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Financing Green Growth

By Gregor Semieniuk[1] and Mariana Mazzucato[2]

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Abstract

This paper surveys the current state of financing green growth in the energy sector, based on the insight that there are different qualities of finance. In past transformational changes in other sectors, public monies played a key role across the innovation landscape. Public financing was central also in a number of past national energy transitions, as reviewed here for Iceland (from fossil to geothermal energy), Norway (from mainly non-electricity energy to hydroelectricity), France (from oil to nuclear) and the United States (from conventional to shale gas). In the current transition to low-carbon energy supplies, there is much public activity, most directed and concerted in China, but also reasons to doubt it is enough and applied in the right places to be able to finance the transition to a low carbon sector on time scales consistent with current climate change mitigation targets. A discussion of opportunities and challenges to a more central role for public financing concludes, drawing also on insights from the recent mission-oriented innovation literature.

Keywords: low-carbon investments, quality of finance, public sector finance, mission-oriented organisations, energy transitions

JEL codes: G20, H54, L32, N70, O33

1) Introduction

Transitioning to a green economy requires both public and private investments. Given the long-lead times and high uncertainty in innovation, such investments must involve patience and welcome risk. The challenge is significant: requiring transformational "public and private investments that reduce carbon emissions and pollution, enhance energy and resource efficiency, and prevent the loss of biodiversity and ecosystem services" (UNEP 2011, p. 2). How to finance these high-risk and long-term investments in

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green real assets is the problem of *financing green growth*.[3] The quantity of finance is as important as the quality. Currently, the rate of green investments is too low for green growth to take off (OECD 2015a; IEA & IRENA 2017), and often too impatient (HLEG 2018). To avoid dangerous global warming, investments in low-carbon technology must increase quickly: time is of the essence (Stern 2015, Sgouridis et al. 2016).

Although the low-carbon transition is not just about low-carbon energy but also about reducing energy intensity across the economy, we use the case of decarbonising the energy sector to illustrate the magnitude of the challenge.[4] Table 1 compares recent global investment trends in low-carbon energy sources with projected ones in the next two decades, which are necessary to achieve cumulative carbon emissions consistent with a 2° Celsius average global warming. While definitions of the clean energy sector and projected investments differ between the three projections, they all emphasise the need for investments to double or even triple over the next 15 to 25 years (rows 1 and 2). This implies compound annual growth rates that are several percentage points higher than recent historical rates (rows 3 and 4). Clearly, current trends in investment are insufficient, and the question is where the funds required for financing the groundswell in investment would come from.

Explaining the lack of finance typically invokes a twin market failure (Jaffe et al. 2005). On the one hand, part of the cost of polluting 'brown' activities has not been properly internalized; on the other hand, the innovation required to develop alternative 'green' technologies and products is underfinanced because private investors cannot internalize the returns from their investments. Therefore, discussions about the acceleration of green finance usually revolve around these market failures.

Table 1: Various projections of global medium-term green finance needs consistent with 2 degree Celsius global warming.

	Scenario	REmap Options (IRENA 2016)	450 Scenario (IEA 2014)	2-degree warming (BNEF 2016)
1	Historical average annual investments (USD bn)*	360 (2011–2015)	263 (2008–2013)	267 (2011–2016)
2	Projected average annual investments (USD bn)*	770 (2016–2030) [113% above historical]	479 (2014–2035) [198% above historical]	524 (2017–2040) [94% above historical]
3	Historical CAGR**	3%	2.7%	-3.0%
4	Projected CAGR***	8.9%	7.7%	5.1%

* Numbers differ because of different time periods, forecasting assumptions and different sets of investments included in the historical averages; e.g., BNEF does not include nuclear energy, while IEA does.

** CAGR = compound annual growth rate. *** Assuming equal annual increments following IRENA (2016).

[3] This definition is wider than the term 'green finance', which is sometimes used to describe the measures in the financial system (by central banks) such as favourable bank reserve requirements for 'green' lending to incentivise investments in change-mitigating activities, see, e.g., Campiglio (2016), Volz (2017), Dikau and Volz (2019).
[4] This is also the sector with the highest greenhouse gas emissions reduction potential (UNEP 2017, p. 27).

In a wide variety of outlets, the standard solution to the question of increasing green finance is to acknowledge that while it is difficult to price pollution effectively,[5] governments can, in principle, provide the funds to correct for the second market failure. This would make green activities competitive even with existing external pollution costs, meaning that investment would be forthcoming through the market mechanism. However, the story goes that the state is incapable of doing this in practice because of (1) the magnitude of the financing challenge and (2) the decreased leverage of actual governments around the world in the current political-economic landscape. Therefore, it is assumed that the private sector should step in and fill the gap (Mitchell et al. 2011; OECD 2015a; Stern 2015), notably 'institutional investors' that are sitting on enormous amounts of funds (Kaminker & Stewart 2012; OECD 2015b; G20 Green Finance Study Group 2016). The rationale is that if appropriate *incentives* could be designed to improve the risk-return profile of renewable energy investments, the floodgates of finance would open. This chapter focuses on the finance needed to shift investments from fossil fuels to low-carbon sources by examining the validity of the above assumption that it does not matter which type of finance is doing the investing; in other words, that it is merely a problem of quantity, and not quality, of finance.

We argue that the quality of finance *does* matter, and that recognising this is key for achieving the rapid decarbonisation of the energy sector. Innovation, in energy as in other sectors, requires patient, long-term, committed finance, which many private investors lack. We highlight the central role of public sources of finance in setting up new markets through their early, risk-taking and patient *direct investments* rather than only through indirect public incentives supporting private investments.[6] We also note that such direct investments have, in the past, been framed in terms of solving problems – or 'missions' – that required direct action co-creating markets, rather than just facilitation or market fixing (Mazzucato, 2016) and mission-oriented agencies with the capacity and capabilities to welcome risk taking and long lead times (Mazzucato, 2018).

We draw on historical evidence from previous structural transformations in other sectors (section 2), as well as successful previous energy sector transitions (section 3), to show how publicly financed innovation was pivotal for co-creating and shaping markets and infrastructure for new technologies, not only through incentives but also through direct investments across the innovation chain. In section 4, we use the insights about historical innovation to analyse the state of finance in the current energy transition, and also take a closer look at China, the most important actor in this transition. In section 5, we conclude by discussing what must be done to ensure that the correct quantity and quality of finance is directed towards green energy, as well as the possible consequences of the privatisation of the energy sector and the increasingly weak public sector institutions. The usual argument is that insufficient private and public finance creates the need to 'fill the finance gap'. However, we argue that policy must also focus on ensuring strong public sector 'mission-oriented' institutions and direct investments if the greening of the energy sector is to be achieved on time scales that are consistent with the aim of mitigating climate change. We do not discuss the limits to growth, and financing of green growth in this

[5] However, see REN21 (2017 Fig 3) for several regional and (sub-)national emission trading systems and carbon taxes.

[6] For reviews focusing primarily on private finance, please see Wüstenhagen and Menichetti (2012), Donovan (2015), Markus et al. (2015), and the annual publications by UNEP & BNEF (2017), Climate Policy Initiative (Climate Policy Initiative 2016), and from 2016 onwards the IEA (2016a). Some publications discuss specific types of private finance: venture capital (Bürer & Wüstenhagen 2009; Ghosh & Nanda 2010; Gaddy et al. 2016), and institutional investors (OECD 2015; Polzin et al. 2015).

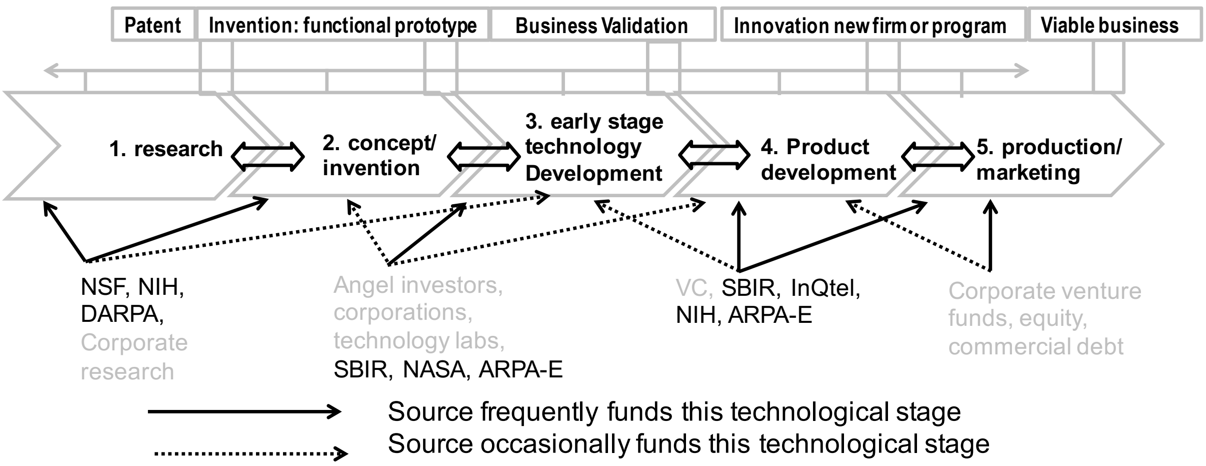
context,[7] focusing instead on the fact that the financing of clean energy is a necessary condition for any green growth trajectory.

2. The central role of government in financing innovation

In *The Entrepreneurial State: debunking public vs. private sector myths*, Mazzucato (2018 [2013]) discussed how active and strategic direct public investments across the entire innovation chain helped create revolutions in IT, biotech and nanotech.[8] The history of policy being used to tilt the playing field rather than level it holds strong lessons for the future of low-carbon energy (Mazzucato and Perez, 2015). These previous transformations included publicly funded R&D (a classic 'public good', hence subject to 'market failure'), which the private sector was unwilling to fund, particularly during the early stages when risk was too high. However, public support not only fixed the public good problem, it also continued to operate downstream on applied research and in supplying the patient long-term finance to innovative companies. Furthermore, demand-side policies – both via procurement and other means – allowed the new technologies to be deployed throughout the economy. Figure 1 indicates some of the key public agencies that have operated across the innovation chain even in the US, which is popularly associated with a free-market approach to financing growth and technological change. These operations include upstream investments by the National Science Foundation, and downstream investments by National Aerospace Agency (NASA), Defence Advanced Research Project Agency (DARPA) and the National Institutes of Health (NIH). Downstream investments include using procurement policy to help create markets for new companies, through the Small Business Innovation Research (SBIR) scheme, which has historically provided more early-stage high-risk finance to small and medium-sized companies than private venture capital (Keller & Block 2013).

Figure 1. Public organisations involved in financing along the US innovation chain.

Source: Mazzucato (2018) addition to Auerswald & Branscomb (2003).

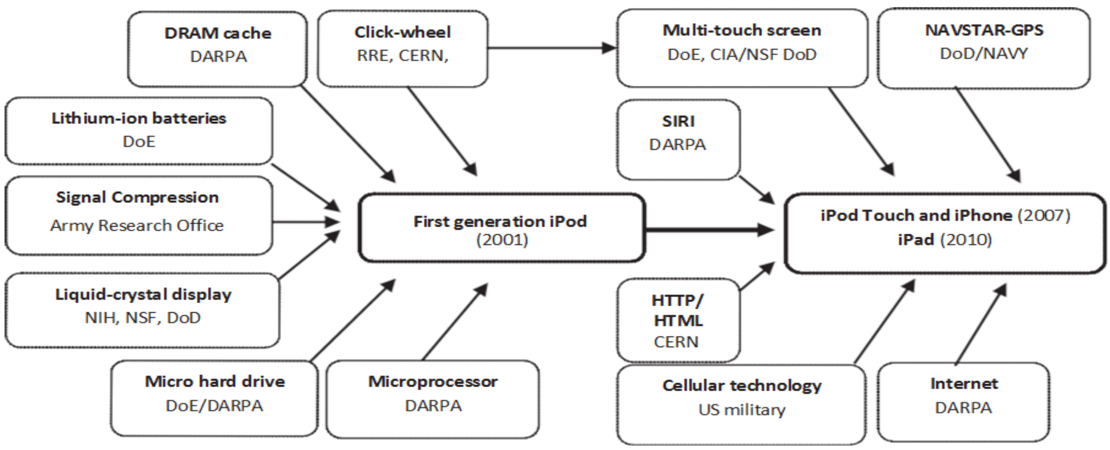


[7] For a cautiously optimistic stance on dematerialized growth, see Bowen and Hepburn (2013) and the careful assessment of various views by the same authors a year later (Bowen and Hepburn 2014). For a sceptical position, see Jackson (2017) and empirical evidence specifically for energy, Semieniuk, Foley and Taylor (2018). Foley (2013) analysed the possibility of dematerialisation from a value theoretical perspective.

[8] Parts of this section and of section 4.1 below draw and expand on Mazzucato et al. (2015).

Crucial to this public funding was the nature and capacity of the organizations themselves: a decentralised network of strategic *mission-oriented agencies* that were actively creating and shaping markets, rather than just 'fixing them' (Mazzucato 2016). Such agencies included the NIH, which has spent billions of dollars on health R&D, stimulating what later became the biotechnology revolution. Between 1936 and 2016, the NIH spent USD 900 billion (in 2015 dollars) on R&D, including USD 32 billion in 2016 alone (Mazzucato and Semieniuk 2017, p. 31). For IT, agencies like DARPA and NASA have been central to the radical innovation that later became key to many 'smart' products. Figure 2 shows how almost every technology that 'smartens' a phone (including the internet, GPS, touch screen display, and SIRI) was publicly financed.

Figure 2. The publicly funded technology behind 'smart' phones. Source: Mazzucato (2018).



DARPA's success was due to its ability to welcome risk, encourage trial and error and wait patiently for returns on its investment, and its ability to attract top-level scientists into the public sector through temporary five-year contracts. Organisations like DARPA in the Department of Defense (DoD) and its sister agency ARPA-E in the Department of Energy are 'mission-driven'; that is, set to actively create new technological landscapes and achieve concrete targets, rather than just fix existing ones (Foray et al. 2012). The organisations had to make decisions about what to fund: tilting the playing field rather than 'levelling it' (Mazzucato & Perez 2015). A key lesson here is that, in activities ranging from putting a man on the moon in the past to fighting climate change today, it is useful for societies to engage innovation policy with missions and create dynamic links between public and private institutions that can together create bottom-up experimentation that tackles the many homework problems embodied in each mission (Mazzucato 2016). Such policies work across sectors, unlike traditional industrial policies that create lists of sectors to support.

3. Publicly funded energy innovation

Evidence of the important role of direct public financing for innovation also exists in the energy sector. Energy transitions – that is, shifts from an economic system dependent on one energy source to another (Fouquet & Pearson 2012), defined as the growth of a particular source in the energy mix from 1 per cent to a 50 per cent or from 10 per cent to a 90 per cent share (Grubler et al. 2016) – have taken place since at least the 17th century, when coal replaced wood as the predominant energy source in Great Britain (Fouquet 2008). These energy transitions require major changes in infrastructure and associated ‘enabling technologies’ and have historically taken many decades to play out (Smil 2010; Grubler 2012). However, the current, planned energy transition is distinguished by its urgency: green growth must happen very soon and is preconditioned on a rapid change in the energy mix (Sovacool 2016). While there is no exactly similar historical case of a rapid *global* energy transition that could serve as a blueprint, a brief look at the sources of finance in four recent rapid changes in national energy mixes in the 20th century reveals the important role of public finance in all of them. Although not all of these examples amount to transitions in the above sense, the histories are instructive for the quality of finance that enable the rapid shifts, as well as the long time it takes until a new energy source acquires a dominant position in the mix.

3.1. Iceland: Coal and Oil to Geothermal

In the second half of the 20th century, Iceland transformed its economy from being reliant on coal and later gas to mainly using geothermal energy. While geothermal accounted for a negligible share of energy before 1930, it is now responsible for two-thirds of Iceland’s primary energy supply, with another 20 per cent coming from hydro power, making the transition from less than 5 per cent in the mid-1930s to above 50 per cent in 1980 (Orkustofnun 2017). Although the use of geothermal energy for driving steam engines was discussed as early as the mid-19th century, drilling to systematically tap the heat only began in 1928 (Gudmundsson 1983, p. 492). This was followed by a remarkable increase in geothermal energy for heating and, by the mid-1980s, some 80 per cent of Iceland’s buildings were heated by geothermal energy (Gudmundsson & Pálmason 1987). Conversely, this transition crowded out coal to a single-digit percentage of primary energy use by 1955, and a drop in oil from a peak share of 59 per cent in 1959 to less than 20 per cent since 2007 (calculations based on Orkustofnun 2017).

Up until the mid-1980s, all of Iceland’s geothermal energy was publicly financed, costing USD 1.2 billion (in 1992 dollars) between 1973 and 1992 (Fridleifsson and Freeston 1994, p. 202).[9] All geothermal field developments were financed and carried out by the Geothermal Division of Iceland’s National Energy Authority, known as Orkustofnun. Where necessary, R&D was carried out in collaboration with the University of Iceland (Orkustofnun 2010). Meanwhile, the State Drilling Company, established in 1945, was responsible for drilling the holes to tap the heat, and municipalities financed, owned and operated the district heating systems. Geothermal electricity technology was developed in the 1960s by the State Electricity Authority with a first set of plants built in 1969–72 (Gudmundsson 1983, p.493). Private actors only entered this picture in 1986, when the State Drilling Company issued shares. This company became effectively privately controlled in 1992, as the government shed its remaining shares (Jardboranir 2017). By that time, part of R&D was also outsourced to private companies (Orkustofnun 2010). Nevertheless, utilities remain in municipal ownership today, and the government continues playing a central role in financing both research and investment in power plants (Orkustofnun 2010).

[9] This made Iceland the fourth-largest financier of geothermal energy in this period after the US (USD 7.5 billion), Japan (5.3 billion) and Italy (2.4 billion) and by far the largest on a per capita basis (Fridleifsson and Freeston 1994, p. 202).

3.2 France: Oil to Nuclear

In 1973, France's primary energy supply was almost 70 per cent supplied by petroleum, most of which was imported from the Middle East. Consequently, France suffered greatly from the OPEC oil embargo in that year (Solomon & Krishna 2011). The French government's response was to switch to nuclear power. While nuclear provided only 2 per cent of France's primary energy supply in 1973, this figure grew to 37 per cent in 1996, the first year it caught up with the share supplied by petroleum. Since 2002, nuclear has regularly provided the largest share in France's primary energy, with around 40 per cent in the energy mix (BP 2016), making the French shift to nuclear within little more than three decades one of the most rapid ones, particularly given the country's size (Grubler 2012).

The underlying deployment of 54 nuclear power plants until 1994 was financed by the state-owned utility Electricité de France (EDF), which had been founded as part of the nationalisation of the French electricity sector in 1946 (Milward 2005, p. 177). R&D activities were financed and carried out by the French nuclear power agency, CEA, and in 1981 France announced it had developed its own nuclear reactor building technology and would export it in competition with the US (Lewis 1981).[10] As the switch to nuclear was a backed and financed by the state, the sustained and determined investments flowing to nuclear power were not deterred either by high risk or business cycle fluctuations, allowing for a very rapid scale up of low-carbon energy supply. This centrally planned transition was highly problematic: the embrace of nuclear power was hotly contested in society (Solomon and Krishna 2011) and beset throughout by problems of high cost (Grubler 2010). Yet, from the point of view of financing a rapid, directed energy transition, this most ambitious example was government-steered and -financed from beginning to end.

3.3 Norway: Hydro from the beginning

Hydro represents 99 per cent of Norway's electricity generation – making it the world leader in this regard – and the country has a state-driven history too. Rather than the result of a transition from one energy source to another, electricity in Norway was, from the beginning, supplied mainly by hydro. After initial dams were erected by private investors, the Norwegian state passed legislation permitting the expropriation of dam sites (1887), and of land for electricity transmission lines (1894), in order to secure rational utilisation of hydropower for urban industry (Thue 1995, p. 16). According to the Norwegian State Power Board (now called Statkraft) history, the Norwegian state became directly involved in generating hydropower in 1895, when it acquired a waterfall to power a railway (Statkraft 2017). At that time, several hydro power plants had also been set up by private foreign companies (Hausman et al. 2011), but most were overseen by municipalities (Milward 2005, p. 84). The central government soon reined in further private development by prohibiting private ownership of large waterfalls in 1909 (Milward 2005), and favouring local government hydro development (Thue 1995, p. 22). In 1920, the Norwegian state placed hydro developments under the oversight of Statkraft, which also became a larger financier itself and today remains the country's premier utility (Milward 2005, p. 121). These

[10] The only company to produce pressurised water reactors in France was Framatome (now part of the state-owned Areva), which licenced technology from the US company Westinghouse, itself built on US federally funded research at the Oak Ridge National Laboratory. The CEA bought 30 per cent of Framatome in 1975 (de Carmoy 1979).

developments led Norway's per capita consumption of electricity to be far higher than anywhere else in Europe by the start of World War II.

Yet, the fastest rate of large scale investments by the government into hydro across the country occurred after 1945. In 1965, hydropower provided two-thirds of Norway's primary energy supply, and this has remained the case until today (BP 2016). Although Norway liberalised its electricity market by 1990, most of the competing companies – notably Statkraft which was incorporated but remained fully state-owned – remained in public ownership (Magnus and Midttun (2000); see also Lie (2016) for the pragmatic Norwegian approach to state ownership). Today, around 90 per cent of hydro electricity generating capacity is publicly owned, with the remaining 10 per cent in private hands (Norwegian Ministry of Petroleum and Energy 2015, p. 21), reflecting the history of mainly public financing and ownership of Norwegian hydro energy.

3.4 US: Conventional Gas to Shale Gas

Section 2 has already demonstrated that although the US is touted as a model private market economy, it supports its private-actor-dominated industries heavily with public-sector-financed innovation. A striking recent case in the energy sector is the Department of Energy's (DoE) role in the research, development and demonstration of shale gas technology, which led to a rapid shift in national energy production in the most recent past. While only 1.6 per cent of US gas production in 2000 came from shale gas, by 2015 this had risen to 50 per cent (EIA 2016, Table 14), meeting about 15 per cent of US primary energy supply (BP 2016). The rapid deployment of hydraulic fracturing technologies enabling this spread was originally motivated by tapping unconventional fuels in the wake of the 1973 oil crisis, and it started with research carried out at national laboratories funded by the Energy Research and Development Administration in 1976, since 1978 under the helm of the DoE. This research, to the tune of USD 157 million (in 1999 USD) between 1975 and 1992 (National Research Council 2001, p. 201), was influential in developing at least two out of four key shale gas technologies (Wang and Krupnick 2013) and helped upscale the industry. In addition, DoE funded development and demonstration projects as well as the federal Gas Research Institute's finance and technology know-how played a role in subsequent private development of unconventional gas sites, particularly by the early industry leader Mitchell Energy (Wang and Krupnick 2013, p. 25), which also had considerable own means for R&D financing thanks to favourable long-term gas contracts (Wang and Krupnick 2013, p.17). At the time of writing, DOE R&D financing for shale gas is continuing (Melchert 2017).

These four examples, from different countries, of different energy production technologies show the crucial role that government financing, both of the 'upstream' research and development as well as the direct financing of the 'downstream' demonstration and deployment as opposed to merely regulating through tax breaks or guarantees, has played in recent successful energy transitions. Typically, the financing and know-how came from a combination of different public organisations that had considerable resources or sway over decisions up to outright complete ownership of the electricity sector, and coordinated their activities. While the counterfactual of development without state involvement is hard to establish, the presence of large government efforts in these massive structural changes in the economy suggests that the quality of public finance, risk-taking and patience is an important component of any energy transition. Moreover, the governments were also – for better or worse – able to push through with these transitions in spite of harsh political contestation in all cases but Iceland. These transitions occurred rapidly compared to other transitions (Grubler et al. 2016).

However, these ‘success stories’ also tell the cautionary tale that even with directed government efforts, transitions took several decades to occur. Furthermore, before significant capacity was installed, R&D efforts had been sustained for decades (particularly evident with French nuclear power and US shale gas).

4. Financing the current energy transition

The financing of the current energy transition is unique, both because of its scale and the attempt to achieve it at a pre-specified, ambitious pace. However, it is useful to contrast trends in R&D and deployment with historical cases to see the extent to which current successful efforts coincide with intensive public financing.

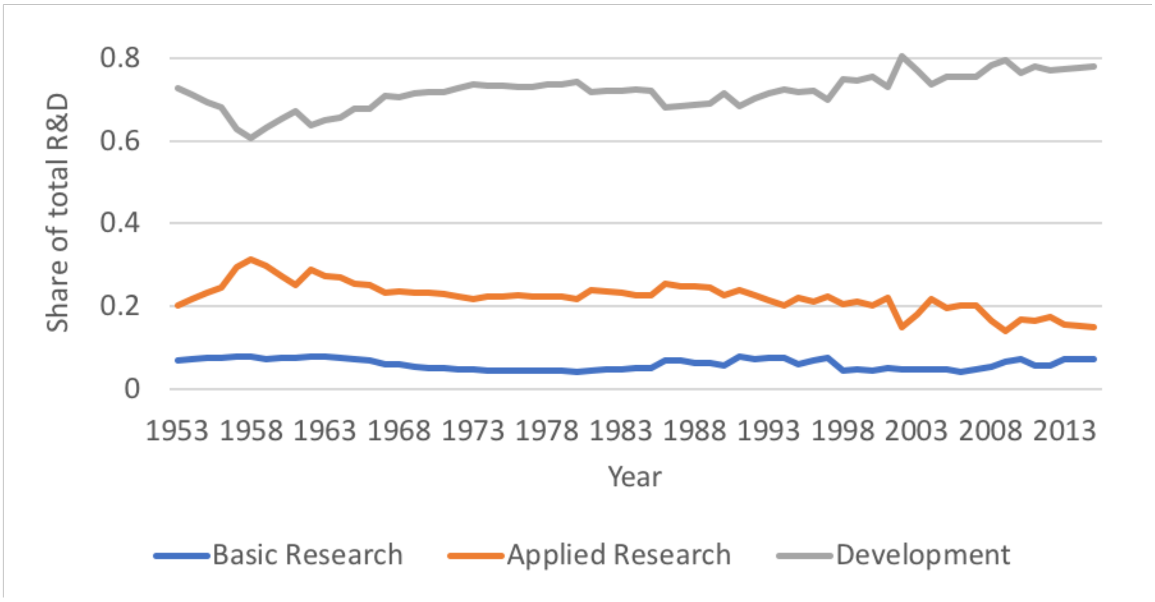
4.1 Research and Development

The historical cases show that the rapid deployment typically took a long run up in terms of research and development. In the current energy transition, we are considering technologies, many of which were pioneered decades ago, such as photovoltaics by the state-controlled US-American Bell Labs in the 1940s (Sørensen 1991); or wind, where early designs were built by individuals in the 1920s (Garud & Karnøe 2003), while important government-funded research and development occurred after the 1973 oil crisis (Loiter & Norberg-Bohm 1999). Yet, current trends in R&D finance do not give grounds for optimism that the shift to a green energy sector is accelerating.

First, there is the issue of scale. The 2015 Paris Conference of the Parties saw promises by 12 major governments to double renewable energy R&D spending until 2020 and by private investors to top this figure up with USD 20 billion. Despite these pledges, current public R&D financing for the energy transition is low. In real terms, public R&D levels for renewables in 2007 were merely twice what they were in 1985 in Europe, while nuclear R&D fell by over 60 per cent over this time and still received more funding than all renewables combined in 2009 (Wiesenthal et al. 2012). In the wake of the recent Great Recession the data show a spike, but renewable energy R&D finance has subsequently fallen again in International Energy Agency (IEA) member countries (IEA 2016b). Moreover, shares of energy R&D have been falling as a share of total R&D across IEA member countries. These trends are problematic when compared with the large increases in R&D in the 1970s, which spurred some of the successful transitions we have documented. An IEA estimate puts the R&D investments that are consistent with effective climate change mitigation at 3–6 times current levels (Skea et al. 2013, 28).

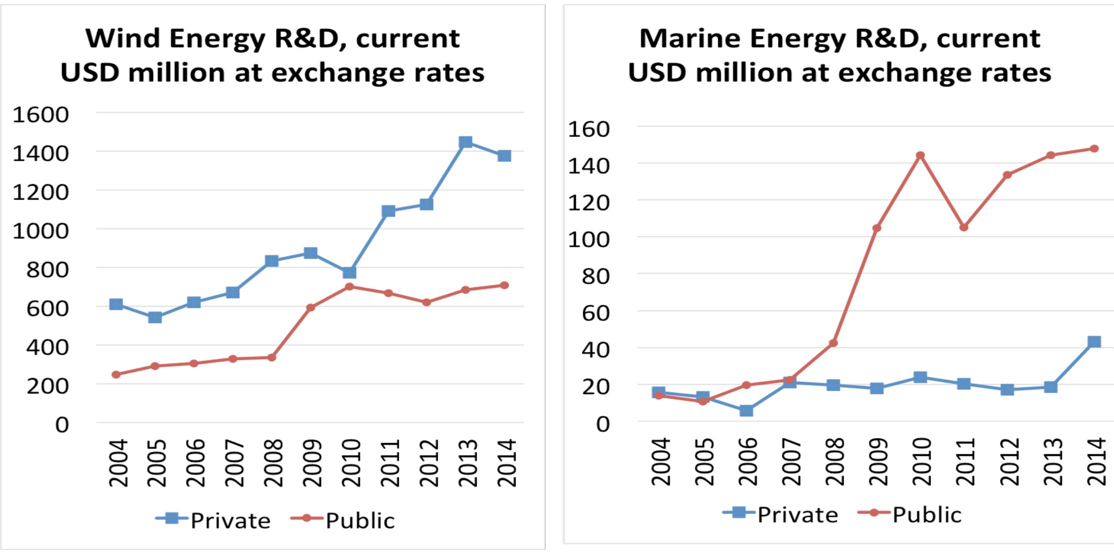
While R&D data for the private sector is harder to obtain, estimates by Nemet and Kammen (2007) suggested that private energy R&D financing in the US had been falling from peak levels in the 1980s, in parallel with public funds. Skea (2014, 23) estimated that private companies spent about USD 1 billion on “alternative energies” in 2011, compared with USD 12.6 billion on fossil energy. A different dataset by BNEF (2015) suggests the corporate renewable energy R&D numbers are much higher, at more than USD 5 billion in that year. These different estimates reflect the problem of the definition of R&D, where the BNEF data must include a substantial portion of ‘development’-related activities that are not accounted for in the other estimates. Aggregate R&D data do not distinguish between basic, applied research and development, which can hide problems with the distribution of spending on different areas. For the US, recent business-funded R&D for all sectors shows that spending on (downstream) development activities has steadily increased its share, while basic and, in particular, applied research spending has declined or stagnated (Figure 3), to the point where Arora et al. (2018) claimed there was a 'decline of science' in US corporations. The concern is that rather than the different shares of funds being allocated for their needs for fast upscaling, the preponderance of development spending is due to preoccupation with short-term returns on investment (Lazonick, 2014).

Figure 3. US business investment in R&D by type of work as a share of total business R&D 1953–2015. Source: National Science Board (2018, data underlying Table 4.3), extending Andes & Muro (2015)



Secondly, there is the issue of diversity. Because innovation always involves failures, a portfolio approach to financing R&D on a diverse set of technologies is important. Figure 4 shows evidence that public funding is important for keeping options open in renewable energy technology innovation. It shows estimates of global R&D investments made by public and private sources into wind (left) and marine (right) energy sources. Wind energy technologies are vastly more developed than marine technologies, where the latter have only deployed demonstration projects, and are nowhere near being cost-competitive. It is striking that the pattern (with wind investments an order of magnitude larger) is exactly the opposite in both technologies – while the private sector finances the majority of less risky wind R&D, public funds dominate the riskier marine sector, suggesting that public funds are very important especially in the early development of green energy. However, it is unclear whether public R&D is consciously directed toward a balanced portfolio of technologies. The problem of focussing only on a few technologies is illustrated by public R&D in the OECD, 53 per cent of which went to nuclear between 1974 and 2008, even though nuclear looks set to play a comparatively minor role in a future low-carbon energy mix (Grubler & Riahi 2010). This is disconcerting, given that public R&D is typically much more able to support a portfolio with less mature, higher-risk technologies via basic research.

Figure 4. Global renewable energy investments in wind and marine energy R&D. Source: Authors' calculations based on data from BNEF (2015).



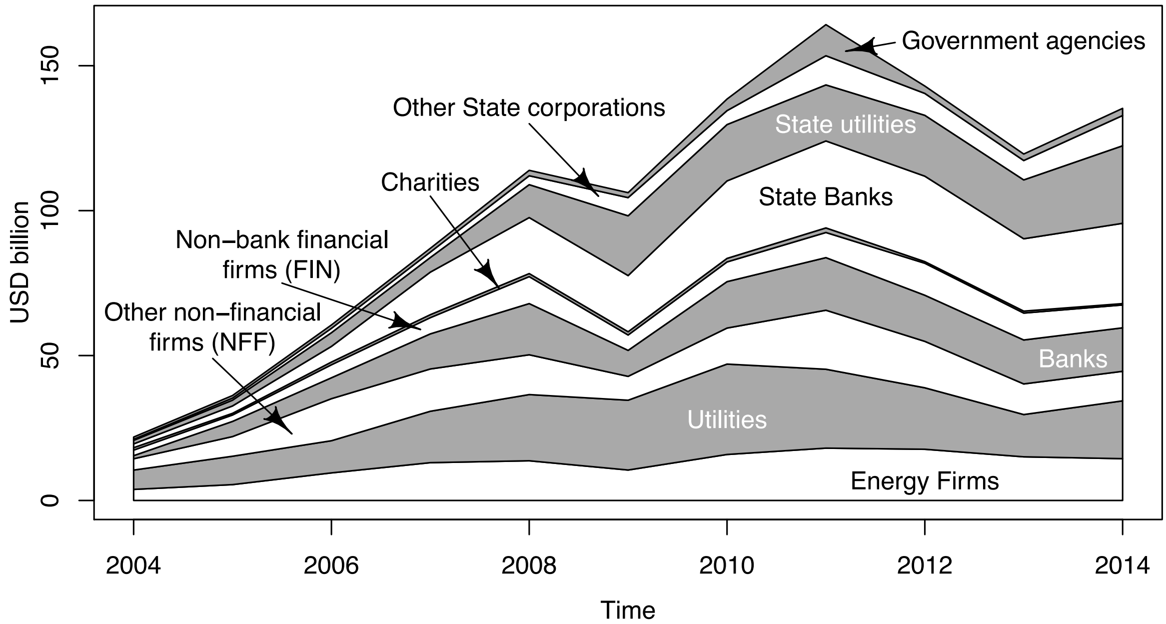
4.2 Deployment

The consideration of historical transitions showed that public actors were not only directly investing in the research phase but across the innovation landscape. For the current transition, no periodical publications have reported the public activity in deployment, although the financing of renewable energy capacity, mainly through wind and solar PV parks, is heavily influenced by public actors. Mazzucato and Semieniuk (2018) showed that, far from being insubstantial, the role of publicly controlled actors in global renewable energy asset finance – for 'utility-scale' power plants with a capacity greater than 1MW – grew constantly between 2004 and 2014, accounting for more than 40 per cent of global annual asset finance by 2014 (Figure 5). In particular, state banks have become the single biggest providers of green finance. In the renewable energy sector alone, they have provided more than 15 per cent of total asset finance since 2011, and four of them are among the top 10 investors into renewables.[11]

It is not only the quantity of finance of the banks that matters but also the quality. Large-scale asset finance, such as that for offshore wind projects, tends to attract a consortium of lenders with one 'lead' bank and a group of others, where the lead bank undertakes due diligence and assesses risk, then steps forward. Having a state bank step in first, often with concessionary interest rates, reduces the barriers for other private lenders to join in the project (Smallridge et al. 2013). That is not to deny the important role played by the project's equity sponsors, often private firms. However, given that large asset finance projects are typically two-thirds debt and one-third equity, getting a lender consortium is crucial to the scaling up of utility-size renewable energy capacity through capital-intensive projects.[12]

[11] State banks have also been important lenders to households and small businesses for financing small distributed capacity, typically solar 'rooftop' power plants with a capacity below 1 MW.
[12] An overview over public support measures is listed in OECD (2016, Table 1), and the special role of state banks is examined in Geddes et al. (2018).

Figure 5. Annual global flows of asset finance by financial actor. Source: Authors' calculations based on BNEF data, explained in Mazzucato and Semieniuk (2018)



Another class of publicly controlled actors that does invest in equity in high-risk sectors are state-owned utilities, which have provided a disproportionately large share of high-risk offshore wind finance (Mazzucato and Semieniuk 2017; 2018). This suggests that the public sector does not withdraw its finance after the research stage and leaves it to private investors to diffuse innovation. On the contrary, financing from publicly controlled actors is becoming increasingly important as the renewable energy industry is supplying a greater share of the energy mix. However, this is not due to crowding out but to division of labour, whereby public finance flows predominantly to higher risk areas that would otherwise find it difficult to get any financing at all (Cárdenas Rodríguez et al. 2014). In fact, without the massive increase in spending by these large public corporations and banks, annual utility-scale asset finance in 2014 would have been lower than in 2006 (Mazzucato and Semieniuk 2018). Against this backdrop, while increases in private investments are necessary, the financing pattern over the last decade suggests that it is mainly public finance that can increase the rate of investment in the energy sector in the current socio-economic situation.

4.3 China

In a discussion of the sources of renewable energy finance, it is important to single out China, which currently finances the largest national share of global investments. Significantly for the current discussion, the Chinese government has played a more central role in financing than in other large countries; moreover, it combines capacity upscaling with an industrial strategy. Since low-carbon energy became a priority in China's 11th five-year plan, the Chinese state has embarked on an unparalleled investment path, financed by the Chinese government and its network of banks and state-owned corporations. Between 2008 and 2012, when other countries' investments languished, Chinese government investments rose by 40 per cent (Mathews and Tan 2014). This surge also accounts for the largest portion of the rise in global asset finance throughout 2014 (Mazzucato and Semieniuk 2018). Instrumental in this were a set of large state-owned utilities that control the electricity market and invested heavily in onshore wind. Their steady financing, abetted by China Development Bank loans, also ensured that China was the only major country to continually grow its asset finance between 2004 and -2015, until 2016 saw a slowdown in line with slowing economic growth.

China has integrated its renewable energy expansion with an industrial strategy (Mathews & Tan 2014). The state investment bank, China Development Bank, extended credit lines totalling USD 47 billion to its big renewable energy companies in 2011, a volume three times larger than global venture capital, private equity and public market fundraising combined in that same year (UNEP & BNEF, 2017). Although the companies did not initially tap much of these funds, companies that were offered them have since become global leaders in solar (Trina Solar) and wind (Goldwind) manufacturing industries, and Chinese companies make up six of the top 10 solar PV manufacturers (Mathews & Tan 2015). The Chinese loans are further complemented by substantive export credit guarantees and other government support programmes, partly through the China Export-Import Bank, a practice also used in other countries with export credit agencies.[13]

Finally, China is the world leader in investing in electricity grids, installing approximately 40,000 km of transmission lines a year (IEA 2016a, p. 151). However, unlike conventional grids installed in Europe and the US, mainly in the 1960s and 1970s, the Chinese investments are geared to providing a 'smart grid' that can distribute electricity more flexibly and thus accommodate a higher share of intermittent renewable energy generation. Under a 10-year plan (2011–2020), China's largest state-owned utility, the State Grid Corporation of China is investing an annual USD 50 billion, with additional investments coming from the only other grid operator, China Southern Power Grid (Wang et al. 2016). In 2011–2015, USD 45 billion was specifically directed towards smart grid technologies (Wang et al. 2016), compared with smart grid investments of USD 8 billion in the United States (4.8 billion of which came from federal funds through the DoE) over the period 2009–2014 as part of the US crisis stimulus (DoE 2015). These massive public investments put China on track not only to have a grid that can accommodate a higher share of renewable electricity, but also to be a world leader in smart grid technology. All this suggests that in the current energy transition, as before, the role of public sources of finance is of a particular quality that is hard to replace with other sources.

5. Implications for financing green growth

This chapter has argued that in the historical major technological innovations, financing from public actors played a central role, not only for research but across the entire innovation landscape. Success resulted from interactions between public and private actors with public organisations that had both the financial depth to sustain long-term funding with a high failure rate, the organisational capacity to identify good funding opportunities and carry out some of the innovative activity in-house, and – especially more recently – the self-esteem to persevere with their high-risk financing in spite of an intellectual climate haranguing the public sector's ability to tackle big challenges. This success required both public and private organisations to take on high risk – and often the public ones to take on the

[13] Mazzucato and Semieniuk (2017) discussed public support for renewable energy manufacturing companies also in OECD countries.

early upscaling of investments, when risk is highest. Since for every success there were also failures, the ability to welcome trial and error was also important.

Since green growth requires an immense structural change in the economy and is therefore dependent on rapid rates of innovation, public financing for innovation will be crucial. Where transitions to new energy sources have been successful, they have had substantial financial and know-how support from the public sector over and above 'levelling the playing field' and 'getting prices right' (such as US shale gas), often to the point where the public sector financed the transition virtually by itself (nuclear in France, hydro in Norway, geothermal in Iceland). In the current global transition to low-carbon energy sources, we have reviewed evidence for why, here too, success was highly correlated with direct public financing across the innovation chain, and why the public sector activities nevertheless appear relatively restricted compared to past efforts. Given that current overall rates of investment in the energy system are deemed far too low, it seems likely that substantive additional public funds will be required to speed them up.

None of this is to deny the very important role that private finance plays in the energy transition. After all, the majority of funds originate here and it is clear that private finance will need to increase by a factor of two or more in order to match the requirements in the forecasts reviewed in the introduction (Condliffe 2016). The Breakthrough Energy Coalition's USD 20 billion pledge for renewables is a good start. We wish to point out here that it would be risky to rely solely on private finance, particularly the seemingly overabundant supply of funds from institutional investors, to implement the transition to green energy sources. As we have argued, different types of finance have different qualities: finance is not neutral. In the 20th century, public sources were crucial for providing the funds to risky, long-term projects that are so central for innovative activities. Neglecting this qualitative difference and betting on private finance only risks derailing the transition because of the lack of one of the crucial ingredients of success in the past: patient mission-oriented public finance.

Against this backdrop, the current retreat of the public sector spells additional challenges for greening the energy sector. Although the 2008 financial crisis brought one-off stimuli into green industries (Robins et al. 2009; Mundaca & Richter 2015), austerity measures subsequently started to bite. In the US, ARPA-E in the DoE, originally a product of the US crisis stimulus (ARRA), could be driving path-breaking innovation, as DARPA did for IT, but it was never allowed to get the critical size it needed to do so. Its 2015 budget of USD 280m was too small, barely a tenth of DARPA's USD 3 billion budget (ARPA-E 2015, DARPA 2015), and globally there are not enough equivalent organisations. The current US president even threatened to discontinue ARPA-E funding entirely in 2018 (Mervis 2017), and – after the Senate upheld 2018 funding – also in 2019 (Guglielmi et al. 2018). The UK recently axed its Department of Climate Change, and Spain killed off its renewable energy investment with a devastating retroactive retreat from renewable energy subsidies in 2012.

Each public curtailment hits finance particularly hard, as there are not many public organisations left. In 2017, for instance, the public UK's Green Investment Bank was privatised (BEIS 2017). Most importantly, the energy sector itself has undergone far-reaching privatisations since the 1980s (Hausman et al. 2011). Hence, the public utilities that the data show are some of the most risk-taking corporations are a minority. They are outflanked by private utilities that are creaking under the weight of low electricity prices in energy markets upended by fluctuating solar and wind electricity (Hall et al. 2015). Ironically, while past energy infrastructure transformation could be bankrolled by strong public sector organisations, often propped up with funds from state banks, today in many countries private investors have to be enticed to partake in 'de-risked' projects and the state banks instead subsidize these private investors, an area that, incidentally, could benefit from further research. While this more-private finance oriented model of transformative innovation may still turn out to work well, the historical evidence, as well as China's current lead role, suggests that private investors are likely to invest on the required scale only once the technologies are well established; that is, when the transition has run part of its course. In the meantime, a strong role of the public sector, including substantial direct financing, is an important component of financing innovation. To get there, the historical analysis offers some advice.

First, it is necessary for public actors to be able to invest directly, with both adequate budgets, and organisational capacity. This means there must be institutions with the capacity to put up funds that may not earn a return for years, and – due to risk – some never will. Current tendencies to establish 'rules' that make it difficult to spend much at once, such as the 'debt brakes' recently enacted in some European countries, are inimical to such investment. If they cannot be avoided, one alternative is to use state-controlled organisations that are not on the government's balance sheet, such as development banks or large energy utilities, to make these investments. To the extent that these are shielded from attacks for temporary unprofitability, they can be either a substitute for or an effective complement to government spending.

Second, finance must fund a variety of technologies to keep open such options as varieties of solar, wind, biofuels, CCS and nuclear. Thus, a portfolio approach that retains diversity is critical so that if any one area suffers, there are other sources available (Stirling 2007; Rodrik 2014). Indeed, we find there to be a non-neutral effect of financial types in this regard: while some financial institutions like public banks are willing to spread their risk across a wide array of renewable energy categories, others put more eggs into one basket (Mazzucato and Semeniuk 2018). Furthermore, some of these technology areas will require specific mission-oriented programmes across the innovation landscape. However, given that some countries will have more limits in terms of budget constraints (whether real or self-imposed), in some cases it is the budget that will limit the scope of diversity and increase the level of specialisation.

Third, due to the high level of risk taking required by public actors to co-create markets (and, in the process, crowd-in business investment), it is only natural that a portfolio approach also leads to portfolio thinking: using some of the upside from lower risk investments (or from those high-risk ones that are more lucky) to cover the downside failures, and the needed next round. In the case of the US DoE guaranteed loan to Solyndra (USD 500m), which made headlines because the taxpayer was asked to foot the bill, the same reasoning was not applied to the success: Tesla. Indeed, the near same level of investment that went to Solyndra also went to Tesla (USD 465m), and yet it was only the risk that was socialised, not the reward.[14] A variety of techniques like temporary shares, royalty, income contingent loans, or conditions on reinvestment can help to socialise both risks and rewards and, in the process, create more flexibility – and political independence – for innovation budgets (Laplane and Mazzucato, 2018).

[14] Strangely, the loan provided by the US DoE was structured so that the government would only get shares (3 million) if the loan was not paid back. As the price per share went from USD 9 in 2009 to USD 90 in 2013, had the opposite logic been applied (getting shares if the loan was successful), the public reward could have been used to cover the Solyndra loss and the next round (Mazzucato 2018).

Fourth, within these portfolios, upstream R&D is not an alternative but a complement to downstream support for demonstration and commercialization. There is often a symbiotic relationship between R&D and demonstration and early deployment – and it is the latter that has driven a lot of the cost reductions we have seen in technologies such as solar PV through economies of scale and learning by doing (Watson et al. 2015). Therefore, to transform the technology landscape, R&D needs to be complemented by targeted public support for demonstration, and strategic procurement that allows the scaling up of new technologies and for deployment and commercialisation (Edler and Georghiu 2007). In other words, increases in energy funding have to be coherent and proportional over the entire innovation trajectory. Another complement is simultaneous investment in energy efficiency and the enabling of technologies such as smart-grids, but also complementary end-use technologies that favour low-carbon energy sources, such as electric instead of gasoline-driven cars (Wilson et al. 2012).

To conclude, different programmes must be thought about more systematically in terms of a portfolio of investments, some of which may ultimately contribute more than others to the aim of decarbonising the economy. However, since it cannot be known ex ante which ones are the more successful technologies, a portfolio approach is needed with tolerance for failure. Because of the long lead time until returns materialise, and the uncertainty about whether they do so in the first place, public finance is crucial for financing green growth. Accelerating the transition through faster rates of investment will likely need a significant boost in public financing. Without this, the global energy transition towards 'green' is at risk.

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