Chapter 7. Bridging the gap: The role of innovation policy and market creation

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7.1 Introduction

By pairing innovation in the use of existing technologies and in behaviour with new technologies, directed innovation has the potential to radically transform societies and reduce their greenhouse gas (GHG) emissions. Therefore, accelerating innovation is a key component of any attempt to close the emissions gap, but it will not happen by itself.

As innovation is inherently uncertain and often costly, it requires access to substantial amounts of finance as well as acceptance of inevitable failures and losses across the innovation landscape. This landscape covers everything from basic to applied research, and from demonstration to scale-up, deployment and diffusion, with feedback effects between the various stages, meaning that funding requirements can escalate quickly. Moreover, as there are often long lead times from the invention of a sophisticated GHG-saving process or material to its transformation into a commercial product and its diffusion through newly created markets, innovators require extraordinary patience.

Well-crafted innovation policy that kickstarts and steadies innovation across the landscape can make a significant contribution to closing the financing gap, and in this case the emissions gap. This means that the public sector must often lead in terms of taking risks through ambitious innovation policy. Such policy requires more considerations to co-create and shape markets than simply fixing market failures. In other words, the public sector plays a crucial role in directing the innovation process rather than just filling the gaps. In the past, direction has been shaped through a mission-oriented approach: framing and solving societal problems and using all available levers to crowd-in other sources (Mazzucato, 2017; 2018a). This includes sustaining and accelerating innovation, not just in research and development (R&D) but across the entire innovation landscape, such as by providing patient finance that risk-averse actors are not willing to provide. No other actor can replace the public sector.

This chapter explores the type of policies that can accelerate low-carbon innovation for closing the emissions gap, and barriers to implementing them. Section 7.2 discusses what we regard as the four policy principles to drive additional investment, while section 7.3 illustrates how these principles have been crucial to the success of solar photovoltaic (PV). Section 7.4 discusses barriers to implementing active policies, before section 7.5 concludes by highlighting challenges and opportunities for accelerating low-carbon innovation through policy.

7.2 Innovation policies

7.2.1 Risk-taking across the innovation landscape

Innovation policy requires attention to be paid to the entire innovation chain: from the supply side (from basic and applied R&D to demonstration) to the demand side (regulations, subsidies and taxes, procurement, and significant changes in consumption patterns) (Polzin, 2017; Mazzucato, Semieniuk and Watson, 2015). In low-carbon sectors, in addition to grant funding, an important share of research, development and venture capital funding comes from public sources (Mazzucato and Semieniuk, 2017) and almost half of the investments into demonstration projects originate in public innovation institutions (Nemet *et al.*, 2018). Similarly, governments are highly active on the demand side with subsidies — whether set administratively (such as feed-in tariffs) or through auctions — loan guarantees and significant direct investment (Mazzucato and Semieniuk, 2017). Public procurement can also help spur innovation by favouring low-carbon technologies (Edler and Georghiou, 2007, see also online appendix A.3) and regulation must be conducive to innovation, which includes avoiding over-regulation while new business models are still forming. Successful innovation is often accompanied by the public sector's lead on taking risks at all stages of the innovation chain.

Box 7.1 Electric vehicle innovation policy across the innovation chain in China

China's efforts to innovate in electric vehicles (EVs) are a clear example of a governmental attempt to coordinate both supply-side (push) and demand-side (pull) measures in order to achieve specific goals. Policies involve a combination of investments in R&D, the creation of multiple demonstration zones for the purposes of experimentation, policies to spur industrial development, deployment subsidies for manufacturers, favourable tax- and fee-based incentives for consumers, and the provision of necessary infrastructure.

China's supply-side policies started during its 8th five-year plan (1991–1995), when public R&D funds were first allocated to EV technology. This supply-side support has continued and increased, taking different forms during subsequent five-year plans (Zheng *et al.*, 2012; Hou *et al.*, 2012). Most recently, the Ministry of Science and Technology issued a National Key R&D Programme for EV for 2016–2018, which is the most influential public R&D programme in China. There has been continuous and strengthening complementary supply-side support.

Industrial policy for EVs lagged behind these early investments in R&D, largely because industrial policy dating from the first auto-industry policy in 1994 originally aimed to establish a domestically competitive conventional automobile industry through a joint-venture formation strategy (Gallagher, 2006). In 2009, however, there was a strategic move to the new-energy vehicle industry, which was listed as one of seven strategic emerging industries in 2010, and later as one of 10 key fields in the Made in China 2025 plan. A combination of policy instruments has been applied, including demonstration programmes, finance and taxation measures, and administrative regulations. An influential regulation was recently issued, under which vehicle manufacturers will face compulsory production targets for new-energy vehicles starting in April 2018. If they fail to meet the targets, they will either need to purchase credits from other manufacturers or pay a fine (Lu, 2018). The emphasis on new-energy vehicle is therefore becoming increasingly explicit in industrial policy.

Demand-side policies also commenced in 2009 with subsidies for the purchase of electric vehicles. In 2016, these subsidies were renewed for up to US$8,736 per electric vehicle, although they are scheduled to be phased out by 2020. Other purchase incentives include exemptions from purchase tax, travel tax and import tax for selected EV original equipment manufacturers. In some of the pilot cities, EVs are also exempt from the licence plate lottery system and the restricted land access applied to conventional vehicles (Harrysson *et al.*, 2015; Du and Ouyang, 2017). Moreover, EVs enjoy waived or reduced parking fees and highway tolls in some pilot cities (Gao *et al.*, 2015). The state government has also issued a series of policies and standards for the construction of charging infrastructure (aiming to build 12,000 charging stations by 2020) and many pilot cities also employ subsidies (Du and Ouyang, 2017; Lu, 2018).

Alongside these supporting policies, clear objectives for industry development and market creation have been set out. By 2020, EV production capacity (including plug-in hybrids) will reach two million, and EV stocks will exceed five million. Moreover, the fuel efficiency standard for average fuel consumption of all passenger cars produced in 2020 is set at 5 litres/100km, down from 6.65 litres/100km in 2015 (The State Council, 2012; Ministry of Industry and Information Technology, 2016).

With this constellation of policies rolled out from 1991, the Chinese Government has pushed and pulled electric vehicles into the marketplace. China's stock of EVs grew at an average rate of 69 percent between 2013 and 2017, and the country was home to almost 40 percent of the world's EVs in 2017.

Table 7.1: China's EV (including plug-in hybrid) stock from 2009 to 2017 (in thousands)

	2009	2010	2011	2012	2013	2014	2015	2016	2017
China	0.5	2	7	17	32	105	313	649	1228
World	7	14	61	179	381	704	1239	1982	3109
China's share	7%	14%	11%	9%	8%	15%	25%	33%	39%

Source: IEA, 2018b

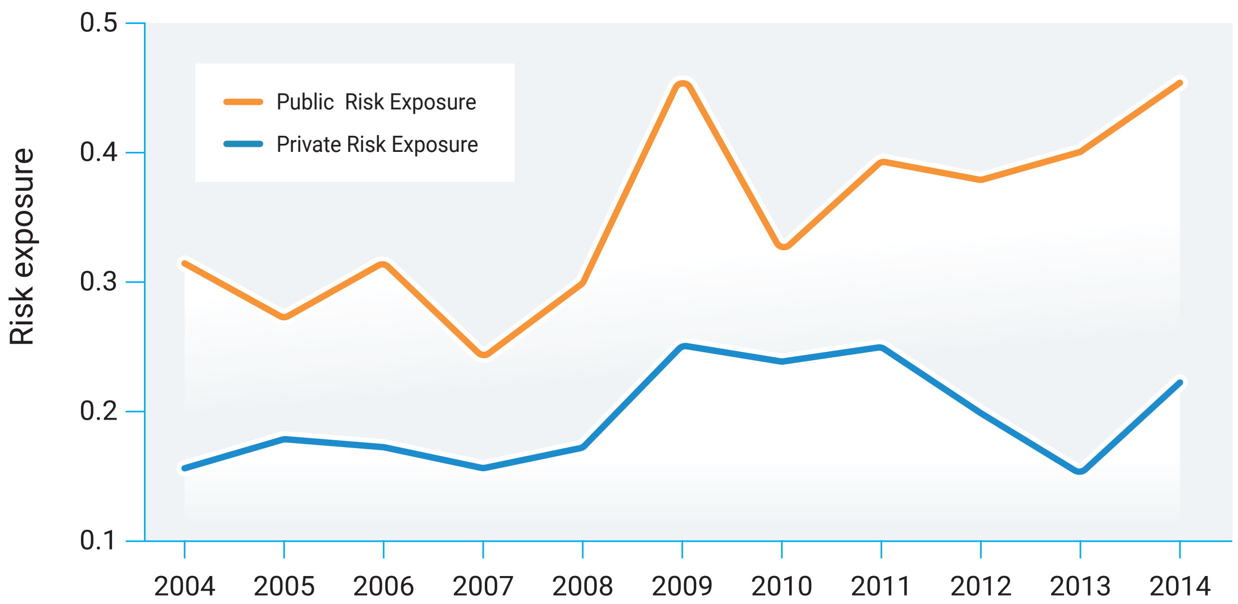
Policy coordination is as important as attention to the whole landscape. For example, procurement policies cannot work unless the demanded products have been developed and demonstrated, but the dependence runs both ways: feedback effects from deployment and diffusion stimulate new product development and enable cost reductions through learning by doing (Lundvall, 1992; Freeman, 1995; Gallagher *et al.*, 2012). This dependence also extends to consumer attitudes and their definition of the 'good life', with consumer demand for low-carbon products having the potential to drive innovation (Perez, 2017). By developing a coordinated policy that heeds these interdependencies, the public sector can not only fix market failures, but also create and shape markets for new innovative technologies (Mazzucato, 2018b).

7.2.2 Patient strategic finance

Innovation policy across the innovation chain is most effective when it involves patient finance for direct investments from public organizations placed strategically at all stages of the innovation process. Private investors often perceive new technologies as risky and are unwilling to provide capital at scale, especially given the long lead times (CPI 2013; Schmidt, 2014; Mazzucato and Semieniuk, 2017). However, innovation feeds off patient finance that is looking for long-term returns. As with any venture, such finance must also welcome risk and endure the failure of several projects (Mazzucato, 2018b). By being patient, such finance becomes strategic and supports innovation programmes until they reach their goal (Chan *et al.*, 2017). The high-risk, long-term and capital-intensive character of the demonstration and deployment stages of innovation makes public investment in this area key.

The growth of renewable energy markets illustrates the importance of public strategic finance. Financing the bulk of the US$120 trillion needed to steer the energy sector onto a low-carbon path by 2050 (IEA and IRENA, 2017) will require considerable public investments. Individual projects are often very capital-intensive; even early-stage demonstrations in energy and manufacturing sectors may require investments exceeding US$1 billion, while the pathway to profitability may take many years (Lester, 2014). Almost half of global investments in the renewable energy sector are now being financed by public agencies and state-controlled enterprises, as private financing has stagnated in absolute terms since around 2008.[1] Public money has been disproportionately directed to high-risk projects, mobilizing, or 'crowding in'[2], additional private business and leaving lower-risk technologies such as onshore wind mainly to private actors, as figure 7.1 illustrates (Mazzucato and Semieniuk, 2018).

Figure 7.1: Average relative risk exposure on a 0–1 scale of public and private investors in renewable energy assets 2004–2014 globally, excluding investments made in China.



Source: Mazzucato and Semieniuk (2018).

1 The public share of finance in directed historical energy transitions was often even higher (Semieniuk and Mazzucato, 2018).

2 Crowding in is a word play on the idea of debt-financed government spending replacing or 'crowding out' private investment. In innovative products, as this chapter shows, government finance (whether itself debt financed or not) may be necessary to mobilise private finance in the first place. (See also online appendix A.4 on state investment banks' crowding in of private investors).

One of the most important policy vehicles for strategic finance and 'crowding in' private investors are state investment banks (SIBs). Several national and subnational governments have founded green state investment banks (such as Australia's Clean Energy Finance Corporation) or mandated existing SIBs to support low-carbon technologies (such as the Brazilian Development Bank) (NRDC *et al.*, 2016; OECD, 2017). In addition, multilateral development banks (such as the World Bank) have pledged to green their portfolios (Steffen and Schmidt, 2017). Geddes *et al.* (2018) identify five functions through which these SIBs have been able to leverage private capital: the provision of capital, de-risking, awareness-raising among investors, market signalling (where an SIB's endorsement improves a technology's reputation) and by providing a crucial early-mover function. These functions are detailed in online appendix A.4.

Together, these five functions can help overcome private investors' initial aversion towards new technology and project types. The de-risking, signalling, and early-mover functions are particularly important for projects that contain non-incremental technological innovation. As SIBs take a financial position in such projects, they can also incur financial losses when a project fails. They therefore need performance criteria (such as portfolio benchmark return or leveraged private finance target) and a capital base that allows them to invest in higher risk immature technologies. Defining the risk exposure that a SIB can take is an important part of their mandate, and should be aligned with the overall ambition of innovation policy, as discussed next.

7.2.3 Directed portfolios

Innovation policy is most effective when it sets ambitious directions, rather than aiming to simply 'level the playing field'. Steering towards a low-carbon economy is one broad direction that involves additional choices as to which set of technologies should receive funding and how much. Unless the public sector sets such directions, private actors' choices will unintentionally create directions, which may be into high-carbon sectors (Wüstenhagen and Menichetti, 2012). Due to the long-lived nature of many assets created today, this carries the risk of locking the economy into a high-carbon path (Unruh, 2000). To avoid doing so, investments into low-carbon innovation must be directed boldly towards several strategically selected sectors within the low-carbon area (Mazzucato, 2017). This portfolio approach preserves multiple pathways, meaning that if one path fails, others are available and some will succeed (Schmidt *et al.*, 2016).

A number of developing countries have highly constrained national budgets that limit their ability to finance a policy portfolio that goes beyond immediate needs, such as national security, health care, education, other infrastructure, and energy access and security.

Nevertheless, several funding mechanisms have the potential to boost countries' finance for innovative projects, such as the Green Climate Fund. This United Nations Framework Convention on Climate Change (UNFCCC) entity catalyses climate finance from both public and private sources to provide investment support to developing countries. Countries retain ownership of where the fund's resources are invested, as such investments are made in the context of their national climate strategies and plans. They can also use the UNFCCC's Technology Mechanism to help develop relevant strategies and technology investment portfolios. Another example, focused more on local business development, is the World Bank's Climate Innovation Centers (infoDev, 2018). Design lessons for these and similar mechanisms are available from the Global Fund in the area of public health (Sachs and Schmidt-Traub, 2017).

7.2.4 Mission-oriented innovation

One way to structure a complex set of policies is to conceive of innovation policy as targeted towards achieving a concrete 'mission'. Mission-oriented innovation policy defines an ambitious goal and then sets specific steps and milestones to achieve it (Foray *et al.*, 2012).[3] The mission requires public innovation organizations to set out tasks that mobilize various actors (business, non-profit, public) for bottom-up experimentation across different sectors (Mazzucato, 2017).

Lessons from past mission-oriented innovation policies suggest that cross-sectoral innovation is necessary to reach goals: for example, the US Apollo Mission required not just 'rocket science' but also innovation in the textile sector for the astronaut suits, for instance. In addition, the German Energiewende [Energy Transition] policy has required all sectors in Germany to transform themselves, such as the steel sector lowering energy consumption through repurpose, reuse and recycling strategies (European Commission, 2018). Meanwhile, in the USA the SunShot Initiative in PV (see section 7.3) has mobilized 347 organizations through grants in nine subprogrammes, covering actors from manufacturing firms to municipalities seeking innovative solutions to permitting, zoning and financing (DOE, 2018). Box 7.2 describes an international mission-driven initiative for accelerating innovation in advanced materials.

This section has outlined the key elements of an innovation policy framework for accelerating low-carbon innovation. One important takeaway from this discussion is that innovation policy itself can and must be innovative: different technologies and different areas of the innovation chain require different support mechanisms (Huenteler *et al.*, 2016). Accelerating innovation may therefore require entirely new approaches to innovation policy.

3 This differs from invention-oriented innovation policy, which focuses on R&D only, or system-oriented policy that seeks to provide a good system conducive to innovation, but does not set a direction (Edler and Fagerberg, 2017).

Box 7.2 The Clean Energy Materials Innovation Challenge — Mission Innovation

Advanced materials – with ever-increasing performance requirements – are the fundamental components of new energy technologies, ranging from non-toxic, high-density batteries and advanced power electronics to low-cost organic solar cells and electric cars (Chu *et al.*, 2016). Discovering and developing such materials much faster would accelerate the transition to a clean-energy future. The Clean Energy Materials Innovation Challenge is part of the larger Mission Innovation, launched at COP 21, which aims for a coalition of countries to accelerate the energy innovation needed for a low-carbon future.

The challenge aims to bring the rate of innovation in materials discovery closer to that in computing power, the 'Moore's Law' of materials discovery. The goal is to combine three cutting-edge technologies (artificial intelligence, robotics, and computing) with materials sciences to accelerate the discovery of advanced materials by at least a factor of 10, from around 20 years to under two years and, eventually, a matter of months.

Mission Innovation launched the Materials Challenge in September 2016 with limited funding from the co-leading countries: Mexico and the United States of America, later joined by Canada.[4] Funding was used to gather leading scientists in academia and business, thought-leaders, government representatives, NGOs and civil society observers from 18 countries for a four-day Basic Research Needs (BRN) workshop to identify the fundamental research needs, challenges and opportunities, and define the path forward. The workshop developed the concept of an integrated Materials Acceleration Platform (Aspuru-Guzik *et al.*, 2018), an autonomous or self-driving laboratory with smart robots that are able to rapidly design, perform and interpret experiments in the quest for new high-performance, low-cost and clean-energy materials (Tabor *et al.*, 2018).

In May 2018, Canada and Mexico funded two international collaborative demonstration projects of US$10 million each. Additional countries are launching similar projects in collaboration with this Innovation Challenge, including India, South Korea, European Union members, and even non-Mission Innovation countries such as Singapore. As such, it is a test-bed for increased intergovernmental cooperation in mission-oriented innovation policy and effective public private partnerships.

7.3 Solar photovoltaic innovation

Innovation in solar photovoltaic (PV) technology illustrates both the nonlinear nature of innovation and how the various innovation policies reviewed above drive and shape it. PV was deployed with a compound annual growth rate of about 38 percent between 1998 and 2015 (Creutzig *et al.*, 2017), continually exceeding forecasts (see figure 7.2a). PV diffusion spurred cost reductions through 'learning by doing', scale economies and R&D, but also lowered profit margins through increasing competition (Nemet, 2006; Carvalho *et al.*, 2017), which in turn stimulated further deployment of ever-cheaper systems. However, PV innovation preceded diffusion by several decades, driving down costs dramatically. From 1975 to 2016, PV module prices fell by about 99.5 percent (figure 7.2b), and every doubling of installed capacity coincided with a 20 percent drop in costs (Kavlak *et al.*, 2017). Public innovation policies were — and continue to be — crucial for this process throughout the innovation chain.

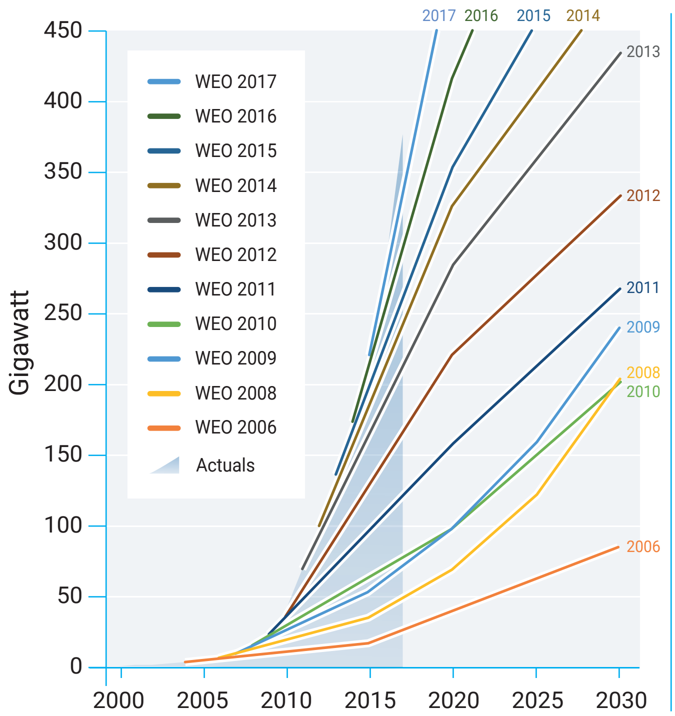
Governments often act as lead risk-takers. For example, the Sunshine Project launched by the Japanese Ministry of International Trade and Industry in 1974 (IEA, 2016) made Japan an early leader in PV manufacturing and deployment (Trancik *et al.*, 2015). As for the US, the first silicon PV cell was demonstrated by researchers at Bell Telephone Labs in 1954, which benefited from large contracts with US government agencies (Chapin *et al.*, 1954). Subsequently, the US government agencies NASA and the Advanced Research Projects Agency developed PV for satellite use (Perlin, 2002). As a result of the 1973 oil crisis, new policies were enacted and research on PV expanded in the laboratories of the newly founded US Department of Energy (DoE) (Ruegg and Thomas, 2011).

Government-funded innovation continues to this day. In a mission-oriented policy approach, the DoE launched the SunShot Initiative in 2011 with the concrete goal of reducing the cost of US solar energy systems – including the costs of installation, permitting and financing – by 75 percent to a levelized cost of US$0.06/kWh by 2020. As SunShot supported innovation that met this goal in 2017 (three years earlier than expected), the target has been revised to US$0.03/kWh by 2030 (Chu *et al.*, 2016).

In 1990, the German parliament enacted the first PV feed-in tariff, which guaranteed the sale of all PV-generated electricity substantially above market price. The feed-in tariff subsequently became a major law, setting a direction for innovation in Germany and effectively creating a PV market. In fact, the feed-in tariff is credited with drawing many producers into the market, thereby pushing Germany to become a global leader in solar installations (Trancik *et al.*, 2015). This built on long-standing collaborations between German PV companies and a network of public research institutes (Jacobssen and Lauber, 2006), while the German SIB,

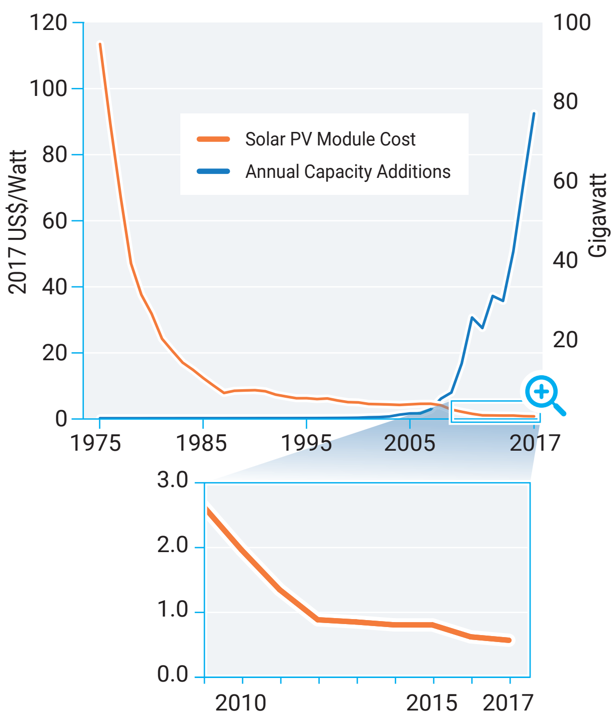
4 Eighteen of the 24 Mission Innovation members participate in this initiative. The Materials Innovation Challenge international workshop and activities have been funded by Mexico's Energy Innovation Funds, managed by the Ministry of Energy of Mexico (SENER), the US Department of Energy (DOE), Natural Resources Canada (NRCAN), and the Canadian Institute for Advanced Research (CIFAR).

Figure 7.2a: Cumulative solar PV installations compared to forecasts from various IEA World Energy Outlooks (WEO).



Source: Updated from ClimateWorks *et al.* (2015).

Figure 7.2b: Historical price reductions and annual installations, 1975–2017.



Sources: Earth Policy Institute (2018) and Barbose *et al.* (2018, Fig. 13) for prices, Earth Policy Institute and IRENA (2018) for capacity.

KfW, boosted German renewable energy deployment by providing strategic finance in the form of concessional loans in 2009. In that year, Germany almost doubled its cumulative PV capacity to 10 GW and 41 percent of all projects benefited from KfW loans (Bickel and Kelm, 2010). The next three years saw unprecedented growth in German PV capacity, which slowed only when the feed-in tariff was reduced in 2012.

The baton of PV leadership then passed to China, whose companies have been manufacturing more than half of global PV cells every year since 2011 (Zhang and Gallagher, 2016). In the 2000s, Chinese manufacturers benefited from the generous demand-pull policies in richer countries (especially in Germany, Italy, Spain and the US), while transferring technology and vertically integrating production processes in China and benefiting from financial support from local governments (Zhang and Gallagher, 2016). In 2011, a feed-in tariff created a major market for PV also within China itself, while the Chinese SIB, China Development Bank, disbursed generous credit lines to Chinese manufacturers (Quitzow, 2015).

Against the backdrop of this comprehensive network of policies across the innovation landscape, solar PV is now nearing cost-competitiveness with electricity from fossil fuels and is being deployed around the world. The story of PV innovation is an international one: from the USA and Japan to Germany and then China and increasingly other countries. Yet, what is a success today looked less certain and faced many obstacles in the early stages, revealing the importance of public policies for PV innovation and market creation along the lines examined in the previous section. The next section discusses some common barriers to implementing innovation policy.

7.4 Barriers to implementing innovation policy

7.4.1 Organizational aims and mandates

The above-mentioned innovation policies recognize the institutions that plan and carry out the various polices as being key to their success. Unlike most public organizations and their fear of failure, the US energy innovation agency (ARPA-E) measures its success by how many risks it is willing to take and the impact of its successes (Mazzucato and Penna, 2015a). Nevertheless, most public organisations are risk averse, so it is important to learn from the US energy innovation agency's (ARPA-E) approach in terms of paying attention to the internal capabilities of public institutions: their willingness to set bold missions and nurture organizational capacity and experimentation, and their ability to evaluate themselves in dynamic ways, rather than by static cost-benefit analysis (Kattel and

Mazzucato, 2018). Staying abreast of how innovation is changing markets also requires these institutions to deliberately engage with a wider set of actors and to track and quickly learn from wider innovation progress (Shakya and Byrnes, 2017). Emboldening agencies and institutions is easier when they are kept apart from political decision makers and thus independent of the short-term political process (Haley, 2016).

Setting strong policy mandates also helps strengthen an institution's capabilities. For instance, for SIBs to effectively address the low-carbon finance gap, their mandate needs to define their sectoral and geographical focus areas, specify the instruments to be used, define 'green' safeguards for project selection, and determine the SIB's own financing. Given the high importance of in-house technological capabilities and the resources needed to build them, the sectoral focus areas must be aligned with the government's mission-oriented low-carbon policy (Mazzucato and Penna, 2016). It is also important that the instruments that a SIB provides are appropriate for their target sectors and project types. For instance, projects with very long loan tenors require long-running loan guarantees. Importantly, these instruments should also be designed in a way that reflects the financial sector's existing structures. One example is household rooftop solar projects in Germany: the KfW channelled loans through Germany's local banks, utilizing Germany's decentralized financial sector (Hall *et al.*, 2016). Depending on the sectors and the scale, governments must also decide whether SIBs can refinance themselves in capital markets, as KfW has done (Mazzucato and Penna, 2015b) and, if so, whether they can utilize a state guarantee.

7.4.2 Funding

Many countries have significant barriers to financing innovative technologies because, on top of the technology being unproven, the countries themselves are considered high-risk places to invest, with high political risk, policy uncertainty and currency fluctuation (Schmidt 2014; BNEF *et al.*, 2016), now exacerbated by an increased exposure of these countries to climate change risks (Buhr *et al.*, 2018). This situation makes both international and domestic investors averse to exposing themselves to additional risk by investing in new technologies and business models without a solid track record (Mehta *et al.*, 2017; Kidney *et al.*, 2017). Most of the poorest countries are also small markets with a large proportion of low-income consumers who lack credit history, which limits potential investors' interest in engaging with the government to improve investment conditions (GOGLA *et al.*, 2017). In addition to these challenges, matching the right type and scale of finance to the opportunities in innovative small-scale distributed technologies has significant transaction costs, as well as the risk of the business models around these technologies having a limited track record (Hystra, 2013; Lewis *et al.*, 2017).

To stimulate innovation in low-carbon sectors, such as distributed energy, several developing countries have set up platforms that aggregate finance for small-scale renewable energy projects, thereby reducing transaction costs to public and private investors and managing risk (Shakya and Byrnes, 2017). Various types of aggregation platforms have successfully reduced the cost of capital to the energy enterprises by bundling the enterprises' small ticket deals or their assets into portfolios that diversify risk across several projects, and standardizing project data to build investors' confidence. This bundling has also allowed the platforms to meet the deal size preferred by larger-scale investors offering cheaper finance (Wilson *et al.*, 2014). In addition, the platforms create a space for dialogue among public policymakers, entrepreneurs and private investors to resolve market challenges (Bertha Centre and WWF, 2016; Simanis, 2012). Once again, it is important to recognize that as not all sources of finance are the same, those with an appetite for risk should be sought out (Mazzucato and Semieniuk, 2018). Financing constraints are also prevalent in developed countries, especially at the municipal level, and the online appendix A.3 explores innovative financing mechanisms to overcome these constraints for low-carbon lighting.

Large amounts of funding are by themselves insufficient, as funding needs to be stable over time. Cyclical spending is problematic on both the supply and demand sides. On the supply side, fluctuations in spending due to political decisions (or the expectation that spending will not be stable) can hinder investments in long-term projects (Chan *et al.*, 2017), whereas on the demand side, the business cycle is an important consideration. While the financial crisis of 2008 led to various 'green stimuli', this increased spending was often soon replaced by austerity measures. Perhaps the most dramatic casualty of tightened fiscal belts was the Spanish support for renewable energy. Until 2008, Spain's feed-in tariff supported one of the fastest expansions of not-yet-commercialized renewable energy. However, the feed-in tariff was paid by the central government and added to its fiscal deficit, so when Spain was hard-pressed to tighten the budget, it was reduced retroactively. Spanish renewable energy investment dropped after 2008 and collapsed completely after 2012 (Mir-Artigues *et al.*, 2018), contributing to a crisis in Spanish PV manufacturing companies (Ibarloza *et al.*, 2018). Ringfencing support policies across the business cycle is therefore crucial for long-lead-time innovation processes.

7.4.3 International competition

Countries' domestic policies are also affected by the industrial policy aspect of innovations. Developed countries fear that their expensive R&D efforts will be appropriated by other, poorer countries that take a large market share due to lower production costs. The most prominent case is perhaps the migration of the PV manufacturing industry to China, reviewed above. 'Free-riding' on others' efforts, whether perceived or real, is prevalent in the literature analysing how countries contribute to global climate change mitigation efforts (Barrett, 2007). The flipside of this fear is the concern of developing countries — which are almost completely excluded from the current corporate R&D activities (Nolan, 2018) — that they will remain excluded from a new, green technological revolution. They see themselves at risk of having to buy the new technology from developed countries, without benefiting economically from the transition to a low-carbon economy, and at risk of 'premature deindustrialization' (Rodrik, 2016). Overcoming these differences touches on some of the most controversial aspects of the global political economy, but may be critical for effective innovation policies around the world.

7.5 Conclusion: opportunities and challenges

Creating markets and shaping innovation policy is crucial to bringing about the technologies needed to close the emissions gap. Public sector institutions can take the lead thanks to their unique ability to take risk and be patient and strategic from a societal rather than strictly financial point of view. Equal attention must be given to the supply and demand sides, with feedback loops key to allowing diffusion patterns to feed into innovation patterns. Common success factors include specialist organizations coordinating activities across the innovation chain, patient and strategic finance that leverages other actors, and setting directions while sustaining a portfolio of innovation processes in that direction. A mission-oriented approach to policy can open the innovation process up to a large number of participants.

International collaboration has the potential to unlock additional innovation capacity through leveraging greater pools of money and talent and providing an avenue for international best-practice-sharing. Mission Innovation and its sister organization, the Clean Energy Ministerial, which exists to accelerate technology diffusion, have the potential to play such a role. Other international initiatives have also set ambitious targets, such as the pledge by tropical nations under the International Solar Alliance to help each other mobilize US$1 trillion for solar energy deployment. They can be even more effective when they join with powerful private international initiatives, such as the Breakthrough Energy Coalition, which is committed to funding clean-energy innovation.

Challenges remain, however. Sustaining portfolios of technologies is expensive and identifying which investments to prioritize is challenging, as the innovation landscape alters so quickly during this unprecedented and rapid transition. Innovation organizations must also constantly innovate themselves in order to match realities with policies, while competing for talent with private sector employers. Developing countries face an uphill battle in competing with better-funded competitors from developed countries; furthermore, finding niches that are both emissions-mitigating and revenue-generating is as uncertain as innovation itself. The new international initiatives have great potential but they also face problems inherent in international cooperation. Governments are inclined to cooperate but less willing to send funds across borders, and the same is true of private actors sharing data and insights when they participate in these initiatives (Cherry *et al.*, 2018). Even if innovation is successfully accelerated, the world must still grapple with unintended consequences like the rebound effect where, in the case of energy-saving innovations, part of energy saved per unit of the innovative product is brought back through an increased consumption of the now more efficient, and hence cheaper product or consumption of other energy-intensive products with the money saved on the innovative product (Sorrell 2008; Gillingham *et al.*, 2016).

Public institutions carry a large responsibility for innovation, but in an era of tight budgets, committing the necessary finance is difficult. Organizations leveraging private initiatives need to continue learning and improving. Meanwhile, other issues such as financial market regulation favouring low-carbon portfolios would be a useful complement (Campiglio *et al.*, 2018). Ultimately, however, the policies rely on confident and stable enough public institutions with good governance that can survive short-term economic and funding fluctuations. If they are willing to learn from mistakes while staying confident of their key contribution, they could help dramatically lower GHG emissions over and above current policies.