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Cost-competitive clean energy through global collaboration

Working with:

Foreign & Commonwealth Office

The Carbon Trust's mission is to accelerate the move to a sustainable, low carbon economy. It is a world leading expert on carbon reduction and clean technology. As a not-for-dividend group, it advises governments and leading companies around the world, reinvesting profits into its low carbon mission.

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Foreword

On 30 November world leaders will meet in Paris to launch UNFCCC COP21. They will demonstrate their commitment to deal with the challenge of climate change and the threat it poses to economic growth, our environment and the well-being of future generations. They have shown their willingness by each tabling a national contribution to emissions reduction thus creating an unprecedented opportunity to galvanise international action against climate change through a global deal.

Some of these leaders, including Prime Minister David Cameron, will also jointly launch 'Mission Innovation' - an exciting programme which aims to accelerate the development, demonstration and deployment of new clean energy technologies and ultimately to increase the scale and reduce the cost of clean energy. Mission Innovation will achieve this through creating a surge in public and private investment in R&D and through increasing transparency and collaboration on clean energy innovation.

For some time I have been championing a surge in clean energy innovation as one of the most important contributors in enabling us to keep global warming below 2 degrees. Energy contributes around a third of global emissions. Energy demand and emissions both continue to increase. There are a number of reasons why conventional forms of energy seem cheaper than cleaner forms - fossil fuel subsidies, the lack of carbon pricing and the immaturity and lack of scale of clean energy technologies. Fortune favours the brave and the bold - we need to take decisive action during this decade to reverse this trend and make clean energy widely affordable. The increased innovation and increased investment in clean energy that Mission Innovation will deliver are two of the most important things we need.

I very much welcome this very timely report from the Carbon Trust who are recognised thought leaders in innovation strategy. The report lays out why international collaboration on innovation is so important and how collaboration can be made more effective. It also suggests an approach to identifying technology leadership thus providing pointers to productive collaboration partnerships. The report provides a very valuable input to the Mission Innovation initiative as it establishes itself and gets to work during 2016.

Sir David King
UK Foreign Secretary's Special Representative for Climate Change

Executive summary

Executive summary

We stand at a crossroads. 2050, the end-of-the-line for all climate change targets is now only 35 years away. Delays and compromises that may have been acceptable fifteen years ago will now critically undercut the likelihood that global warming will be kept at or below 2°C above the pre-industrial average.

In practice, we have ten years to lay the foundations for the radical economic and technical transition that is required to avoid dangerous climate change. If you take home anything from the 21st Conference of the Parties in Paris, take this: The time for words is over. The time for action has come.

The actions that are needed cannot be solely national in scope – they need to be global. The first and most important is creating the technological base we need to sustain the conversion of our energy infrastructure to a low carbon one. While most of the technologies we need already exist, challenges remain in deploying them at scale. Innovation can help, not just in basic science but especially in both manufacturing and deployment.

We will need large scale demonstrations of technologies that are yet unproven; we will need to adapt what works in the developed world to newly industrialising countries; and we will need to create new markets through better policies and regulations so that private sector innovators have the confidence to invest in the technologies we all need.

We need to develop new technologies and we need to deploy existing ones at scale. We need to do it fast. And for that to be possible, we need to work together.

What is international collaboration?

Our aim in this report is to highlight what is happening internationally within low carbon energy, whether it is enough to achieve a 2°C world, and what more collaboration can bring to the table.

In this study, international collaborative initiatives refer to agreements between private or public institutions from two or more countries working together on a common challenge or priority. This can cover anything from broad goals (fight climate change) to specific programmes (reducing the cost of offshore wind) to projects (joint lithium-air battery demonstrations).

Collaborative initiatives can take many different forms, covering all types of policy actions and interventions along the innovation chain and may include a range of stakeholders: from government agencies and departments to technology developers and users.

Competition should not be seen as the polar opposite of collaboration. Instead, governments can work together to create enabling environments and regulatory frameworks that lead to more effective competition in the private sector.

Why collaborate?

While governments have a crucial role to play in making international collaboration more effective, it is the private sector that will ultimately drive action; both in terms of providing the required technical know-how and as a primary source of investment. In part, private sector investment will be driven by policies, such as a carbon price. However, before such policies become effective in driving the diffusion of low carbon technologies, a greater degree of demonstration and cost-reduction is required.

Demonstrations and cost reduction are expensive, but this is where collaboration comes into its own by allowing countries and industry to pool resources. Collaboration also avoids free rider problems, where one actor shoulders the burden of funding a particular technology and others capture the value.

There are also other benefits. Collaborative initiatives are effective at accelerating innovation by leveraging larger resources, increasing knowledge bases and skillsets, sharing risks and costs, and facilitating feedback mechanisms from local adaptations back to high-level strategic planning, particularly in developing country contexts.

Furthermore, in collaborating, governments can create larger markets that give companies the confidence to invest and compete in the pursuit of market shares. In short, collaboration can spread the costs and share the risks of innovation, while increasing the size of the overall pie.

We estimate that for electricity and transport alone, to be on track to meet the IEA 2015 2DS scenario we need to invest US$5 trillion[1] by 2025 – but that could be reduced by more than US$550 billion through innovation, plus US$270 billion of system benefits from storage and smart grids. This is the huge prize available to countries that decide to set aside their differences and start working together strategically on making the low carbon energy transition a reality.

What is already happening and why is more needed?

There are hundreds of overlapping bilateral and multilateral agreements, and independent global institutions carrying out roadmapping exercises.

Nonetheless, the latest IEA World Energy Outlook finds that *"despite the shift in policy intentions catalysed by COP21, more is needed to avoid the worst effects of climate change. There are unmistakeable signs that the much-needed global energy transition is underway, but not yet at a pace that leads to a lasting reversal of the trend of rising CO_2 emissions."* (IEA, 2015)

Collaboration is an especially difficult endeavour. Existing initiatives might not align incentives effectively. Transaction costs and bureaucratic hurdles at government level make it hard to organise and coordinate. IP legislation and its ancillary conflicts are difficult to manage, and some actors may lack the capacity to manage it. In general, countries find it troublesome to collaborate in areas where they perceive to have competing national interests.

As for competition, so for collaboration: Individual actors are driven by personal interest. If interests and incentives clash, there is no collaboration. But if this conflict is harnessed and competing incentives are aligned effectively, the resulting initiatives overcome the gap between words and action.

For governments, this means reaping the economic benefits of investing in innovation. However, this desire can be a barrier to collaboration when it leads to excessive competition, resulting in trade and tariff conflicts for example.

For the private sector, the incentive is acquiring valuable new IP, securing access to new markets, and sharing high risk/ high cost investments with other players, reducing the respective impacts on balance sheets.

The gaps are clear: a lack of implementation, a lack of coordination, persistent policy uncertainty, misaligned incentives, different legal and regulatory frameworks, and an unwillingness to bring to bear the financial resources required to deliver on the ambitious goals and commitments contained in international agreements. What is the solution?

[1] Estimates are based on technology deployment projections from the IEA ETP 2015 report in the 2DS scenario, plus other sources. Total figures are cumulative 2015-2025 discounted at 10%. Technology costs and cost reductions are based on Carbon Trust analysis. For a breakdown of savings by technology and a complete bibliography, see Table 2.

How can collaboration be made more effective?

Our study shows that to be effective, international collaboration needs to find ways to fully align the incentives of all participants and stakeholders.

As a first step, governments need to firmly commit to material action on climate change and low carbon energy, at the highest level possible. Already at this stage, governments should be thinking of mechanisms for joint accountability that will ensure that the desired outcomes are effectively delivered.

This commitment needs to be translated into strategic direction, such as technology priorities and systemic challenges that need to be overcome. This stage can already identify common areas of need and align incentives at a government level.

Improved coordination, at both a national and global level, helps streamline existing initiatives and pinpoint specific gaps. In some cases, transparency and knowledge sharing will be sufficient. In others, additional enabling actions, such as policy and regulatory alignment are required. Additionally, a comprehensive design process may be needed to create new initiatives.

It is at this point that efforts should be made to understand mutual needs and capabilities and to identify who the most likely actors for collaboration are. Thus it becomes easier to create organisational structures that effectively align incentives for all stakeholders involved to deliver the required end outcome.

Finally, we need to monitor that ongoing implementation mechanisms are proceeding according to plan, and feed the results back into the decision making process.

At every stage, the participation of the private sector is of fundamental importance. Ultimately, knowledge on what the innovation needs are resides with technology developers and users. The most successful collaborative initiatives have always seen governments take a low profile role of providing an enabling environment, while allowing the private sector to set strategic direction and milestones.

What we suggest is not the wholesale creation of an entirely new organisational structure, rather we recommend the reorganisation of what already exists, adding transparency, coordination, and prioritisation, with a real focus on accountability towards the end outcome. Thus creating the environment needed for technology-specific initiatives to be set up by groups of countries and companies that share common needs.

Even a piecemeal approach looking to fill the gaps that exist – from a strategic level down to individual technology needs – could prove extremely effective at accelerating the development and deployment of low carbon energy technologies, bringing a 2°C world closer to our grasp.

The decision is no longer when to act, but how.

Technology case studies

We have created five technology case studies in order to demonstrate how international collaborative initiatives could be structured. Each technology has different innovation needs and collaboration drivers at different stages of the framework described above. The case studies illustrate how different interventions are needed by technologies to plug remaining gaps, align stakeholder incentives and accelerate low carbon development and deployment.

Carbon Capture & Storage (CCS)

The key components of CCS are quite mature, as they have been used by the oil industry for decades. The main innovation needs are multiple source-to-sink demonstrations to iron out how the technology could work in practice and assess cost-effectiveness.

The key **collaboration drivers** are sharing the costs and risks of running multiple high-cost demonstrations. For industry, a solid commitment by several countries to support a pipeline of demonstrations would be a fundamental incentive to invest in the technology.

On the **enabling** side, a carbon price will clearly be needed. If demonstrations can prove definitely that CCS works at an acceptable price, this will make it easier for the private sector to accept a carbon price.

Our recommendation is for a group of countries to work together to build numerous commercial scale source-to-sink demonstration plants in localised contexts. On the longer term, collaboration around policy incentive mechanisms such as carbon prices is also needed.

Energy Storage

Energy storage technologies broadly divide into two categories; distributed and bulk storage. The main **innovation need** for the former is additional cost reduction through innovation. For the latter, it is large scale demonstrations in different electricity grid settings. Both also need development of common systems integration procedures, including performance and operating standards.

Collaboration is key to **enable** both advances, through better knowledge sharing, coordination and transparency, and through sharing of costs and risks of demonstrations.

New collaborative test centres could support standardisation efforts, including new business and contractual models to help incentivise grid operators to innovate. For bulk storage, government funded large pilot and joint-industry demonstration projects are needed.

Offshore wind

The main **innovation needs** that must be addressed to facilitate further diffusion of offshore wind relate to the development of new foundations, improved wake and load models, as well as control and maintenance systems to reduce costs.

Collaborative initiatives can play a key role, not only in spreading the investment costs across actors to overcome risks, but also in providing mechanisms to share Monitoring, Reporting and Verification (MRV) data and to invest jointly in areas of mutual benefit.

Long term policy certainty around offshore wind deployment objectives and its role in the energy system is the main **enabling** measure needed.

In order to bridge existing gaps, governments need to collaborate in setting long-term offshore wind targets paired with appropriate support structures. These are required to reduce supply chain costs through investment, innovation and economies of scale. In particular, international collaboration needs to align academic and industry RD&D with the aforementioned targets to adapt support to reflect both technology maturity and returns on investment.

Smart grids & electricity networks

Due to the relatively small nature of the technological components involved, innovation in smart grids is already taking place quite efficiently in the private sector. The main **innovation need** is the development of common technology standards for smart grid components, which play a crucial role in accelerating deployment and cost reduction. Further, there is a need for large pilot and demonstration projects, which are required to test both grid integration and business models.

Collaboration drivers focus on the need for standardisation and interoperability of smart grid components, and support for large scale on-grid demonstrations and the creation of new business models to **enable** deployment.

Our recommendation is for large-scale system level consortia-led demonstration projects that link smart grids to other technologies, and prove both their technical feasibility and the potential business models to capture their value. A strong push on standardisation across different electricity markets, involving transmission and distribution network operators, is also needed.

Marine energy

Marine breaks down into wave energy and tidal energy, each of which has different **innovation needs**. Wave energy needs additional research and development into main components and subsystem wave converters to reduce costs and improve reliability – here, concepts must be demonstrated at a single device level before making the leap to small arrays.

Tidal stream power has already undergone a broad convergence in design. Current needs relate to transitioning from device demonstrations to initial array demonstration projects, plus additional innovation in subsystem technologies such as foundations and moorings.

Collaboration on wave energy is needed to support technology development to converge on a single design, and on tidal for array demonstrations.

For wave, the main recommendation is a targeted innovation programme that supports devices and components in small scale R&D settings, backed by more coordination at government level to facilitate convergence. For tidal energy, countries need to support array scale demonstrations. Across the board, more policy commitment for marine is also needed.

Part A

Global Collaboration Framework

1 What is international collaboration?

1.1 The three stages of collaboration

Collaboration initiatives on innovation are agreements between two or more national governments, government agencies or private sector institutions to work together on a common challenge or priority.

The structure of collaboration initiatives changes along two main axes, one in terms of level of detail or definition, and the second in terms of the maturity of the technology being addressed.

At an institutional level, three broad stages of collaboration can be identified (Anadon, et al., 2011):

1. High level intergovernmental **agreements**, usually establishing a common goal or recognising shared needs and priorities, taking the form of signed agreements or discussion agendas for international dialogues. The UNFCCC is the most high profile example (see text box)
2. International cooperation **programmes**, which are more specific than agreements, usually involve executive government agencies or departments, and have specified sets of practical activities
3. International cooperation **projects**, usually focusing on specific technology-level challenges, often at the component level

These three stages should not be seen as separate. Rather, they flow one into the other, driving increased implementation at each stage as the details and action focus become more defined.

UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE

The UNFCCC is an international agreement aimed at fostering collaboration between all countries in the world to stabilise concentrations of GHGs in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Actions undertaken under the Framework have included the creation of national GHG inventories and the Kyoto protocol, which involved commitments by individual countries to reduce their GHG emissions. The Framework also supports enabling bodies providing implementation and policy support through centres such as the Climate Technology Centre & Network (CTCN), and funds such as the Green Climate Fund. Conflicting national priorities, particularly between developed and developing countries, have led to difficulties in implementing further actions after Kyoto.

Stage one provides commitment and a degree of strategic direction, but is not likely to lead to implementation, unless it already specifies very concrete actions such as a doubling of R&D spending on a specific technology area or group of technologies. Even so, it is hard for such a commitment to be translated into practical action without a more directed focus on programmatic initiatives.

While high level strategic roadmaps and potentially action plans can already be drawn at this stage, they are likely to face difficulties in moving forward with implementation, particularly involving private sector actors.

Stage two creates the programmatic initiatives within which implementation activities can take place. At this stage inputs from the private sector and academia become more important to help define technology needs and how collaboration can address these. While more concrete than the previous stage, it can be more difficult to set up due to the emergence of concerns around national competitiveness and value capture, Intellectual Property (IP) conflicts, and unwillingness to share costs (see section 2 for more detail).

Finally, **stage three** covers technology-specific projects and is entirely focused on implementation. This type of project can usually fit within the broader scope of a programmatic initiative.

The second axis, concerning technology maturity, generally comes into play at this stage as different technologies or sub-components will be at different stages of the innovation chain[2], and this affects the type of activities that may be more useful.

Collaborative initiatives can include programmes and projects focused across the innovation chain and cover all the main types of policy interventions, from technology push to market pull to enabling mechanisms. This includes basic R&D, pilots and demonstrations, knowledge sharing, policy and regulatory coordination, strategic planning, and monitoring for feedback mechanisms.

1.2 Types of collaboration initiatives

As mentioned in the preceding section, collaboration initiatives can be broadly divided into three main categories: agreements, programmes and projects.

When discussing incentives for innovation, it helps to divide these into push, pull and enabling mechanisms. Push is a form of direct funding for research, both at basic and applied level and up to demonstrations. Pull is used to sustain deployment and commercialisation through market-creation measures such as subsidies (feed-in tariffs being the classic examples). Finally, enabling mechanisms are measures that facilitate the development of a technology, both at the research stage and through to commercialisation (through knowledge and data sharing, IP support, standardisation and regulatory measures).

EUROPEAN SOLAR TEST INSTALLATION (ESTI)

In 1977 the EU's Joint Research Centre created the European Solar Test Installation centre specifically dedicated to testing solar PV equipment. ESTI was created in a crucial period of the development of solar PV, with only one other comparable test centre in the world at the time, in Japan. ESTI testing underpinned EU-wide performance standards for PV, supporting the industry in converging upon a single standard. By establishing strict but achievable industrial standards in the photovoltaic conversion area, ESTI significantly contributed to the development of the industry, providing certainty of output, assuring quality, and providing feedback on R&D projects.

Collaboration initiatives can contain all three of these elements, or be focused more strongly on one or two.

Figure 1 presents examples of relevant initiatives at all three levels. The illustration is not meant to be exhaustive, but rather to provide an idea of the primary purpose and coverage of different types of initiatives. The UNFCCC is a good example of a high level agreement including elements of all three policy types, while the US-China Clean Energy Research Centre is a basic to applied R&D initiative covering multiple technologies and as such does not have the specificity of a programme or project.

The Offshore Wind Accelerator (OWA) is a good example of a collaborative initiative involving the UK government and most major European offshore wind developers. It runs competitions to identify promising innovations and supports their demonstration in the field. The OWA covers multiple technologies within the broader offshore wind area such as access vessels, foundations, cables, etc.

At project level, CERN and ITER are two well-known examples of single-purpose, large scale facilities with multinational funding. On the pull-enabling nexus, ESTI was instrumental in getting the European PV industry off the ground by supporting standardisation efforts (see text box).

[2] The innovation chain is a concept to describe the 'journey' that a given technology or component has to go through to become a product. It begins with basic science research, usually in a lab, progresses through applied research, demonstration, early deployment, and full commercialisation.

At programme and project level, a further taxonomic step can be defined based on the stage of the innovation chain that the target technology is at. This will affect the source of funding for the programme or project, the stakeholders involved, and thus the structure of the collaboration initiative itself (Sagar, De Coninck, & Ockwell, 2012).

Table 1 illustrates this distribution along three broad areas of the innovation chain. Section 3 goes into greater detail on how these different models work to achieve the aims of collaborative initiatives.

Figure 1: Collaboration initiatives and policy types

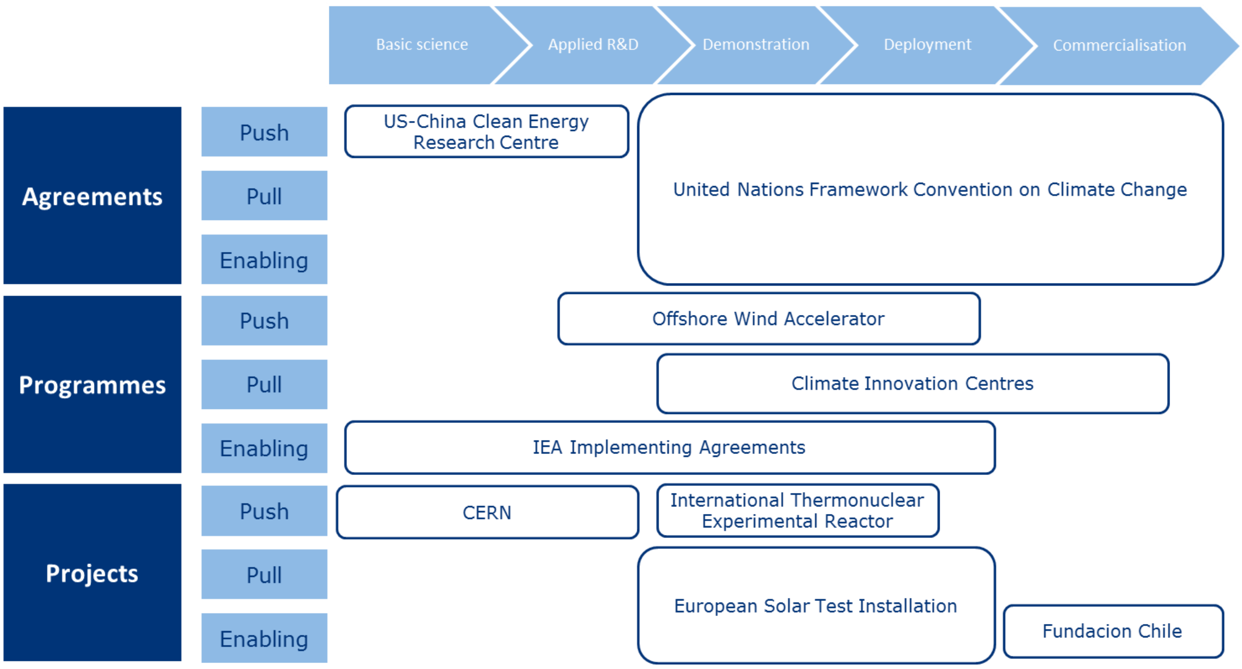


Table 1: Funding, stakeholders and collaboration models along the innovation chain

Activity	Early R&D to applied research	Applied research to demonstration	Demonstration, deployment and commercialisation
Funding	Almost completely public	Mostly public, some private	Private and public
Stakeholders	Governments, universities, dedicated laboratories	Governments, universities, dedicated laboratories, industry, NGOs	Governments (pull policies & regulations), industry, dedicated laboratories
Collaboration models	University-university, network models, global facility	University/laboratory-industry, network models, innovation centres	Industry-industry (horizontal & vertical), university/laboratory-industry, network models

1.3 The role of competition

While the focus of this report is on international collaboration, not mentioning competition would be a crucial omission, both because the latter is often a driver of innovation on its own, and because competition itself can operate within the broader framework of international collaboration.

At a basic level, competition between private sector technology developers is one of the main drivers of innovation. Companies seek to be the first to develop a new product or business model that will allow them to gain market share and increase their profits at the expense of their competitors.

However, this process is often exceedingly focused on applied research and commercialisation, and has a short time horizon. While collaboration between universities and industry to turn basic science into products is not unheard of, governments remain by far the largest funders of basic R&D. As such, international collaboration remains a more effective mechanism for incentivising effective basic R&D than competition between private sector stakeholders.

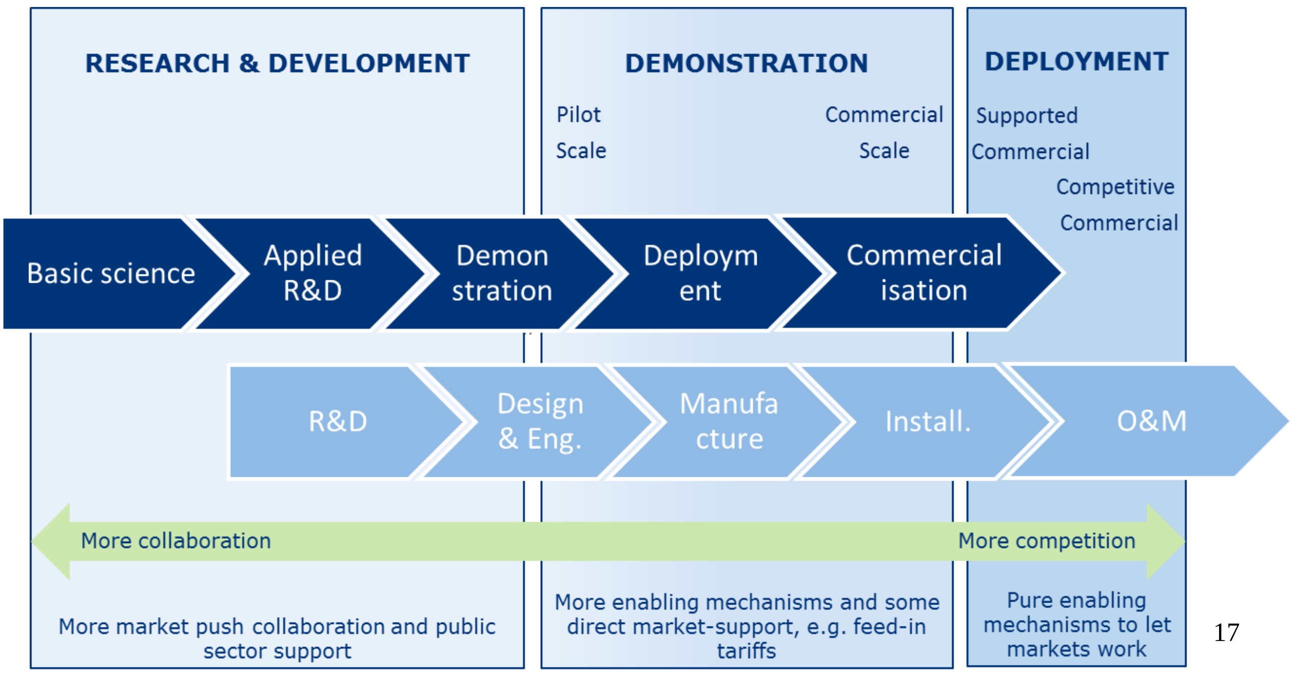
In the early demonstration to deployment stages, the private sector becomes more important. Large corporations have run their own research facilities and test centres, and have carried out large scale demonstrations. However these remain quite rare, particularly for more innovative technology areas where the future market potential is uncertain. This is particularly relevant for low carbon energy technologies.

As such, in the middle of the innovation chain international collaboration is essential to provide enabling mechanisms, such as standardisation, the streamlining of market regulations and policy incentives that can give companies the certainty they need to invest in low carbon innovation.

The differing roles of collaboration and competition are in part explained by the degree of overlap between the innovation and value chain.

The value chain is a similar concept to the innovation chain, with partial overlap. At its most basic, a value chain is a set of activities that a firm performs in order to deliver a product or service to the market, and it breaks down where value is captured. In Part B of this report, we look at technology specific case studies, and rank countries according to their competitiveness on the value chain (see section 4.6 for more detail). Figure 2 shows how this process works, and how the balance between collaboration and competition changes between the innovation, in dark blue, and value chain, in light blue, and the role of competition.

Figure 2: Overlap between the innovation and value chain and the role of competition



2 Why collaborate?

2.1 Collaboration as a means to accelerate innovation

The challenge presented by climate change is beyond the ability of any single country to tackle individually. As recognised by the UNFCCC process, global solutions are needed.

Transitioning to a low carbon world presents difficulties along all axes of economic activities, but the most urgent is energy. For the planet to successfully bring GHG emissions under control, clean and low carbon energy needs to become reliable, secure and affordable. Innovation is key to making this happen.

By and large, the technologies we need to make this transition already exist. Some, such as onshore wind, are fully mature and require only a degree of policy support. Others, such as offshore wind, are well understood but still too expensive. Some, such as CCS, are proven in theory but will require expensive demonstrations to iron out the details. And some other ones are moving rapidly across the innovation chain towards commercialisation but still need efforts around standardisation, regulatory alignment, and market demonstrations, such as energy storage and smart grids.

The investment needs to deploy all these technologies at the required scale however, are immense. The private sector will have to bear the brunt of them. As such, the public sector should strive to create the necessary enabling environment where this investment can happen.

While policies such as carbon prices could theoretically be sufficient, until all of the required technologies have reached a certain level of cost-competitiveness and have been fully proven commercially, introducing carbon taxes or similar initiatives will be politically difficult.

At the same time, policy in support of early deployment such as feed-in tariffs can catalyse massive cost reductions – as happened in solar photovoltaics – but at the potential cost of seeing countries supporting deployment 'leak' large shares of the value to others, such as technology exporters. A classic example is the German feed-in tariff essentially acting as a subsidy to Chinese solar PV manufacturers.

International collaboration can be a mechanism to resolve these disputes and conflicts. Collaboration catalyses innovation by allowing more R&D and demonstration investment, thanks to shared costs and risks. It also accelerates innovation through shared knowledge and technology transfer, and accelerates deployment by supporting tailored demonstrations and adaptations to local contexts.

The cost of expensive subsidies or demonstrations can be shouldered by more countries, and agreements can be put in place to ensure that, in so far as it is possible within the framework of a competitive market-based global economy, the benefits of these policies are captured by the countries that are actually paying for them.

Furthermore, by collaborating, governments can create larger markets that will give companies the confidence they need to invest and compete in the pursuit of market share. In short, collaboration can spread the costs and share the risks of innovation, while increasing the size of the overall pie.

We estimate that for electricity and transport alone, to be on track to meet the IEA 2015 2DS scenario, we need to invest US$5 trillion[3] by 2025 – but that could be reduced by more than US$550 billion through innovation, plus US$270 billion of system benefits from storage and smart grids. This is the huge prize available to the countries that decide to set aside their differences and start working together to make the low carbon energy transition possible. A full breakdown by technology is provided in Table 2.

All the drivers to collaboration are largely shared by countries. When they overlap with specific technology needs, effective collaborative initiatives can be created.

[3] Estimates are based on technology deployment projections from the IEA ETP 2015 report in the 2DS scenario. Total figures are cumulative 2015-2025 discounted at 10%. Technology costs and cost reductions are based on Carbon Trust analysis.

2.2 The importance of developing countries

Developing and newly industrialised countries will represent 90% of the growth in future energy consumption by 2050. Without massive innovation, it is likely that they will satisfy most of these energy needs through fossil fuels, leading to unsustainable increases in emissions. This challenge is different from the one faced by developed countries, which need to replace existing high-carbon energy infrastructure with a low carbon one in the context of very low growth and decreasing populations.

Developing countries can only be successful in their low carbon transition if effective innovation mechanisms are in place that will allow not only for 'top down' technology transfer, but more importantly for feedback processes between local demonstrations and R&D, leading to adaptations to local needs. It is very likely in fact that new innovations will emerge from this very process of adaptation and 'tropicalisation'.

As such, international collaborative initiatives in low carbon innovation will have a key role to play in going beyond joint R&D funding and towards local pilots and demonstrations and the related knowledge sharing and feedback mechanisms. Any successful effort to accelerate clean energy innovation must, therefore, recognize the central role that developing nations will play as innovators themselves (Singh, 2012, p. 2).

Table 2: Investment and benefits from selected low carbon energy technologies

Technology area	Technology	Investment need to 2025 ($bn)	Cost reduction through innovation to 2025 ($bn)	System benefits to 2025 ($bn)
Wind	Onshore wind	896	82	-
Wind	Offshore wind	186	15	-
Solar	Photovoltaics	404	41	-
Solar	Concentrated Solar Power	243	22	-
Bioenergy	Biomass	394	71	-
Bioenergy	Biofuels	275	50	-
Bioenergy	Waste to Energy	111	-	-
Geothermal	Geothermal	54	5	-
CCS	Carbon Capture & Storage	287	14	-
Marine	Tidal	16	8	-
Marine	Wave	32	8	-
Smart Grids	Demand Management	341	24	200
Smart Grids	Transmission & Distribution	274	17	13
Energy Storage	Batteries	58	7	36
Energy Storage	Hydrogen Fuel Cells	31	9	6
Energy Storage	Flywheels	0.3	0.05	2
Energy Storage	CAES [4]	11	2	11
Energy Storage	Capacitors	8	2	3
Transport	BEVs and PHEVs[5]	1,339	177	-
Total	**Total**	**4,959**	**554**	**271**

Source: (IEA, 2015), (Green Energy Storage, 2015), (GBI Research, 2013), (Navigant Research, 2013), (IEA, 2012), (Vision Gain, 2015), (Ernst & Young, 2013), (Chang, et al., 2014), Carbon Trust analysis

[4] Compressed Air Energy Storage
[5] Battery Electric Vehicles and Plug-in Hybrid Electric Vehicles.

3 What is already happening and why is more needed?

3.1 Existing energy innovation collaborative initiatives

The recognition that international collaboration is effective at supporting low carbon innovation is supported by the existence of hundreds of bilateral and multilateral agreements on energy innovation worldwide, involving all developed countries and a majority of the developing ones.

A 2011 report on US energy innovation estimated that *[...] the U.S. government is involved in 175 bilateral agreements, at least 21 international multilateral agreements with an ERD3*[6] *component, and ERD3 programs and projects in 9 U.S. government departments and 10 agencies* (Anadon, et al., 2011, p. 284).

Several multinational enabling bodies also exist, producing technology roadmaps and providing knowledge sharing and other support services. The most relevant ones are the International Energy Agency (IEA), the International Renewable Energy Agency, and the European Union (due to its stated goal of transforming the continent into an integrated "Energy Union").

The role of enabling bodies, such as the IEA, is particularly important to successful collaborative initiatives. Ideally, their purpose would be to act as a conduit between high level commitments and agreements stipulated between national governments, and implementation activities such as programmes and projects at bilateral and multilateral levels, ensuring effective involvement of the private sector.

However, gaps remain that make their activities less effective than they could be. This is because despite all the benefits described before, collaboration remains a really difficult endeavour. Existing initiatives might not align incentives effectively. Transaction costs and bureaucratic hurdles at government level make it hard to organise and coordinate. IP legislation and its ancillary conflicts are difficult to manage, and some countries or companies might lack the capacity for IP management. Also, in general, countries do not find it easy to collaborate in areas where they might perceive they have competing national interests. To define the remaining gaps and devise solutions to address them, we have carried out an extensive consultation with experts on international collaboration from 12 different countries.

3.2 Barriers to collaboration

There are several issues that hinder the successful establishment of collaboration initiatives. These are usually centred on contrasting interests or priorities on the part of stakeholders. As such, depending on the stage of collaboration initiative and the stakeholders involved, different barriers might apply:

- *Desire for local development* – countries might privilege developing more expensive local solutions that might generate more growth domestically rather than risking losing value to international partners.
- *IP and knowledge sharing* – for technology developers, retaining IP is the most important thing, and they may be concerned that by participating in collaborative initiatives with larger corporates they will be unable to defend their IP in the case of conflict due to their inferior legal resource. Similarly, developing countries with lower IP management capabilities might see less innovation happen for similar reasons, and might not be chosen as collaboration partners.

[6] Energy Research, Development and Demonstration

- ***Policy and legal differences*** - collaborations are influenced by policy, regulations and legal structures that in many cases differ across countries. It is hard for two countries to work together on a joint technology project when their electricity markets are completely different and require tailored technological solutions.

- ***Power differences*** - participants usually have strategic goals and desire control. In this context, geopolitical agendas may also hamper international collaboration.

- ***Bureaucracy*** – existing collaborative structures can be less effective if access to their resources requires going through exceedingly onerous processes, particularly for smaller innovators. This is just as true for national innovation programmes.

- ***Lack of flexibility*** - national governments and funding agencies might be less receptive to innovative ideas for collaborative initiatives coming from the private sector if they appear to contradict priorities established by the government at the beginning of the fiscal year, or of the funding cycle. This also ties back to the desire for local development, where funding agencies might be unwilling to spend on initiatives where the benefits are shared internationally, especially if there isn't a clear case for national benefits.

The relative importance of these barriers also changes along the innovation chain:

- ***R&D and design*** – stronger issues around protecting IP or acquiring ownership of it at the end of the collaboration.

- ***Demonstration and early deployment*** – for developing countries, concerns around prioritising national development through "local content" rules; for owners of IP, concerns around losing control of IP.

- ***Deployment scale up and commercialisation*** – scarce incentives to share performance data, concerns around retaining a competitive advantage.

For a collaboration initiative to work as intended, it is essential that these barriers are addressed in the initial design phase. In particular, involving the private sector will require creating a structure where the management and ownership of IP is extremely clear from the start, and where small technology developers with innovative ideas can feel safe in the knowledge that they will not have to fight large corporates with considerable legal budgets for

OFFSHORE WIND ACCELERATOR

The Offshore Wind Accelerator (OWA) is a successful collaborative initiative run by the Carbon Trust with funding from the UK's Department of Energy and Climate Change and the Scottish Government (one third) and 9 major European offshore wind developers (two thirds). The programme focuses on accelerating cost reductions by supporting the development of innovative technologies such as access vessels, wind resource measurement technologies, cables and other technologies, which together make up 70% of the cost of offshore wind (the rest is the turbine itself). The OWA runs open competitions to select the most promising new technologies and then funds their piloting and demonstration. It is a successful example of a private sector led initiative and has so far managed to reduce the cost of offshore wind by at least 10%. The secret to its success is the alignment of incentives across all participants. The government gets cheaper offshore wind technology for its renewable energy targets without having to pay the full cost of the technology development process. Technology users (offshore wind developers) get to influence the development of new technologies from the start, ensuring it will fit their needs, while also paying only a tenth of the development costs, as these are shared with all other developers. Technology providers (start-ups and SMEs primarily) get direct access to their primary market plus funding to demonstrate and commercialise their products. In terms of IP, technology providers retain most of it but technology users get licenses at preferential rates. IP management was defined upfront in consultation with the technology companies and this was crucial in ensuring the success of the programme.

the right to retain their own IP. An example of a programme successfully aligning incentives for all players is the Offshore Wind Accelerator (see text box on previous page).

3.3 The role of roadmaps

One of the main instruments that is supposed to fill the gap between high level commitments / strategy and actual implementation through programmatic initiatives is the 'roadmap'. Enabling bodies such as the IEA usually create roadmaps which are global in scope. However, national governments and departments also create roadmaps, usually centred on local technology needs.

The IEA defines a roadmap as *"a specialised type of strategic plan that outlines activities an organisation can undertake over specified time frames to achieve stated goals and outcomes"* (IEA, 2014). An effective roadmap should outline a set of priorities – e.g. policy advances or demonstration projects – that are needed to achieve goals. Engaging stakeholders to address near-term priorities is a key first step in implementing a roadmap. Milestones should be included to allow delivery partners to assess progress towards implementation.

However, the practical experience with global roadmaps has highlighted a distinct lack of implementation actions following from the publication of the document.

We have identified several problems affecting global roadmaps:

- ***Lack of implementation*** – global technology roadmaps have proven to be too high level and generic to lead to any actual implementation. What little activity there has been has generally focused on identifying needs and knowledge sharing.
- ***Lack of coordination*** – there is no centralised repository where roadmaps and other collaborative initiatives are stored in order to avoid duplication and oversee existing programmes.
- ***Lack of certainty*** – roadmaps have generally lacked a financial component to identify possible funding routes, leading to uncertainty on the part of the private sector on whether to follow their recommendations or not.

3.4 The challenge of implementation

Successfully structuring collaborative initiatives that harness all the incentives for the different players in a synergistic way is difficult. This fact is demonstrated by the lack of implementation of programmes or projects based around the needs identified by governments or enabling bodies.

At an international level, the IEA supervises a series of mechanisms called Implementation Agreements which are explicitly meant to lead to the creation of programmes and projects, from policy studies to full scale demonstrations and large facilities.

Nonetheless, the same 2011 report which looked at the US innovation system found that *[…] out of the 117 IEA Implementing Agreements, fewer than a third of them support R&D activities (37), and even fewer than that support demonstration (10). Except for solar PACES, there are no IEA IA projects where countries are jointly building demonstration* projects […] (Anadon, et al., 2011, p. 207)[7].

Our interviewees have also indicated that while IAs are useful as a means of bringing together experts from different countries and institutions, sharing knowledge and lessons learned, they often have very little funding available to carry out joint R&D or demonstration projects[8].

[7] It is worth noting that the definition of 'R&D' used by the Harvard Kennedy School report (quoted above) is narrower than definitions typically used by the IEA and the OECD Frascati Manual.
[8] Though IAs do not at present offer direct access to funding, our interviewees at the IEA indicated that IAs have been used to do so in the past. In principle, they could be used to do so again in the future.

While moving from strategic commitment to implementation is perhaps the hardest challenge, problems also remain at programme and project level, including IP conflict, contrasting national regulatory and policy systems, and an outright lack of technical and institutional capacity (particularly in developing countries).

We have summarised the main gaps around international collaboration in six key bullet points:

1. ***Alignment of incentives*** - Positive incentives are crucial – for nations, for companies, for universities, and for individuals. If they clash, there will be no collaboration. But if this conflict can be harnessed and competing incentives aligned effectively, the resulting initiatives will manage to overcome the gap between words and action.

2. ***Global roadmaps*** are not useful – except for prioritising and creating a global vision. To be more effective, roadmaps need: government commitment, an implementation mechanism, location specificity and stakeholder engagement; particularly technology developers and users.

3. ***IP conflict*** - We mentioned the role of IP conflict in deterring smaller technology companies in bringing their innovation to the table. While this is certainly an issue, IP overall has not been identified as a major barrier to collaboration per se. Rather, clear ownership structures must be defined at the design stage of a new collaborative initiative, so that smaller players can be reassured and incentivised to participate.

4. ***Capacity building*** - For developing countries more support and capacity building is needed, both to strengthen their IP protection capabilities and allow them to both incorporate innovations more effectively and provide useful feedback on the adaptations needed to make a particular technology work in different contexts.

5. ***Standards*** (technological and legal) - policy and legal frameworks act as a barrier to innovation on account of increased transaction costs, including risks of vetting collaborators, and also as a barrier to diffusion. A key role for government exists in breaking down these barriers and creating facilitating environments, allowing for the private sector to effectively feed in and take the lead on technology specific initiatives.

6. ***Funding*** – despite the stated advantage of collaboration as a risk and cost sharing mechanism, pooling of funds and resources is surprisingly rare, at least at government level.

4 How can collaboration be made more effective?

4.1 Solving the implementation challenge

At a very high level, the problem with international collaboration is that while hundreds of initiatives, roadmaps and action plans already exist, they are not leading to sufficient investment and implementation.

The solution, therefore, is not necessarily to create new structures, but to make existing ones more effective.

To do so, some essential steps are:

- Mapping out the key stakeholders and the role they play in the innovation process.
- Understanding the incentives and barriers to collaboration for each of them.
- Defining national goals and priorities and assessing how they match against the potential collaboration models.

4.2 Stakeholder mapping

Figure 3 shows how governments, academia, the private sector and enabling bodies all have an essential role to play in the innovation process. Any collaborative initiative focused on innovation will have to involve each of these actors in some way. The challenge becomes how to ensure that each individual actor is interested in participating, and that the goals of the collaboration initiative align with their incentives. Table 3 shows the barriers and incentives by stakeholder type.

To be effective, collaborative initiatives will have to be designed with these incentives and barriers in mind. Successful programmes are those that manage to combine the potentially competing interests of all the different stakeholders in a way that encourages them to collaborate instead of compete, and where everyone is aligned with the overall goal of the initiative.

Figure 3: Map of innovation stakeholders

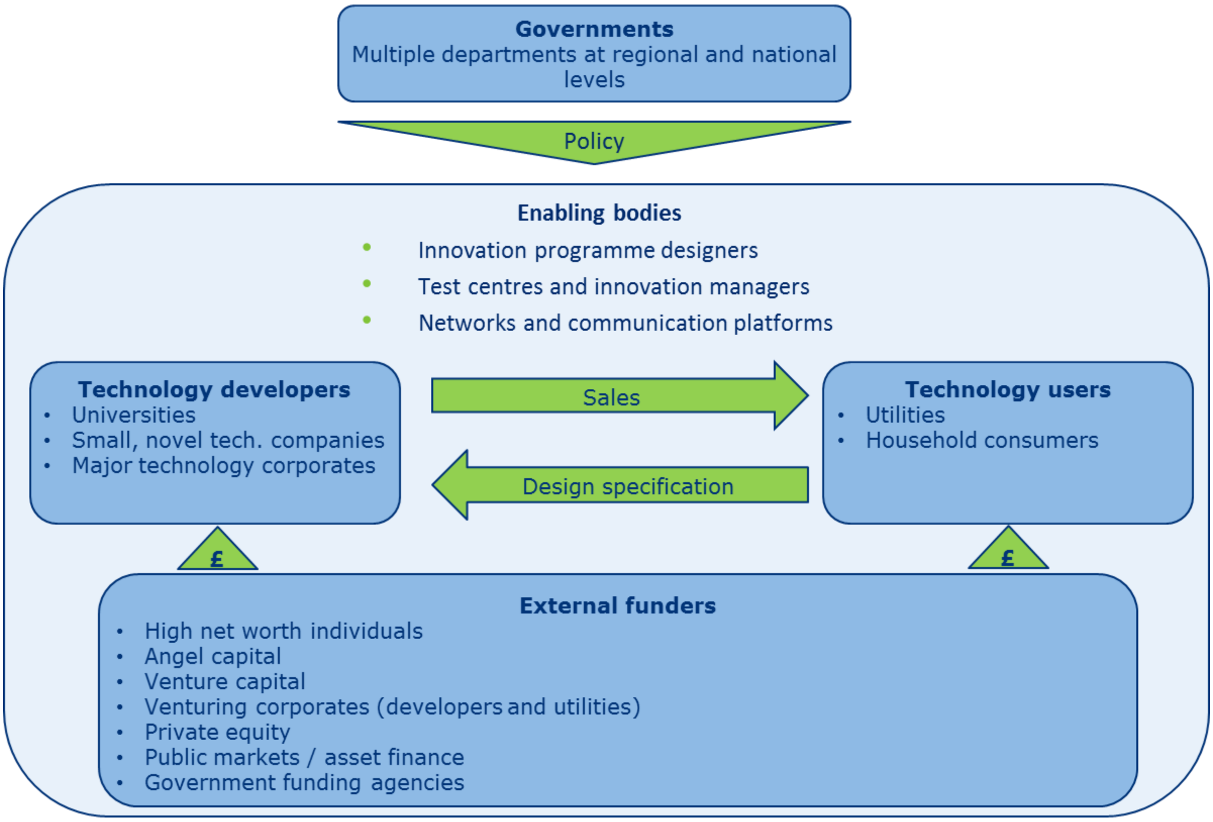


Table 3: Barriers and incentives by type of stakeholder

Entity	Incentives	Barriers
Government	• Acquiring valuable know-how from partners • Economic growth • Sharing the cost of demonstrations and subsidies	• Desire for domestic ownership of most of the value • Budgetary process to approve funding R&D abroad • Regulatory and policy differences
Technology developers	• More opportunities for fundraising during high-risk early R&D stages • Ability to speak directly with technology end-users • Access to markets	• IP leakage and loss of control • Potential loss of first mover competitive advantage
Technology users	• Ability to liaise with technology developers to tailor R&D process to actual needs • Sharing the cost of supporting technology development	• Potential loss of first mover competitive advantage • Potential reduction of market share • Risk of investing in innovation
External funders	• Spreading costs • Spreading risk	• Sharing the returns with other partners • Loss of overall strategic control

4.3 Coordination

The energy research landscape is already filled with agreements and collaborative initiatives of various kinds. However, there is a lack of coordination and transparency.

Efforts should be made to streamline existing initiatives, aiming at reducing duplication and eliminating those that are not leading to implemented programmes or projects.

Ideally, countries should have mechanisms in place, either nationally or internationally, to identify common needs and opportunities around low carbon innovation that would lead to mutual benefits if pursued collaboratively. This should also include an analysis of skillsets, knowledge bases and existing capabilities, enabling either fully horizontal collaborations or technology transfer activities. In this sense enabling bodies such as the IEA could play a central role in providing this coordination and transparency mechanism.

At the same time, roadmapping and action plans should be created with implementation in mind, which means national governments and private sector stakeholders should be much more directly involved in sketching out actual milestones and activities at technology level.

STEPPING STONES

In 2004, the Carbon Trust developed the concept of a "Climate Change Technology Challenge" which would identify, develop and put in place a set of material projects or "stepping stones" designed to move promising technologies along the innovation chain to commercialisation. The three essential elements of the stepping stones initiative are: strong political leadership and commitment; a willingness and ability to build large scale Government/private sector financing partnerships; and the development of a forward-looking, stable market-based framework to incentivise risk-taking and investment. Each stepping stone is d be designed by the partners. They would have their own objectives, deliverables, exit strategies and structures. Each one would be different: e.g., the technologies, the partners, and the relative mix of public and private capital investment in relation to technology maturity and risk.

In a way, governments would set the high level commitments and strategic goals and lay out favourable policy environments, enabling bodies would prepare more specific roadmaps and action plans, and then private sector stakeholders would help create technology-specific implementation plans, programmes and projects to accelerate innovation and achieve the high level objectives. A similar approach was originally proposed to the UK government by Carbon Trust under the description of "stepping stones" (see text box).

Figure 4 lays out how a more streamlined and coordinated collaboration framework would look like, with specific activities outlined for each type of stakeholder in a way that matches their incentives (NREL, 2010).

4.4 Technology innovation stage

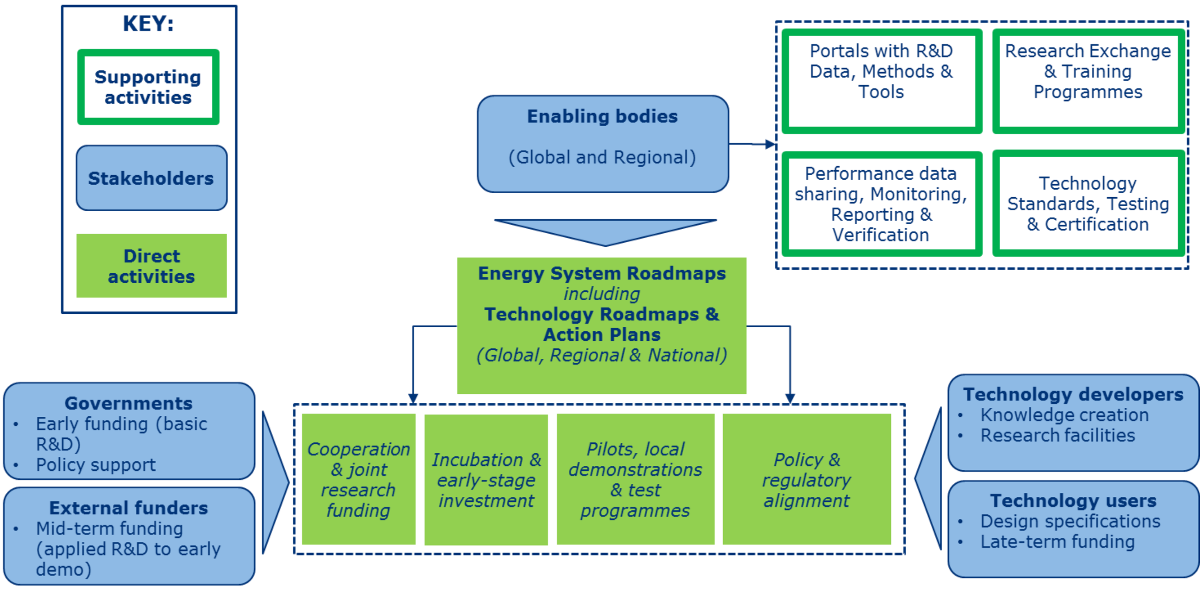
'Low carbon energy' is a simple description for what is in reality a complex taxonomy of tens of different technologies and applications. While a common overarching structure is needed to make collaboration work at a higher level, to actually move on from strategy to implementation the differences between various technologies will have to be fully accounted for.

At a basic level, differing technologies and components will be at different stages of innovation, and as such will require different kinds of programmatic interventions or projects. Figure 4 already touched upon this with the four different boxes at activity level, showing projects from joint R&D to pilots and policy interventions.

However the entire structure of a collaborative initiative can change depending on what level of development a technology is at. We already touched upon collaboration models in section 1.2. Figure 5 shows how these map against the innovation chain, and in terms of where most of the funding is expected to come from.

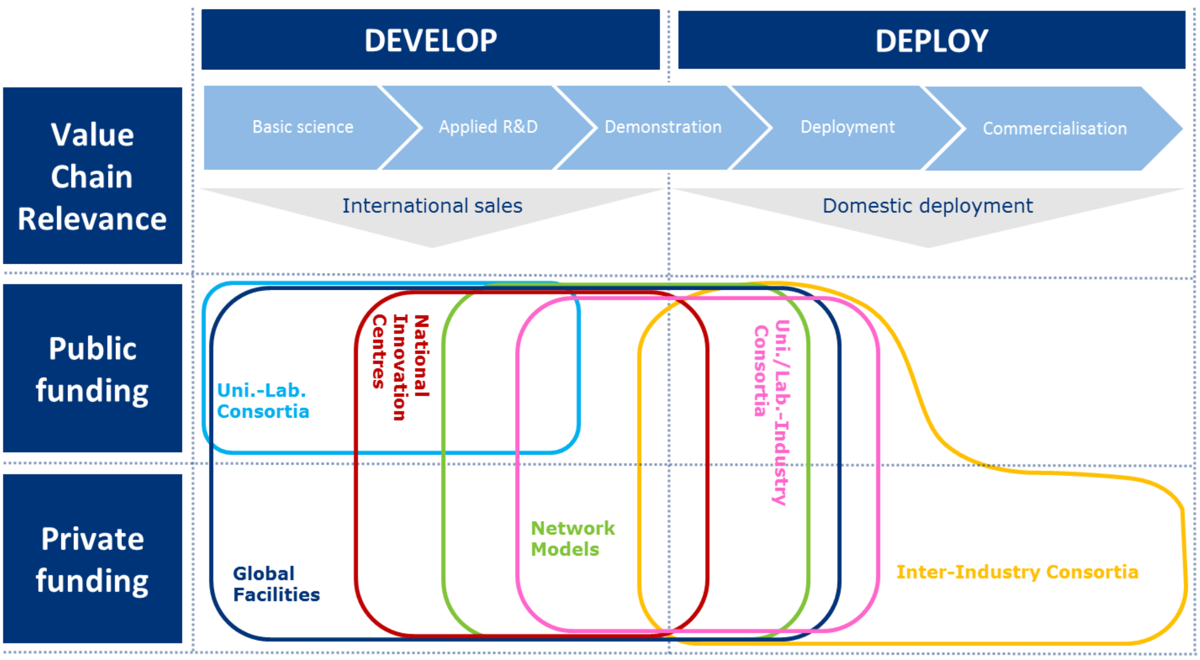
These models are able to cover the full spectrum of needed initiatives: basic science, joint demonstrations and pilots, common policies and regulatory frameworks, mutual learning from adaptation to local contexts, and capacity building for developing countries. They will need to be complemented by effective monitoring processes that match with the criteria used to set up the initiative in the first place. In summary, it is essential that collaborative initiatives adopt a tailored approach that reflects different technology needs – no one size fits all solution.

Figure 4: Proposed collaboration structure



Source: adapted from *NREL, ECN & UNEP – Strengthening Clean Energy Technology Cooperation under the UNFCCC: Steps toward Implementation (August 2010)*

Figure 5: Distribution of collaboration initiatives vs. funding and innovation stage



4.5 A framework for international collaboration

Having defined which stakeholders should be involved and how to motivate them, and how different collaborative models are needed at different stages of the value chain, we can develop a comprehensive framework for designing effective collaborative initiatives.

We can lay out this process in five basic steps which move hierarchically from a more general, cross-cutting view of every technology, down to technology and component specific programmes and projects. This is shown graphically in figure 6, which shows the various "steps" of the plan, the main actions, and the actors and stakeholders which are expected to play an important role.

Step I is commitment – the establishment of high level goals by national governments, and the agreement to collaborate to realise those goals. One example would be 'make clean energy cheaper than dirty'. The more time bound and accountable these goals are, the better to avoid the risk of 'empty words' not leading to any action.

Step II is direction – translating the commitment into more concrete action plans that can lead to implementation. These will include an effective prioritisation exercise to understand which technologies are likely to be the most relevant, and how different countries can be incentivised to collaborate based on their different technological needs. This process ought not to be necessarily technology focused; it could instead consider broad challenges, for example how to provide low carbon energy to a rapidly growing city, and try to understand at a system level which combination of technologies could address that challenge.

Step III is coordination, programme design and enabling environments. As we have stressed several times there is no single one-size-fits-all solution to the issues faced by low carbon energy innovation. At this stage, participation by enabling bodies with broad strategic oversight either at national or international level is essential to translate the priorities laid out in the Direction phase into more practically implementable programmes and projects.

Coordination will be needed to assess what current initiatives already exist in a given area, understand what gaps they leave unaddressed, and streamline them so that no new programmes are created unless they are truly needed. Better coordination will also allow countries to understand what their mutual needs and capabilities are, so as to better align their incentives towards collaboration. This does not mean that a single centralised coordinating entity should be created to oversee global activities. Rather, each country should put in place its own mechanisms, and central institutions such as the IEA could provide additional support, for example around transparency.

Programme design will be needed for those areas in which a new initiative is called for. It is at this stage that issues around how to manage IP and how to align incentives for all participants are dealt with. It is also at this stage that the private sector should be involved and provide key inputs, to ensure that the proposed programme or project is grounded in the technological and economic realities of the targeted area.

CARBON PRICING AS A COLLABORATIVE INCENTIVE

Carbon pricing could be used as a mechanism to incentivise countries and industry to collaborate. If one or more countries were to establish a common carbon pricing or carbon tax system, part or all of the revenue could be allocated to financing collaborative initiatives, focusing on innovation broadly defined. Further, investing the revenues derived into decarbonising industries affected by the tax in the first place, would incentivise industry participation. The benefits of these initiatives would be largely captured by the participating countries and industry, which could be a subset of those within the carbon pricing scheme. This would align incentives across the public and private sector and provide a strong incentive to both join the carbon pricing scheme, and to participate in the collaborative initiative.

Finally, **enabling environments** will assist with the creation of favourable policy and regulatory environments that can lead to the creation of new markets, giving confidence to private sector technology developers that their investments in new technologies will not go to waste, and that they will be able to sell beyond the confines of a single nation or market.

Step IV is implementation – where the initiatives designed in the previous step are turned into action. Programmes and projects can support activities across the innovation chain, from joint R&D calls to incubation and early investment support to large scale demonstrations and policy and regulatory alignment efforts.

In this phase the involvement of the private sector as a delivery partner is crucial, and the structures created must allow for sufficient flexibility so as to be reactive to changing market conditions and other volatile factors.

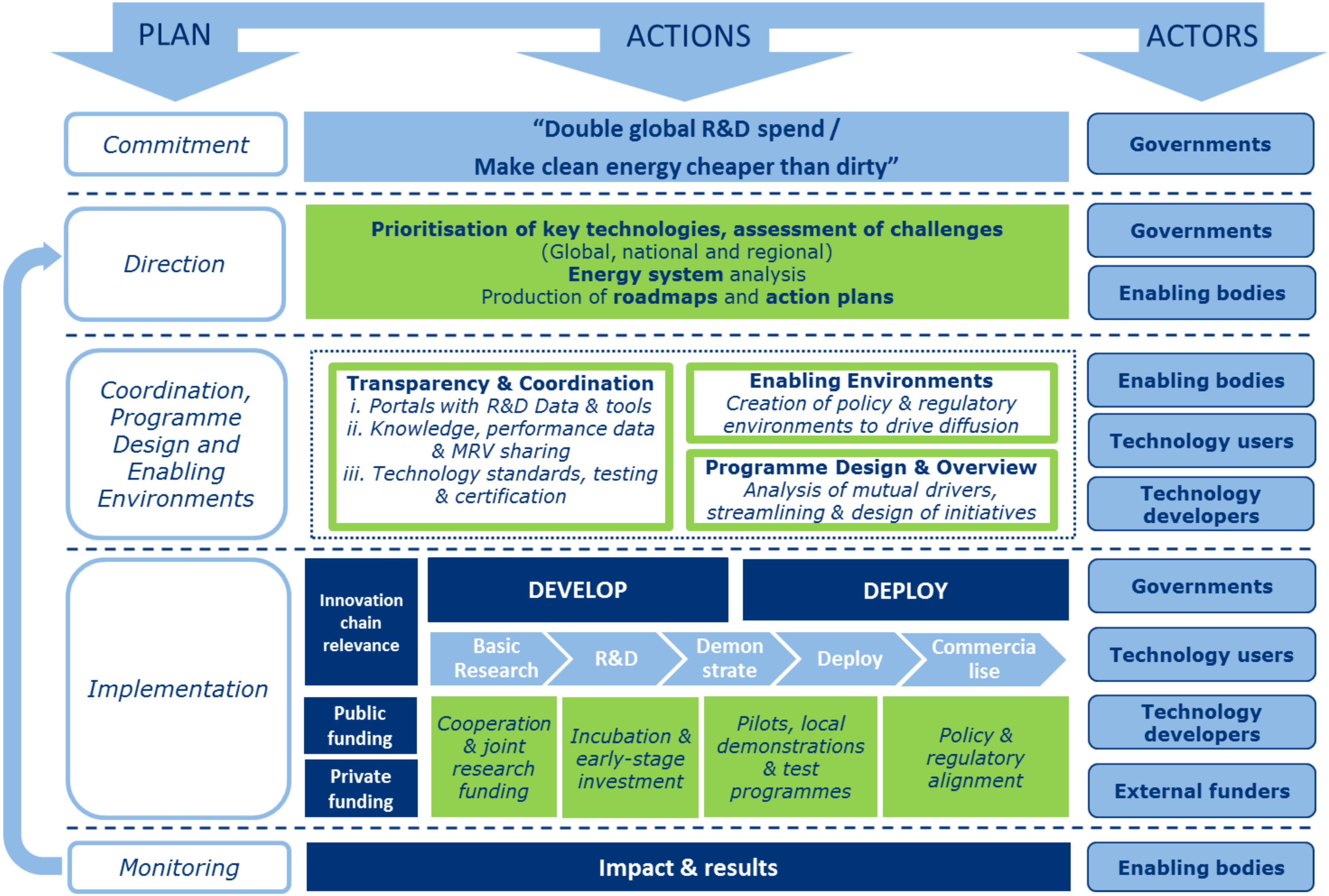
Step V is monitoring - monitor impact and results and feedback the information to the decision making process. This is particularly important to capture local adaptations as they emerge, for example in developing countries, and integrate them back into the innovation process. Monitoring is also important to verify that programmes are meeting the milestones set for them and making progress towards targets.

4.6 Applying the framework

What is described in the preceding section is an idealised version of what the collaboration framework could look like. However, many of the mechanisms described already exist, and given the urgency of accelerating low carbon innovation, there is a need for making existing moving parts work together smoothly, rather than create entirely new structures.

Therefore, our recommendation is for national governments and enabling bodies to work together on a case by case basis, identifying the largest gaps preventing implementation and acting on those. This might simply be strengthening existing structures such as the IEA to deliver greater collaborative functions; carrying out more implementation-geared prioritisation exercises, working together to identify groups of countries that share common challenges and priorities, and then creating specific initiatives that can address these. This would include robust monitoring mechanisms to ensure that existing programmes and initiatives can more easily be held accountable to the goals they were set up to achieve.

Figure 6: A framework for international collaboration



Part B of this report will provide a number of practical examples to help bring the framework to life. Technology case studies will look at specific innovation needs and collaboration drivers in order to identify the kind of implementation programmes best suited to fill the gaps left by existing initiatives.

The resulting collaboration structure will depend on a number of variables:

MATRIX OF TECHNOLOGY LEADERS

As part of our analysis, we have created a quantitative 'technology leaders' matrix. The matrix identifies countries that are most likely to have a particular interest in a chosen technology by assessing the relative competitiveness of countries along four different segments of the value chain; *i.* Raw material inputs, *ii.* Research, development & design, *iii.* Product manufacturing, *iv.* Installation, operations & maintenance. The matrix combines indicators from a variety of public sources – including the World Bank, IEA, and UN – and can rank countries along the value chain for a total of 20 different low carbon technologies, including offshore wind, CCS and smart grids. We have used this matrix in our technology case studies in order to identify countries that are likely to collaborate with one another.

It should be noted that the methodology is not a definitive assessment of the position of each country in a global ranking, as some countries, particularly developed ones, had a richer data coverage than others. Where possible this has been accounted for through different weightings, however potential biases should nonetheless be kept in mind. In general, the matrix provides an indication of which countries are interested in a technology, without necessarily providing an answer as to who is a leader at what.

N.B. In our case studies below:

i. EY RECAI = Ernst & Young Renewable Energy Country Attractiveness Index 2014
ii. Deloitte GMCI = Global Manufacturing Competitiveness Index 2013
iii. Cleantech Group GCII = The Global Cleantech Innovation Index 2014

- The barriers & opportunities to collaboration for a technology
- The innovation and collaboration gaps for a technology
- The steps of the innovation and value chain affected by gaps
- Country competitiveness for the technology and value chain segment in question

We will not provide specific recommendations on which countries or institutions should collaborate on specific technologies. That would require a far more detailed level of analysis than can be presented in a two page case study. However, some factors should be kept in mind when assessing the likelihood that countries decide to collaborate:

- **Entities with similar sizes**, financial resources and technical endowments are more likely to collaborate, compared to when the balance is one-sided
- **Previous relationships** through customer/suppliers, licensing agreement or training may influence the willingness to collaborate
- Limiting collaboration to a **single stage of the R&D process** and delineating technology contributions to reduce risks can contribute to collaboration
- **Strong incentives** – identifying what every stakeholder needs and finding ways to provide this for joining the initiative

The low carbon technologies needed to address climate change are being developed too slowly, in part due to a lack of incentive alignment that has stilted global progress. As we will demonstrate in Part B, in order to be effective, collaborative initiatives need to manage competing interests and be designed with incentives in mind. Not only can collaborative initiatives de-risk stages of the innovation chain suffering high investor uncertainty, they can ensure we achieve more together than we would apart.

Part B

Technology Case Studies

1. Carbon Capture & Storage
2. Energy Storage
3. Offshore Wind
4. Smart Grids & Electricity Networks
5. Marine Energy

1 Carbon Capture & Storage (CCS)

1.1 The strategic importance of CCS

Carbon capture & storage (CCS) has the potential to be cost-competitive with other forms of low-carbon power generation, especially when considering energy system requirements. Beyond being attractive for countries with high fossil fuel dependence, CCS allows for the energy security benefits of extractives to be maintained, while simultaneously reducing GHG emissions and averting the risks for corporates linked to stranded assets.

Further, CCS can leverage cross-sector benefits, by decarbonising industrial sources of GHG emissions, and when applied to biomass co-firing, has the potential to realise negative emissions. Though greater innovation is required to realise this benefit, CCS has the potential to harness the benefits of load-following flexible power generation.

COST REDUCTION POTENTIAL FOR CCS

Our research indicates that the global CCS technology investment need to 2025 covers **$287 bn**. This could be reduced by **$14 bn** through innovation. Greater cost reduction will be driven by technology commercialisation.

1.2 Innovation needs

CCS is a relatively mature technology, in the sense that most of its components have been used in commercial oil extraction for decades, mostly to support Enhanced Oil Recovery (EOR). However, the full suite of components has never been demonstrated in a source-to-sink setting, with differing capture modes (e.g. pre and post combustion) and different storage modes (e.g. offshore storage).

1.3 Collaboration drivers

Single countries have been wary of shouldering the full cost of CCS demonstrations by themselves due to high costs and a general inclination to wait for others to push the technology to maturity. This has led to the abandonment of some demonstrations, such as the oil refinery and gas power plant at Mongstad, Norway.

Collaboration can address these barriers by allowing countries to share the costs and risks of CCS demonstrations. Also, committing to a robust pipeline of demonstrations would create sufficient market incentives for private sector technology developers to contribute some resources of their own. Again, policy uncertainty and a lack of commitment on the part of governments has led to the private sector pulling out of CCS demonstrations, such as Drax in the UK.

EXAMPLES OF CCS COLLABORATION

I – *Four Kingdoms Initiative*: An initiative between the UK, Norway, the Netherlands and Saudi Arabia to explore the potential for collaboration on CCS.
II – *Carbon Sequestration Leadership Forum*: A ministerial-level organisation, including 23 member countries and the European Commission, with the mission to facilitate the development & deployment of CCS through collaborative efforts.

1.4 Remaining gaps & enabling environments

The main gap left by existing initiatives revolves around large scale source-to-sink demonstrations in differing contexts. In parallel, a firmer long term commitment both to a programme of demonstrations and eventually policies – leading to carbon prices or similar instruments – are essential to provide sufficient certainty for private sector investment.

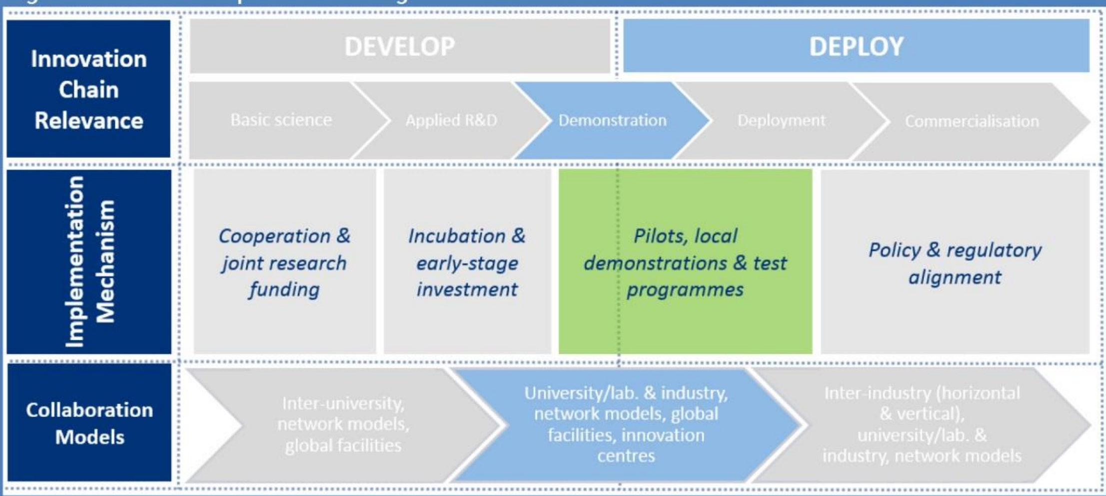
1.5 Project design & implementation

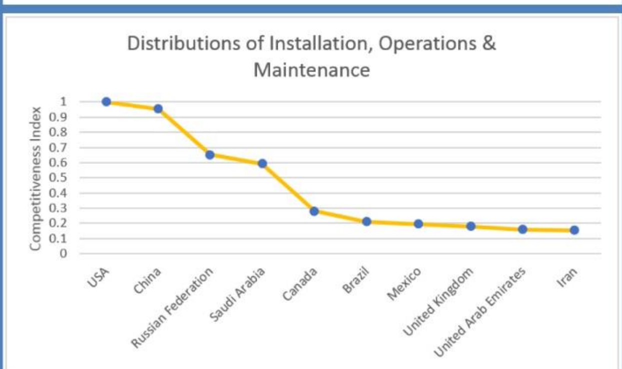
The key to bridging the gaps left by existing collaboration initiatives and reducing the costs of CCS plants is to build numerous commercial scale source-to-sink demonstration plants in localised contexts. Due to the unsure future of CCS, joint public sector support for these projects is crucial to incentivise private sector finance. Government backed collaborative initiatives would not only supply investor confidence, but also have the added benefit of unlocking innovation by enabling learning to pivot on actual full-scale systems.

Beyond integrating component technologies into commercial demonstration programmes, governments and industry must ensure that regulatory frameworks and incentive structures are appropriately aligned.Currently, the high cost of finance and insufficient return on investment due to the absence of financial incentives, such as carbon pricing, has created a market failure for the implementation of integrated CCS systems. A critical role of government is to collaborate around policy, enabling environments and market pull mechanisms in order to make business sense of CCS.

OPPORTUNITIES FOR COLLABORATIVE CCS INITIATIVES

Figure 7: Carbon capture & storage - Collaboration across the innovation chain





As indicated by figure 7, in order to create facilities that demonstrate commercial scale source-to-sink CCS plants, international collaboration initiatives should focus on both the manufacture and IO&M segments of the value chain – as opposed to earlier stages such as RD&D.

In order to give an indication of which countries are strong in CCS manufacture, we used UN Comtrade exports for filtering equipment, paired with the Deloitte GMCI. Our analysis indicates that Germany, the USA and China are likely to be leaders.

Using deployment projections from the IEA, data on petroleum production and the EY RECAI, we estimated which countries had the greatest potential to deploy CCS over the next ten years. The USA, China and Russia rank strongly in our analysis.

Source: Carbon Trust analysis (2015)

2 Energy Storage

2.1 The strategic importance of energy storage

Electricity storage can provide the flexibility required by future energy systems with *(i)* a greater share of intermittent renewables, *(ii)* more distributed generation, and *(iii)* customers that increasingly generate their own electricity. An increased deployment of energy storage technologies can reduce system costs by supplying more effective balancing and peak shifting services, as well as provide savings from fuel costs and defer the need for network upgrades.

COST REDUCTION POTENTIAL FOR ENERGY STORAGE

Our research indicates that the global technology investment need to 2025 covers **$108 bn**. This could be reduced by **$20 bn** through innovation, also realising **$58 bn** of system benefits.

2.2 Innovation needs

There exists a crucial distinction between distributed and bulk storage. In the former, breakthroughs in new battery technologies, such as lithium-air or redox flow, are still needed. In the latter, covering compressed air energy storage and other large scale technologies, the main need revolves around large scale demonstration. Across both areas, there is an overarching need for common systems integration procedures, including performance & operating standards.

2.3 Collaboration drivers

At the distributed level, collaboration can support better knowledge sharing mechanisms, and help drive research towards solving the challenges that different countries may face. Countries can also work together to agree on common standards and operating procedures, as well as facilitating policy environments for energy storage technologies.

For large scale demonstrations of bulk storage, the drivers are very similar to those for CCS – in terms of sharing costs and risks. In addition, jointly funded demonstrations make it easier to test the same technology in different electricity markets and grid infrastructure systems, helping developers understand how to tailor products to needs.

2.4 Remaining gaps & enabling environments

EXAMPLES OF ENERGY STORAGE COLLABORATION

I – *ADELE*: A 1000MWh CAES demonstration project, and a joint effort between RWE, GE, Zueblin and the German Aerospace Centre – in part funded by the German Ministry of Economics.
II – *ALISE*: A €6.9 billion Horizon2020 funded pan-European collaboration to develop lithium sulphur battery technologies, especially for their application in electric vehicles (EVs).

At the distributed level, the primary gap is mostly around coordination, transparency and knowledge sharing. A good example is the US Department of Energy's Global Energy Storage Database, which collects information on all storage projects around the world. More enabling action is needed to support the creation of larger markets for energy storage, allowing the private sector to invest with more confidence. A greater degree of investment in budding technologies, such as lithium air, is also required.

At the bulk storage level, more concrete efforts are required around large scale demonstrations. In this case, the pooling of funds will likely be essential for multiple demonstrations looking at different bulk technologies in different electricity markets.

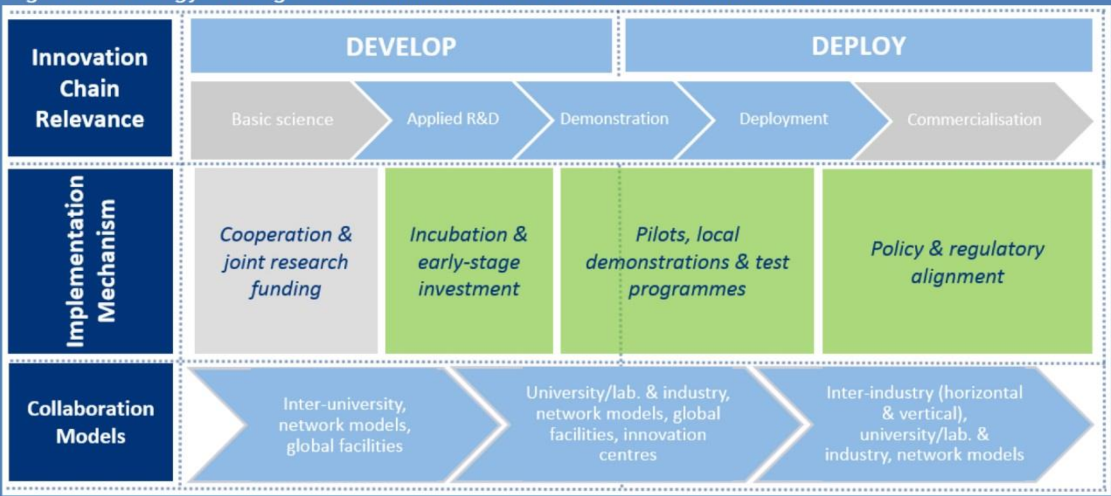
2.5 Project design & implementation

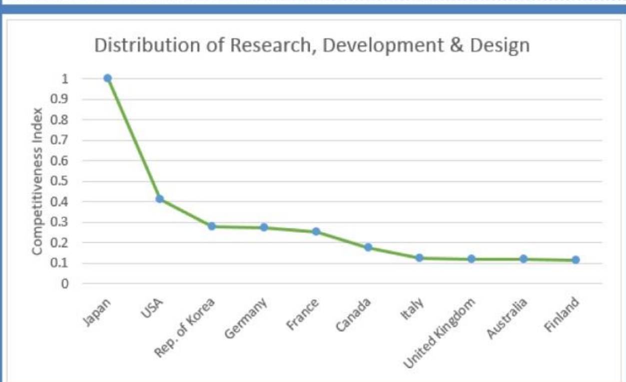
There exists a decisive need for international collaboration on performance and operating standards in order to provide certainty and guidance to technology providers. This could be achieved through test centres setting industrial standards for selected technologies, for example, similar to what ESTI did for solar PV. Similarly, contractual standards require government involvement, especially in countries where grid ownership may disincentivise energy storage integration. In many instances, the benefits of storage do not accrue to the investor (utility or distribution network operator). Countries should work together with the private sector to create new business models that can help capture the value of storage and create incentives for its deployment at a commercial level.

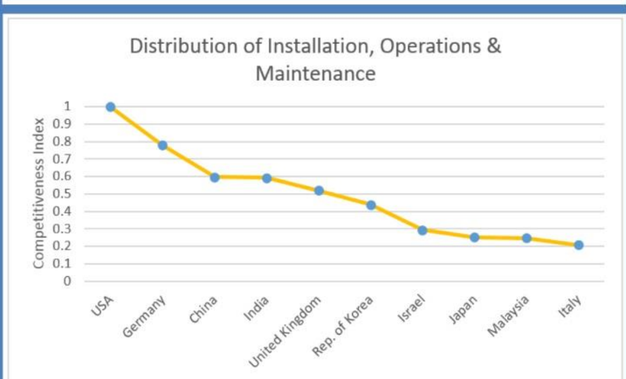
For bulk storage, government funded large pilot and joint-industry demonstration projects are needed. In particular, international collaboration is required to test both system level grid integration and business models. Funding mechanisms should be based on well-defined applications aligned with system needs, rather than specific technologies.

OPPORTUNITIES FOR COLLABORATIVE ENERGY STORAGE INITIATIVES

Figure 8: Energy Storage - Collaboration across the innovation chain







Source: Carbon Trust analysis (2015)

As indicated by figure 8, in order to develop and deploy energy storage technologies, a greater degree of international collaboration is required at the RD&D, manufacture and I,O&M segments of the value chain – collaboration between laboratories, universities and industry could prove particularly fruitful.

We used IEA and World Bank data on patents and R&D spending, as well as the Cleantech Group GCII, in order to estimate country competitiveness in energy storage RD&D. Japan, the USA and Korea are likely to be highly competitive.

In order to gauge which countries are likely to deploy energy storage over the next 10 years, we used IEA and IRENA data on current and future installed capacity, as well as the EY RECAI. The USA, Germany and China are identified as being particularly strong.

3 Offshore Wind

3.1 The strategic importance of offshore wind

Compared to onshore wind, offshore is more scalable. Further, while the cost-competitiveness of offshore wind, compared to baseload generation, is uncertain in the future against both nuclear and CCS, it is currently deployable sooner and faster than either of these. This means that offshore wind is a low carbon alternative to combined cycle gas turbines (CCGT), which can be deployed at the scale required to replace aging fossil fuel power plants.

COST REDUCTION POTENTIAL FOR OFFSHORE WIND

Our research indicates that the global technology investment need to 2025 covers **$186 bn**. This could be reduced by **$15 bn** through innovation.

3.2 Innovation needs

The offshore wind sector has advanced quickly and already deployed large-scale farms on numerous sites, especially in the UK, Denmark and Germany. The main technology needs that must be addressed to facilitate further diffusion relate to the development of new foundations, improved wake and load models, control and maintenance systems.

3.3 Collaboration drivers

There is a lack of coordination between different actors in the value chain, as well as insufficient investment by industry due to a high uncertainty of demand. The former relates to an insufficient sharing of measuring, reporting and verification (MRV) data across different players, paired with a lack of incentives for industry actors to invest in innovations that will ultimately benefit the industry as a whole. The latter concerns investments in IO&M in particular, where a high degree of demand uncertainty and doubt regarding payback timelines reduces the incentives to invest in innovation.

Collaborative initiatives can play a key role not only in spreading the investment costs across actors to overcome risks, but also in providing mechanisms to share MRV data and to invest jointly in areas of mutual benefit.

EXAMPLES OF OFFSHORE WIND COLLABORATION

I – *LIFES50+*: A European Horizon-2020 funded programme worth €7.3 million, involving 12 partners from 8 countries, set to drive the development of next generation floating wind substructures.
II – *IEA Task 30 OC4*: A project managed by the National Renewable Energy Laboratory (NREL) and the Fraunhofer Institute to compare dynamic computer codes and models to design offshore wind turbines.

3.4 Remaining gaps & enabling environments

The main gaps revolve around enabling mechanisms, particularly providing long term policy certainty, performance data sharing and other MRV instruments. For key ancillary technologies, there is a lack of early stage and incubation support to bring new products to market, and there are insufficient initiatives that support private sector actors, particularly wind farm developers, to work together to pool their resources and support innovation. Government backed demonstration programmes in particular could provide a vehicle for sharing MRV data and securing developer participation.

3.5 Project design & implementation

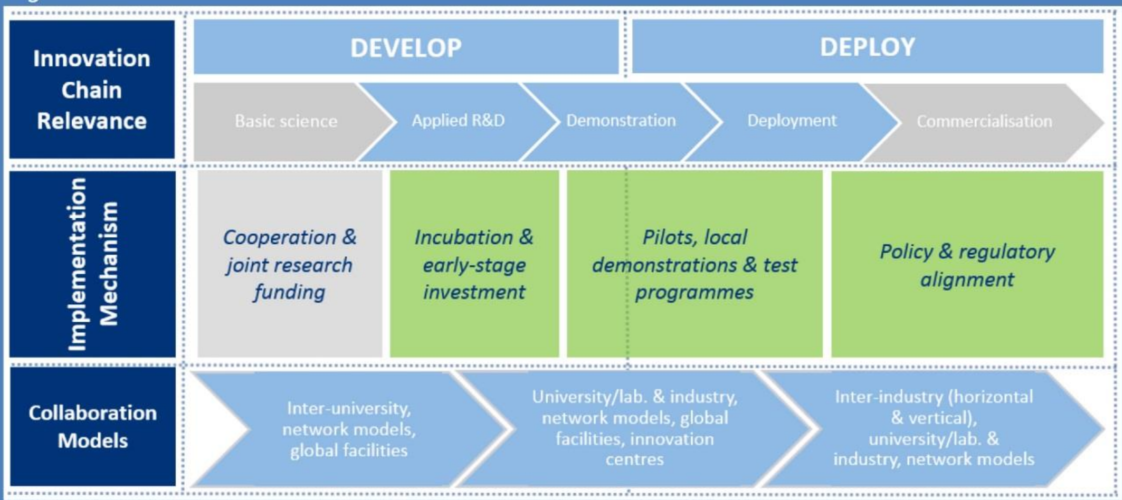
In order to bridge existing gaps, governments need to collaborate in setting long-term offshore wind targets paired with appropriate supports structures. These are required to reduce supply chain costs

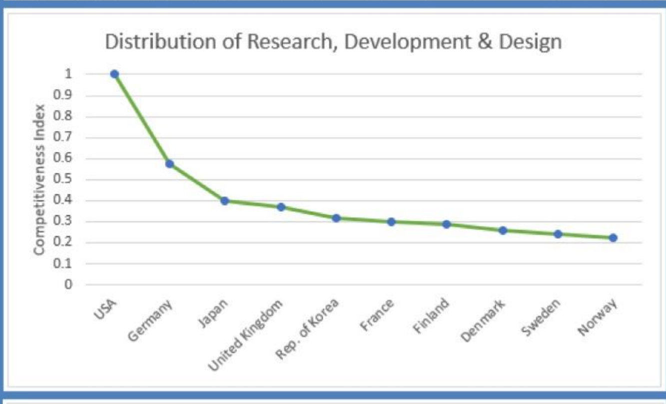
through investment, innovation and economies of scale. In particular, international collaboration needs to align academic and industry RD&D with the aforementioned targets to adapt support to reflect both technology maturity and returns on investment.
In order to incentivise industry, governments must commit to market-pull by creating multi-year RD&D programmes in which governments set the overarching agenda while industry defines programme specifics. These type of structures must be complemented with mechanisms in which intellectual property is retained by innovators and core MRV data is openly available.

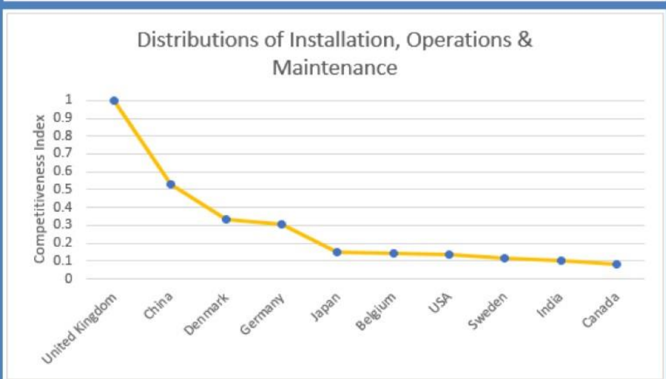
As seen in figure 9, the highlighted innovation chain segments translate into a number of collaborative models and implementation mechanisms. Of particular relevance are collaborative mechanisms that effectively share performance data across actors, and policy environments that incentivise private sector investment by ensuring reliable returns on capital invested.

OPPORTUNITIES FOR COLLABORATIVE OFFSHORE WIND INITIATIVES

Figure 9: Offshore Wind - Collaboration across the innovation chain







As indicated by figure 9, In order to drive the diffusion of offshore wind technologies, international collaboration initiatives should focus on the RD&D, manufacture and IO&M segments of the value chain, as these have the greatest innovation needs.

In order to give an indication of which countries are strong in offshore wind RD&D, we used IEA and World Bank data on patents and R&D spending, as well as the Cleantech Group GCII. Our analysis indicates that the USA, Germany and Japan are likely to be leaders.

By using deployment projections from the IEA and IRENA, paired with the EY RECAI, we estimated which countries had the greatest potential to deploy offshore wind over the next 10 years. The UK, China and Denmark rank strongly in our analysis.

Source: Carbon Trust analysis (2015)

4 Smart Grids & Electricity Networks

4.1 The strategic importance of smart grids

Globally, electricity systems face numerous challenges, including *(i)* an ageing grid infrastructure, *(ii)* a continual growth in energy demand, and *(iii)* a need for both a greater security of supply and lower GHG emissions. Taken together, these challenges lead to both a greater number of intermittent renewables, as well as smart grids, which are crucial for coordinating system components and meeting energy system challenges more broadly.

COST REDUCTION POTENTIAL FOR SMART GRIDS

Our research indicates that the global technology investment need to 2025 covers **$615 bn.** This could be reduced by **$41 bn** by innovation, also realising **$213 bn** of system benefits.

Conventional methods of integrating renewables and energy vector electrification is likely to be both inefficient and cost-restrictive. Indeed, smart grids should be seen an essential infrastructure investment to decarbonise electricity systems rather than being tied to specific technologies. The benefits of smart grids in reducing system costs are plural – ranging from integrating EVs to deploying heat pumps at lower costs – while simultaneously providing greater security and flexibility of energy supply.

4.2 Innovation needs

Due to the relatively small nature of the technological components involved, innovation in smart grids is already taking place efficiently in the private sector. The main outstanding need is the development of common technology standards for smart grid components, which play a crucial role in accelerating deployment and cost-reduction. Further, there is a need for large pilot and demonstration projects, which are required to test both grid integration and business models.

4.3 Collaboration drivers

There are critical failures regarding coordination across smart grid stakeholders. To unlock smart grid benefits, there is a greater need for targeted intervention by the public sector to catalyse private sector investment. The institutional and physical complexity of smart grids means that the market cannot integrate the technology at scale by itself. Collaborative initiatives are not only an effective measure for the public sector to incentivise private investment in large-scale demonstration projects, they can also facilitate the sharing of programme findings and experience in a coordinated and integrated manner.

EXAMPLES OF SMART GRIDS COLLABORATION

I – *GRID4EU*: A large scale smart grid project under the EC FP7 research programme including 27 partners – ranging from DSOs to research institutes – to test the potential of smart grids in areas such as renewable energy integration and load reduction

II – *IEA ISGAN*: The International Smart Grid Action Network, part of the IEA implementing agreements, is a mechanism for multilateral collaboration to advance the development and deployment of smart grid technologies, practices and systems.

4.4 Remaining gaps & enabling environments

The main gaps for the specific technology components revolve around coordination, standardisation and knowledge sharing. At a systems level, large scale demonstration on live grid systems are also needed.

There remains a high degree of policy uncertainty regarding targets for smart grid deployment. Different electricity markets will also face very different challenges in terms of incentivising distribution and transmission network operators (D/TNOs) to innovate, with greater sharing of lessons learned from national initiatives (such as the UK's Low Carbon Networks Fund) being needed.

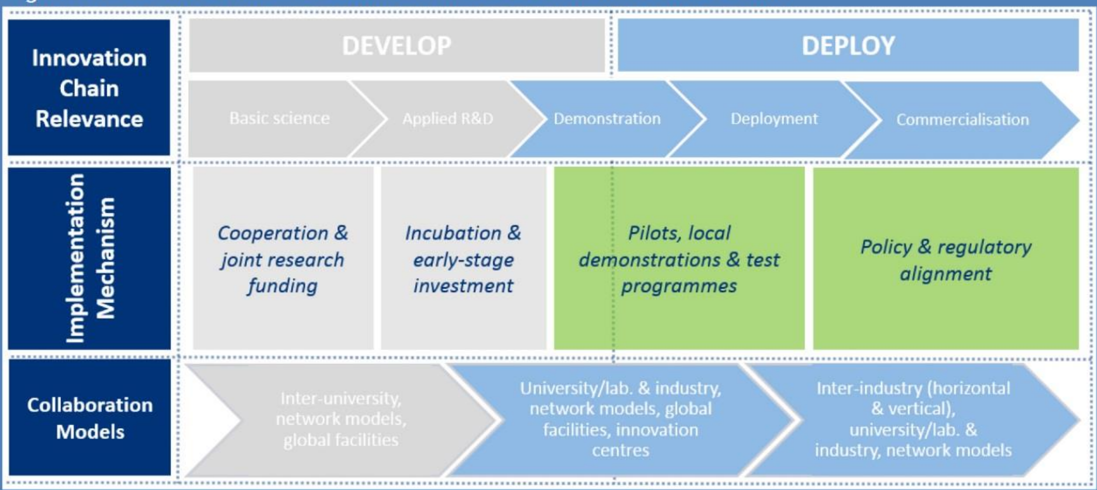
4.5 Project design & implementation

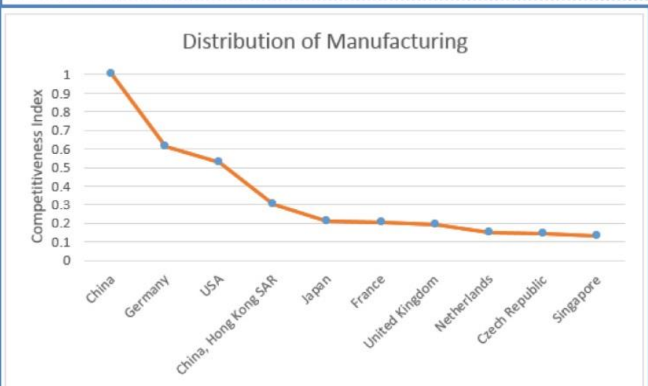
Collaboration is of particular relevance for integrating smart grids with other technology areas including transport electrification, demand response and storage. Large-scale system level consortia-led demonstration projects that link smart grids to other technologies are crucial to prove technology feasibility and provide investor confidence. A greater degree of coordination between government and T/DNOs is also critical in order to tackle electricity system regulation and planning, as well as policies that hinder smart grid diffusion.

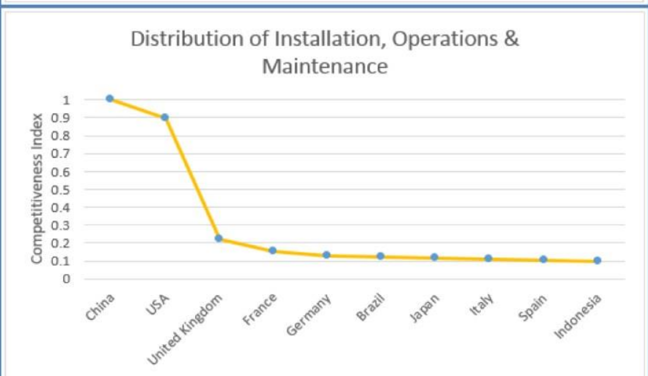
Practical next steps should include a strong push on standardising smart grid components for interoperability across different electricity markets. Incentive mechanisms that push DNOs towards innovation should also be considered.

OPPORTUNITIES FOR COLLABORATIVE SMART GRID INITIATIVES

Figure 10: Smart Grids - Collaboration across the innovation chain







As indicated by figure 10, collaborative smart grid initiatives should focus on both the manufacture and IO&M segments of the value chain in order to drive technology diffusion.

We used UN Comtrade exports for electric transformers and multimeters, as well as the Deloitte GMCI in order to estimate country leadership in the manufacture of smart grid technologies. Our analysis identifies China, Germany and the USA as being potentially strong.

To be able to evaluate the countries that are likely to install smart grid technologies in the next 10 years, we combined the demonstration and deployment budget of smart grids and the EY RECAI. Our matrix identifies China, the USA and the UK as being likely to lead the push in smart grid IO&M.

Source: Carbon Trust analysis (2015)

5 Marine Energy

5.1 The strategic importance of marine energy

Both tidal and wave power resource have the potential to play critical roles as sources of emissions-free energy production, especially for countries with long coastlines. In the short term, tidal stream energy can play an important role in providing electricity to remote coastal communities with decentralised energy systems. Further, unlike other intermittent renewables such as wind and solar, marine power resources have a highly predictable energy generation pattern.

COST REDUCTION POTENTIAL FOR MARINE

Our research indicates that the global technology investment need to 2025 covers **$48 bn**. This could be reduced by **$17 bn** through innovation.

5.2 Innovation needs

The innovation needs differ for both wave and tidal stream. The main innovation needs for wave power relate to additional research and development into main components and subsystem wave converters to reduce costs and improve reliability – here, concepts must be demonstrated at a single device level before making the leap to small arrays. Further, alongside the need to develop wave technologies at a component level, through advancing mooring and control systems for example, there is a critical need to optimise device designs across technology developers.

Unlike for wave, tidal stream power has already undergone a broad convergence in design. Additionally, the reliability of demonstrations have made significant progress allowing for clearer cost reduction pathways. Current needs relate to transitioning from device demonstrations to initial array demonstration projects, which is a stage in the innovation chain with high investment costs. There is also a need for additional innovation in subsystem technologies such as foundations and moorings, similarly to offshore wind.

EXAMPLES OF MARINE ENERGY COLLABORATION

I – *CEFOW:* A €17-24.5 million Horizon 2020 project, coordinated by Fortum, to research and develop Penguin – a Finnish wave power technology – in collaboration with British and Swedish experts

I – *MERIKA:* An initiative coordinated by the University of the Highlands and Islands, funded by the EU FP7 programme, involving 10 additional partners, with the aim of establishing a marine energy research and innovation hub.

5.3 Collaboration drivers

In the case of wave, there are multiple differing wave energy technologies being developed around the world, the majority of which are in early stages of research and development. There is a critical role for collaboration to accelerate technology development, design convergence and the sharing of lessons learned. In the case of tidal, the drivers are more on sharing the costs and risks of array-scale demonstrations in different environments.

5.4 Remaining gaps & enabling environments

Currently, the levelised cost of energy (LCOE) of wave energy technologies is highly uncertain as a result of the diversity of device designs and the lack of reliable cost data due to site to site cost variability. Further, delays in technology developments have led to a loss of investor confidence in the technologies financial viability. Tidal faces barriers in terms of a lack of support for demonstrations at the array scale. Both technologies have also suffered from a private sector retreat as public sector support has wavered and the policy environment has become more uncertain.

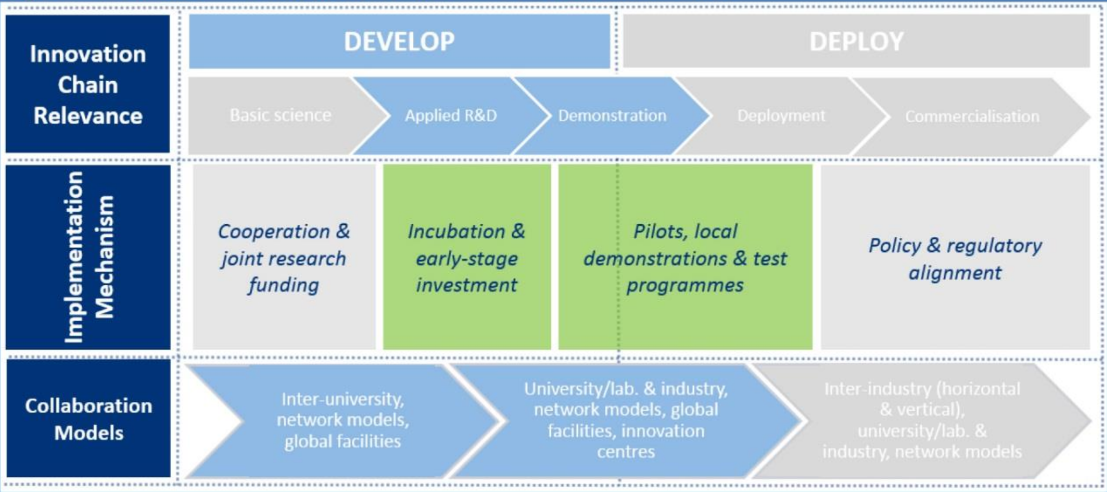
5.5 Project design & implementation

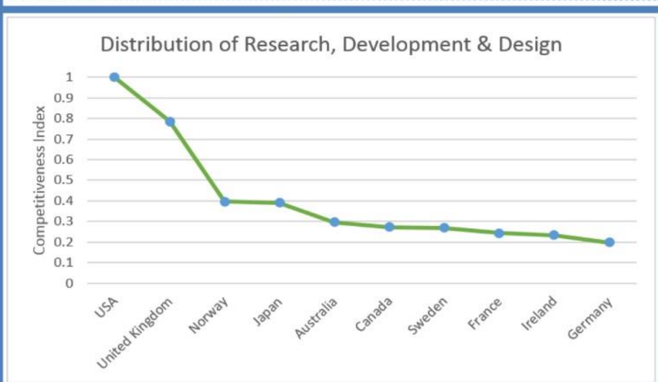
In order to reduce the risk profile of wave energy and attract support from industrial partners and OEMs who can assist with a transition to commercialisation, the public sector needs to focus its support on the main technical challenges facing developers. Given the lack of convergence in device designs, a targeted innovation programme that supports devices and components in small scale R&D settings would provide a more robust development pathway than supporting the deployment of large-scale devices. Further there is a critical need for collaboration at a government level to facilitate the coordination of designs and push the technology towards the market for all parties.

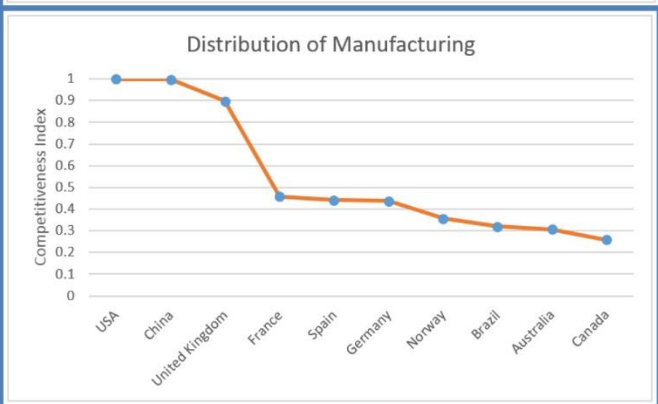
Countries with strong potential for tidal energy should come together to support array scale demonstrations and provide certainty of long term commitments to the private sector. Policy frameworks need to become more supportive.

OPPORTUNITIES FOR COLLABORATIVE MARINE INITIATIVES

Figure 11: Marine - Collaboration across the innovation chain







Source: Carbon Trust analysis (2015)

As indicated by figure 11, in order to develop tidal stream and wave energy, a greater degree of international collaboration is required at the RD&D and manufacture segments of the value chain – collaboration between laboratories, universities and industry could prove particularly fruitful.

In order to give an indication of which countries are strong in marine energy RD&D, we combined IEA and World Bank data on patents and R&D spending, as well as the Cleantech Group GCII. According to our analysis, the USA, the UK and Norway are likely to be particularly competitive.

Using UN Comtrade exports for hydraulic turbines, EMEC data on wave developers and the Deloitte GMCI, we estimated which countries are likely to be leaders in marine manufacture. The USA, China and the UK are likely to be particularly competitive.

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