value inventions), using simple counts. Data for 2013 and 2014 are provisional. Low-emissions technologies include Climate change mitigation technologies (CCMTs) related to energy, GHG (greenhouse gases) and agriculture. The patents related to energy are from CPC classes Y02E (CCMTs related to energy generation, transmission or distribution), Y02T (CCMTs related to transportation) and Y02B (CCMTs related to building). The patents related to GHG are from CPC classes Y02C (CCMTs related to capture, storage, sequestration or disposal of GHG). The patents related to agriculture are from CPC classes Y02P60/1 (CCMTs related to Agricultural machinery or equipment), Y02P60/2 (CCMTs related to Reduction of GHG emissions in agriculture) and Y02P60/8 (CCMTs related to Reduction of greenhouse gas [GHG] emissions in agriculture).
Source: PATSTAT (2018).

1.2. The challenge: Barriers to creation and diffusion of low-emissions innovations

Many of the technologies needed to hold the global temperature rise below the 2°C Paris Agreement target already exist, but some are not cost competitive and are subject to specific barriers. Many more, such as Artificial Intelligence or nanomaterials, promise to advance low-emissions technologies even further, provided there are sufficient incentives for public and private investment in R&D. Still, many existing solutions are not yet deployed at scale: out of 38 low-emissions technologies fundamental to achieving the 2°C target, only four – PV, lighting, data centres and networks, and electric vehicles – are on track to sufficiently penetrate markets. Some, such as carbon capture and storage, are only at the pilot stage (IEA, 2018b).

Barriers

The main barriers to the development and diffusion of low-emissions innovations relate to financing environments, policy setups and environmental and social externalities. Often, they reinforce one another.

- Financial barriers emerge because investors lack the knowledge necessary to accurately evaluate the risk-return profile of low-emissions technologies. Often the threat of a lack of finance down the line will restrict the willingness of financiers to put money on the table now (see section 2.2 on the "valley of death"; Young In, Monk and Levitt, 2017).

Lack of adequate financing along the entire innovation chain is one of the main obstacles in the commercialisation of science. For example, in the EU there is a structural problem with access to financing for disruptive science and R&D-based companies ("deep-tech"), especially for early-stage companies whose products are not finalised and therefore cannot generate enough revenue for seed funding, series A/B funding, or to finance later rounds.

- Failure to take environmental externalities into account (e.g. negative externalities from fossil fuel-based technologies, or positive externalities from low-emissions technologies) means that market prices under-incentivise the uptake of low-emissions innovations. Despite efforts to price this information in, market pricing is still in its infancy.
- Lack of business dynamism (i.e. lack of market entry and exit) means that low-emissions innovations may not overtake fossil fuel-based incumbents and secure their place in mainstream markets, even if they are more efficient. Concentration of market power means that long-term investors (e.g. asset-heavy banks, institutional investors) may favour incumbents because of perceived stable returns. Though alternative forms of financing (e.g. business angels and VC) can take greater risks, they do not invest with a sufficiently long time horizon to drive the transition.
- Political and institutional barriers result from governance and co-ordination failures due to incoherence or inconsistent timing across policy areas. Misalignments can be horizontal (i.e. between innovation policies and sectoral policies), vertical (i.e. between ministries and implementing agencies) or multi-level. Especially in large-scale systems, technologies can be subject to lock-in or dominant design that prevents other technologies from emerging. For example, diffusion of low-emissions vehicles is hindered not only by price or battery storage capacity, but also the lack of a charging network along motorways.
- Social barriers result from lack of public acceptance and engagement with new technologies (e.g. due to lack of information or perceived negative health and safety consequences). Communicating, preventing, correcting and mitigating adverse effects has become important for the deployment and diffusion of new technologies. This is increasingly challenging as innovations become more complex.
- Compared to large firms, smaller firms are more dependent on external sources of technology and knowledge. Managers may have insufficient information about production processes or are unaware of best available low-emissions technologies and practices applied elsewhere. Similarly, potential suppliers may have learning costs, lack expertise or face other structural barriers to promoting the diffusion of low-emissions technologies.

Regulation and environmental policy stringency

Another issue is that regulation often struggles to keep pace with rapidly evolving technological and financial innovation. This is particularly relevant in sectors (e.g.

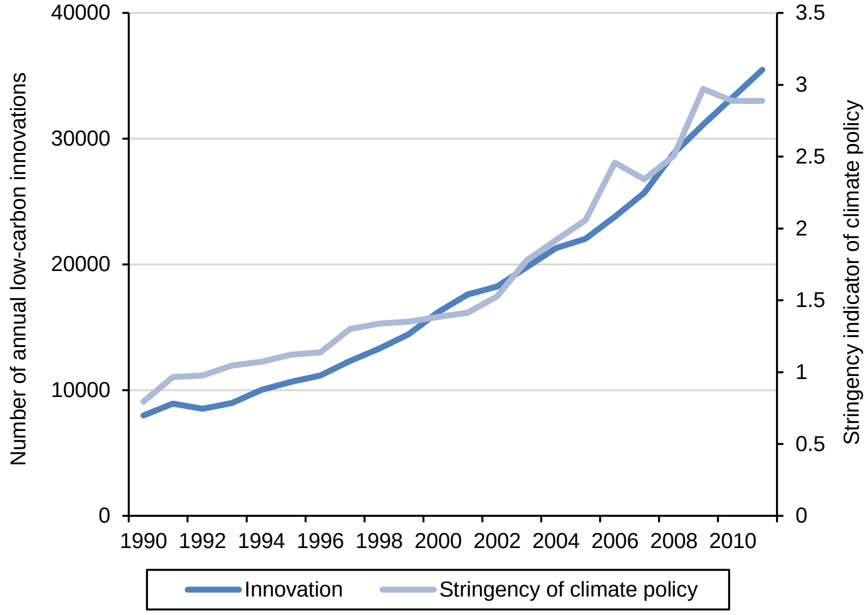
chemicals, steel and cement) that rely on new practices or technologies (e.g. digital technologies used in logistics, process management and commercialisation of outputs). For example, cement kilns and heat plants increasingly use waste as fuel to reduce CO_2 emissions and landfill, but their ability to do so is sometimes hindered by outdated waste management regulations at local, national and even international levels.

Regulating too much or too soon can stifle new innovations and business models, especially when innovations have applications in other product markets with different regulatory traditions (e.g. 3D printing in automobile and health applications). On the other hand, regulating too late can result in missed economic opportunities as well as negative environmental and social consequences. The challenge for governments is to design and apply regulations that do not stifle competition between new innovations (entrants) and existing technologies (incumbents).

The environmental stringency of policies can also influence efforts towards low-emissions innovation (Figure 5). These effects can materialise rather quickly – in some cases within just two to three years. For example, innovation activity diverged rapidly between participating and non-participating countries after the introduction of the European Union Emissions Trading Scheme (Calel and Dechezleprêtre, 2016).

Figure 5. Low-carbon innovation increases with climate policy stringency

Low-carbon innovations and climate policy stringency in OECD countries, 1990-2011



Note: Number of inventions: authors' own calculations from the PATSTAT database; Climate policy stringency indicator: OECD Environmental Policy Stringency Index, 2014. Individual countries are weighted by their GDP in order to calculate the average policy stringency across the OECD.
Source: Dechezleprêtre, Martin and Bassi (2016).

1.3. The changing role of innovation policies

Science, technology and innovation policies are important for meeting the challenges of climate change. They support basic research in universities, encourage businesses to invest in R&D through grants or tax incentives and promote collaboration between companies and universities as a way to transfer technology to industry. The OECD Innovation Strategy (OECD, 2015) outlines several key policy domains and instruments to enable the development and deployment of innovations (Box 1).

While this approach has proven useful in increasing the intensity of R&D in sectors such as petrochemicals, transport, automobiles and IT, the current scale and pace of innovation is not sufficient to shift the *direction* of innovation towards achieving a carbon-neutral economy.

Box 1. Key policy domains for innovation policy

Policy domain	Policy instruments
Education and Skills	Public support to higher education and workforce training; support to STEM education and digital skills
Business environment	Competition policy, tax policy, entrepreneurship policy
Knowledge creation and diffusion	Public support to basic and applied R&D, intellectual property (IPRs) technology transfer and commercialisation support; support to open science/open data; support to research mobility across sectors and internationally; support to technology demonstration and standards development
Innovation finance	Public support to venture capital and alternative sources of funding; support for proof-of-concept
Knowledge-based entrepreneurship	Start-up support, business incubators/accelerators
Policy governance	Evaluation of public policies, institutions and mechanisms for cross-ministry co-ordination (vertical) and co-ordination across different levels of governments (horizontal); engagement with social partners and civil society.

Source: Adapted from OECD (2015a).

Allocation of public R&D funds in most OECD countries is often guided by criteria such as excellence and expected contribution to economic and societal goals. Research projects are evaluated on their ability to meet these objectives, with some variance for different types of research (e.g. fundamental, innovation-oriented) and disciplines.

This approach has not always led to sufficient progress in tackling environmental, economic and societal challenges. It has had difficulties ensuring sufficient research with long-term horizons, and in some cases has generated a large concentration of funding towards very few recipients.

Countries such as Sweden are experimenting with longer-term innovation programmes that provide stable funding for five to ten years and bring together universities and business around specific missions that can help de-risk technology development. Support for large-scale demonstrators is also increasing. There is also a case for designing specific tax credits for SMEs that can provide critical cash flow as innovators test and scale up solutions.

A systems-based approach to innovation

One model for guiding innovation investment and policy decisions is "systems innovation". Recent work by the OECD shows that policies aimed at transitioning sociotechnical systems to more environmentally sustainable configurations differ significantly from those aimed at increasing the economic performance of existing systems. Aligning these objectives requires policy makers to develop a vision of what future sustainable systems will look like, including what technologies are likely to play a role, what infrastructures will be needed, and how business models and patterns of behaviour will need to change.

In order to facilitate the transition, policy makers also need to lengthen planning and investment horizons; co-ordinate across ministries and different levels of government; establish and maintain long-term collaborative partnerships; place increased emphasis on diffusion of knowledge and existing technology, as well as invention of technology; and manage and overcome resistance to socio-technical change.

1.4. The goal: Innovation, structural, tax and other policies in sync

Policy alignment is key

A systems-based approach implies that innovation policies need to be aligned with policies in other areas that affect the rate and direction of innovation, notably (OECD, 2015b):

- Education and labour market policies, to help people prepare for the transition by equipping them with critical thinking, analytical expertise and the skills necessary to contribute to and benefit from innovations (e.g. science, technology, engineering and mathematics (STEM) degrees, entrepreneurship skills, communication skills, digital literacy).
- Investment policies, to support not only physical investment in low-emissions technologies but also complementary investment in process-based innovations and knowledge-based capital (e.g. software, data, organisational capital).
- Competition policies (e.g. easing trade barriers or services regulation), to promote open markets for the exchange of knowledge and innovations beyond sectors and jurisdictions in order to enable exit of fossil fuel-based business models and allow for experimentation with new ideas, technologies and business models that underpin the success of innovative firms.
- Tax policies, to encourage business R&D (e.g. through contracts, grants, awards, tax credits) with a focus on social returns and international good practices (e.g. the Paris Collaborative on Green Budgeting).
- Framework policies such as intellectual property rights (IPRs). The infrastructure for collaboration between research institutes and firms needs to be continuously adapted to support the entry and growth of innovative firms – and facilitate the exit of those with climate-unsustainable business models. Existing IPR policies are not always well suited to the fast-changing nature of innovation and firms that tend to privilege trade secrecy and confidentiality agreements for protecting their intellectual assets (OECD, forthcoming).

Taking life cycle and maturity into account

In terms of maturity, innovations can be grouped into three broad categories:

- *"Low-hanging fruit"* (i.e. most easily adopted) – readily available, commercialised and relatively low-cost innovations compared to fossil fuel options (e.g. hydropower, solar thermal power).
- *"Mature innovations"* (i.e. harder to adopt on a mass scale) – innovations that are not yet fully commercially viable or competitive in terms of costs and deployment relative to fossil fuel options (e.g. geothermal energy, PV).
- *"Frontier innovations"* (i.e. hardest to adopt) – breakthrough technologies that only frontier firms or countries are capable of bringing to the market (e.g. solar electrification, solar-powered water pumps, long duration energy storage, and building materials with less embedded energy and chemical inputs).

In general, the less mature a technology, the more it might need supply/push policies to drive the generation of innovation (e.g. by reducing innovation costs), while more mature technologies may need demand/pull policies to drive the market provision of an innovation (e.g. by increasing innovation payoffs) (IEA, 2015). Appropriate targeted measures and incentives may depend on the context of the technology. Types of R&D investments or technologies may be predetermined, however, by existing industrial structures, research capabilities and specialisation or other supporting framework conditions.

Public procurement can help bring low-carbon innovation to the demand side. Procurement of functionality (e.g. commissioning a low-emissions, high-efficiency ferry rather than one running on biofuels) has encouraged new business models, and sustainable criteria (e.g. mandated increases in energy efficiency) are institutionalising good practices. However, some innovations are under-used because public procurement goes on business as usual, or procurement offices fear becoming captive to certain suppliers. There are arrangements to avoid this, but more needs to be done to give buyers a sense of what low-emissions products and services are available (Baron, 2016).

Deployment and diffusion policies

Governments have long supported the diffusion of technologies, for example through agricultural extension services and manufacturing centres to support the adoption of ICT and manufacturing technologies by SMEs. The US Manufacturing Extension Partnership (MEP) programme, for example, is a network of centres that provide services related to process improvement, product development, marketing, training, and sustainability services such as energy conservation and environmental management. Most centres also connect manufacturing SMEs with other private and public assistance sources. However, as many of the obstacles to the successful adoption and use of technology are internal to firms and stem from labour, organisational and managerial deficiencies, greater attention is given to addressing these barriers.

Technology diffusion institutions are increasingly adapting their technological focus to include business model development. They are also seeking to connect to their surrounding innovation ecosystems. For example, governments and business groups are supporting the diffusion of energy-efficient and low-emissions technologies through training events with national standardisation bodies and accreditation institutes to exchange experiences on standards and the long-term performance and environmental and economic impacts of new technologies.

This illustrates that diffusion not just the one-way flow of technology embodied in equipment, but a process whereby technology, including the “tacit” knowledge of how it should be applied, spreads from the original innovator to other users. It involves a range of private and public institutions and individuals, including large firms, clusters of firms, suppliers, customers and public research institutions.

IPRs and diffusion of low-emissions technologies

Intellectual property rights (IPRs) play a crucial role in the development of new technologies by granting inventors a temporary monopoly in exchange for disclosing their inventions. This encourages investment (by allowing firms to recover their investment costs) and encourages diffusion. IPRs can also facilitate access to finance; many firms use patents as collateral.

Various market mechanisms exist for diffusing low-emissions innovations based on IPRs. These include: a) cross-licensing agreements that give each party freedom to commercialise inventions in their respective markets; b) patent pools which allow firms, subject to competition law, to combine patents, share them with other patent holders and, in some cases, license them to other firms as a package; and c) patent pledges, i.e. voluntary disclosure and non-assertion of patents whereby the assignee retains ownership but pledges not to assert patent rights.

Governments have also encouraged the development and diffusion of green technologies through lower application fees, prioritised examination, expedited examination and approval procedures, and diminished standards (OECD, 2012). Fast-track programmes for green patents have recently been introduced in several national IP offices (e.g. Australia, Canada, Japan, Korea, United Kingdom and the United States). These vary widely in their eligibility requirements and process parameters (Lane, 2012). Some national and regional patent offices also facilitate access to search and patent mapping services in the green technology space.

Other patent data repositories include the World Intellectual Property Organization’s online marketplace WIPO GREEN brings together IP owners of green technology with potential users. Open science initiatives that support access to research data, such as the OECD Principles and Guidelines on Access to Research Data from Public Funding, can help strengthen research capabilities in public research as well as innovation in firms.

2. FINANCING INNOVATIONS FOR LOW-EMISSIONS TECHNOLOGIES

2.1. Leveraging public and private investment

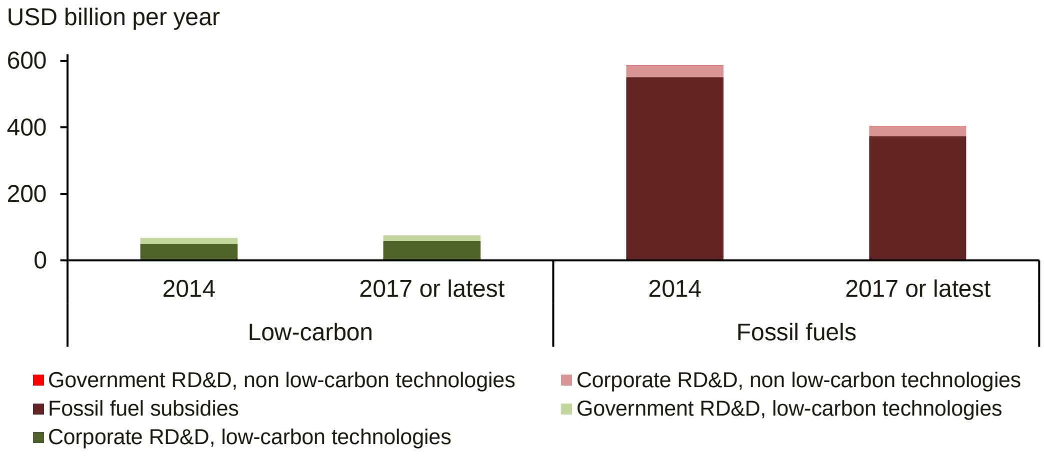
The IPCC estimates that achieving the 1.5°C target requires USD 2.4 trillion to be invested in the energy system each year from 2016 to 2035 – about 2.5% of global GDP (IPCC, 2018). Increases in R&D investment will also be needed for new low-emissions technologies.

The climate financing environment can have a strong and positive impact on the allocation of investment towards low-emissions innovations. The OECD-World Bank and UNEP initiative on *Financing Climate Futures* stresses the need to green infrastructure investments through, *inter alia*, better planning, empowering cities to invest by aligning national and local fiscal regulations and integrating land-use and transport policies. Outside OECD countries, attracting global finance flows for low-emissions investments in developing countries will also require reducing the cost of capital channelled to emerging economies (which have higher credit risks, but also present greater opportunities for deploying low-emissions technologies) and providing incentives for multilateral development banks (MDBs) to crowd-in private financing.

While changes in the broader financial system can incentivise firms to invest in renewables and deploy low-emissions technologies in the marketplace, they are not sufficient to increase investments in R&D. Governments can use public money and policies to spur private action, and a number of initiatives exist to this end (see section 3.1 on Mission Innovation).

In 2017, total public spending on low-emissions R&DD rose for the first time in years – by 13% to over USD 20 billion (IEA, 2018a). Importantly, public sector funds are targeting technologies that are "difficult" for the private sector to support (i.e. those that are further from the market or have high development or demonstration costs, e.g. nuclear, carbon capture and storage (CCS) and ocean energy) (IEA, 2017a). Nonetheless, public and private sector finance continues to flow overwhelmingly to fossil fuel rather than low-carbon RD&D (Figure 6).

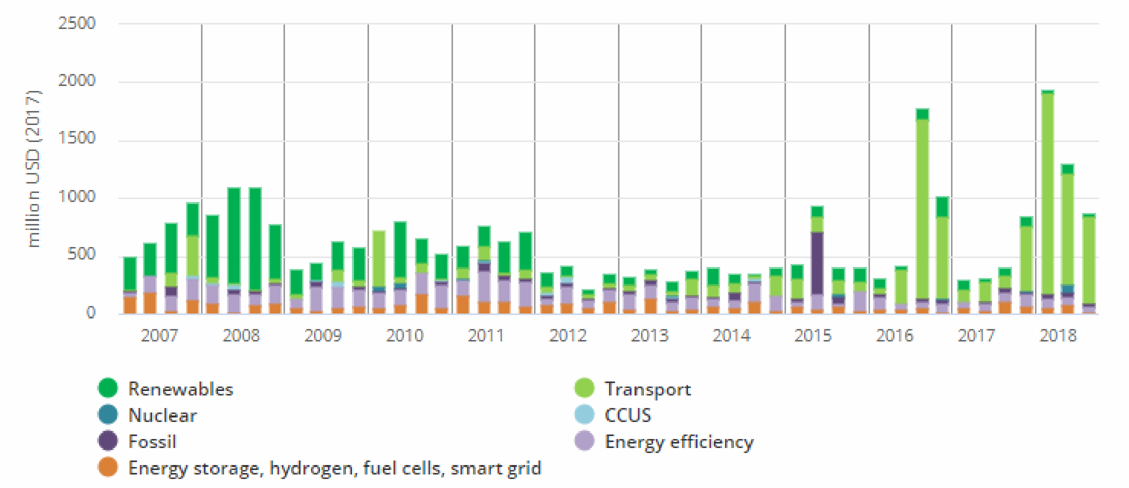
Figure 6. Global support to low-carbon technologies and fossil fuels



Note: The combined IEA and OECD estimates for fossil fuel support among 76 economies totals between USD 370 and USD 620 billion annually over the period 2010-2015. Note that no distinction is made for the part of R&D investment labelled as fossil fuels R&D that may be oriented towards carbon capture and storage technologies. These estimates do not include some of the additional forms of direct or indirect support to low-carbon technologies or fossil fuels, such as tax expenditures associated with company car taxation that can be quite substantial – estimated at USD 34 billion for 2012 in OECD countries alone.
Source: Authors' calculations based on the OECD Companion to the Inventory of Support Measures for Fossil Fuels 2018; the IEA Energy Technology RD&D Budgets 2018.

Progress is being made, however. In 2018, more venture capital (VC) went to energy technologies than in the first two quarters of any previous year – and this time the boom is being led by demand- rather than supply-side technologies (i.e. EVs over solar), as in 2008 (Bennett, 2018).

Figure 7. Venture capital investments in energy technologies, by quarter



Source: Bennett (2018).

2.2. Setting the course from development to deployment

New models to support early-stage innovation, scale up new technologies and build companies that can deploy low-emissions solutions globally require funders who are willing to invest early, stick with nascent companies, and provide more capital than other early-stage investments typically need.

This is a big challenge. Over the past decade, many investors have shied away from energy hardware investments either because they were too difficult, the payoff was too far out, or they simply could not make a profit. This is why, in 2015, Mission Innovation countries committed to double clean energy R&D, spurring creation of the Breakthrough Energy Coalition, a global group of high net worth investors committed to funding clean energy companies (see section 3.1 on Mission Innovation).

The innovation-financing-policy loop

The problem of financing R&D and innovation is primarily one of uncertainty associated with outcomes. In the climate space, in addition to technological and market uncertainty, policy uncertainty can also inhibit financing. Because of this, most existing firms finance their R&D activities through internal sources before pursuing external ones.

External bank finance is an important source of capital for innovative start-ups, even those without IP-based assets (Robb and Robinson, 2014). Strong public equity markets have also been shown to play an important role in the financing of radical innovation associated with start-ups. Institutional investors can provide different vehicles to fund green projects, such as indices and mutual funds, fixed income investments (notably green bonds), and direct investment via private equity or green infrastructure funds. Institutional investors are not venture capitalists, however; they tend to look for steady income streams and are therefore more likely to invest in mature and more established technologies (OECD, 2017d). Increasingly, institutional investors are integrating climate risks and opportunities in their investment decisions.

As with the innovation chain, different stages of technologies require different policies and financing:

- In the **R&D stage**, markets tend to undersupply private R&D because knowledge spillovers prevent firms from fully appropriating returns on their investments. This creates a strong rationale for government to fund public R&D and provide grants, subsidies and tax relief to private R&D. Because tax incentives for R&D are generally technology-neutral, grants tend to be preferred for public support to R&D in specific fields such as energy. Still, tax-based support can stimulate R&D for low-emissions technologies provided there are complementary policy signals such as a carbon prices or a reduction in government R&D fossil fuel subsidies to shift corporate R&D towards low-emissions technologies.
- Support to industry financing for **demonstration and deployment** is generally not covered in R&D grants, but traditional sources such as public banks and institutional investors may be mobilised, especially where large and expensive infrastructure projects are involved (Polzin et al., 2015). For example, the European Investment Bank’s InnovFin Energy Demonstration Projects provide loans, loan guarantees or equity-type financing typically between EUR 7.5 million and EUR 75 million to innovative demonstration projects in the fields of energy system transformation. For small firms and start-ups, governments and universities in many countries provide proof-of-concept funds and demonstration support, as do public and private incubators and accelerators. Similarly, energy crowdfunding platforms, such as greenXmoney in Germany or TRINE in Sweden, are being developed to address the financing gap for demonstration in green tech.
- At the **adoption and diffusion** stages, policy makers can use subsidies (e.g. refund schemes) to accelerate adoption and diffusion in the short run, but these risk repelling investors due to the fact that they are not long-term (Polzin et al., 2015). Fiscal instruments such as withdrawing subsidies on fossil fuel-based technologies or taxing incumbent fossil-fuel based products (or fossil fuels themselves) can help low-emissions innovations compete against incumbent technologies, thus aiding their adoption and diffusion (Lucas, 2016). Investments to enhance absorptive capacity (e.g. in education) are also important (Baron, 2016).

Financing can be hindered by worries about the size of the final market. Governments can reassure investors by using demand/pull policies such as tax breaks and other incentives to give entrepreneurs a competitive advantage vis-à-vis incumbent firms or by using lead-market creation and public procurement as a mission-orientated innovation policy (Mazzucato, 2016). Due diligence and risk-equity reserve regulations can ease the divestment of existing assets (e.g. coal fired power plants) and help integrate climate-related factors into risk-management strategies.

Technologies with a high unit cost of demonstration (e.g. CCS and nuclear) require asset-heavy investments up front that often need to be leveraged by public funds. For technologies with a high modularity (i.e. those that can be mass-produced, such as solar PV, LEDs, batteries, passenger vehicles and energy-efficient appliances), attracting private capital is linked to commodity cycles. This calls for government to incentivise R&D and multiple deployment phases through market-pull policies such as performance standards and consumer and countercyclical support. Technologies with ease of product differentiation (i.e. those that allow different consumer segments to be offered differentiated products, such as high-performance electric vehicles (EV) for wealthy, early adopters) are able to raise finance more easily if an initial market exists, but imply a role for governments in their promotion (IEA, 2017a).

The literature refers to the potentially deadly void between finance sources as the "valley of death". Its two distinct manifestations – the "technology valley of death" at the demonstration phase, and the "commercialisation valley of death" – are ultimately linked, because awareness that commercialisation requires an exceptionally large sum of money can limit the amount of money willing to flow into earlier stage companies, thereby exacerbating financing issues at the demonstration stage. The fragmented nature of the investor network and information asymmetries are largely to blame (Young In, Monk and Levitt, 2017).

The reasons private (venture) capital under-invest in science and R&D-based companies are largely structural. Investing in such companies is significantly riskier than investing in software or apps, for example, often due to:

- inherent *technology risk* in science-based companies;
- higher probability that founders are not experienced entrepreneurs, which requires more involvement from venture capitalists to make start-ups successful;
- higher capital requirements, especially in early stages of the company life-cycle when the risk is highest;
- longer market lead times (sometimes significantly so).

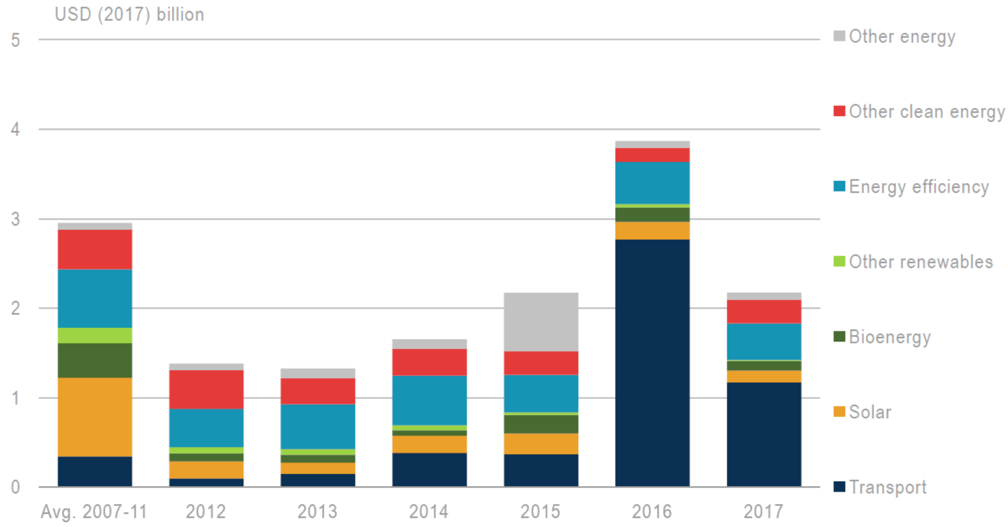
Public support to R&D in start-ups can help bridge the gap in early stage financing. Small business innovation and R&D programmes in the Netherlands and the US, for example, provide start-ups with funding to develop technologies with longer-term horizons. Government R&D start-up funds can also expose firms to procurement opportunities. There are drawbacks to government funds, such as limited funding areas, but overall they can help firms develop technologies to a sufficient level of maturity to attract private venture capital.

2.3. Getting to the market

Venture capital (VC) plays an important role in the uptake of low-emissions innovations. VC led both the solar boom in 2008 and the boom in electric vehicles in 2018. Early-stage VC for clean energy has grown at 20% per year since 2013 (although it is not yet at pre-2012 levels), and in 2016, VC invested around USD 2 billion in early stage clean energy firms – one quarter of total corporate spending on clean energy R&D (Figure 8; IEA, 2017a). This is in part due to digitalisation (e.g. cloud computing, computer simulation, rapid prototyping and object-oriented programming), which has lowered the costs of learning about the commercial viability of a technology's early stages.

The time frame necessary to establish the viability of clean energy projects can be long, with high capital requirements and low consumer value. Venture capital, by contrast, tends to seek out projects with high risk-return profiles. For example, energy has to compete with hundred-billion-dollar VC markets such as biotechnology and software, and still accounts for a small share of total VC funding; in 2016, it was just 3% (IEA, 2017a). The VC model is also more appropriate for some types of innovations (e.g. complementary software) than others (e.g. renewable energy). Many of the most significant innovations are likely to come from areas that are not "obviously" green.

Figure 8. Global VC investment in low-carbon energy and other energy



Note: Transport does not include start-ups developing mobility services (e.g. ride-hailing).
Source: IEA (2018a), Cleantech Group i3 database (2018).

Governments can help to overcome this mismatch by addressing two features that make low-emissions innovation risky for VC investors:

- *Poor risk-return profiles*. VC tends to seek out high levels of technology risk in exchange for high rates of return, which does not sit well with the risk-return profile of commercialising low-emissions technologies (Gaddy, Sivaram and O'Sullivan, 2016). For example, in the case of CCS, demonstration projects currently cost around USD 1 billion, take five years or more, and have a market value of around one-tenth of their cost (IEA, 2017a).
- *Lack of exit strategies*. Exit strategies are typically public market transactions, e.g. corporate merger and acquisition (M&A), private equity (PE) buyout, and initial public offerings (IPO). When it comes to low-emissions innovation, exit strategies are ill-aligned with VC time frames. For example, there is a discrepancy between the average investment period of VC funds (7-8 years) and the average time to IPO (12-13 years or longer), which may leave investors with committed or illiquid capital (Young In, Monk and Levitt, 2017).

3. BEST PRACTICES: HOW TO ENSURE THAT LOW-EMISSIONS INNOVATION CAN TRANSFORM CARBON BASED PRODUCTION AND CONSUMPTION

3.1. Catalysing global efforts

Low-emissions R&D is under-supplied by the private sector, owing to long time horizons and uncertainty surrounding future commercial viability. There is a strong case for international co-ordination of efforts – also because knowledge spillovers from R&D can cross borders, which hinders the willingness of individual governments or firms to act alone.

Mission Innovation (MI), an intergovernmental initiative comprising the European Union and 24 countries[1] representing 58% of the world's population and 80% of public budget for clean-energy research, was launched in 2015 to co-ordinate global efforts to scale up clean-energy R&D. MI countries have pledged to double related investment over five years (accounting for USD 35 billion by 2020) and promote knowledge-sharing and collaboration among governments, businesses and investors (Mission Innovation, 2018a).

So far, an additional USD 4 billion of public sector funding in clean-energy innovation has been invested since 2015, with nearly 40 new international research and innovation partnerships broadly aligned with the eight MI Innovation Challenges: smart grids; off-grid access to electricity; carbon capture; sustainable biofuels; converting sunlight; clean energy materials; affordable heating and cooling of buildings; and renewable and clean hydrogen. An example is the UK-Canada transatlantic collaboration on smart grid and energy storage, worth GBP 11 million, announced in 2018. (Mission Innovation, 2018b).

In addition to steering government action, MI helps to catalyse private sector efforts. The Breakthrough Energy Coalition[2], an unprecedented commitment by private investors to provide risk-tolerant investments, was formed to finance early-stage technologies emerging from MI countries.

MI is a big step in the right direction, and so far, results have been promising. The question is whether the targets for doubling public funding are set over the right time frame. Longer-term targets (such as to 2030 rather than 2020) could reduce public funding spikes and associated adjustment costs, and ultimately reduce the overall cost of decarbonisation (Dechezleprêtre, Martin and Bassi, 2016).

There is also a question as to how MI R&D investment estimates are standardised. Given that MI is a voluntary initiative, the methodologies behind countries' investment estimates are not formally co-ordinated, which leads to discrepancies in what countries count as "clean" energy. For example, nine member countries include nuclear energy and twelve include cleaner fossil energy. Renewables and energy storage are the only technology areas included by all countries (IEA, 2017a). Further progress on measuring private RD&D is needed.

3.2. Leveraging funds and aligning policies to help innovators cope with risk

Immature but potentially transformative low-emissions innovations often must compete against hefty incumbent technologies in markets with high barriers to entry and exit, which makes them risky for innovators. Governments can help to break path dependence in these circumstances – as has been the case for renewable electricity. The rise in global investment in renewable power capacity (to USD 266 billion in 2015 – more than double the allocation to new coal and gas generation) was driven in large part by significant support to technology deployment through targeted incentives (e.g. fixed prices and guaranteed purchase for renewable electricity) (FS-UNEP and BNEF, 2016).

For example, to help innovative European companies develop and bring radically new clean energy technologies to the market, the European Commission, together with Bill Gates-led Breakthrough Energy, recently launched a EUR 100 million clean-energy investment fund, creating a Breakthrough Energy Europe (BEE) to become operational in 2019. This investment fund can help to bridge public funding with long-term risk capital, focused on reducing emissions and promoting energy efficiency (e.g. in electricity, transport, agriculture, manufacturing, and buildings).

Through such and similar initiatives, governments can smooth out the flow of finance by using public funds to invest directly (e.g. the US loan to Tesla[3]) or by using public funds or policies to leverage private finance. For example, policy support coupled with investments from multilateral development banks (MDBs) and the Clean Technology Fund (CFT) helped to leverage private sector capital, transforming Turkey's renewable energy and energy efficiency markets from a virtually non-existent to one that could be financed on commercial terms over 2009 to 2014 (World Bank, 2015)[4].

Policies are sometimes not well aligned, for example, in the EU: public VC funds remain fragmented, and heterogeneity between national tax systems exists, which creates competition and also imposes transaction and information costs (Ständer, 2017). Several international initiatives have emerged to cope with the harmonisation challenge. Some public VC funds are now co-ordinated at the European level (e.g. through the new European Innovation Council, the EU fund of fund program Ventured, and the European Investment Fund)[5] and some tax regimes are harmonised at the international level (e.g. the Common Consolidated Corporate Tax Base and the OECD/G20 Base Erosion and Profit Shifting (BEPS) Package)[6].

Budgeting processes can be used to improve coherence and policy alignment. The Paris Collaborative on Green Budgeting promotes the use of the policy tools of budgeting (taxes, financial outlays, and co-ordination) to promote the alignment that is essential to meet environmental goals (OECD, 2018a).

Also, governments are promoting collaborative innovation networks – which may matter more than a traditional menu of fiscal measures for de-risking innovation (Bennett, 2018). Dedicated platforms that foster cooperation between researchers, companies and governments can enhance innovation performance and help funding it (e.g. the Fraunhofer Institute in Germany, the Environmentally Sound Technology (BEST) Cooperation Platform for Brazil, Russia, India, China and South Africa).

But policies are not effective in isolation. Taxation that favours low-emissions innovation is best coupled with structural reforms, for example, to enhance innovation development and adoption capacity, competition policy enforcement to create more fluid markets, and policies to promote collaborative networks of low-emissions innovators. However, any national efforts that implement taxation of public spending programmes to leverage private finance for low-emissions innovations can be undermined by policy misalignments internationally (Ständer, 2017).

3.3. Making digitalisation work for decarbonisation

Digitalisation has the potential to drive decarbonisation across the economy, from transportation, agriculture and manufacturing to waste management and end-of-life treatment of products and materials (OECD, forthcoming b). For example, in the agricultural sector, the Internet of Things (IoT) and big data analytics have enabled farmers to use resources more efficiently and enhance productivity by applying fertiliser and herbicides only where needed (OECD, 2017b). Digital technologies also offer opportunities to reduce waste and improve the efficiency (including energy efficiency) of agri-food supply chains. In the manufacturing sector, innovations in robotics and AI, blockchain, and 3D printing could increase resource efficiency and bring down emissions (OECD, forthcoming b).

Contributions of digitalisation to different sectors

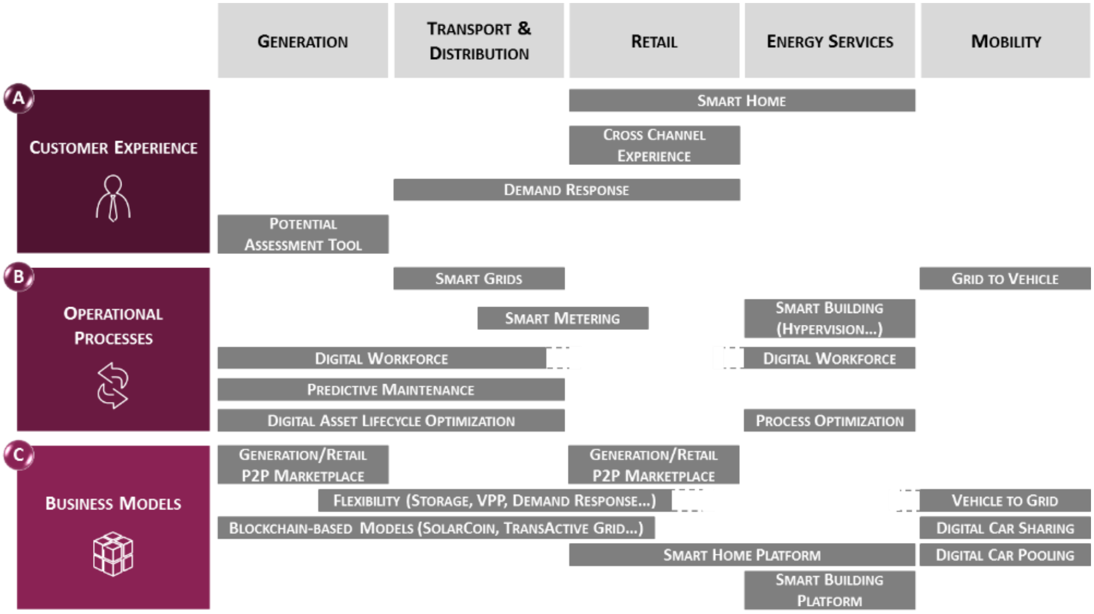
Energy

Digitalisation is accelerating the pace of the energy and environmental transition by 1) enhancing customer interaction with the energy system, 2) optimising operations, and 3) enabling new business models for traditional energy actors and creating space for new entrants from other sectors and energy start-ups (Figure 9; Reinaud et al., 2017).

Digitalisation can help to integrate variable renewables by enabling grids to better match energy demand to supply. It can facilitate the development of distributed energy resources, such as household solar PV panels and storage, by creating better incentives and making it easier for producers to store and sell surplus electricity to the grid. New tools such as blockchain could help to facilitate peer-to-peer electricity trade within local energy communities by providing transparency and security in transactions, thereby improving access to energy.

Figure 9. How digitalisation is accelerating the energy transition

Percentage of enterprises with 10 or more employees, 2016.



Source: Capgemini Consulting, adopted from Reinaud et al.i24c (2017).

While digital technologies can improve efficiency, some could also induce rebound effects that increase overall energy use. As billions of new devices become connected over the coming years, they will draw electricity at the plug while driving growth in demand for – and energy use by – data centres and network services. However, sustained gains in energy efficiency could keep overall energy demand growth largely in check for data centres and networks over the next five years. Over the long term, under a best-case scenario of improved efficiency through automation and ride-sharing, energy use could halve compared with current levels. Conversely, if efficiency improvements do not materialise and rebound effects from automation result in substantially more travel, energy use could more than double.

Transport

Technological innovations such as electric mobility, autonomous vehicles or new shared mobility solutions (e.g. peer to peer car sharing services) are likely to change mobility patterns radically, notably in cities. Some of these innovations provide opportunities to reduce the CO_2 footprint of transport (ITF, 2017).

In the maritime sector, for example, the Swiss-Swedish conglomerate ABB is expanding its activities in electrification, robotics and industrial automation towards maritime applications, particularly in hybrid propulsion and optimised efficiency of electrical power systems and fuel cells. The electric ferries that run between Sweden and Denmark are powered with batteries from ABB and supported by automated shore-side charging stations using an industrial robot, making them the largest 100% electrically-powered cargo and passenger vessels in the world (ITF, 2018).

Chemicals and plastics

Petrochemical products are everywhere – from consumption goods such as plastics, fertilisers, packaging and digital devices to integral parts of energy and transport systems (e.g. solar panels, batteries and electric vehicle parts). They are set to become the main driver of global oil consumption, projected to represent over one third of the growth in oil demand to 2030, and nearly half to 2050 – more than trucks, aviation and shipping combined (IEA, 2018c).

While plastics can bring environmental benefits (e.g. their use in vehicles lowers GHG emissions due to reduced weight), their disposal also implies considerable costs. Only 15% of plastic waste is collected and recycled into secondary plastics, creating plastics pollution, and energy-intensive plastics production accounts for approximately 400 million tonnes of GHG emissions annually. Digitalisation can improve sensoring and sorting in the recycling process. For example, there are a number of initiatives to find ways to identify black polypropylene packaging in automatic sorting units – an element of packaging that is not typically recycled (OECD, 2018b).

Buildings

Buildings account for nearly one-third of global final energy consumption and 55% of global electricity demand. Digitalisation, including smart thermostats and smart lighting, can help cut buildings-related emissions. Digital innovations can help ensure that energy is consumed when and where it is needed by improving the responsiveness of energy services (e.g. using lighting sensors) and predictively with respect to user behaviour (e.g. through learning algorithms that auto-programme heating and cooling services). It can also enable demand response to reduce peak loads (e.g. shifting the time of use of a washing machine), to shed loads (e.g. adjusting temperature settings to lower energy demand at a particular time) and to store energy (e.g. in thermal smart grids) in response to real-time energy prices or other conditions specified by the user (IEA, 2017b).

Challenges across sectors

Different sectors face different challenges for harnessing digitalisation for decarbonisation, some linked to the way these sectors are regulated and structured. For example, in the agricultural sector, knowledge and technical gaps, high start-up costs with a risk of insufficient return on investment, and structural (e.g. small farm size) and institutional constraints are key obstacles to the adoption of precision agriculture by farmers (OECD, 2017b). Given this diversity, there is no one-size-fits-all policy solution.

While digitalisation can provide benefits in many respects, it also opens up a host of ethical issues concerning fairness and inclusion, security, privacy and autonomy, and accountability and transparency. It can also spur unintended environmental, societal and economic outcomes. These overarching issues for policy consideration are not exclusive to innovation and climate change policy objectives, and may require further changes in law-making and regulatory design (UN, 2018).

Current policy setups may need to cope more quickly with digitalisation. For example, 3D printing as it is used now does provide the environmental benefits that it potentially could.[7] Policies (e.g. targeted R&D grants or investments, or sustainability certification labels and corresponding public purchasing programmes) may be needed to bring 3D printing from the fringes of the manufacturing industry into the mainstream. At the same time, low-energy printing processes (e.g. using chemical processes rather than melting material and automatically switching to low-power states when idle) and low-impact materials with useful end-of-life (e.g. compostable biopolymers with high print quality) may need a stimulus (OECD, 2017c).

3.4. Different solutions for different places: Cities, households and sectors

Cities as hubs of innovation

Because innovation and economic activity has strong place-based dimensions, local and subnational governments can set higher and more ambitious climate goals than national governments. Cities and regions are responsible for 55% of climate and environment-related spending, and 64% of investment over the period 2000-2016 in 30 OECD countries (OECD, 2018d).

With support from coalitions such as ICLEI, C40 Cities, and the Global Covenant of Mayors, 32 cities worldwide – including Paris, London, New York and Mexico City – have pledged to become carbon neutral by 2050. Copenhagen aims to be the first carbon-neutral capital in the world by reaching this target by 2025.

Cities and regions also have an important role to play in making low-emissions innovation inclusive. Income inequality tends to be higher in cities relative to their respective countries[8] and climate change is poised to exacerbate the effects of structural inequalities within cities, as low-income and vulnerable populations have higher exposure and susceptibility to climate-related damage, as well as lower ability to recover (OECD, 2018d).

Greening household behaviour

People do want to “green” their behaviour, and prices and costs can be hugely influential in household decisions.[9] Carefully crafted policies (e.g. water and waste charges, subsidies, taxes and grants), better, more targeted information (e.g. sustainability labels on food and appliances), clearer communication on the environmental and economic benefits of policies (e.g. environmental taxes), and more intelligent infrastructure (e.g. charging stations for electric cars) can help people make “green” decisions (OECD, 2014). By making it easier for households to act on good intentions, policy makers can help create stronger market-pull for low-emissions innovations.

Sector specific solutions: the case of agriculture

Barriers to the diffusion of a low-emissions innovation can be sector specific. For example, in the agricultural sector, precision farming techniques are most easily advanced among arable farmers with large farm sizes (e.g. in the main arable-crop areas of Europe, the US and Australia) (OECD, 2017b). Soil management is a focus of attention, including for its role as a carbon sink – as increasing productivity (yields) is one way to reduce emissions per output. The European Commission’s Bioeconomy Strategy for a sustainable Europe, launched in October 2018, includes research and innovation funding, including research on bio-technologies to capture carbon and re-use wastes (e.g. to produce biogas).

Similarly, conservation agriculture (where crop residue is retained after harvest) has been successfully introduced in high-input and high-yielding smallholder farms in the rice-wheat region of Asia, but is more challenging to implement in low-productivity smallholder farm systems in the tropics and subtropics with competing alternative uses of crop residues (e.g. animal feed) and cultural norms (e.g. the tradition that residues are grazed by animals in the community in Sub-Saharan Africa) that stand in the way of adoption (OECD, 2016).

Efforts to accelerate low-emissions innovations can also be borne out of context. For example, Kas als Energiebron ("Greenhouse as a Source of Energy"), a Dutch programme that aims to make all new greenhouses climate-neutral by 2020 and a source of sustainable energy supply by 2050, emerged because of the country's exceptional position in terms of the energy consumption of its agriculture and horticulture – the sector accounts for 6.3% of energy consumption and approximately 12% of greenhouse gas emissions in the Netherlands, and energy represents 20% to 25% of the greenhouse sector's total production costs (Moreddu, 2016).

Collective action, knowledge-exchange and data are key to scaling up micro solutions

Data are very limited to track climate finance in general and even more so at the subnational level (OECD, 2018d). There is an important role for policy in prioritising the development of indicators to track progress, and for local, regional and national authorities to identify appropriate institutions to collect and report data in a consistent format (OECD, 2015c). The OECD has proposed a preliminary methodology to track environmental and climate-related spending investment at the subnational level, based on Classification of Function of Government (COFOG) data from the National Accounts and focusing on sectors that have a direct implication for climate change (OECD, 2018d).

3.5. Boosting the benefits of innovation for society

New ethical, social and environmental concerns and expectations shape the ways in which key stakeholders (i.e. consumers, customers, employees and investors) engage with business; for example by forming partnerships such as the OECD-BSR Business for Inclusive Growth Initiative that complements the OECD Framework for Policy Action on Inclusive Growth (OECD, 2018e).

Corporate social responsibility (CSR) initiatives have helped to support communities over the last decades by improving corporate culture and employee engagement. Progressive businesses are now looking at the next phase of evolution in corporate social responsibility from a perspective of social and environmental innovations – but in a way that contributes to the success of the business. One example of how this can be done includes new business models with a zero-footprint supply chain to radically shrink the negative environmental impact of operations and improve the standard of living for marginalised populations (e.g. KPMGs Breaking Through for CSR to Create Business Opportunity).

For example, Unilever's Sustainable Living Plan touches upon every segment of business operations from product design, marketing, sourcing, and manufacturing to customer engagement. This is part of the company's public commitment to double its growth while halving its environmental footprint and helping one billion people improve their health and well-being. Another example of the all-inclusive approach to innovation is Pipistrel Aircraft's strategy, which integrates social and environmental aspects in their operations and innovations, with energetically self-sufficient and environmentally-friendly facilities for research, development and demonstration.

Innovations that bring together the expertise of multiple stakeholders from across the business spectrum can yield benefits for companies and society at the same time. For example, two seemingly unrelated companies, Pipistrel – which produces and sells energy-efficient and carbon-neutral aircraft – and Uber, a modern mobility platform, are now co-operating to reduce noise and pollution while creating new markets and improving the quality of life for citizens by providing cleaner and stress-less mobility solutions.

However, this environment needs to remain competitive and conducive to experimentation with new ideas.Taking part in new discoveries and acceptance of new technologies and ways of doing things with climate change in mind requires new skills. Upgrading and diversifying workers' skills can further help to boost business dynamism and strengthen resilience to risks and shocks, particularly where opportunities to efficiently re-locate and contribute to innovations for low-carbon growth are limited.

3.6. Effective governance beyond national jurisdictions

One of the main challenges to aligning innovation policies with climate goals is narrowing the gaps between the governance frameworks of each domain. Institutionally, many of the responsibilities for innovation policy are nested in national innovation and research funding agencies whose principal mission is to fund excellent research and to promote innovation in firms in general. This is not to say that green innovation or eco-innovation programmes are not promoted by national research or environmental ministries, just that environmental sustainability must be given equal weight as employment and growth objectives.

Moreover, in climate as well as in the innovation policy domain, multi-level governance approaches have been developed independently from one another. Governance frameworks for climate policy have sought to reduce fragmentation in planning, policy, regulation and implementation at local and national levels. By contrast, governance frameworks in innovation policy have focused on steering research systems towards economic development and domestic societal concerns through stronger co-ordination processes. This has resulted in missed opportunities to leverage climate policies to stimulate green innovation, notably at regional and local levels. Cities, for example, have little R&D capacity themselves, but host leading universities whose research agenda is tied to scientific excellence goals rather than local solutions.

While global governance for climate has emerged through treaties and target such as the Paris Agreement's Nationally Determined Contributions (NDCs), global governance for technology and innovation has been more preoccupied with issues of safeguarding society against technological risks (e.g. nuclear proliferation, cybersecurity risks) and the ethical use of new technologies (e.g. UN Declaration banning human cloning) than with promoting international co-operation on climate-friendly technologies.

Linking multilevel governance frameworks across the two policy domains would enable national research systems to better respond to internationally agreed climate goals (top-down) and to demands from cities and regions to enhance local innovation capabilities to meet climate goals (bottom-up). It could facilitate the engagement of public research institutes and universities with national and local governments and stakeholders in order to provide the underlying scientific research to quantify and measure local progress on various climate-related goals or to mobilise innovation capabilities of universities to foster entrepreneurship and start-ups in the area of low-emissions innovations.

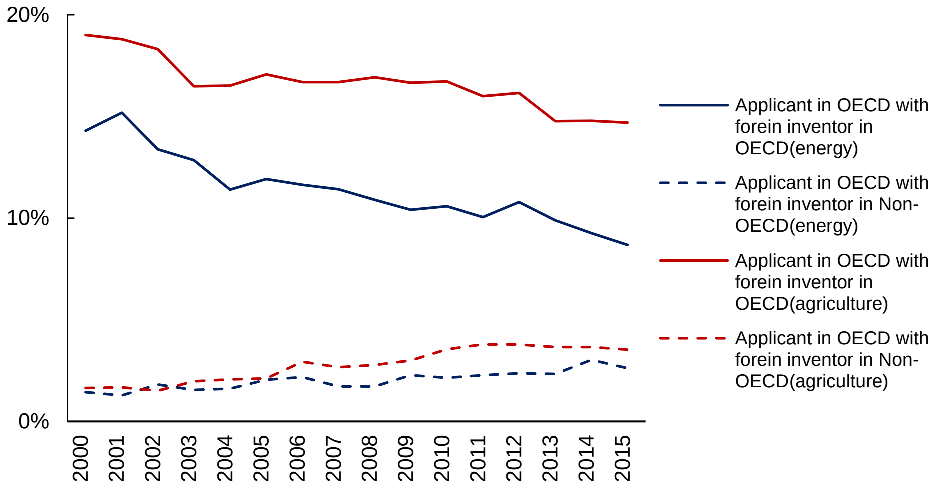
Efforts beyond borders

International co-operation (e.g. the Global Research Alliance on Agricultural Greenhouse Gases) is key to addressing the low-emissions technology divide between developed and developing countries; to overcome the reluctance of individual governments or firms to act alone owing to the transboundary externalities associated with low-emissions innovations (e.g. knowledge spillovers, pollution); and to harmonise policies across nations, preventing opportunities for arbitrage which can undermine efforts to stimulate low-emissions innovation.

While multilateral agreements can create political momentum for accelerating innovation, implementation will require multi-faceted approaches to cross border co-operation that involve bilateral and regional approaches. Multi-stakeholder partnerships that bring together foreign firms, universities and community actors and consumers can help build capacity in developing countries as well as facilitate international transfer of knowledge and technology. However, patent data in agriculture and energy, for example, show that international co-operation in agriculture is mainly taking place among OECD countries (Figure 10).

Figure 10. International co-patenting in agriculture and energy, 2000-2015

Patent under the Patent Co-operation Treaty (PCT).



Note: Patents of International co-operation are from inventions filed by applicants having residence in OECD with foreign inventor. Patent counts are based on the priority date (first filing of the patent worldwide), with patent family size of two or more (high-value inventions), sorted by the applicant's country of residence, using simple counts. Energy technology includes patents related to Nuclear power generation(Nuclear engineering, Gas turbine power plants using heat source of nuclear origin), Alternative energy production(Bio-fuels, Integrated gasification combined cycle (IGCC), Fuel cells, Pyrolysis or gasification of biomass, Harnessing energy from manmade waste, Hydro energy, Ocean thermal energy conversion (OTEC), Wind energy, Solar energy, Geothermal energy, Other production or use of heat, not derived from combustion, e.g., natural heat (OPoUH), Using waste heat, Devices for producing mechanical power from muscle energy), and Energy conservation (Storage of electrical energy, Power supply circuitry, Measurement of electricity consumption, Storage of thermal energy, Low energy lighting, Thermal building insulation, in general) .Agricultural patents include whole agricultural technologies.
Source: Authors' calculations based on the OECD Patent Database, 2018.

Leapfrogging frontier technologies

While developed countries grapple with frontier technologies, developing countries have often not yet adopted existing ones. More than 1 billion people in developing countries still do not have access to electricity (UN, 2018).

This chasm could, in theory, present developing countries with “leapfrogging” opportunities – the option to bypass less efficient technologies or overcome entrenched installations and infrastructure and adopt low-emissions technologies. For example, people and firms in developing countries are now bypassing fossil fuels and leaping directly to solar energy as their starting point (UN, 2018) (Box 2).

Box 2. Case Study: Solar powered drip irrigation in developing countries

Drip irrigation technology saves water and fertiliser by delivering droplets of water to the base of plants. Until recently, off-the-grid farmers in developing countries have not able to use this technology without expensive diesel generators. New solar-powered irrigation technology offers an alternative while also saving farmers time that can be used to carry out other activities.

The World Bank, in partnership with the Bangladesh Climate Change Resilience Fund (BCCRF), Global Partnership on Output Based Aid (GPOBA), and U.S Agency for International Aid (USAID), is supporting the government of Bangladesh to install 1,250 solar-powered irrigation pumps by 2018. The implementing agency, Infrastructure Development Company Limited (IDCOL), channels grant and credit funding to the nongovernmental organisations and private investors who install the solar pumps.

So far, about 300 pumps are in operation benefitting more than 8,000 farmers. They are more affordable and easier to install than traditional systems. They have no moving parts, function without noise or pollution, and require little maintenance. Once all 1250 pumps are in operation, they will reduce the country’s carbon emissions by 5,000 tonnes per year.

Kenya has 5.4 million hectares of arable land, but only 17% is suitable for rain-fed agriculture; the rest must be irrigated. Petrol, electric, and manual systems are all available but are “constrained by high input costs and labour inefficiencies.”

Kenyan private start-up SunCulture designs and installs irrigation tube networks and solar panels on farms, offers training and brings in agronomists to maximise yields. The company has set up 350 systems in Kenya, and recently put down its first system in Ethiopia. Financing is an issue, but here business models offer solutions such as company financing or crowdfunding.

Source: World Bank (2017).

Despite opportunities to grow, major challenges hold “leapfrogging” back, in particular limited absorptive capacity due to lack of physical and human capital (i.e. an educated and healthy workforce).

The role of multilateral fora

The G20 has the scale and scope to create a policy and regulatory framework that fosters innovation and enables fair competition between industrial companies on a global playing field, which in turn would enable the low-emissions innovation industry to flourish. To this end, the Business 20 Energy, Resource Efficiency and Sustainability Task Force (B20 ERES) has called for the establishment of a G20 carbon pricing platform to accelerate the development of global pricing mechanisms; a G20 energy innovation action plan to enable governments to create incentives to develop and use innovative technologies, including digital technologies; and a G20 resource efficiency platform (International Chamber of Commerce, 2017).

The G20 could also help improve investment and climate change risk-related data, which could ultimately boost investments in low-emissions innovations. In 2017, the G20/OECD Task Force on Institutional Investors and Long-term Financing launched the Infrastructure Data Initiative, a joint initiative of the European Investment Bank, Global Infrastructure Hub, Long-term Infrastructure Investors Association, the OECD and the Club of Long Term Investors, to improve the collection and availability of infrastructure investment data.

Supporting low-emissions innovations in emerging economies

In 2015, BRICS[10] energy ministers pledged to promote access to advanced and applicable low-emissions technologies over the next ten years through technology and policy sharing, mobilising investment into energy efficiency, and promoting collaborative R&D and personnel exchange for capacity building (IPEEC, 2017). The 10th BRICS Summit, held in July 2018 in Johannesburg, reaffirmed countries' commitments to the Paris Agreement, as well to a number of initiatives specifically targeted at boosting low-emissions innovations, such as the Environmentally Friendly Technology Platform and the Environmentally Sound Technology (BEST) Co-operation Platform.

4. CONCLUSION

Low-emissions technologies have existed for some time, but more needs to be done to effectively shift the *direction* and *pace* of innovation towards a net zero carbon economy. Science, technology and innovation policies can do more to lift up existing technologies and help radical innovations break through. However, these efforts need to be well-aligned across the economy and help agents overcome the barriers.

As this paper points out, many barriers still persist - from economic and financial to institutional and regulatory. Often these barriers reinforce each other and can make piecemeal policies ineffective. For example, providing subsidies to R&D for renewables may result in a new patent, but not necessarily transform energy or transport sectors if regulations and consumer policies are not aligned with climate objectives. Slow progress on Carbon Capture and Sequestration (CCS) technologies, for example, illustrates the need for policy alignment.

A systems-based approach to innovation is therefore called upon. This requires strong and consistent policy signals that can help financial markets more effectively price in the climate risks and rewards of investments in low-emissions innovations. It also means redirecting fossil R&D fuel subsidies to low carbon solutions. Innovation can be supported from the supply side (R&D stage and deployment) as well as from the demand side (public procurement, challenge-prizes, and regulations). To help de-risk and accelerate innovation, governments can further promote collaborative innovation platforms that include researchers, companies and public research within and across countries. The Mission Innovation initiative for clean energy research is one such example of government, research and business coming together.

Because of the importance of emissions in certain key sectors such as transport, energy, and agriculture, interdependencies and interactions between different sectors need to be taken into account (e.g. energy, land-use, water). Seizing the benefits of digitalisation and other emerging technologies such as blockchain and AI can further help to decarbonise the energy and transport sectors and improve circular economy business models.

Policy reforms and actions – such as emissions reductions targets at the level of cities and municipalities – can help to redirect investment towards more sustainable infrastructure. Promoting the adoption of green technologies in cities often begins with encouraging green behaviour in households and consumers which can stimulate demand.

Meeting the goals of the Paris Agreement will require all countries to adopt low-emissions technologies across their economies. However, much of the technology remains concentrated in the OECD countries, even if some emerging economies have increased their capacity to carry out R&D and innovation in green technologies. Building technical, financial and human skills capacity in emerging countries will help them further develop and deploy technologies, help them to "leapfrog" and avoid locking in carbon-heavy infrastructure and technologies. Greater efforts will be needed to strengthen international co-operation for the diffusion of low emissions technologies. There are some mechanisms currently in place, such as green investment banks and green technology banks, but these are insufficient.

Notes

1 Mission Innovation members: Australia, Austria, Brazil, Canada, Chile, China, Denmark, European Union, Finland, France, Germany, India, Indonesia, Italy, Japan, Mexico, Netherlands, Norway, Republic of Korea, Saudi Arabia, Sweden, United Arab Emirates, United Kingdom, United States.

2 A group of 28 key investment players from ten countries, including Bill Gates, Mark Zuckerberg and Richard Branson, who are mobilising to deliver patient investments in clean energy technologies.

3 Tesla Motors received USD 465 million from the US' Advanced Technology Vehicle Manufacturing loan programme just months before the company went public, to support two future projects: financing a manufacturing facility to make an all-electric, zero-emission five-person sedan; finance an advanced battery and powertrain manufacturing facility to supply Tesla's EV powertrain to other automakers, both domestic and foreign. With help from the loan, Tesla built out its production facility in Fremont, Calif., and launched the Model S sedan in 2012. The company has since sold roughly 150,000 of them globally, company records show.

4 In a first phase, USD 172 million from the CFT supported private sector investment through complementary programmes to address barriers to renewable energy and energy efficiency finance (e.g. building technical capacity in banks to evaluate projects, educating industry about the benefits of energy efficiency, providing loans at more favourable terms). The CTF investment attracted nearly USD 2 billion co-financing through 430 sub-projects.

5 The new European Innovation Council (EIC) brings together the parts of Horizon 2020 that provide funding, advice and networking opportunities for those at the cutting edge of innovation. VentureEU is a new EU mega-fund which targets start-ups. It aims for the initial EUR 410 million worth of EU funding to trigger a snowball effect and raise private finance, too, ultimately doubling the amount of VC currently available in Europe. The European Investment Fund (EIF) is increasingly involved in national VC efforts, including, for example, the joint VC investment of EUR 75 million in 2015 between the EIF, Bpifrance and KfW (EIF, 2015).

6 The Common Consolidated Corporate Tax Base (CCCTB), which was revamped in 2016 to support innovation by allowing companies a super-deduction on their R&D costs (European Commission, 2016).

The Inclusive Framework on BEPS brings together over 115 countries and jurisdictions to collaborate on the implementation of the OECD/G20 Base Erosion and Profit Shifting (BEPS) Package.

7 In some situations 3D printing already brings environmental benefits, e.g. it already reduces manufacturing-phase environmental impacts for certain types of prototyping or small-run production, and reduces user-phase environmental impacts in some applications, such as saving weight space in aerospace parts. However, most standard printers operating in typical conditions cause higher impacts per part than injection-moulding plastic at high volumes.

8 In 10 out of 11 OECD countries surveyed for the OECD (2018) Financing Climate Futures study.

9 This is according to the OECD's second Environmental Policy and Individual Behaviour Change (EPIC) survey, carried out in 2011, which collected information on over 12,000 households in Australia, Canada, Chile, France, Israel, Japan, Korea, the Netherlands, Spain, Sweden and Switzerland.

10 Brazil, Russia, India, China and South Africa.

REFERENCES

Baron, R. (2016), The Role of Public Procurement in Low-carbon Innovation, Background Paper for the 33rd Round Table on Sustainable Development, available at: https://www.oecd.org/sd-roundtable/papersandpublications/.

Bennett, S. (5 September 2018), "IEA steps up its work on energy innovation as money flows into new energy tech companies", IEA News blog, https://www.iea.org/newsroom/news/2018/september/commentary-iea-steps-up-its-work-on-energy-innovation-as-money-flows-into-new-en.html.

Calel, R. and A. Dechezleprêtre (2016), "Environmental policy and directed technological change: evidence from the European carbon market", *Review of Economics and Statistics*, 98 (1), pp. 173-191.

Dechezleprêtre, A. (24 October 2016), "How to reverse the dangerous decline in low-carbon innovation", Grantham Institute on Climate Change and the Environment blog, http://www.lse.ac.uk/GranthamInstitute/news/how-to-reverse-the-dangerous-decline-in-low-carbon-innovation/.

Dechezleprêtre, A., R. Martin, and S. Bassi (2016), "Climate change policy, innovation and growth", Grantham Research Institute on Climate Change and the Environment Policy Brief January 2016.

European Investment Fund (27 October 2015), "The European Investment Fund, Bpifrance and Kfw co-invest EUR 75m in growth-capital fund Partech Growth", Press release, http://www.eif.org/what_we_do/equity/news/2015/partech.htm.

FS-UNEP and BNEF (2016), *Global Trends in Renewable Energy Investment 2016*, https://www.actu-environnement.com/media/pdf/news-26477-rapport-pnue-enr.pdf.

Gaddy, B., V Sivaram, and F. O'Sullivan (2016), "Venture Capital and Cleantech: The Wrong Model for Clean Energy Innovation", MIT Energy Initiative Working Paper 2016-06.

IEA (2018a), "World Energy Investment 2018", International Energy Agency, OECD Publishing, Paris, https://doi.org/10.1787/9789264301351-en.

IEA (2018b), "Tracking Clean Energy Progress", International Energy Agency, OECD Publishing, Paris,https://www.iea.org/tcep/.

IEA (2018c), "The Future of Petrochemicals: Towards More Sustainable Plastics and Fertilisers", International Energy Agency, OECD Publishing, Paris, https://webstore.iea.org/download/summary/2310?fileName=English-Future-Petrochemicals-ES.pdf.

IEA (2017a), "Tracking Clean Energy Innovation Progress", International Energy Agency, https://www.iea.org/media/etp/tracking2017/TrackingCleanEnergyInnovationProgress.pdf.

IEA (2017b), "Digitalization & Energy", International Energy Agency, OECD Publishing, Paris, https://doi.org/10.1787/9789264286276-en.

IEA (2015), “Energy Technology Perspectives 2015”, International Energy Agency, OECD Publishing, Paris, https://doi.org/10.1787/energy_tech-2015-en.

International Chamber of Commerce (4 July 2017), “Industry is a driver of innovation for global climate protection”, News & Speeches, https://iccwbo.org/media-wall/news-speeches/industry-driver-innovation-global-climate-protection/.

IPEEC (26 September 2017), “BRICS: A force for energy efficiency cooperation”, Bulletin, https://ipeec.org/en/bulletin/25-brics-a-force-for-energy-efficiency-cooperation.html.

IPCC (2018), “Global Warming of 1.5 °C”, http://www.ipcc.ch/report/sr15/.

ITF (2018), "Decarbonising Maritime Transport: Pathways to zero-carbon shipping by 2035", *International Transport Forum Policy Papers*, No. 47, OECD Publishing, Paris, https://doi.org/10.1787/b1a7632c-en.

ITF (2017), “ITF Transport Outlook 2017”, International Transport Forum, OECD Publishing, Paris, https://doi.org/10.1787/9789282108000-en.

Lane, J. (2012), “The “Need to Knowledge” Model: An operational framework for knowledge translation and technology transfer”, *Technology and Disability*, 24 (3), pp. 187-192.

Lucas, A. (2016), “Stranded assets, externalities and carbon risk in the Australian coal industry: the case for contraction in a carbon-constrained world”, *Energy Research and Social Sciences*, 11, pp. 53–66.

Mazzucato, M. (2016), “From market fixing to market-creating: a new framework for innovation policy”, *Industry and Innovation*, 23 (2), pp. 140-156.

Mission Innovation (2018a), “Mission Innovation: Accelerating the Clean Energy Revolution”, webpage, http://mission-innovation.net/ (accessed 29 October 2018).

Mission Innovation (2018b), “Third Mission Innovation Ministerial (MI-3)”, webpage, http://mission-innovation.net/mi-3/, (accessed 29 October 2018).

Moreddu, C. (2016), “Public-Private Partnerships for Agricultural Innovation: Lessons From Recent Experiences”, *OECD Food, Agriculture and Fisheries Papers*, No. 92, OECD Publishing, Paris, https://doi.org/10.1787/5jm55j9p9rmx-en.

OECD (fothcoming a), “OECD Science, Technology and Innovation Outlook 2018”, OECD Publishing.

OECD (forthcoming b), “Scoping of digitalisation and the circular economy”, OECD Publishing, Paris.

OECD (forthcoming c), “OECD SME and Entrepreneurship Outlook 2019”, OECD Publishing, Paris.

OECD (2018a), “Paris Collaborative on Green Budgeting”, webpage, http://www.oecd.org/environment/green-budgeting/, (accessed 29 October 2018).

OECD (2018b), "Examples of innovation in plastics", in *Improving Markets for Recycled Plastics: Trends, Prospects and Policy Responses*, OECD Publishing, Paris, https://doi.org/10.1787/9789264301016-28-en.

OECD (2018c), “Financing Climate Futures: Rethinking Infrastructure: Synthesis and Key Messages for High-level Discussion”, http://www.oecd.org/environment/cc/climate-futures/synthesis-financing-climate-futures.pdf.

OECD (2018d), "Financing Climate Futures: Rethinking Infrastructure: Key Findings: Financing climate objectives in cities and regions to deliver sustainable and inclusive growth", http://www.oecd.org/cfe/Financing-Climate-Flyer.pdf.

OECD (2018e), "Opportunities for All: A Framework for Policy Action on Inclusive Growth", OECD Publishing, Paris, https://doi.org/10.1787/9789264301665-en.

OECD (2017a), "Green Growth Indicators 2017", OECD Green Growth Studies, OECD Publishing, Paris, https://doi.org/10.1787/9789264268586-en.

OECD (2017b), "Improving Energy Efficiency in the Agro-food Chain", OECD Green Growth Studies, OECD Publishing, Paris, https://doi.org/10.1787/9789264278530-en.

OECD (2017c), "The Next Production Revolution: Implications for Governments and Business", OECD Publishing, Paris, https://doi.org/10.1787/9789264271036-en.

OECD (2017d), "Investing in Climate, Investing in Growth", OECD Publishing, Paris, https://doi.org/10.1787/9789264273528-en.

OECD (2016), "Farm Management Practices to Foster Green Growth", OECD Green Growth Studies, OECD Publishing, Paris, https://doi.org/10.1787/9789264238657-en.

OECD (2015a), "The Innovation Imperative: Contributing to Productivity, Growth and Well-Being", OECD Publishing, Paris, https://doi.org/10.1787/9789264239814-en.

OECD (2015b), "Aligning Policies for a Low-carbon Economy", OECD Publishing, Paris, https://doi.org/10.1787/9789264233294-en.

OECD (2015c), "Monitoring the Transition to a Low-carbon economy: A strategic approach to local development", https://www.oecd.org/cfe/leed/Monitoring-Green-Transition-Final2.pdf.

OECD (2015d), "Fostering Green Growth in Agriculture: The Role of Training, Advisory Services and Extension Initiatives", OECD Green Growth Studies, OECD Publishing, Paris, https://doi.org/10.1787/9789264232198-en.

OECD (2014), "Greening Household Behaviour: A review for Policy Makers", *OECD Environment Policy Papers*, No. 3, OECD Publishing, Paris, https://doi.org/10.1787/5jxrcllp4gln-en.

OECD (2012), "OECD Science, Technology and Industry Outlook 2012", OECD Publishing, Paris, https://doi.org/10.1787/sti_outlook-2012-en.

Polzin, F., P. von Flotow, and L. Klerkx (2015), "Addressing barriers to eco-innovation: exploring the finance mobilisation functions of institutional innovation intermediaries", *Technological Forecasting and Social Change*, Vol. 103, pp.34–46.

Reinaud, J., N. Clinckx, K. Ronzeau and P. Faraggi (2016), "Scaling up Innovation in the Energy Union to Meet New Climate, Competitiveness and Societal Goals: Scoping the Future in Light of the Past", i24c and Capgemini consulting manuscript.

Reinaud, J., N. Clinckx and P. Faraggi (2018, forthcoming), "Accelerating Energy & Environmental Transition in Europe through digital", i24c and Capgemini consulting manuscript.

Robb, A. and D. Robinson (2014), "The Capital Structure Decisions of New Firms", *The Review of Financial Studies*, 27 (1), pp. 153-179.

Ständer, P. (2017), "Public Policies to Promote Venture Capital: How to get national and EU measures in sync", Jaceques Delors Institut Policy Paper 203.

Technology Executive Committee (2017), "TEC Brief #10: Technological Innovation for the Paris Agreement: Implementing nationally determined contributions, national action plans and mid-century strategies", http://unfccc.int/ttclear/tec/brief10.html..

UN (2018), "World Economic and Social Survey 2018: Frontier technologies for sustainable development".

UNFCCC (2015), "Adoption of the Paris Agreement", FCCC/CP/2015/L.9, 12 December.

World Bank (2015), "Finance Climate Action: A snapshot of the World Bank Group's climate work", Working Paper no. 121068.

World Bank (30 May 2017), "Solar Water Pumping for Sustainable Water Supply", *The World Bank Brief*, http://www.worldbank.org/en/topic/water/brief/solar-pumping.

Young In, S., A. Monk and R. Levitt (2017), "An Integrated Control Tower: Unlocking Long-Term Investment Capital for Clean Energy Innovation", Stanford Precourt Institute for Energy.