Economic Report Series 2014

Green innovation:
industrial policy for a low-carbon future

UCL TUC

The TUC would like to thank Will McDowall and Paul Ekins at the UCL Institute for Sustainable Resources for writing this report

Contents

Section one

Executive summary

As the economic recovery continues, debate has focused on how best to stimulate investment to support sustained growth. Many of these discussions have highlighted the central role of innovation, and a wide variety of commentators—both within government and outside it—have argued that government can do more to support the innovation that underpins growth.

But there has been less discussion about the direction that growth should take, and the role of innovation policy in directing growth towards a recovery that is more durable, more equitable and more sustainable in terms of its resource use and environmental impacts. It is widely recognised that technology and innovation are central to aspirations for a prosperous, low-carbon economy. Not only are new technologies essential to meeting carbon targets at an affordable cost, innovation is also the key to a vibrant economy. But despite this consensus on the role of innovation for both economic growth and environmental sustainability, there is much less agreement on how governments can best promote innovation, and particularly how governments can drive innovation in a low-carbon and resource-efficient direction.

Traditional arguments for public policy support for low-carbon and environmental innovation (variously called green innovation or eco-innovation) centred on market failures, such as the failure of markets to properly respond to the costs associated with environmental damages. While these arguments based on market failure are important, they are increasingly recognised to provide an insufficient account of the relationship between public policy and innovation, and the ways in which policymakers can and should support innovation. Researchers now understand innovation to be the product of a complex system of interacting firms, public bodies, institutions, markets and technological opportunities: an 'innovation system', in which government plays an essential role. This perspective reveals that innovation policy is not so much a choice between government 'intervening' or not, since government involvement in the complex innovation processes of a modern society is inevitable and necessary. Rather the challenge of green innovation policy is to understand how government can participate in ways that create a dynamic and vibrant innovation system that meets society's environmental and economic aspirations—and in particular for the UK, its commitments to decarbonisation.

Globally, it is clear that many other countries are seizing the initiative, and investing in the technology systems that can achieve radically improved environmental performance in transport, water systems, energy, buildings and

other key areas. The UK has clear strengths and opportunities in green innovation, but decades of under-investment in R&D in general and energy research in particular, coupled with structural weaknesses in the UK innovation system, have hampered progress. While governments have gradually increased the level of support for low-carbon innovation, the scale and organisation of support is not yet commensurate with the scale of the challenge and opportunity.

This essay argues that government can take a more active role in driving a green industrial policy, and in doing so can secure both economic and environmental benefits for the UK. The essay sets out the core elements of such a policy. First, this recognises that decarbonisation and greening the economy is not simply about expanding a few niche 'green' sectors. All sectors must play a role in achieving a low-carbon economy, and opportunities for greater levels of resource efficiency and low-carbon innovation are to be found across the economy. Greening the direction of innovation across the economy requires a range of cross-cutting, 'horizontal' measures, including increasing the share of taxation that is derived from environmental taxes, smarter and more innovation-friendly environmental regulation, and green public procurement for innovation. Second, it is clear that there are core sectors and areas of technology that are necessary for achieving a green and low-carbon economy. Here, targeted 'vertical' industrial strategies are required, encompassing long-lived and well-funded R&D support, dedicated green innovation financing and institutions, and formal and transparent processes for prioritisation and review.

Both economic success and the sustainable increase of human well-being in the twenty-first century are likely to require systematic eco-innovation that progressively moves the UK towards becoming a green economy. This paper provides the essential features of the policy approaches through which such innovation can be achieved.

Our core recommendations

The overall recommendation is that government commits to a green innovation and industrial policy that is commensurate with the UK's ambitious carbon reduction targets and wider aspirations for a green economy. The details of such a strategy should include both cross-cutting, 'horizontal' measures, which focus on enabling eco-innovation across the economy, and targeted 'vertical' measures that support core green technology areas.

Cross-cutting 'horizontal' measures. These involve four essential sets of actions from government:

Committing to a vision of an innovative green economy. Having committed to decarbonisation (through the Climate Change Act) and more generally to a green economy, government should consistently articulate a vision of an innovative and green economy in which the UK strives to take a lead in

resource-efficiency and decarbonisation. This vision should be embedded in the institutional structures that support innovation in the UK, by: incorporating a sustainable development objective within the mandates of innovation agencies, including the Research Councils and InnovateUK (formerly the Technology Strategy Board); and reviewing existing industrial strategies to ensure that they adequately address the imperative for eco-innovation within each sector. This vision should go hand-in-hand with an across-the-board expansion of publicly supported R&D in the UK, in particular through further funding for InnovateUK and through the regional growth fund, including long-term funding commitments enabling business to have greater certainty in future R&D spending.

Creating demand-pull for eco-innovation across all areas of the economy by: increasing the share of taxation raised through environmental taxes; strengthening existing environmental regulatory policies and ensuring that regulations have been developed in such a way as to provide incentives for innovation; and enhancing public procurement processes to ensure that they are used most effectively to stimulate eco-innovation.

Providing enabling conditions for eco-innovation. Greening the direction of innovation requires a broad landscape of supporting physical infrastructures, since long-lived critical infrastructure can 'lock-in' particular technological systems for many decades. This requires alignment of infrastructure planning processes with decarbonisation targets, ensuring that low-carbon technologies are facilitated, and preventing 'lock-in' to high-carbon infrastructure that dampens incentives for eco-innovation. In addition to physical infrastructure, the 'knowledge infrastructure' for a green economy needs to be further developed, through integration of material flow and natural capital data into national accounting processes conducted by the Office for National Statistics. This would facilitate identification of opportunities for innovation to raise resource efficiency across the economy.

Ensuring policy consistency across government. Government needs to reduce the policy risks of private investors and entrepreneurs by ensuring consistent signals across government, and especially in the core areas of energy, water, transport, resource management, land-use planning, and waste, of its commitment to eco-innovation and the greening of the UK economy more generally.

Targeted, 'vertical' measures: the development of a new green industrial strategy targeted at technologies that can underpin emerging green industries. This should include:

A clear and transparent approach for the selection of technology priority areas, along predictable periodic re-evaluations to assess progress and end support to areas that are not delivering. This requires cross-government collaboration,

which can be achieved through further support and a higher profile for the low-carbon innovation co-ordination group, which has been under-resourced.

The enhancement of existing 'mission-driven' R&D agencies, such as the Energy Technologies Institute and the offshore renewable energy catapult. These require long-term commitments, providing business with confidence to invest alongside public money

The development of long-term patient-finance vehicles for green innovation, including a green innovation arm of the British Business Bank.

Better alignment of support across the life cycle of support, requiring greater collaboration between BIS, InnovateUK and DECC. This is necessary to move technologies from demonstration into early deployment, a key stage during which both risk and opportunities for learning are high. Clear criteria and processes for the withdrawal of support are essential, and have been lacking in many previous support measures.

Section two

What kind of growth?

As the economic recovery continues, debate has focused on how best to stimulate investment to support sustained growth. Many of these discussions have highlighted the central role of innovation, and a wide variety of commentators—both within government and from opposition—have argued that government can do more to support the innovation that underpins growth.

But there has been less discussion about the direction that growth should take. The argument in this paper is that the UK faces choices about the economy that should emerge from the crisis, and that there is a role for government in steering the UK innovation system towards a green, sustainable and equitable recovery.

The UK government has already made major and ambitious commitments on decarbonisation. Alongside this sit other resource and environmental challenges—from ensuring that the economy is resilient in the face of volatile resource prices, to delivering cleaner air and protecting the UK's natural capital.

We believe that the evidence supports a policy approach in which government takes a more active strategic role not only in strengthening the UK innovation system but in orienting it towards 'eco-innovation' – the development of new products, business models, processes and ideas that make more efficient use of resources – increase resource productivity – and reduce environmental harm. We first set out the core ideas that underpin this conclusion, addressing the environmental and economic promise of green innovation in section 2, the nature of path dependence and lock-in, and the directionality of innovation in section 3, and the role of government in section 4. We then consider three important contextual issues: the kind of innovation required for a green economy (in section 5), the international dimension (in section 6) and the current position of the UK (in section 7). We then provide (in section 8) what we see as the core elements of a green industrial and innovation strategy, bringing together both cross-cutting 'horizontal' measures that support green innovation across the economy, with targeted 'vertical' measures that support specific core green technologies.

Section three

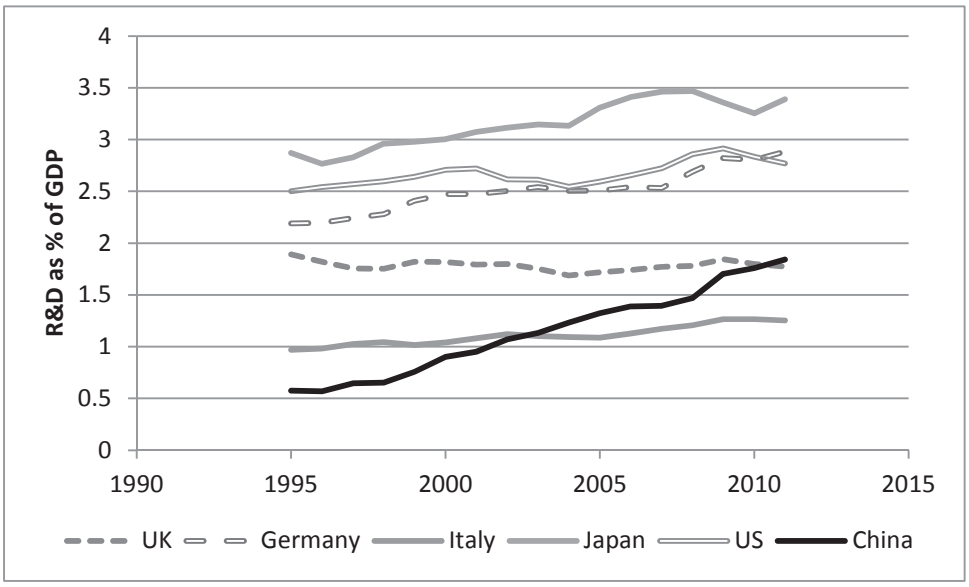
The promise of innovation: a core pillar of green economy strategy

That innovation is central to addressing the global and national environmental challenges of the 21st century is perhaps obvious and has been widely discussed[1,2,3]. Less obviously, the promise of a green innovation strategy is not only that it makes environmental targets more easily affordable, it is also that it can stimulate productive investment and new growth paths.

Technological change has been identified as a key driver of economic growth since path-breaking work by Robert Solow in the 1950s[4], and economists continue to understand innovation as a driving force for growth[5]. Indeed, if there's one thing about innovation that practically everyone can agree on, it is that innovation is critical for long-term growth and prosperity: innovation policy is growth policy[6]. Nevertheless a number of commentators have highlighted that the UK's short, medium and long-term growth prospects could be undermined with stagnant or falling investments in innovation (see Figure 1)[7]. While it is clear that government has limited fiscal room to manoeuvre, it is also clear that innovation is an investment necessary for long-term growth[8], and that the social returns to investment on both private and public R&D are high[9]. Increases to public investment in innovation, and particularly measures to stimulate private investment in innovation, are key to delivering the innovation that drives growth.

[1] Aghion et al., 2009. *No green growth without innovation*. Bruegel Policy Brief. Brussels.
[2] OECD 2011. *Fostering innovation for green growth.* OECD, Paris.
[3] Stern 2007. *The Economics of Climate Change*. HM Government, TSO, London.
[4] Solow 1956. "A Contribution to the Theory of Economic Growth". *Quarterly Journal of Economics*. Vol. 70.
[5] See, e.g, the work of Paul Romer, Philippe Aghion and Peter Howitt.
[6] Tassey 2012, *Beyond the Business Cycle: the need for a technology-based growth strategy*. National Institute of Standards and Technology; Atkinson and Ezell 2012, *Innovation Economics*. Yale University Press
[7] Tera Allas (2014) *Insights from international benchmarking of the UK science and innovation system.* Report to the Department of Business, Innovation and Skills.
[8] NESTA, 2012, *Plan I: the case for innovation-led growth.*
[9] Frontier Economics (2014) *Rates of return to investment in science and innovation*. A report for the Department for Business, Innovation and Skills

Figure 1. R&D intensity of GDP in the UK and key competitors
Source: OECD



For a society that has committed itself to ambitious decarbonisation and a general commitment to sustainable development, the close relationship between innovation policy and environmental policy is clear, since new and cleaner technologies are clearly needed. At the same time, environmental policy can foster greater innovation, leading to higher levels of energy, resource and material productivity. Indeed, the positive effects of innovation on productivity growth provide an additional rationale for environmental policy[10], though it should be clear that such productivity effects are not expected to occur in every case. As environmental regulations are introduced, firms respond by investing in innovative solutions—which not only reduce the expected costs of regulation, but can also generate productivity growth.

As the OECD commented:

'The potential spillovers arising from green innovation could well be larger than for other forms of innovation, precisely because the market is still underdeveloped and the potential for future innovation and growth may well be very large. Overcoming the barriers to green innovation, including the dominance of existing technologies and systems, could possibly lead to a new wave of innovations comparable to those of other major technological revolutions' (OECD, 2011[11]).

[10] Hallegatte et al 2012. *From growth to green growth: a framework*. Policy Research Working Paper 5872. World Bank.
[11] OECD 2011. *Fostering innovation for green growth*. OECD, Paris.

Section four

Innovation, direction and choice

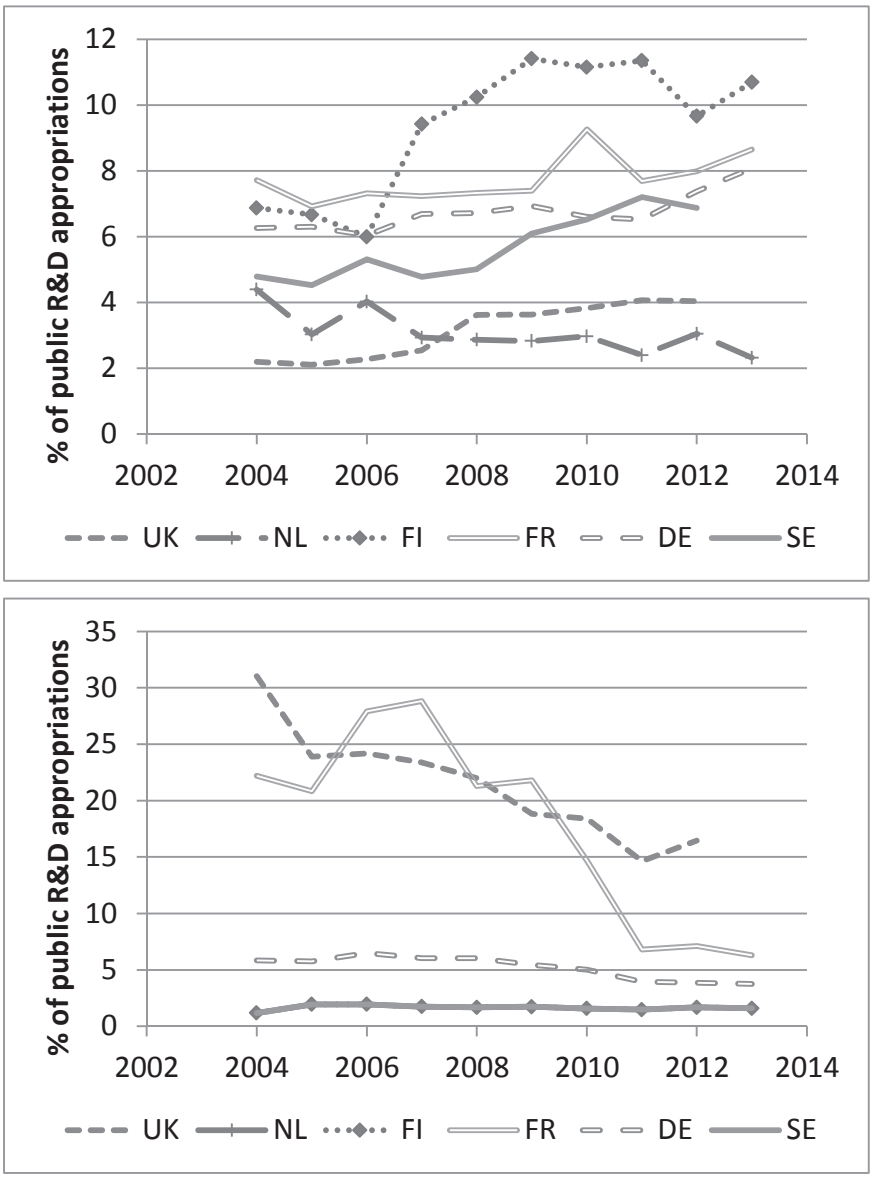
Science and technology is often characterised as an inevitable and linear march of progress: the choice is only to 'stay in the race' or get left behind. But for every set of technologies and areas of science we pursue and develop, other possible development paths are abandoned. This means that there is not a single optimal path – there are many paths that we could pursue but do not.

Importantly, technological change is path-dependent, and 'lock-in' effects mean that it can be difficult to shift development paths. This is particularly true of large technological systems such as energy, transport, waste management, water or food systems. These depend on long-lived physical infrastructure, and on a whole system of related technologies, behaviours and habits co-evolving with the core technologies. The implication is that early effort to influence the greening of these systems pays off: what we see as 'abatement costs' incurred now become investments in the development of new technologies and systems that will spawn new industries.

The point here is that there are choices to be made, and that the government plays a key role in making those choices—whether consciously or not. As a nation, the UK has already made big commitments on climate change as embodied in the Climate Change Act, and has made some progress on delivering those commitments. The task is now to follow through and reap the rewards of that early commitment and investment. But the data suggest that our innovation priorities are not yet aligned to achieve this, particularly compared to our European competitors. Data on government budgetary outlays on R&D show that the UK commits many times more money to military R&D than to any other social goal except health. Compared to others in Europe, the UK commits much less to energy and environmental priorities, as a portion of the overall R&D commitment, than most European competitors (see Figure 2). This is not to suggest that defence R&D budgets are over-inflated, but rather that the UK's R&D spending is too low (a point echoed by many other commentators)[12], and that R&D priorities are not aligned with the core long-term challenge of decarbonisation.

[12] e.g. Adonis (2014) *Mending the fractured economy, the report of the Adonis Review*; Allas, 2014, *Insights from international benchmarking of the UK science and innovation system*, Report to the Department of Business, Innovation and Skills.

Figure 2. Percentage of public R&D budgets committed to defence (top panel) and energy and environment (bottom panel)



Section five

What is the role of government in setting a strategic direction for innovation?

Government plays a strong role in shaping both the rate and direction of innovative activities. Decades old debates between 'laissez-faire' and 'picking winners' have missed the point: evidence shows that innovation and technological change are shaped not only by the possibilities of science and the opportunities of the market but also by government decisions. These decisions are made through the structure of funding and choices in R&D funding priorities, through government procurement choices, and through the entire structure of regulation throughout the economy.

Recent years have seen a shift in economists' and policy makers' thinking about why and how government should be involved in the innovation process. In traditional approaches, the basic rationale for a public policy role in innovation was centred on market failures (particularly the under-supply of R&D arising from knowledge spillovers)[13]. More recent approaches see innovation as arising from a complex system of interacting firms, public bodies, institutions, markets and technological opportunities: an 'innovation system'[14] in which government is an irreplaceable player. While arguments about market failures for innovation are important, they do not provide a sufficient account of the complex relationship between public policy and innovation, and the ways in which policymakers can and should support innovation[15].

Rather than focusing on 'fixing' the problems left by an otherwise effective market mechanism, innovation system perspectives understand the role of government as broader, with government playing an important role in shaping the incentives, structures and rules through which innovation takes place. Government investments in R&D are often critical in exploring innovation trajectories that would otherwise be too risky and expensive for the private sector.

---

[13] Popp 2010. "Innovation and Climate Policy". *Annual Review of Resource Economics* 2(1): 275–298.
[14] Lundvall et al 2002, "National systems of production, innovation and competence building". *Research Policy* Vol. 31; Perez (2002) *Technological revolutions and financial capital: the dynamics of bubbles and golden ages*
[15] NESTA, 2012, *Plan I: the case for innovation-led growth.*

The point here is that innovation policy is not so much a choice between 'intervening' or not. Indeed, this language of 'intervention' presumes that government has to justify its presence in innovation activity, that it is somehow an interloper. This is not a good description of how innovation works in a modern economy[16]. Rather than worrying about the rationale for and mode of 'intervention', the challenge of innovation policy is to understand how government can participate in ways that create a dynamic and vibrant innovation system that meets our social and economic aspirations.

The 'innovation systems' view—in which market failures are recognised to be an important but limited guide for policy action—is becoming more widely accepted in governments around the world, including in the UK[17]. At the same time, governments have shown increasing interest in various forms of industrial policy, particularly since the financial crisis[18]. Debates about sector and technology-specific support in the UK were for many years weighed down by the UK's particular historical experiences and the spectre of failed industrial policy. For many, targeted intervention in specific technologies or industries was seen as a doomed attempt at 'picking winners', which in turn conjured images of failed past national champion projects (such as Concorde, the AGR reactors, and British Leyland, to name a few). These historical images are based on a model of industrial policy that focused on supporting particular firms or technological designs that may be more aptly described as picking losers, or even losers succeeding in picking a soft-touch government.

However, perceptions have changed and so has the practice of industrial policy. It is now more widely recognised that intelligent sector-specific or mission-driven policies are not inevitable recipes for 'government failure'[19]. It is now clear that 'getting out of the way' is not good innovation policy (because of the systemic nature of innovation discussed above), and that government support has been an important factor in the success of many leading industries and businesses. The UK's strengths in pharmaceuticals and aerospace are in part a result of decades of policy support and research investment. And the demand from business for this kind of approach is clear. In the run-up to Budget 2013, the CBI argued that Government needs to 'deliver a shared vision

[16] Lundvall, Johnson, et al. (2002). "National systems of production, innovation and competence building". *Research Policy* 31: 213-231; Malerba, F. (2002). "Sectoral systems of innovation and production". *Research Policy* 31(2): 247-264; Mazzucato 2013, *The entrepreneurial state*, Anthem Press

[17] BIS 2011. *Research and innovation strategy for growth*. HM Government.

[18] Warwick, K. 2013. *Beyond Industrial Policy*. OECD.

[19] Mazzucato 2011. *The Entrepreneurial State*. Demos; Gross et al 2012, *On picking winners: the need for targeted support for renewable energy technology*. Imperial College; Pryce 2011, *Britain needs a fourth generation industrial policy*. CentreForum.

for an industrial strategy that champions key sectors and protects investment in R&D and innovation'[20].

Modern adherents of industrial policy recognise the failures of previous models. In particular, it is recognised that industrial policy: should be targeted not at specific 'champion' firms, but at sectors and technology fields[21]; should avoid stop-start or one-off initiatives or rescue missions to prop up failing firms, and should instead focus on building long-term effective collaborative relationships; tends to be less successful where it aims to support mature, incumbent industries that are in decline (emerging, innovation-based sectors are better targets for support[22]); and requires a combination of 'horizontal' measures that improve the framework conditions for all parts of the economy and 'vertical' or selective measures that target particular sectors[23]. The idea that competition and industrial policy are mutually exclusive has also given way to a more sophisticated understanding of industrial policy in which governments promote competition and facilitate entrepreneurship within key strategic sectors, rather than supporting ailing national champions[24].

The UK Government has accepted that industrial strategy has a central place in economic policymaking, and BIS is producing a series of strategies for priority industries. Yet despite venturing into the development of specific sectoral industrial strategies, there is a reluctance within Government to articulate an overarching vision of a future growth path. The result is a mismatch between both broad aspirations for a green economy and specific decarbonisation targets on the one hand, and innovation and industrial policy on the other. While there are industrial policies for some key low-carbon technologies, such as offshore wind, government has failed to ensure that the industrial strategies as a whole are compatible with green economy objectives, a point raised by the Environmental Audit Committee.

[20] www.cbi.org.uk/media/1986677/cbi_letter_to_the_chancellor_-_budget_2013.pdf
[21] Aghion et al. 2011 *Rethinking industrial policy*. Bruegel Policy Brief, Brussels.
[22] Warwick, K. 2013. *Beyond Industrial Policy*. OECD.
[23] Ibid. (Warwick, K. 2013. *Beyond Industrial Policy*. OECD.)
[24] Ibid. (Aghion et al. 2011 *Rethinking industrial policy*. Bruegel Policy Brief, Brussels.)

Industrial policy and the rejuvenation of the UK automotive sector

The recent success of the UK automotive sector provides an inspiring example of effective business-government partnership in industrial policy. In the 1990s, the decline in the UK automotive manufacturing sector was seen as inevitable—almost as natural. In the last decade, thanks in large part to effective business-government co-operation, the sector has rebounded and gone from strength to strength.

Recent analysis of the UK automotive sector found that the long-term focus on low-carbon vehicle technologies, coupled with a more active and engaged government approach to working effectively with industry, had been critical in enabling the renewal of the sector. The report concluded that "…the cumulative impact of consistent policy emphasis on environmental achievement and green growth has provided the foundations for a renaissance of the UK automotive sector."[1]

Of course, challenges remain, including the challenges associated with decarbonising the energy system while constraining energy costs and the potential impacts of high energy prices on competitiveness1. However, the long-term government-business relationship, built around a shared vision of cleaner, low-carbon road transport, provides the UK automotive sector with a stronger foundation than it has enjoyed for many years.

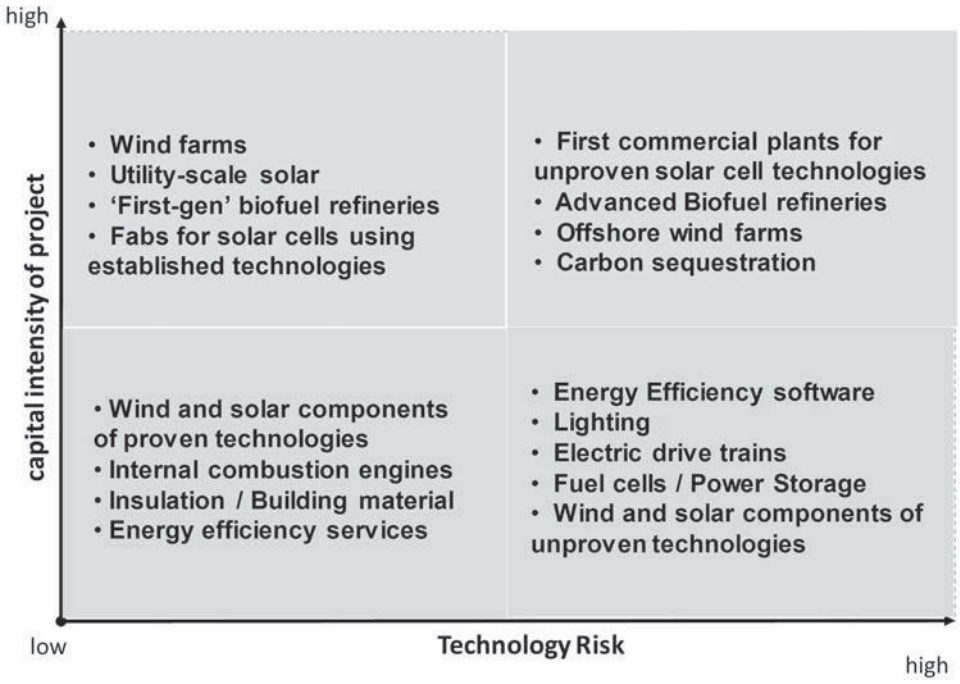
Yet strong industrial and innovation policy is most clearly needed where market signals for innovation do not always match social objectives, as is the case with low-carbon and green innovation. A number of scholars have highlighted that more capital-intensive, long-term and risky forms of technology are harder to fund, and simply do not attract either conventional debt finance or venture capital.

Figure 3 below shows quadrants on a matrix of capital intensiveness and technology risk, developed by Ghosh and Nanda[25]. Low-risk technologies can be financed with bank debt if they have low capital intensity, while capital-intensive but low-risk technologies are typically financed through project finance and existing firms. Venture capital tends to operate within the bottom right quadrant, and even here tends to operate at the lower end of technology risk and where early exit opportunities are possible (which is often not the case for clean energy). It is the top right quadrant of the figure that most requires

[25] Ghosh and Nanda 2010, *Venture capital in the cleantech sector*. MIT Industrial Performance Centre, Working Paper MIT-IPC-10-004.

targeted state support, and it is here where the state has often shown leadership in the past[26].

Figure 3. Typology of clean energy innovation by capital intensity and technology risk. Source: Ghosh and Nanda 2010



However, the matrix developed by Ghosh and Nanda misses a further and critically important dimension for green innovation support. The potential for a technology to result in radically improved environmental performance is ignored. This is somewhat correlated with technology risk (which refers to the risk that the technology will fail to deliver as expected), but a key part of the risk profile of such opportunities is not simple 'technology risk', but includes substantial policy and 'socio-technical' risk.

Policy risk exists because the returns to investment in green technology depend on public policy action to reflect environmental externalities in prices. Socio-technical risk is a product of the phenomenon of lock-in and path dependency. Most innovation takes place along well-established trajectories, making incremental improvements to existing products and services. Occasionally radical new approaches emerge: from sail to steam; from horse and cart to motorcar; from letters to email. Responding to climate change and other environmental problems is likely to require these kinds of radical transitions to

[26] Mowery, D. C. and T. Simcoe (2002). "Is the Internet a US invention?—an economic and technological history of computer networking". *Research Policy* 31(8): 1369–1387.

wholly new ways of doing things[27]. It is this kind of radical innovation that begets new industries and the economic opportunities that come alongside them. Resource efficiency, for example, may require new approaches to supply-chain management and manufacturing, enabling the re-manufacturing and repair of products, requiring completely new ways of organising industrial production. Path-breaking technologies that create the opportunities for radically more sustainable systems face barriers considerably higher than simple technology risk and high capital intensity (that is, large amounts of capital required to bring the technology to market). It is here that the state has a particularly important role in shaping the institutional context required for radical new green technologies to emerge.

The Wright Review noted that a core principle for effective policy support of competitive UK manufacturing was policy stability, and a clear long-term direction of travel. An overarching role of government is thus to strive to avoid frequent changes in policy direction or political narrative. The need for deep, sustained reductions in CO2 emissions, as articulated in the Climate Change Act, provides a clear long-term direction of travel. Politicians and policymakers should work to ensure that confidence in decarbonisation policy is maintained, as this confidence is key to enabling investment in low-carbon innovation.

[27] Kemp, R., J. Schot, et al. (1998). "Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management". *Technology Analysis & Strategic Management* 10(2): 175–195.

Section six

What innovation is required for a green economy?

Green innovation is not only about those sectors typically labelled as 'green' or 'cleantech', like renewable energy, but is much broader, encompassing a wide diversity of technical, organisational and business innovations. The opportunities associated with higher levels of energy and resource efficiency are pervasive and economy-wide, as are the anticipated impacts of both climate change itself and global policy initiatives to reduce emissions. Needs and opportunities differ among sectors. Energy-intensive, trade-exposed industries, such as chemicals and basic metals production, may require particular efforts to support the innovation and technological change that can reduce carbon emissions while supporting competitiveness. Some established, mature industries, such as the automotive sector, have already made great strides in identifying and developing zero-carbon technologies, such as hydrogen and electric vehicles. In other areas, the opportunities associated with re-manufacturing and moving towards a circular economy are only just starting to be recognised. Innovation support is required across all these sectors, and others. A green innovation strategy thus requires measures that facilitate green innovation across the innovation system.

It is also clear that achieving a green economy requires the development of core technologies, especially low-carbon energy and transport technologies. Energy system modelling work from UCL shows that it is very much more expensive to meet climate change targets without key technologies such as wind, carbon capture and storage, and either battery electric or fuel cell vehicles[28]. Many of these technologies require dedicated support, because of the innovation characteristics of the energy sector, and the risk profile and capital intensity of the technologies, and of the activities required to develop them.

A green innovation strategy thus requires both facilitation of green innovation across the economy, and targeted support for core green technologies. This includes generic support mechanisms and demand-side policies that enable the development of technologies that are currently not foreseen or even imagined.

[28] UKERC 2013. *The UK Energy system in 2050: comparing low-carbon, resilient scenarios*. UK Energy Research Centre.; Anandarajah, G., W. McDowall, et al. (2013). "Decarbonising road transport with hydrogen and electricity: Long term global technology learning scenarios." *International Journal of Hydrogen Energy* 38(8): 3419–3432.

Section seven

The global competitive dynamics of green innovation

Core green technologies and innovation leadership

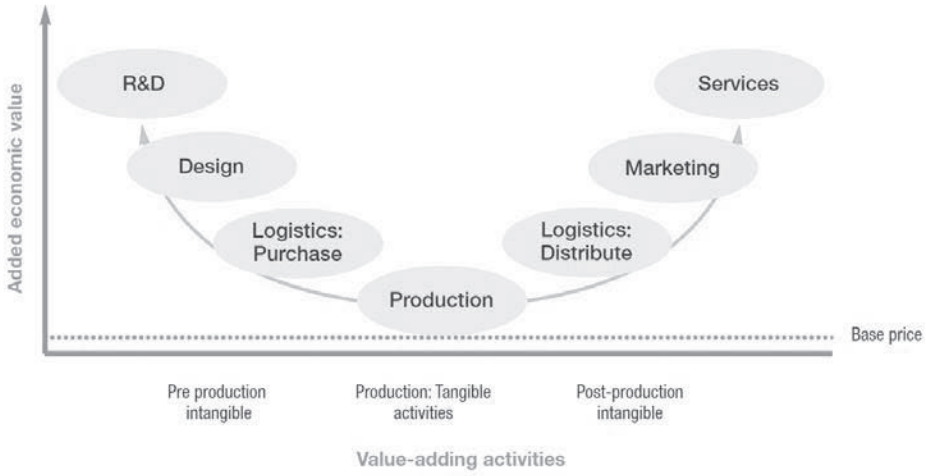
Markets for core green technologies are growing and becoming more globally competitive, as countries increasingly support a transition to low-carbon energy systems[29]. The most prominent example is in clean energy, where investments increased more than five-fold from 2004 to reach $238 billion by 2012[30]. This is clearly an area of significant economic opportunity, but as emerging economies with low manufacturing costs enter clean energy markets, it is legitimate to question the rationale for the UK to support the development of such sectors. There may be a concern that attempts to support domestic markets for renewable energy simply result in the transfer of manufacturing jobs to China. The key question is how the UK can capture value in these—and other—growing markets for core green economy innovations.

Importantly, there is a critical moment in the development of a technology area in which the opportunity to establish leadership is greatest—the formative phase of technological development that occurs just as the market is becoming established[31]. Countries that are successful in establishing and maintaining innovation leadership can continue to capture large shares of the value of such technologies, even when manufacturing takes place overseas. A great deal has been made of China's relative success in manufacturing solar and wind technologies, with some US commentators bemoaning the fact that China appears to be 'winning the clean energy race'. However, while China has developed comparative advantage in assembly and high-volume manufacturing of final products, the US produces higher-value high-technology components across a wide range of clean energy technologies, resulting in a net trade surplus of $1.6bn in this sector in 2011[32]. This pattern echoes wider findings by the OECD on global value chains, which illustrates that the high-value stages in the value chain are often those most associated with knowledge-

[29] REN21, 2013. *Renewable energy global status report*. Renewable Energy Network for the 21st Century (REN21).
[30] BNEF(2013). Global Trends in Clean Energy Investment: Fact Pack as at Q2.2013. (London: Bloomberg New Energy Finance): http://about.bnef.com/fact-packs/global-trends-in-clean-energy-investment-q2-2013-fact-pack/
[31] Livesey 2012, cited in Warwick, 2013. *Beyond Industrial Policy,*.
[32] Pew(2012). *Advantage America: The U.S-China Clean Energy Technology Trade Relationship in 2011*. (Washington D.C: Pew Charitable Trusts).

intensive activities (see Figure 4; although note that this is not true for all sectors).

Figure 4. 'Smile Curve' of value-added in global supply chains. Source: OECD.



design stages—the highest value stages in the global value chain. There tend to be strong 'first-achiever' (if not always first-mover) advantages in R&D strengths in particular industries. Particular places become hubs for key technologies—often known as 'clusters'—and these tend to be very durable. Silicon Valley is of course the classic example, but the phenomenon is widespread. In the UK, good examples include the automotive cluster in the Midlands and the aerospace cluster around Bristol[33]. The agglomeration externalities within 'innovation hubs' or 'clusters' for particular core technologies mean that skills, tacit knowledge and expertise, supportive financial institutions and regulatory frameworks become difficult to replicate. The spill-overs between companies in a cluster are substantial, and in today's globalized economy, clusters need to be networked into global supply chains.

In short, there are opportunities to capture the highest value-added stages through early innovation efforts at the formative phases of core green technologies, since the successful economies who capture a position as a leading innovation hub for a core technology are likely to continue to reap high value-added returns as the sector develops. The nature of global competition for innovation is that once an economy has achieved a strong position of leadership during the market expansion phase, it is difficult for others to catch up. Seizing the initiative requires bold policy action, and clearly policy action that is prioritised on sectors and technology areas that the UK is well-placed to exploit.

[33] Centre for Cities and McKinsey and Company (2014) *Industrial Revolutions: capturing the growth potential.*

Implications of the global green transformation for comparative advantage

A global 'race' in core green technologies has already become clear. Less obvious, but perhaps just as important, is the increasing importance of energy and resource productivity innovations across the economy, outside those core green sectors.

Global resource constraints and environmental imperatives are driving green innovation across all sectors. This is in part driven by policy responses to environmental pressures, and in part a result of increasingly stringent consumer demands for cleaner products and services as incomes rise. If these trends continue—and they appear likely to do so—then countries may see existing patterns of comparative advantage challenged by newcomers developing greener alternatives to incumbent products and services[34]. Patent data suggest that invention is increasingly becoming eco-innovation, as entrepreneurs respond to policy and market signals, and to the possibilities created by ICTs to develop more-efficient, optimised ways of doing things (see Figure 5).

Figure 5. Estimate of share of global patents that are related to eco-innovation. Source: UCL analysis of WIPO data.[35]

[34] Fankhauser, S., Bowen, A., Calel, R., Dechezleprêtre, A., Grover, D., Rydge, J., & Sato, M. (2013). "Who will win the green race? In search of environmental competitiveness and innovation". *Global Environmental Change*, 23(5), 902-913.

[35] Based on searches of patent full text, using Patent Cooperation Treaty patents in the World Intellectual Property Organisation database. This approach shows a similar trend to studies using patent classification-based approaches to measuring green innovation, as for example reported in Dutz and Sharma (2011), *Green growth, technology and innovation*. Policy Research Working Paper 5932, World Bank.

Section eight

UK innovation: performance and priorities

Challenges for UK innovation

Commentators broadly agree that the UK has key innovation strengths, but that it is not in the top tier of innovative economies. In particular, shortfalls in innovation performance are often seen as a key driver behind the UK's productivity 'gap' in comparison to leading economies such as the US[36]. Scholars typically highlight the UK's strong science base, but weaker performance in other areas of innovation, particularly in commercialisation[37] and in SME innovation activities[38]. At the same time, while policy has supported progress on a number of fronts, the policy focus has often been on a narrow range of issues. A focus on small business has been important for enabling those companies who lack internal capacity, but neglects the critical innovation role of larger firms. A focus on venture capital has strengthened what had been a weakness in the UK innovation system, but does not address wider barriers within the financing of innovation[39]. The emphasis on commercialisation and spin-offs from academia has generated some success, but represents only one of many ways in which basic research can be better used as a platform for innovation[40].

Many of the weaknesses of previous innovation strategies have been recognised, but a number of problems remain. There are several basic elements of the UK's innovation system that remain barriers to innovation in general, and to green innovation in particular, which we discuss below, with a particular focus on finance. Overcoming these barriers through system reform is an important step.

Firstly, finance: The financing of innovation in the UK is not working effectively. Many forms of finance are not sufficiently available, and a particular problem is the paucity of 'patient' finance arising from:

---

[36] ESRC and LSE 2004, *The UK's Productivity Gap*; NESTA, 2012, *Plan I: the case for innovation-led growth*

[37] Levy and Brinkley 2013, *A manifesto for innovation and growth*. The Big Innovation Centre.

[38] Allas, 2014, *Insights from international benchmarking of the UK science and innovation system*, Report to the Department of Business, Innovation and Skills.

[39] NESTA, 2012, *Plan I: the case for innovation-led growth.*

[40] Ibid. (NESTA, 2012, *Plan I: the case for innovation-led growth)*

- short-termism of UK business and finance arising from issues related to the corporate governance regime (share buy-backs, excessive focus on quarterly results, etc.[41])
- there is evidence that small, innovative firms have particular difficulties in accessing finance[42]
- lack of supportive state investment institutions, now being to some extent remedied with the Green Investment Bank (GIB) and British Business Bank (BBB), though these are limited—in structure and mandate but also in size
- a focus within policy on venture capital rather than long-term forms of investment in innovation.

Despite pre-crisis commitments to increase R&D spending as part of the Lisbon Agenda, and post-crisis rhetoric about 'ring-fencing science', government-funded R&D has continued to fall as a percentage of GDP. This is partly because the science 'ring fence' is in nominal rather than real terms, and partly because the ring fence does not protect the R&D budgets of central Government departments, including those funding core research for eco-innovation. Both DEFRA and the Department for Transport (DfT) slashed their R&D budgets in response to pressure to reduce spending, with R&D suffering bigger cuts than overall departmental budgets[43].

While Government R&D investments have fallen, UK Business Enterprise R&D (BERD) is also much lower as a proportion of GDP than most of our competitors. With relatively low business and Government investment in R&D, R&D intensity overall is relatively low compared to most of the UK's major competitors (and has fallen since 1995)[44]. In 2011, China for the first time surpassed the UK in terms of the R&D intensity of GDP[45]. Of particular concern is continual decline in business investments in R&D. Policy initiatives have been introduced to support R&D funding by business, including R&D tax credits and the patent box, although concerns have been raised about the cost effectiveness of both approaches. The effectiveness and additionality of R&D tax credits has been hotly debated, with empirical evidence showing that the evidence for additionality of R&D tax credits is inconclusive[46]. The patent box in particular has been received by many innovation scholars with considerable scepticism[47], and is seen as a costly subsidy (with an annual value

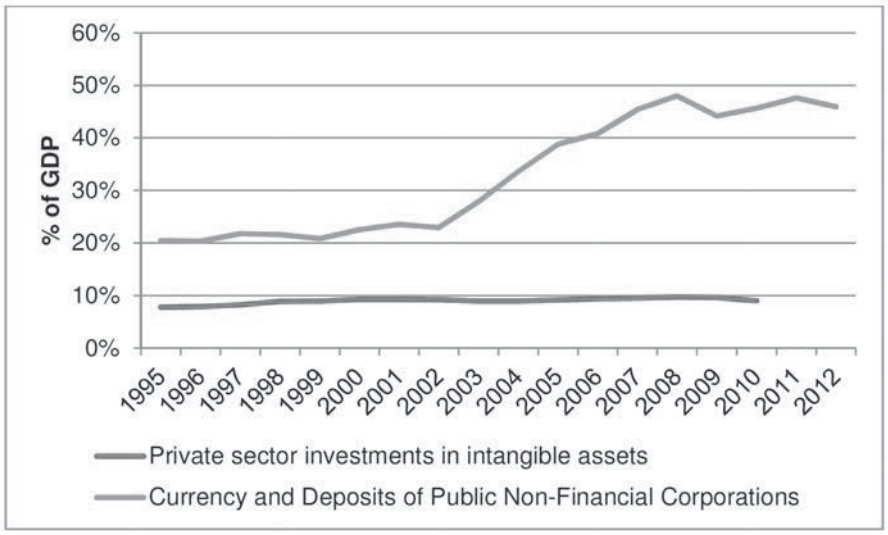
[41] Kay, J. 2012. *The Kay Review of UK equity markets and long-term decision making*.
[42] Lee et al 2013, *Credit and the crisis: access to finance for innovative small firms since the financial crisis*. Big Innovation Centre.
[43] Campaign for Science and Engineering 2012. http://sciencecampaign.org.uk/?p=11131
[44] National Audit Office 2013. *Research and development funding for science and technology in the UK*.
[45] OECD *Main Science and Technology Indicators*.
[46] Lentile, D. and J. Mairesse (2009). "A policy to boost R&D: Does the R&D tax credit work?" *EIB Papers* 14(1): 144–169.
[47] Levy and O'Brien 2013, *Will the patent box boost the UK innovation system?* Big Innovation Centre.

of around £1bn) which various analysts, including the IFS, have suggested is unlikely to have a large impact on R&D activity in the UK[48,49]. While Government has provided a range of support mechanisms, NESTA has noted that many of these schemes are short-term or one-off, and they are fragmented and relatively small in volume[50]. While the BBB will pull together some of these into a coherent whole, the overall level of funding is still too low.

At least part of this apparent weakness in UK innovation is a result of the structure of the UK economy, and the type of innovation activity that is captured by traditional measures such as BERD and patents. BIS analysis shows that, when corrected for industrial structure, UK BERD intensity is higher than that in Germany—though still lower than the US, Japan and France[51.] The UK has large business services, finance and creative industries, whose innovative activities are not captured by traditional metrics. When intangible investments in innovation are considered (a much broader measure of investments in innovation than R&D that includes training, software development and design) the UK picture looks rather better. Even when intangibles are included however, the flow of finance into innovation is disappointing: despite UK firms holding increasing cash surpluses before the crisis, investment in innovation did not rise (see Figure 6)[52]. The recent Allas report concluded that "there are few compelling explanations for the low levels of private sector R&D", and that industrial structure could explain only a small portion of the gap with competitors[53].

[48] Griffith et al, 2010. "Corporate taxes and intellectual property: simulating the effect of patent boxes". IFS Briefing Note 112, Institute for Fiscal Studies.
[49] Evers, Lisa; Miller, Helen; Spengel, Christoph (2013) : *Intellectual property box regimes: Effective tax rates and tax policy considerations*, ZEW Discussion Papers, No. 13–070
[50] NESTA, 2012, *Plan I: the case for innovation-led growth*.
[51] BIS *Annual Innovation Report* 2012.
[52] Levy and Brinkley 2013, *A manifesto for innovation and growth*. Big Innovation Centre.
[53] Allas, 2014, *Insights from international benchmarking of the UK science and innovation system*, Report to the Department of Business, Innovation and Skills. P.32.

Figure 6. Estimates of UK corporate cash and investments in intangibles (including R&D) as a percentage of GDP. Source: Levy and Brinkley 2013, Big Innovation Centre.



However, concerns about levels of finance flowing into innovation are not only a problem of the supply of finance. The UK's performance in stimulating venture capital is, for example, very good compared to many competitors, particularly in core green economy areas such as clean energy. Rather, part of the problem is that much of the finance available is of the wrong type: it is not 'patient', seeking to invest in long-term value; rather it is impatient, focused on short-term returns. Following a boom in "cleantech" venture capital in recent years, it has become increasingly clear that many clean technologies require substantially longer term investments than venture capitalists are typically willing to accept[54].

Furthermore, various scholars[55] have suggested that the UK has a problem of demand for innovation finance as well as a problem of supply. Not enough entrepreneurial firms are seeking finance to invest in new products, services and business models, often because of weak capabilities, skills, or lack of confidence in emerging opportunities. The UK scores very poorly in international comparisons of the proportion of SMEs introducing innovations, and in the share of business turnover attributable to new-to-market or new-to-firm innovations[56]. These are not problems that can be solved by providing

[54] Marcus, A., Malen, J., & Ellis, S. (2013). "The Promise and Pitfalls of Venture Capital as an Asset Class for Clean Energy Investment: Research Questions for Organization and Natural Environment Scholars". *Organization & Environment*, 26(1), 31–60

[55] Mazzucato 2013, *The Entrepreneurial State*; Tredgett and Coad 2013. *The shaky start of the UK Small Business Research Initiative (SBRI) in comparison to the US Small Business Innovation Research Programme (SBIR)*. SSRN.

[56] Tera Allas (2014), *Insights from international benchmarking of the UK science and innovation system*. Report for the Department of Business, Innovation and Skills.

further tax incentives for investments in R&D, or providing a flexible and welcoming tax environment for venture capital through low capital gains taxes. They require restructuring of the financial and institutional support of the innovation system. These are issues that will take many years to address, and which clearly go beyond the scope of green innovation alone. However, part of that process of restructuring can be achieved by committing to a green innovation strategy as outlined in Section 8, and aligning innovation policy with legislated carbon targets and broader commitments to sustainable development and a greener economy. This can support the long-term vision, direction and confidence that facilitates investment in innovation by companies working in different sectors across the economy.

Secondly, relative weakness of support for regional strengths: many of the most obvious national and international success stories in innovation arise from regions that have built-up a cluster of expertise in a particular sector or field of science and technology – and indeed the regional spill-overs that characterise successful clusters are a good rationale for industrial policy that can support them[57]. A number of countries have attempted to pursue this as a strategy by developing 'cluster policies', with mixed success. A key lesson from such experiences is that establishing successful clusters takes time and dedicated effort over many years – and that it is typically not best undertaken by central government. It is unfortunate therefore that the UK's innovation support system is highly centralised, with a great deal of decision-making based in Whitehall. This has become more acute since the abolition of the Regional Development Agencies, which provided a vehicle for decentralised funding dedicated to innovation.

Recent analysis of clusters in the UK has revealed that clusters of innovation leadership can be found across the UK, with obvious examples in the City of London's financial sector, distilling in Scotland, and motorsports in the Midlands[58]. Support for these and other clusters should be delivered from regionally-embedded institutions. There seems to be a strong case for enhancing the ability of local enterprise partnerships (LEPS) to drive innovation, in particular by providing the Regional Growth Fund with an innovation funding mechanism[59]. Recent analysis from across the political spectrum has highlighted the importance of regionally-based economic and

[57] Crafts, N. 2012. *Creating comparative advantage: policy lessons from history*. ESRC Research Centre CAGE.
[58] Centre for Cities and McKinsey and Company 2014, Industrial Revolutions: capturing the growth potential. http://www.centreforcities.org/assets/files/2014/14-06-26-Final-web-Industrial-Revolutions.pdf
[59] See also Andersen et al 2011, *Making the UK a Global Innovation Hub*. Big Innovation Centre 2011.

innovation policy, and the relative weakness of UK performance in this regard[60].

Thirdly, absence of vision. A wide variety of stakeholders have complained that the innovation and industrial strategies articulated by BIS are not aligned under a broad strategic vision of future UK prosperity[61]. This is particularly true in the case of low-carbon technologies, an area in which political rhetoric has sometimes undermined confidence in long-term objectives, and a lack of commitment to a long-term funding mechanism for low-carbon innovation is likely to have held back investment[62]. The lack of strategic vision has gone hand in hand with instability in support measures for innovation. Funding has tended to be delivered through short and one-off initiatives, rather than long-lived programmes[63]. This has detrimental effects on emerging technology areas and sectors, who are unable to attract talent, finance and support on the basis of occasional short-term initiatives.

Finally, Skills. A well-functioning innovation system is underpinned by talented and skilled people. Recent reviews of the UK have indicated that technical skills are a major problem, particularly in manufacturing and advanced technology sectors[64]. While the UK has world-leading researchers in academia, the UK ranks much lower in terms of numbers of people working in research in industry. In particular, while the UK has a strong performance in terms of numbers of doctorate holders, too few of these end up working in research and innovation careers, suggesting that the career paths for those with research backgrounds are unclear[65].

UK performance in core green innovation markets

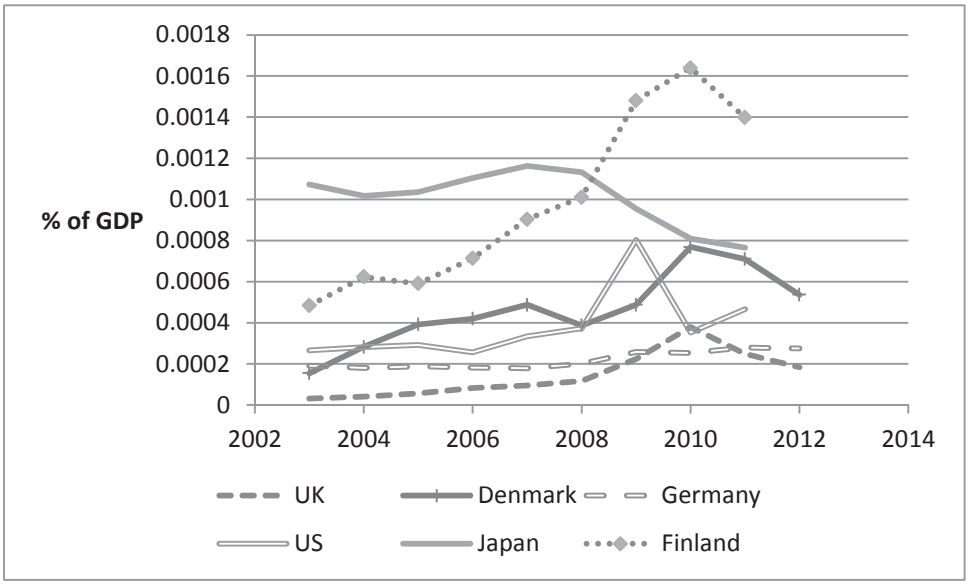
Low-carbon energy is a core green innovation arena, and has been subject to the greatest levels of scrutiny. A number of organisations have developed various indices of low-carbon innovation performance, and have typically found that the UK has some key areas of strength, but is not an overall leader.

---

[60] Heseltine (2013) *No stone unturned in the search for growth, A report to the Chancellor of the Exchequer*; Adonis (2014) *Mending the fractured economy, the report of the Adonis Review*.
[61] House of Commons Science and Technology Committee, 2013, *Bridging the valley of death; Eighth report of session 2012-2013*; CBI 2012, *Playing our strongest hand: maximising the UK's industrial opportunities*.
[62] House of Commons Energy and Climate Change Committee (2014) "Innovate to accumulate: the government's approach to low carbon innovation". Second report of session 2014-2015. Parliament.
[63] Allas, 2014, ibid.
[64] Adonis (2014) *Mending the fractured economy. Final report of the Adonis Review*, An independent review for the labour party, supported by Policy Network.; Perkins (2013) *Professor John Perkins' Review of Engineering Skills, Department for Business Innovation and Skills*.
[65] Allas (2014) ibid.

Innovation inputs for key green economy sectors are low, and particularly so for some sectors of importance for the green economy. Despite recent increases, the UK still has much lower levels of publicly funded R&D in the energy sector, as a proportion of GDP, than most competitors (see Figure 7). Similarly, the 2009 Cave Review66 found that investment in R&D by water companies in England and Wales had declined substantially since the 1990s, while another report in the same year, from the Council for Science and Technology, found that innovation performance in the water sector has been poor.[67]

Figure 7. Public funding for energy R&D as a proportion of GDP Source: IEA



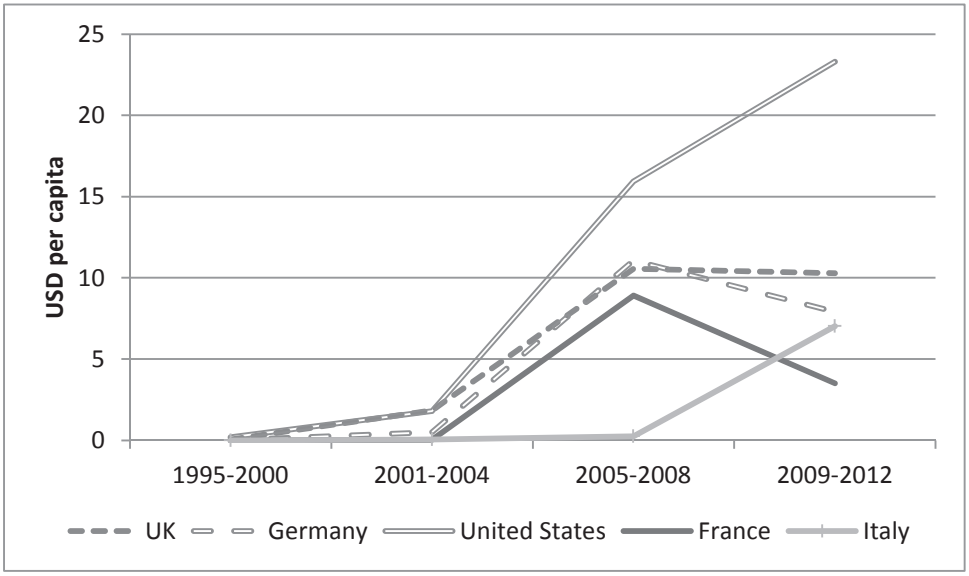
Yet as discussed earlier, the problem is not solely one of 'lack' of finance. On a per capita or per GDP basis, the UK is a strong performer in terms of venture capital into clean energy technologies, second only to the US among major competitors (see Figure 8). There has been less UK success in enabling more forward-looking, long-term 'patient' finance, with lower discount rates, which is increasingly argued to be essential for the development of an industry[68].

[66] Independent Review of Competition and Innovation in the Water Markets: Final Report; https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69462/cave-review-final-report.pdf

[67] Council for Science and Technology 2009. *A National Infrastructure for the 21st Century* (http://webarchive.nationalarchives.gov.uk/+/http://www.cst.gov.uk/reports/files/national-infrastructure-report.pdf); and House of Commons Science and Technology Committee. *First Report:* Report on Water Quality: Priority Substances. 2013. (http://www.publications.parliament.uk/pa/cm201314/cmselect/cmsctech/272/27202.htm)

[68] Hopkins and Lazonick 2013. *Soaking up the sun and blowing in the wind: clean tech needs patient capital*. University of Massachusetts; Mazzucato, M. 2013, *The Entrepreneurial State*.

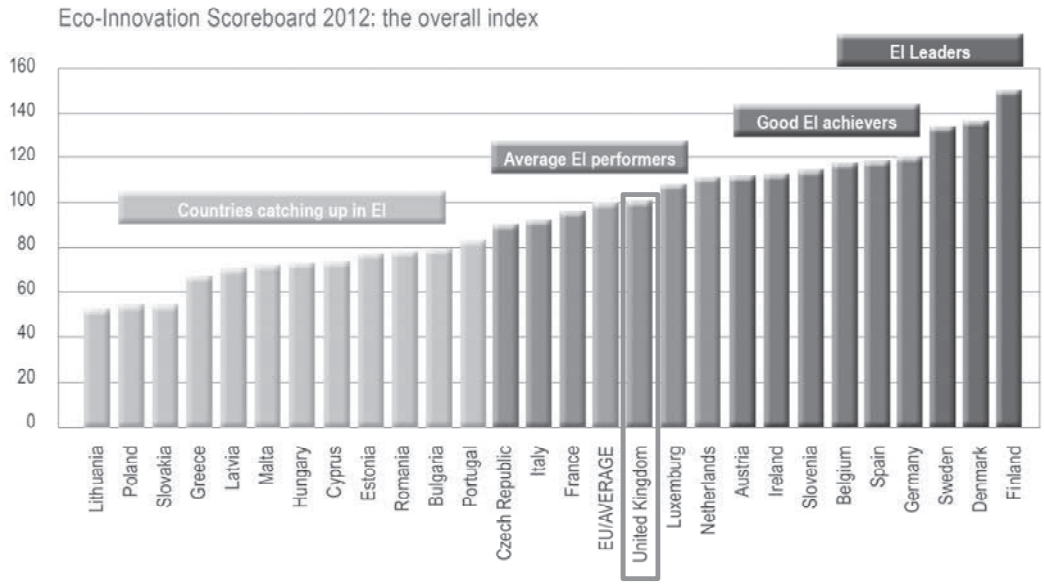
Figure 8. Average annual per capita venture capital investment in clean energy technologies in the UK and major competitors. Source: BNEF and World Bank.



Offshore wind policy and the importance of confidence

Over the past five years, the UK has established a leading position in the deployment of offshore wind. The UK's approach to offshore wind today can be contrasted with the UK attitude to onshore wind in the 1990s. At that time, policy focused on providing incentives to develop the least-cost wind technologies—but the process provided too little support, ignored barriers to new entrants, and failed to establish the nucleus of a domestic industry1. Offshore wind offers a substantial new opportunity, as the sector is still confronted with huge technology and business challenges crying out for innovative solutions. The UK should be very well placed to capture the benefits of overcoming these problems—and Government policy has been hugely supportive of the sector. While the December 2013 Autumn Statement made clear that government continues to support offshore wind, there is ongoing uncertainty about support beyond 2020 – particularly given the absence of a 2030 renewable energy target or power sector decarbonisation target. During this decade, British consumers have paid to demonstrate offshore wind at a hitherto unimagined scale, with more offshore wind deployed in the UK than the rest of the world put together; they have paid to go further offshore and into deeper waters; and they have paid for innovative designs, new business models and the development of a new industry and supply chain. But have they simply paid to enable German factories and Danish firms to benefit? Periods of policy indecision have put at risk the UK's down-payment on offshore wind leadership, and the outcome may yet be the worst of both worlds: UK consumers pay the high costs of proving and developing the new technologies while UK businesses fail to develop future export markets are lost1. UCL analysis of patent data suggests that the UK is a leading nation in terms of inventions specific to offshore wind1. If that inventive activity is to translate into innovation leadership policymakers need to provide the kind of long-term signal that will enable real supply-chain development. The announcement in March 2014 by Siemens to build a major wind manufacturing site in the UK is a welcome sign that the policy signals may be sufficiently credible to enable such investments to be made in the UK.

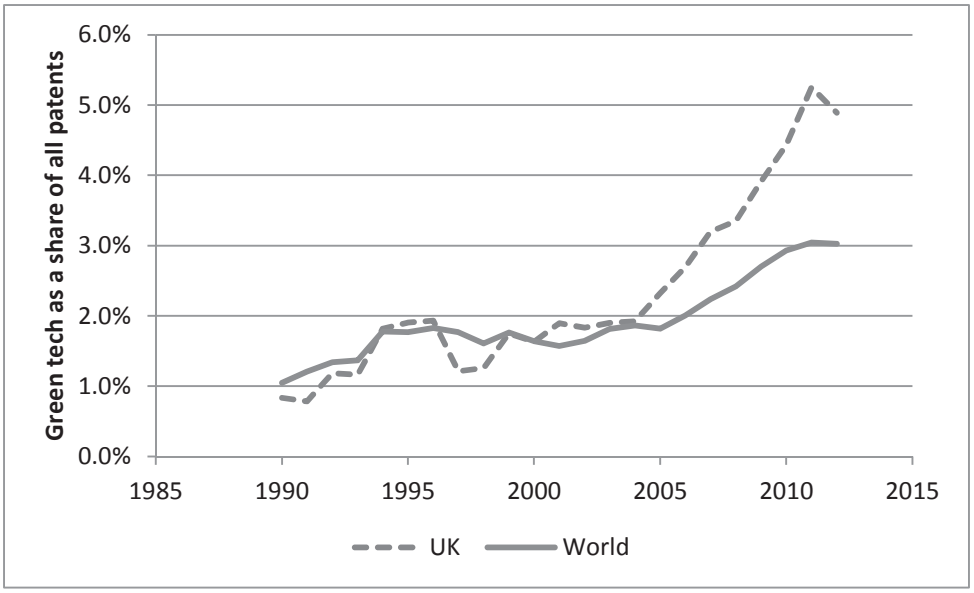
Figure 9. European Eco-Innovation Observatory: 2012 Scorecard



Ultimately, no single ranking scheme can capture the diversity of innovation activities and performance across the whole range of environmental goods and services. However, the UK's performance across these indices delivers some clear messages: the UK has some key areas of global strength, but overall performance in eco-innovation is lower than it could be. The UK clearly has the potential to do better, and the opportunity to take leading roles in key areas.

Patent data shown earlier suggested that global innovation is increasingly 'eco-innovation', at least in the sense that the proportion of environmental-related inventions is growing. This suggests that innovation systems worldwide are responding to both policy signals and environmental constraints. Despite the UK's mediocre performance on wider measures of eco-innovation, it is encouraging that patent data indicate that the UK appears to be making this transition relatively quickly (see Figure 10). This may suggest that the UK has the basic inventive capacity for strong green innovation performance, in particular a strong research base, but has a less strong record on commercialisation of green technologies, which is excluded from the patent-based indicators.

Figure 10. Share of patents that are related to eco-innovation, showing the UK and the world as a whole. Source: UCL analysis of WIPO PCT patent data



Section nine

A green innovation strategy for industrial and economic success

Standard economic approaches to environmental technology policy typically start from the observation that such technologies suffer from two distinct sorts of market failure. First, environmental externalities mean that demand for such technologies does not reflect their economic benefits, because prices do not reflect environmental damage. Second, the market failures relating to innovation in general (particularly the difficulties for entrepreneurs to appropriate the full value arising from innovations) also apply to environmental technologies. The policy prescription has generally favoured a combination of 'demand-pull' measures in the form of environmental pricing (to fix the market failures around environmental externalities) and 'technology-push' measures in the form of R&D funding (to fix the market failures around innovation).

The approach set out here, based on understanding innovation as the product of a complex system, provides an alternative perspective. Rather than fixing a broken market mechanism, government has a key role as part of the innovation system itself, helping to structure and address the systemic issues that characterise successful innovation: linkages between firms, physical infrastructures, regulatory frameworks, adequate skills provision, a financial system that meets the needs of innovation, and so on.

Cross-cutting measures: greening the UK's innovation system

Here, we focus on the ways in which government action can promote not just more innovation, but greener innovation across the economy. We recommend a mix of demand-side approaches that provide incentives for green innovation, along with enabling measures that create a more conducive economic environment for green innovation, and supply-side measures that ensure that environmental priorities are embedded in R&D prioritisation processes across the research landscape.

Vision

First, **long-term green vision backed up with tangible commitments**. The direction and framing of research and innovation activities are shaped by social and policy influences. Research has demonstrated that expectations and guiding visions play an important role in aligning innovation system players around common goals and problems, hence the rise of 'roadmapping' and other foresight mechanisms as innovation policy tools[69]. Government plays a key role in articulating a strategic vision of a low-carbon, resource-efficient and green economy, and this has a role in fostering green innovation even where it is not tied to specific funding decisions or programmes.

Long-term green objectives need to be embedded in the institutional structures that govern and direct innovation system activities. The 'sustainable development duty' of Ofgem provides a good example of a way of incorporating environmental objectives alongside others in the mandate of statutory bodies. Similarly, the establishment of legislated environmental targets—at both UK and European levels—helps to entrench confidence in the green direction of development. Innovators respond to expectations. In the US, patenting rates for technologies to reduce sulphur emissions skyrocketed during the year before strong legislation was passed[70]. The Government had articulated a clear determination to tackle the problem of sulphur pollution and acid rain, and it had a credible vision of cleaner power generation. The UK is harming its green innovation prospects by dithering over its decisions, first over the Fourth Carbon Budget, and still over the 2030 carbon intensity target for electricity, and by failing to support an EU-wide renewables target allocated to and binding on Member States.

Green fiscal reform

Second, **green fiscal reform.** Foremost among cross-cutting demand-side policies is appropriate resource and carbon emissions pricing, achieved through the tax system. Pricing is the most efficient and effective way to change consumer and producer behaviour, being transparent and non-discriminatory and thus leaving private agents to choose technologies, practices and behaviours. In so doing, it is also less liable than more targeted policy to special pleading for favourable treatment from affected industries. Credible, long-term environmental policies such as taxes on pollution have impacts on the perceived future demands for environmental goods and services: they thus stimulate innovative activities in a greener direction. Once introduced, and with the tax rate maintained or increased, they also provide a powerful signal

[69] McDowall, W. (2012) "Technology roadmaps for transition management: The case of hydrogen energy". *Technological forecasting and social change*, 79(3), 530-542.
[70] Taylor, M. R., E. S. Rubin, et al. (2005). "Control of SO2 emissions from power plants: A case of induced technological innovation in the U.S." *Technological forecasting and social change* 72(6 SPEC. ISS.): 697-718.

to innovators of settled policy intention. There is thus a good case for a shift to more green taxation, offset by reduced taxes on labour, capital or income.

In the short and medium term, there are important questions about the underlying cost structure of production sectors exposed to such pricing policies, particularly manufacturing. Recent years have seen concerns about the costs and competitiveness impacts associated with energy and energy policies, in both the automotive sector[71] and in energy-intensive industries[72]. These concerns must be placed in context: international studies show that the UK is now a highly cost competitive manufacturing location for many sectors, particularly when compared with western European competitors[73]. However, competitiveness risks are important and need to be addressed, both through working towards international harmonisation in emissions pricing (particularly within Europe), and through measures to ameliorate competitiveness impacts associated with emissions pricing for sectors in which this is a particular concern.

In the case of energy intensive, trade-exposed sectors, the potential for demand-side pricing policies is limited by the risks associated with production moving offshore, resulting in job-losses and economic costs without any environmental benefit. Here the case for targeted supply-side support, facilitating cost-saving innovations, may be particularly strong, and the case for demand-side pricing measures less emphatic. However, in the long-term, economy-wide pricing is the most effective way of ensuring that incentives to reduce carbon are felt throughout the economy.

There are similar concerns about the potentially regressive nature of green taxation, and the impact of consumer levies on fuel poverty has been the subject of considerable media interest. These are important issues, and must not be brushed aside. However, universal tax breaks for fossil fuel consumption (such as the VAT rate of 5% on domestic gas) are very poorly targeted at supporting lower income and vulnerable households. In the long term, governments should commit to reducing and ultimately abandoning the reduced rate of VAT on domestic fuels, while putting in place better-targeted measures to reduce or offset impacts on the poor[74].

---

[71] Autoanalysis 2014, *The cost base of the UK supply chain: perspectives from the automotive industry*. Research paper prepared for the SMMT, as an input into the Wright Review of Manufacturing.

[72] Orion Innovations (2014) *Walking the carbon tightrope: energy intensive industries in a carbon constrained world*. Final report prepared for the Trades Union Congress.

[73] Boston Consulting Group 2014; *The Shifting Economics of Global Manufacturing: How Cost Competitiveness Is Changing Worldwide*.

[74] "Designing carbon taxation to protect low-income households" by Ian Preston, Vicki White, James Browne, Simon Dresner, Paul Ekins and Ian Hamilton, March 2013, http://www.jrf.org.uk/sites/files/jrf/carbon-taxation-income-full.pdf

Regulation

Third, **intelligent regulation.** Environmental policies frequently drive the development and diffusion of technologies and management practices that reduce inefficiencies and waste. Currently, around 40% of manufacturing firms surveyed indicated that environmental regulation is a driving factor behind their innovation activities. This has certainly been true in the automotive sector, where vehicle emission standards have been the spur to the development of both incremental efficiency improvements such as hybrid electric vehicles, as well as radically new ultra-low-emission electric and hydrogen vehicles. The innovation impacts of environmental policies therefore at the very least reduce the net costs of environmental regulation, and have frequently been observed to have a net positive impact on firm or sector-level productivity[75]. This is often surprising to those who assume firms are profit maximising, but it occurs because businesses and households often fail to identify opportunities for waste reduction because of bounded rationality, limited information, principal-agent problems and other barriers.

The innovation effects of green policies, targeted at overcoming the market failures that lead to environmental damage, mean that such policies can also help address market failures for innovation, leading to Pareto-improving gains to productivity[76,] an idea known as the "Porter Hypothesis". As with the benefits from resource efficiency policies, it is not expected that this occurs in every case, and some theorists argue that there is a risk that R&D induced in response to environmental policy 'crowds out' R&D that would result in even higher growth[77]. Decades of evidence gathering on the contentious Porter Hypothesis have started to coalesce around some conclusions. First, it is clear that environmental regulation does frequently induce innovation; and that innovation does reduce the burden of the regulation in terms of costs to business. Evidence on the bolder claim—that such innovation will actually improve the productivity of regulated firms—is mixed. Quite simply, sometimes it does, sometimes not.

However, the green economy argument is not that green policies lead to the highest possible levels of growth but that they lead to a sustainable pathway for growth. Whilst higher short-term growth that undermines the natural capital basis for the long-term (particularly climate stability) is possible, in the long-term it risks locking in socio-technical systems to patterns that may be both unsustainable and difficult and expensive to change.

The point here is that environmental regulation does not need to be burdensome 'red tape'. Well-designed regulation provides the stimulus

[75] Ambec et al 2011. *The Porter Hypothesis at 20*. Resources for the Future.
[76] Ibid. (Ambec et al 2011. *The Porter Hypothesis at 20*. Resources for the Future.)
[77] Hallegatte et al 2012. *From growth to green growth: a framework*. Policy Research Working Paper 5872. World Bank.

innovation requires[78]. To maximise the potential for regulation to simulate innovation, regulation should be outcome-oriented rather than prescriptive; it should be stringent, providing incentives for innovation[79]; and it should set clear long-term goals as well as short-term compliance requirements, so that innovators can plan for future compliance requirements as well as those in place now. Regulation escalators—like Japan's Top-Runner Programme—provide a mechanism for incentivising innovation while keeping compliance costs manageable.

It is surprising that the HM Treasury's guidance for the appraisal of regulation and Government spending, the Green Book, contains no guidance on assessing the potential of Government action to stimulate innovation, despite supplements on a wide range of other topics (from 'optimism bias' to 'competition' and 'air quality'). Regulation isn't only about setting tough challenges. 'Nudge'[80] approaches to regulation change the choice framework through which decisions are made. Here the role of regulation is to establish the contexts – the 'choice architecture' – in which people are ultimately still free to make their own decisions but they are induced to change their behaviour towards greener choices.

Innovation-friendly regulation: Japan's Top-Runner Programme

Energy efficiency of products is a classic area in which market signals for adopting more-efficient options appear to have a weaker effect on consumer decisions than economists expect. Regulators have responded by introducing minimum appliance performance standards, and energy labels to help consumers understand the implications of purchase decisions.

Japan has taken this approach one step further, by adopting a regulatory framework that, allied to Green Public Procurement (see below), drives up the minimum standard over time, based on rewarding the market-leading technology and removing the worst performing products from the market. While environmental economic text books continue to teach that a weakness of 'command and control regulations' is that they provide no incentive for innovation, this example shows that well-designed regulation can lead to considerable and ongoing pressure to innovate.

[78] BERR 2008. *Regulation and Innovation: evidence and policy implications*. Economics Paper 4; NESTA evidence compendium report on regulation and innovation.
[79] Ashford, N. A., C. Ayers, et al. (1985). "Using regulation to change the market for innovation." *Harvard Environmental. Law Rev*iew 9: 419.
[80] *Behaviour Change and Energy Use*, Cabinet Office, Behavioural Insights Team https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/60536/behaviour-change-and-energy-use.pdf

Procurement

Fourth, **innovative and green procurement.** In times of austerity, governments must focus on value for money in procurement. But from an innovation perspective it becomes clear that smart procurement can yield dividends[81]. The importance of the NHS and BBC in the UK's pharmaceutical and creative industries respectively are well recognised examples[82]. Furthermore, governments can use green intelligent procurement to identify opportunities for savings in resources and energy, seeking innovative solutions and innovative business models that get the best value in both economic and environmental terms, so that government's considerable buying power is consciously used as one of the levers of public policy to facilitate a successful eco-innovation system.

Government has introduced various schemes to use procurement to stimulate innovation. The continued development of the UK's Small Business Research Initiative (SBRI), inspired by the successful US Small Business Innovation Research (SBIR) programme, is important. Forward procurement commitments, which commit Government to purchasing products or services that meet a given performance standard that currently is not available, have been successfully used in the past83. However, as the House of Lords Science and Technology Select Committee highlighted in 2011[84], progress has not been as great as it could have been. The Committee said that: 'It is striking the number of documents and reports published in recent years that make recommendations about innovation in public procurement. Yet it is disappointing that we have seen no evidence of a systematic and coherent use of public procurement as a tool to stimulate innovation.' Clearly more progress could be made to use procurement to further innovation in general, and eco-innovation in particular, perhaps by following the Committee's recommendation that there should be 'a Minister in each Government department with specific responsibility for procurement and innovation'. Similar points have recently been made in both the Cox Review of short-termism in business and the Adonis Review[85].

---

[81] Edquist, C. and J. M. Zabala-Iturriagagoitia (2012). Public Procurement for Innovation as mission-oriented innovation policy. *Research Policy* 41(10): 1757-1769

[82] NESTA, 2012, *Plan I: the case for innovation-led growth*.

[83] BIS 2011 Delivering the best value through innovation. http://www.bis.gov.uk/assets/BISCore/innovation/docs/F/11-1054-forward-commitment-procurement-buying-innovative-solutions.pdf

[84] House of Lords 2011, Public procurement as a tool to stimulate innovation. House of Lords Select Committee on Science and Technology. http://www.publications.parliament.uk/pa/ld201012/ldselect/ldsctech/148/14802.htm

[85] Cox (2013) "Overcoming short-termism within British business". An independent review by Sir George Cox, commissioned by the Labour Party; Adonis (2014) *Mending the Fractured Economy. Final report of the Adonis Review*, An independent review for the labour party, supported by Policy Network.

Facilitating deployment of green technologies: infrastructure for a UK green economy

The economic rationale for a strong public policy involvement in infrastructure provision is well-established. In short, the characteristics of infrastructure define the need for government involvement, since the operation of markets will provide inadequate levels of infrastructure[86]. Large critical infrastructures are beset by market failures. Economists describe these problems as relating to at least three issues: the public goods nature of many network infrastructures (meaning that everyone benefits from such infrastructures, even if they do not pay for them); network externalities (which means that a network system becomes more valuable as more people use it—the ultimate example being a telephone network, which obviously has no value at all if only one person has a telephone); and market power (meaning that network infrastructures tend to be natural monopolies in which the infrastructure owner potentially has the power to exploit consumers and avoid the pressures of competition. Moreover, the long time-scales involved in infrastructure investment highlight differences in social and private time preferences, with the public sector more willing to invest for future generations[87]. There is widespread agreement on these issues, and in particular there is agreement on the need for government to stimulate private sector investment in infrastructure.

From a green innovation perspective, one of the most important features of infrastructure decisions relate to processes of 'lock-in'[88]. Once built, infrastructure shapes the context in which the economy develops, and infrastructure can thus enable or constrain a greener development path. The risk with the Government's infrastructure policy is that the UK will build itself into an unsustainable corner from which retreat will be costly. The long-lived and structural character of infrastructure means that short-sighted investments now may lock in high-resource, high-carbon and high-waste patterns of economic activity, which will become an increasing burden in decades to come. Infrastructure owners and operators are not always exposed to the full economic risks of infrastructure failure, reducing incentives to ensure adequate resilience in the face of climate change, for example[89].

Government has been working hard to stimulate greater private sector investment—particularly from institutional investors—in Britain's

---

[86] Helm, Wardlaw and Caldecott 2009, *Delivering a 21st century infrastructure for Britain*. Policy Exchange; LSE Growth Commission 2013, *Investing for prosperity: skills, infrastructure and innovation*.

[87] Llewellyn Consulting 2013, *UK Infrastructure: the challenge for investors and policymakers*. Pension Insurance Corporation; LSE Growth Commission 2013 ibid; CBI 2011, *Making the right connections*. CBI/KPMG.

[88] Unruh 2000, *Understanding carbon lock-in*, Energy Policy; Geels 2002, *Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study*, Research Policy Vol 31.

[89] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69269/climate-resilient-infrastructure-full.pdf

infrastructure. The establishment of Infrastructure UK within HM Treasury, and the development of a national infrastructure plan have been seen as important steps forward in this regard. Unfortunately, the current institutional structures for promoting infrastructure investment—with the exception of the Green Investment Bank—fail to establish clearly the need for infrastructure to be compatible with long-term environmental goals, or to reduce exposure to environmental and resource risks. The risk is that we build a future Britain that is less resilient to expected resource constraints and climate risks, that is less flexible to the economic changes brought about by the ICT revolution and the global low-carbon transition, and that faces high costs to shift to a green development path.

A new 'knowledge infrastructure' for a green economy

Innovation relies on knowledge—both about technological possibilities and market opportunities. Public policy in its turn plays a major role in shaping the availability of environmental and economic information and the way in which it is collected and communicated in statistics, accounts and labels. Government's role in shaping the 'information infrastructure' for a green economy therefore requires explicit attention. Historically, governments have played a critical role in developing reliable economic information through national statistical agencies, providing business and innovators with key data on market trends and opportunities. However, information on the environmental and natural resource basis of the economy remains patchy.

The UCL Green Economy Policy Commission set out a series of recommendations in this area, the most central of which concerns the need for better accounting of the natural resource inputs to the economy and its environmental impacts. The recommendations, and the analysis underpinning them, are set out in the UCL report[90], and includes two key elements:

- **natural capital** accounts to increase understanding as to how and where natural capital should be maintained and augmented, and to act as an interface between the economy and the environment, to facilitate the detailed modelling of the impacts of the economy on the environment and the contribution of the environment, resources and ecosystem goods and services to the economy.
- **material flow** accounts for the UK economy that will track the flow of different materials through the economy. This would facilitate the appropriate management of materials at the end of product lives, and would make clear where there are opportunities for innovators to develop techniques and products to capture value in material flows through the economy.

[90] Ekins, P., W. McDowall and D. Zenghelis (2014) *Greening the Recovery: the report of the UCL Green Economy Policy Commission*, UCL, London, https://www.ucl.ac.uk/public-policy/policy_commissions/GEPC/GEPC_report_ES_FINAL.pdf

Embedding green priorities within the mandates of research and innovation agencies

In addition to these demand-side measures, there is scope to promote **a greening of innovation from the supply-side**. The most obvious supply-side approaches are those that are targeted specifically at core green technologies, such as renewable energy. These are discussed below, as part of the 'vertical' green industrial strategies. However, there are also some 'horizontal' (i.e. not targeted) measures that can support greening across the innovation system, by incorporating green priorities into the mandates of research and innovation agencies.

Recent years have seen a narrowing of the Government's articulated priorities for innovation and a near exclusive focus on economic growth[91]. To promote greener innovation, environmental objectives should be incorporated explicitly into the framework of decision-making around long-term science and technology priorities. While it is clearly right that the Haldane Principle applies to Research Council decision-making on programme design and grant allocation, ministers exercise considerable influence on the development of major priority areas[92]. Current processes for determining these priorities can be unclear—for example, the process by which the Government arrived at its '8 great technologies'. We follow the recommendations of the Nuffield Council for Bioethics in arguing for greater explicitness in research policy, and see an opportunity for promoting environmental (and social) objectives alongside growth.

In particular, recent years have seen the rise of the 'impact agenda', with Research Councils requiring academics to consider the kind of impact that their research might have. Though academics often read this as a thinly veiled attempt to shunt academic research towards more economically useful activities, the Research Councils' framing of impact is broad, incorporating both social and economic priorities. The environment, however, is not highlighted alongside (i.e. at the same level as) society and economy—researchers are therefore not given incentives to consider or articulate the environmental impacts that their work may have, unless they can frame these in terms of social or economic benefits.[93] This is a missed opportunity to embed environmental objectives alongside social and economic objectives in research policy. Finally, environmental objectives should be made more prominent in the mandate of Innovate UK (formerly the Technology Strategy Board), whose mandate is strongly framed around economic growth, rather than broader social objectives. While Innovate UK has shown some leadership in addressing

[91] Nuffield Council on Bioethics 2012. *Emerging biotechnologies: technology, choice and the public good*.
[92] Ibid. (Nuffield Council on Bioethics 2012. *Emerging biotechnologies: technology, choice and the public good*.)
[93] http://www.rcuk.ac.uk/documents/innovation/missionsei.pdf

environmentally relevant innovation areas, environmental objectives (and social objectives) should sit alongside growth as part of its core remit.

Targeted 'vertical' measures: green industrial strategies

Vertical, targeted measures require the development of coherent strategies for key technologies and sectors. Such strategies need to be developed collaboratively with industry, and should together establish a clear vision of the green economy for the UK. The details of particular sectoral or technology strategies will be highly contingent on the technology field. Offshore technologies require the kind of innovative leasing approach that the Crown Estate has pioneered. Vehicle technologies may require partnerships with local authorities that can facilitate support schemes: in Norway, the city of Oslo has played a leading role in supporting the development of the market for both electric and hydrogen vehicles. Rather than attempt to develop a prescriptive set of policies that form the basis for 'green industrial policy', the following sets out core principles for such a policy within a coherent framework.

A successful 'vertical' approach requires the following components.

Choosing the missions: Formal and systematic approaches to prioritisation and selection of core technologies and sectors

Government uses a range of processes for prioritising sectors and technologies for support, including foresight and technology roadmapping. In the context of the industrial strategies, Government has addressed this with analysis of areas of comparative advantage. In the context of a green economy strategy, there is a clear case for adding the environmental rationale to decisions about which technology areas and industry sectors to support. The BIS analysis used to identify sectors for industrial strategy support is very strongly framed as growth policy, and briefly refers to responding to climate change and ensuring social inclusion as economic policy goals. The environment features as a resource constraint ('strains on suppliers of some raw materials'), and as a consumer choice following rising incomes ('Rising incomes are also associated with increased demand for environmental amenities'). This is a misinterpretation of the era in which we find ourselves, in which climate change poses potentially catastrophic risks.

Furthermore, it is unfortunate that the bodies within Government that analysed and championed environmental innovation (the Environmental Industries Sector Unit and the Environmental Innovations Analysis Group) have been disbanded. Environmental innovation no longer appears to have a dedicated team within BIS. This reduces the Government's ability to identify and support emerging technologies and sectors of importance for meeting environmental goals. Examples of strategic prioritisation approaches include: Japan's Strategic Technology Roadmapping process; the US Quadrennial Energy Technology Review; and the Committee on Climate Change

prioritisation of low-carbon technologies for the UK[94]. The recently produced strategic framework of government's Low Carbon Innovation Coordination Group highlighted the intention to conduct further work on prioritisation in this area. The UK Government should seek to adopt similar strategic prioritisation approaches for eco-innovation more broadly.

Predictable, periodic re-evaluation of targeted priorities and support

A stage-gate model provides an approach for ongoing review of Research, Development and Demonstration (RD&D) prioritisation[95]. It embeds a formal and predictable process of prioritising technology and innovation needs with clear frameworks for decisions on whether to continue or reduce support. Following each stage of development, sectoral innovation programmes must pass through a 'gate' of critical appraisal. These monitoring and evaluation processes have been previously identified as inadequate within the UK low-carbon innovation system[96], and are likely to be weak elsewhere.

In response to that critique, the Government has established a Low Carbon Innovation Co-ordination Group, which attempts to provide strategic leadership across the various Government activities funding low-carbon innovation. The thematic 'technology and innovation needs assessment' (TINA) process[97] formalizes the strategic vision and technology assessment for low-carbon technologies, and provides leadership. If successful, this kind of innovation needs assessment and co-ordination could be replicated across other strategic areas of eco-innovation, such as resource productivity, encompassing high-tech manufacturing and industrial design, and agriculture and ecosystems, encompassing the UK's agri-science strengths. Finally, the evaluation approach should embed precautionary appraisal[98].

Mission-driven R&D agencies and institutions to support key technology fields

The success of the US Defense Advanced Research Projects Agency (DARPA) in stimulating the US innovation system has been well documented[99]. Other

---

[94] CCC 2010. *Building a low carbon economy: the UK's innovation challenge*. Committee on Climate Change, London.
[95] European Commission 2009. *The role of community research policy in the knowledge-based economy*. European Research Area Expert Group Report.
[96] National Audit Office 2010. *Government funding for renewable energy technologies*.
[97] See www.lowcarboninnovation.co.uk
[98] See EEA 2013, *Late Lessons from Early Warnings II*. European Environment Agency, Copenhagen; Stirling, A. (2008). 'Science, Precaution, and the Politics of Technological Risk.' *Annals of the New York Academy of Sciences* 1128(1): 95-110.
[99] Mowery, D. C., & Simcoe, T. (2002). "Is the Internet a US invention?—an economic and technological history of computer networking". *Research Policy*, 31(8), 1369–1387; Mazzucato, M. (2013). T*he Entrepreneurial State: Debunking Private vs. Public Sector Myths*: London: Anthem

mission-driven R&D and innovation agencies, including the US National Institutes of Health, have also played a critical role in supporting innovation that underpins particular social and economic objectives. The establishment of seven 'Catapult' centres is an important step in developing the UK's innovation system. However, the scale and ambition of the centres is not yet commensurate with the challenge. Recent analysis has suggested that the centres should be 'bold, ambitious and enterprising'[100] if they are to replicate the success of similar bodies elsewhere.

In addition, the Catapault centres should:

- **Build on existing regional strengths** to support the formation of hubs and clusters. Regional strengths are a fundamentally important source of long-term competitive advantage and innovation success. Experience shows that building clusters from scratch rarely works, but that existing and emerging clusters can be effectively underpinned by a keystone public institution.
- **Have a high degree of independence,** with an expectation that many projects and initiatives will fail. An absence of failures is not a sign of success. It is as likely to be a sign of timidity and a lack of entrepreneurialism – but of course failures are difficult to manage effectively. Distancing the day-to-day running of innovation agencies from ministerial control helps to shield risk-taking innovation activities from the politics of short-term value-for-money debates.
- **Be judged appropriately.** Catapults should sponsor environmental innovations that are truly radical. It is important to ensure that performance metrics for such agencies are appropriate to this task. It is often assumed to be desirable to achieve high 'leverage' ratios of public funding to private investment, showing that public money is 'crowding in' investment into target areas. But truly radical ideas will often be precisely those that are too risky to attract significant private finance in early stages. Judging programmes solely by their co-funding or leverage ratios would incentivise timidity on the part of programme managers. Similarly, the objective should not be to emulate the private sector. Public "VC" funds tend to attempt to do this – but part of the point about public equity finance for growth firms in challenge-led areas is that they are too risky for the private sector. Government has to take on the challenge of doing this, but shouldn't expect to receive similar rates of return, since part of the returns are expected to accrue socially and through spill-overs.
- **Link development with targeted early deployment in niche markets.** Niche markets play a key role, particularly in fostering technologies that can enable more radical shifts in technological paradigm[101].

[100] Andersen and Le Blanc (2013) *Catapult to success: be bold, ambitious and enterprising*. Big Innovation Centre.
[101] Kemp, R., J. Schot, et al. (1998). "Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management." *Technology Analysis & Strategic Management* 10(2): 175-195

A caricature of government funded programmes is one of capture and refusal to admit failure. In this caricature, good money flows after bad, and too long passes before failing projects, technologies or firms are abandoned. Innovation agencies need a culture that is humble about its ability to predict, and that is focused on success for the portfolio, not success for the individual project or technology. Cheryl Martin, the Director of the US energy innovation agency ARPA-E (modelled on DARPA), has described the culture required by saying that "The only thing we know about energy is that it will be different from what we think…[so] we create options. We are the optionality agency".[102]

Develop long-term patient finance vehicles for green innovation

As discussed in section 7, the UK has a particular weakness in the supply of patient finance for innovation. The Carbon Trust and ETI have been valuable vehicles for public investment in low-carbon innovation. These models could be expanded. As the British Business Bank takes shape, one option would be to consider establishing a dedicated green innovation investment arm or subsidiary.

The Green Investment Bank Commission, which reported in 2010, argued that the GIB could take on this role, providing a dedicated vehicle for early stage equity funding for clean technology enterprises. In 2011, the government decided against this, arguing that the there is a "broad landscape of government support for early-stage green and low carbon technology development". However, of the forms of support that the government lists, only the Carbon Trust provided equity investments in clean technology companies, and public support for the Carbon Trust has now come to an end. Enterprise capital funds, the key mechanism through which government has supported growth businesses, have not focused on environmental or energy-related firms, with the exception of the Sustainable Technology Fund, now closed to new investors, which provided £20m of government support to a handful of firms, not all of which were clearly targeted at "green" technologies. In addition to enterprise capital funds, the government's Innovation Investment Fund has supported low-carbon firms (more than half of the 16 firms receiving investments were in low-carbon activities), with £50m of government money earmarked for this purpose when the fund was established in 2009[103]. The environmental fund leveraged £80m of private sector money, falling well short of initial hopes.

Earlier efforts have met with mixed success, partly because they were one-off, piecemeal initiatives rather than a supporting financial infrastructure for clean-technology enterprise; and partly because they aimed to emulate the private

[102] Cheryl Martin comments at Mission Oriented Finance for Innovation, Royal Society of the Arts, London, 22–24 July.
[103] http://erawatch.jrc.ec.europa.eu/erawatch/opencms/information/country_pages/gb/supportmeasure/support_mig_0038

sector while failing to recognise the higher risks inherent in policy-dependent sectors such a low-carbon technologies.

Key ingredients include both long-term funding commitments for RD&D in core technology areas, and the development of dedicated enterprise capital support mechanisms. Note that evaluation of public sector initiatives for risk financing in 'challenge-led' areas should not hold public agencies to the same expectations as private sector VC. Public sector support may be needed precisely because the private sector cannot justify the opportunity costs of investing in a long-term, high-risk challenge-led area. Public sector 'VC' should thus not be expected to perform to private sector VC benchmarks[104]

A clearly articulated approach to the life cycle of support

Understanding of industry and technology life cycles makes clear that the timing of support is important. Support is most relevant for new industries that are becoming established around a new technology field, rather than well-established industries that have run into trouble. Similarly, early-stage technologies require dedicated support but this should shift to technology-neutral policies as the market matures. Sunset clauses and support reduction strategies should be clear from the start, and based on transparent processes of evaluation. Technologies may require support, in some cases lasting for many years, to become commercially viable. These supports are critical for success, but they must be designed in such a way as to provide the right incentives for technology improvement and cost reduction. Clear milestones and decision points over future support are critical but have been lacking in previous UK technology support measures[105].

Support should avoid premature scale-up. One-off grand projects—like full-scale CCS demonstrations—may hinder rather than help the process of developing effective technologies. The lessons from historical developments in energy technologies show that premature scale-up has frequently been less successful than incremental scale-up approaches[106].

Encourage diversity

Evolutionary processes like innovation rely on the generation of diversity. This is the fuel for the evolutionary process. Historical approaches to industrial policy often failed precisely because they neglected competition and diversity and focused on identifying champions. Sector and technology-field strategies must enable a diversity of approaches, business models and firms to

[104] Murray, G (2014) "Is public venture capital an oxymoron… or merely moronic?" Paper presented at Mission Oriented Finance for Innovation, Royal Society of the Arts, London, 22–24 July.
[105] National Audit Office 2010. *Government funding for renewable energy technologies*.
[106] IIASA 2012, Global Energy Assessment,. International Institute for Applied Systems Analysis, Laxenburg.

participate. The German support system for the earliest wind turbines restricted support for each firm and design, ensuring that a diversity of approaches was developed[107].

- This means ensuring that new entrants can access support as well as incumbents
- Diversity is enhanced by decentralising control of innovation policy, enabling regions to pursue different models of support.

Innovation, economic regulation and network infrastructures

In 'natural monopoly' infrastructures such as electricity and water networks, the Government's emphasis on competition as the driving force for innovation has been a clear failure. In energy networks this has been recognised, and Ofgem's new 'RIIO' price control process is driving a transformation of investment in energy infrastructure innovation for electricity and gas transmission and distribution. The Council for Science and Technology recommended a similar approach for water in 2009, but these recommendations have been more or less ignored, with Ofwat preferring to avoid explicit innovation incentives and rather assuming that increased competition combined with a 'totex' price control system will create sufficient incentives to invest in innovation1. The TSB conducted a review in 2011 and decided not to fund a water innovation platform, despite clear UK strengths and global export opportunities. This decision was at least partly taken because of low innovation and technological entrepreneurship within the regulated companies—itself partly a result of the structure of market regulation imposed by Ofwat. Adopting a specific innovation incentive within the price control could provide an important way of reinvigorating the innovation system around water technologies in the UK.

[107] McDowall et al, 2013. Ibid.

Section ten

Conclusions

The systemic nature of innovation in a modern economy means that governments play an important and inescapable role. It is not a matter of governments 'intervening' or not: governments are players in the innovation system and need to decide how to engage with the innovation system in an effective way. By committing firmly to a green innovation strategy, government can both facilitate the achievement of environmental goals at lower overall cost and stimulate the UK's innovation system, which has not been performing to its full potential. The UK has already committed to deep decarbonisation targets and wider commitments to a green economy. Innovation is a central mechanism by which these goals can be achieved, and an active role for government is essential in achieving this goal.

Green innovation policy is not only about supporting a few niche technologies or sectors. It combines horizontal measures that aim to facilitate energy and material savings in all sectors, with vertical measures that support key technologies and sectors that are known to be required for achieving decarbonisation targets and wider resource efficiency, and in which the UK can seek to gain some comparative advantage.

Our core recommendations for these measures are set out in the Executive Summary to this document and need not be repeated here. The policies that we outline, and have elaborated in the main body of this report, provide the essential conditions for sustainable prosperity in the future.

The TUC produces regular reports on economic and social issues, providing up to date analysis and commentary on key policy debates.

You can also read TUC policy officers' comments on the issues in the report series and the ongoing economic situation at the TUC public policy blog: **www.touchstoneblog.org.uk**

TUC

Published by
Trades Union Congress
Congress House
Great Russell Street
London WC1B 3LS

Tel: 020 7636 4030
Fax: 020 7636 0632
www.tuc.org.uk

November 2014