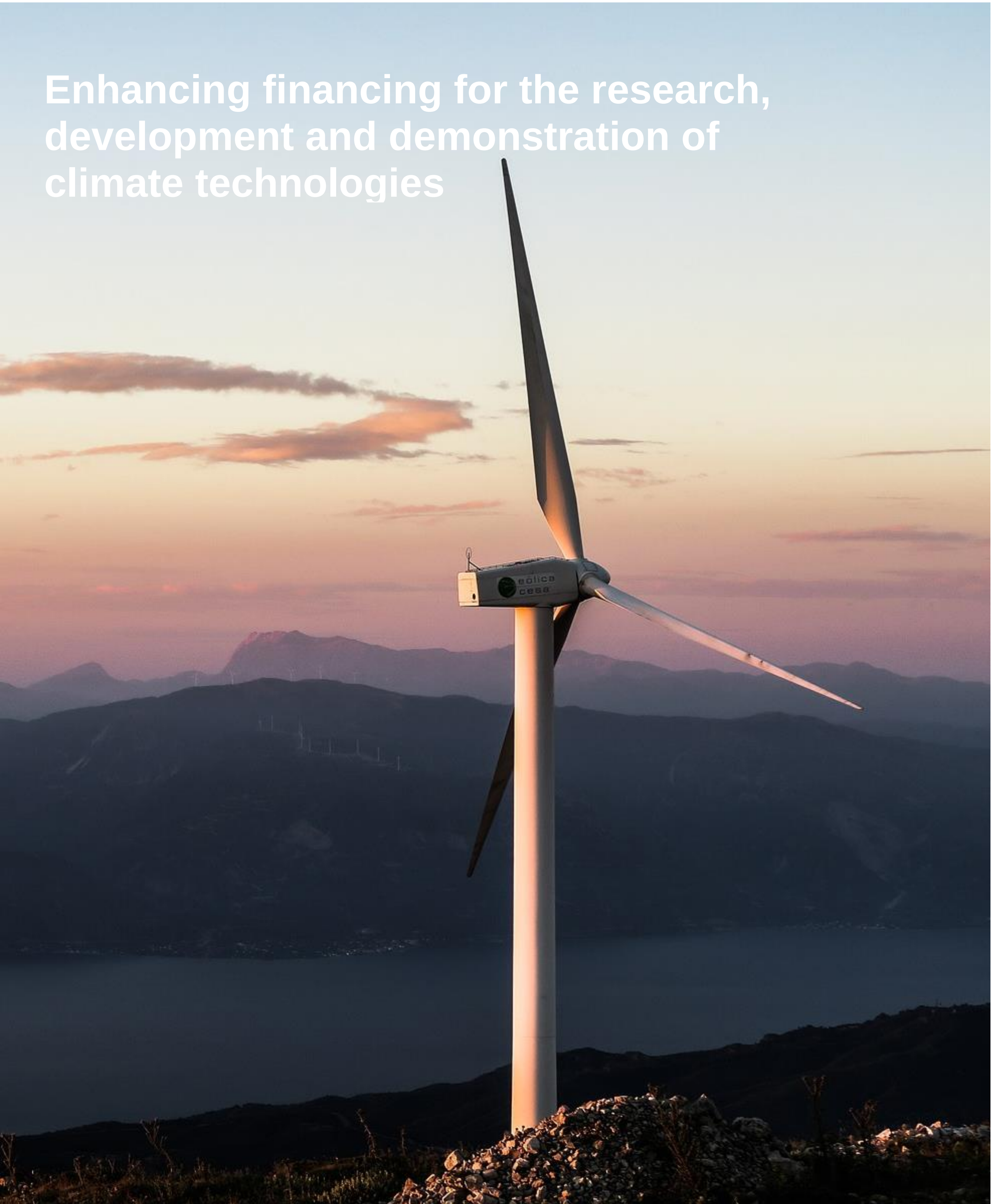
Technology Executive Committee
Working Paper

Enhancing financing for the research, development and demonstration of climate technologies



SUMMARY

In recent years, climate technologies have been deployed on an unprecedented scale around the globe. Renewable energy technologies especially are now often competitive with fossil fuel options. But the global average temperature continues to rise. 2016 was the hottest year on record and the global temperature is almost 1°C above pre-industrial levels. To achieve the Paris Agreement's objectives, we need to deploy climate technologies on a much greater scale.

Researching, developing and demonstrating (RD&D) climate technologies is one part of the solution. Effective RD&D programmes improve the performance and reduce the cost of climate technologies, and yield new ones. Through such programmes, countries also modify technologies to local conditions, which will help them achieve their nationally determined contributions in a cost-effective manner. These programmes can also have significant social and economic value, supporting countries to develop capacities for undertaking the long-term technological transformation to a low-emission and climate-resilient future. Since its inception, the Technology Executive Committee (TEC) has explored how countries and the international community may enhance climate technology innovation, including RD&D.

In this paper, the TEC continues this work by exploring how we may enhance financing for RD&D of climate technologies. It notes that R&D spending for renewable energy and agriculture technologies has been rising broadly, although it only accounts for a small share of global R&D expenditures. In recent years, though, renewable energy R&D finance has plateaued. The paper highlights that the private sector often plays an important role in the RD&D of climate technologies. Private R&D spending likely exceeds public funding for renewable energy while in agriculture the opposite seems to be true. It also notes that mechanisms exist for international R&D collaboration on agriculture and energy, but the scale of those efforts is small (either in global coverage, scope or resources). No information was found on RD&D expenditures for adaptation technologies.

Based on the urgency of addressing climate change and RD&D financing trends, the paper notes the importance of RD&D financing for climate technologies, in addition to enhancing enabling environments and building capacity for deploying climate technologies. Governments may accelerate efforts to meet climate challenges by increasing public expenditure for climate technology RD&D. Indeed, in recent years some countries have pledged to significantly increase their clean energy R&D budgets. The paper notes that to stimulate private RD&D spending for climate technologies, governments can provide a clear policy signal of a long-term national commitment to reduce greenhouse gases and build resilience to climate change and support enabling environments that accelerate private investment.

The working paper also highlights the importance of international collaborative RD&D programmes focused on climate technologies. By complementing national activities, these programmes may play a key role in supporting countries to accelerate climate action by drawing on comparative strengths and sharing the cost of investment. While some collaborative RD&D programmes exist, these could be enhanced both in scope and scale, paying attention to developing country needs. The paper also notes that UNFCCC bodies can support efforts to enhance financing for climate technology RD&D.

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1 INTRODUCTION

The Paris Agreement notes that "accelerating, encouraging and enabling innovation is critical for an effective, long-term global response to climate change..."[1] To facilitate this, COP 21 requested the Technology Executive Committee (TEC) and the Climate Technology Centre and Network (CTCN) undertake further work relating to research, development and demonstration (RD&D) of climate technologies.[2] Subsequently, the TEC included activities on climate technology RD&D in its 2016–2018 workplan.[3] In 2016, the TEC prepared a concept note on assessing climate technology RD&D financing needs[4] and considered an RD&D scoping note[5] at its 13th meeting (September 2016). Also at this meeting, the TEC decided to continue its work on RD&D and innovation in 2017 by preparing a technical paper on enhancing climate technology RD&D financing (this paper). It also decided to:[6]

- Hold a special event during the forty-sixth sessions of the subsidiary bodies in May 2017 on how innovation can support implementation of the technology elements of nationally determined contributions (NDCs) and the Paris Agreement mid-century strategies;[7]
- Prepare a TEC Brief for COP 23 based on the technical paper and the special event;
- Prepare key messages and/or recommendations for COP 23 based on the technical paper and the special event.[8]

The TEC prepared this technical paper with the aim of informing key stakeholders on ways to enhance financing for the RD&D of climate technologies. The paper's section 2 provides background information on why this issue is important: it highlights relevant provisions of the Paris Agreement and sets out the problem. Section 3 gives an overview of the issue at hand: how do we finance RD&D activities for climate technologies? In section 4 the paper provides a picture of current R&D financing for climate technologies.[9] It describes trends and patterns in current such financing. Building on sections 3 and 4, section 5 considers ways to enhance RD&D finance for climate technologies. Section 6 concludes.

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[1] Paris Agreement, Article 10.5
[2] Decision 1/CP.21, paragraph 67(a).
[3] https://goo.gl/iqFzbm
[4] TEC, 2016, Concept Note. Assessing global technology RD&D financing needs. TEC/2016/13/14.
[5] https://goo.gl/yyef4Y
[6] https://goo.gl/iqFzbm
[7] For more information, see <http://unfccc.int/ttclear/events/2017_event2>.
[8] UNFCCC, 2016. Joint annual report of the Technology Executive Committee and the Climate Technology Centre and Network for 2016. FCCC/SB/2016/1, para. 31, p. 8.
[9] While the scope of this technical paper is research, development and demonstration (RD&D), available data relate only to research and development (R&D).

2 BACKGROUND

Emissions pathways likely to limit warming to below 2°C relative to pre-industrial levels require substantial greenhouse gas emission reductions over the next few decades and near zero emissions by the end of the century.[10] In recent years the support for the development of mitigation technologies has been promising. The prices of such technologies are falling, and we are observing greater deployment of these technologies than ever before. 2015 saw the largest deployment of renewable technologies ever.[11] However, countries will need to reduce emissions earlier and in even larger scale if we are to achieve the Paris Agreement's objective of pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels.

Improving climate technologies so that they are more effective, cheaper and available for a broader range of national circumstances would facilitate achievement of national climate contributions and the Paris Agreement's objectives. Thus, the Agreement recognizes that "[a]ccelerating, encouraging and enabling innovation is critical for an effective, long-term global response to climate change and [for] promoting economic growth and sustainable development"(§10.5). It specifically calls for "collaborative approaches to research and development, and facilitating access to technology, in particular for early stages of the technology cycle, to developing country Parties"(§10.5). The Paris Agreement also recognizes the importance of finance for technology development and transfer activities (§10.5). Furthermore, developed country Parties to the Agreement agreed to provide financial and other support to strengthen "cooperative action on technology development and transfer at different stages of the technology cycle..."(§10.6).

Building on these articles, this paper seeks to identify how we can enhance financing for climate technology RD&D to help Parties achieve the Paris Agreement's goals. The paper will seek to achieve this by addressing three key questions:

1. *How can we increase global RD&D finance for climate technologies to help countries fulfill their NDCs?*

Many developing countries seek support to modify or implement commercial or nearly commercial technologies.[12] By asking this first question the paper intends to develop an understanding of how we can increase global RD&D finance to reduce the cost or increase the effectiveness of commercial and near commercial technologies. It also seeks to understand how we can support countries to modify and implement such technologies. These efforts will help them to implement their NDCs and thus shift onto low-carbon and climate resilient development pathways.

2. *How can we enhance the effectiveness of climate technology RD&D finance?*

As a complement to the first question, the paper aims to develop an understanding of how we can enhance the effectiveness of the finance available for climate technology RD&D. Regardless of the funds available, it is important that they be spent in a way that maximizes cost-effectiveness.

3. *How can we enhance climate technology RD&D collaboration between developed and developing countries?*

By answering this third question, the paper seeks to contribute to the actualization of article 10.5 of the Paris Agreement. Collaborative efforts may be key ways of maximizing RD&D outputs on a limited amount of resources. These need to be strengthened and expanded to produce climate technologies, including those for large-scale implementation after 2030. Such efforts will support countries to implement their NDCs as well as mid-term strategies after 2030.[13]

[10] IPCC, 2014. Climate Change 2014: Synthesis Report, p. 20.
[11] http://www.irena.org/News/Description.aspx?mnu=cat&PriMenuID=16&CatID=84&News_ID=1446
[12] See Annex A, which draws on information from TNAs, NDCs and submissions to the CTCN.
[13] In accordance with Article 4, paragraph 19, of the Paris Agreement.

However, before striving to answer these questions it is necessary to develop a deeper understanding of the issue that we are considering. The following section provides this overview.

3 Key definitions

This section describes the process of financing the RD&D of climate technologies.

3.1 What are climate technologies?

Before discussing RD&D and financing, let us take a step back: what are climate technologies? Climate technologies are those used to address climate change. Technologies that reduce greenhouse gas emissions include wind energy, solar power, energy-efficient technologies, and hydropower. To adapt to the adverse effects of climate change, technologies such as drought-resistant crops, early warning systems and sea walls are used. Defining adaptation technologies is more difficult because of the diversity of possible measures across a wide range of sectors, including agriculture, coastal resources, disaster risk management, infrastructure, public health, and water resources. “Soft” technologies, such as energy-efficient practices or training for using equipment are also climate technologies. In general, a climate technology is any equipment, technique, practical knowledge or skill to reduce greenhouse gas emissions or adapt to climate change.

3.2 What is research, development and demonstration?

With this understanding of climate technologies, what is the RD&D of climate technologies? RD&D is the process through which new, improved and cheaper technologies are developed and their utility demonstrated in a real-world context. Research refers to the search for new knowledge and solutions, the starting point for the emergence of new technologies. Development refers to the next step where new possibilities emerging from the research phase are translated into concrete technologies. This technology is then refined through testing in the laboratory or simulated field conditions to improve its performance and give it the shape of a usable product. The demonstration stage refers to the use of the product in actual field conditions where its performance and feasibility can be demonstrated and evaluated by actual or potential users.

RD&D applies to existing commercial products as well as to completely new products. It is inherently a not-fully-predictable activity, yet it is the only process through which new technologies are developed and brought to market. It is also the process through which technologies already used in some locations are modified to suit the conditions of another. For example, many mitigation and adaptation technologies need to be modified to operate in developing countries. Since a new technology’s ability to displace an incumbent or create a new market greatly depends on its cost or performance attributes, the role of RD&D in delivering improvements on these fronts is critical.

The results of RD&D programmes are uncertain. It takes time for an RD&D programme to yield results and even longer for it to have a real-world impact. And not all RD&D activities are successful, since research often delves into the unknown and therefore has uncertainty and risk. Due to this, governments often reduce public RD&D budgets when faced with budget pressures, and find it difficult to increase these budgets later given competing demands from measures with more certain (short-term) impacts.

Since the results of RD&D efforts are uncertain and may not find straightforward real-world applications, measuring the outcomes of RD&D is difficult. In addition, the impacts of real-world applications may be diverse and vary over time. It is also difficult to establish clear causality between economic and social benefits and specific RD&D expenditures. To bridge these difficulties, evaluations of specific R&D programmes often span decades, to allow the programme research impacts to unfold.[14] Despite these difficulties, existing assessments of R&D programmes indicate that RD&D for climate technologies yields significant benefits.

Economic analyses estimate the economic and broader social benefits of R&D programmes. Results for renewable energy, energy efficiency and agriculture R&D programmes often show annual rate of returns of more than 20% for research expenditures.[15] The economic returns may not capture benefits such as increased food production, reduced GHG emissions, reduced water use and poverty reduction.[16] Other benefits may include economic development, productivity growth, accelerated learning rates and development of patents.[17]Because the benefits take time to materialize, the results are sensitive to the period analysed.

Data on patent applications is another way to examine R&D activity.[18] The rate of increase of patent applications for biofuels, solar PV, and wind is far higher than that of overall patents for all fields during the past decade. Patent applications for agriculture and water supply also increased rapidly between 1990 and 2010.[19] Furthermore, RD&D programmes help to build professional networks among researchers and organizations that advance the industry. In addition, research focused on other goals may also improve climate technologies. However, it is important to note that not all patents result in a commercialized product or service and that these developments take time. Annex B considers the analysis of RD&D performance in greater detail.

3.3 Who finances research, development and demonstration activities?

RD&D is mainly funded by governments and businesses, although some other entities (such as philanthropic and private sources) also contribute. Governments, including sub-national governments, are key funders of RD&D.

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[14] Ruegg, R and Thomas, P, 2011, Linkages from DOE's Solar Photovoltaic R&D to Commercial Renewable Power from Solar Energy, Office of Energy Efficiency and Renewable Energy, DOE: Washington DC.; Ruegg, R and Thomas, P, 2009. Linkages from DOE's Wind Power R&D to Commercial Renewable Power Generation, Office of Energy Efficiency and Renewable Energy, DOE: Washington DC.; Ruegg, R and Thomas, P, 2011. Linkages from DOE's Geothermal R&D to Commercial Power Generation, Office of Energy Efficiency and Renewable Energy, DOE: Washington DC.; Ruegg, R and Thomas, P, 2011. Linkages from DOE's Vehicle Technologies R&D in Advanced Combustion to More Efficient, Cleaner-Burning Engines, Office of Energy Efficiency and Renewable Energy, DOE: Washington DC.

[15] Dowd, J., 2016. "Aggregate Return on Investment for R&D Investments in the U.S. DOE Office of Energy Efficiency and Renewable Energy," US DOE. https://energy.gov/sites/prod/files/2016/10/f33/Aggregate%20ROI%20impact%20for%20EERE%20RD%20-%2010-5-16.pdf; Pardey, P.G., Andrade, R.S., Hurley, T.M., Rao, X. and Liebenberg, F.G., 2016. Returns to food and agricultural R&D investments in Sub-Saharan Africa, 1975–2014. Food Policy, 65, pp.1-8.; Hurley, T.M., Pardey, P.G., Rao, X. and Andrade, R.S., 2016. Returns to Food and Agricultural R&D Investments Worldwide, 1958-2015 (No. 249356). University of Minnesota, International Science and Technology Practice and Policy; Mogues, T., Yu, B., Fan, S. and McBride, L., 2012. The impacts of public investment in and for agriculture. ESA Working paper No. 12-07, FAO: Rome.

[16] CGIAR, 2014. CGIAR: A Global Research Partnership for a Food Secure Future; CGIAR, 2012. The CGIAR Fund: Securing Investments for a Food-secure Future.

[17] IEA (International Energy Agency) (2010), Global Gaps in Clean Energy Research, Development and Demonstration, IEA/OECD, Paris, p. 14.

[18] Dechezleprêtre, A., Glachant, M., Haščič, I., Johnstone, N., & Ménière, Y. (2011). Invention and transfer of climate change mitigation technologies: A global analysis. Review of Environmental Economics and Policy, 5, 109–130. doi:10.1093/reep/req023; Dechezleprêtre, Antoine, Ralf Martin and Samuela Bassi, 2016. Climate change policy, innovation and growth, Grantham Research Institute on Climate Change and the Environment and Global Green Growth Institute. Retrieved from http://www.lse.ac.uk/GranthamInstitute/publication/climate-change-policy-innovation-and-growth/ December 15, 2016.

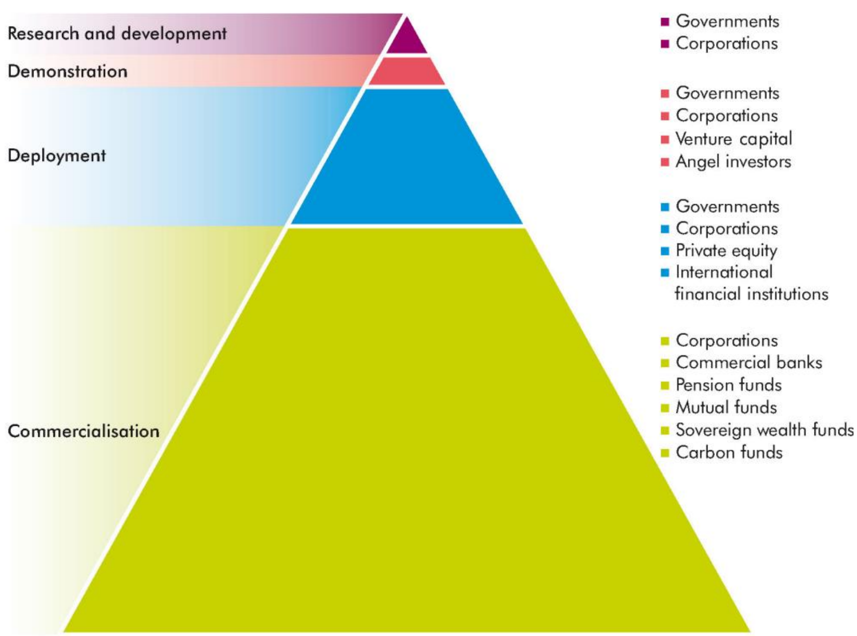
[19] Lippoldt, D. (2015), "Innovation and the Experience with Agricultural Patents Since 1990: Food for Thought", OECD Food, Agriculture and Fisheries Papers, No. 73, OECD, Paris; Dechezleprêtre, A., Haščič, I, and Johnstone, N. 2014. Invention and International Diffusion of Water Conservation and Availability Technologies: Evidence from Patent Data, OECD Environment Working Papers
No. 82; Paris: OECD.

Typically, a large share of a government's RD&D budget supports public research laboratories and facilities to undertake RD&D. The remaining funding often supports businesses, universities and other institutions in RD&D efforts. Each government has its own process for determining the size of its RD&D budget, its research priorities, and the allocation process for funds.

Generally, RD&D of new technologies relies more heavily on public funds, as this is where the risk is highest and commercial viability is most remote. Private sector firms generally fund less risky RD&D to improve the performance, reduce the costs of existing products, or build on the results of publicly-funded early stage efforts. Research intensity – R&D spending as a share of sales revenue – varies widely by industry from over 10% for the health sector to less than 1% for industries including oil and gas producers and electric utilities.[20] For confidentiality reasons, normally the firm's own research staff performs the RD&D. For some products, parts suppliers may perform critical RD&D, for example, chip suppliers for mobile telephones, tyre and battery suppliers for automobiles, and building management systems suppliers for the construction industry.

A more recent phenomenon for financing climate RD&D activities, particularly at the demonstration stage, is venture capital. These investments focus on helping small firms to turn a successfully demonstrated new technology into a commercial product.[21] The venture capital investors usually provide advice on business development and injections of finance over a five to seven-year period to help the firm get its technology established in the market.[22] The firms may use some of the invested capital to fund the additional development or demonstration of the technology to turn it into a commercially viable product. Figure 3.1 illustrates the scale of investment for the different stages of the technology cycle and the key financing actors for each stage for clean energy innovation.

Figure 3.1 Scale of investment and key financing actors for clean energy innovation[23]



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[20] Rhodes et al., 2014, p. 5602.

[21] Like RD&D expenditures, venture capital investments are risky because there is a significant risk of failure. To continue to attract capital, successful investments must provide a reasonable return on the money invested including the funds invested in companies that fail. Providing the investment in two or three injections as the company grows reduces losses.

[22] National Venture Capital Association (NVCA), 2016. 2016 National Venture Capital Association Yearbook, NVCA and Thomson Reuters. Retrieved from http://nvca.org/research/stats-studies/ December 12, 2016.

[23] IEA, 2010, p. 11.

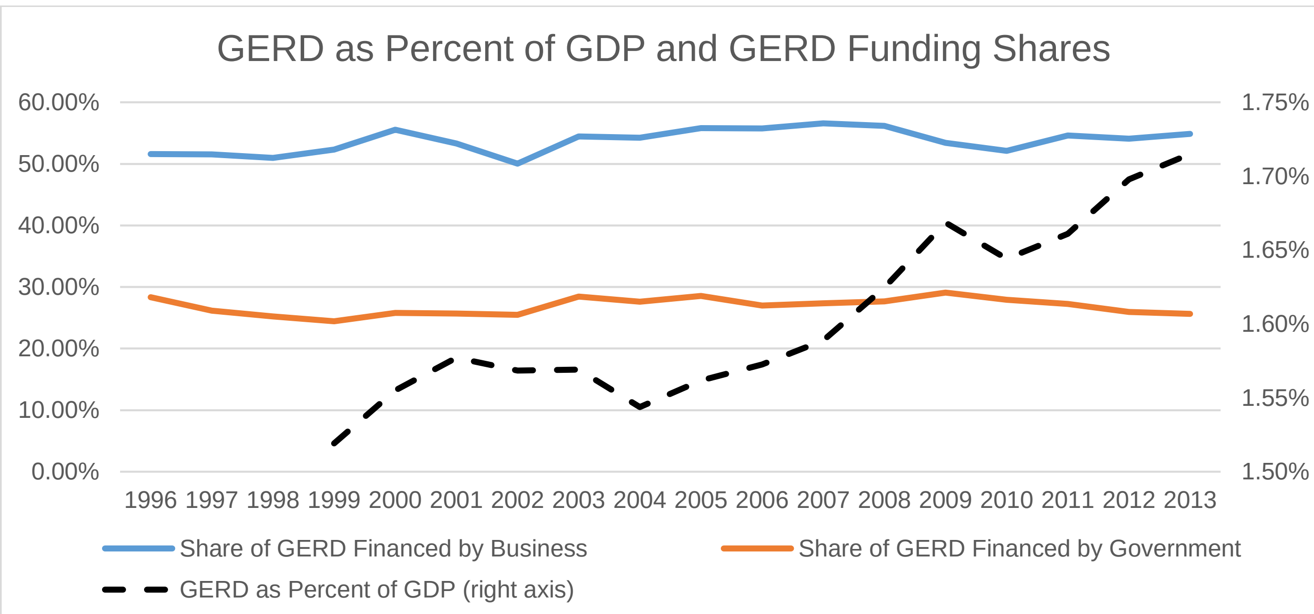
4 TRENDS

This section provides an overview of trends in RD&D financing for climate technologies. It starts by presenting data on overall global R&D[24] expenditures and venture capital investments. This provides context for the data relating to such expenditures for climate technologies. It then analyzes trends related to R&D investments for energy technologies and for renewable energy technologies. Finally, it highlights trends in R&D spending for agriculture technologies. No data was found on RD&D investment for adaptation technologies (such as early warning systems, sea walls, or improved rainfall harvesting systems) or other mitigation technologies (for example improved building construction technologies).

4.1 Global research and development expenditures and venture capital investment

Countries have reported on gross expenditures on research and experimental development (GERD) to the United Nations Educational, Scientific and Cultural Organization (UNESCO) since 1996.[25] Coverage and definitions vary somewhat across countries and the number of countries reporting varies.[26] GERD as a percent of GDP corrects for inflation and incomplete country coverage. The percentage increased from 1.52% in 1999 to 1.71% in 2013 as shown in Figure 4.1.[27] UNESCO also reports data on GERD funders – business, government, higher education and other. Business funded between 50% and 55% of global GERD between 1996 and 2013.[28] Over the same period, the government funded between 25% and 30%, while funding from higher education[29] and other sources ranged between 15% and 20%.

Figure 4.1 Gross expenditures on research and experimental development[30]



[24] Where simply R&D is used, it indicates that data are available only for the research and development stages.
[25] Data available at http://data.uis.unesco.org/ Retrieved November 16, 2016. The figures do not include expenditures for demonstration.
[26] From 2001 to 2013 inclusive, the number of countries reporting fluctuates between 78 and 93. From 1996 through 2000 the number reporting rises from 53 to 71.
[27] UNESCO data. http://data.uis.unesco.org/
[28] UNESCO data, shares of current PPP dollars. http://data.uis.unesco.org/
[29] Higher education is a separate category in the UNESCO GERD statistics.
[30] UNESCO, <http://data.uis.unesco.org/>.

The Organisation for Economic Co-operation and Development (OECD) collects similar data from its member countries and the patterns are similar.[31] R&D expenditures by OECD countries are higher than the global level, rising from 2.14% of GDP in 2000 to 2.38% in 2014. Business funded between 58% and 62% of the R&D while government funding accounted for 28% to 32% of the total.[32] The OECD share of global GERD has fallen from almost 85% in 2000 to just over 65% in 2014. This reflects the increase in R&D spending of developing countries such as China and India. Both data sets indicate that global R&D spending has increased in absolute terms and as a percent of GDP since 2000.

Data on venture capital finance is collected by industry associations and private data providers rather than national governments or international organizations.[33] Venture capital is primarily a private sector activity, and data on the public and private shares of venture capital investments are not available. Global venture capital commitments increased from USD 36 billion in 2009 to USD 140 billion in 2015, an average growth of 25% per year.[34] Based on data from the United States of America, approximately one-third consists of initial investments in new companies and the remainder represents additional financing for companies as they grow.[35] While venture capital investment has been growing rapidly, it is still small (5% to 10%) relative to the GERD noted previously. As with GERD, global venture capital investment is dominated by the United States of America and the European Union where the largest financial markets are located. Although their share declined from about 85% in 2009 to 60% in 2015, the absolute amount invested continued to increase (as noted previously). Venture capital investment in China and India has grown rapidly since 2009.[36]

4.2 Expenditures for the research and development of energy technologies

The International Energy Agency (IEA) has tracked the public energy R&D budgets of member countries since 1974.[37] Total energy R&D budgets and budgets for energy technologies for the period 1974 to 2015 are shown in Figure 4.2. The main features to note are:[38]

- Government energy R&D budgets grew steadily from the mid-1990s until 2012, almost returning to the levels of the post-oil crisis peak of 1980. Since 2012 they have declined.[39] Energy's share of the government R&D budgets of IEA countries has declined from over 10% in the early 1980s to about 4% in 2015.
- The share of government energy R&D budgets allocated to climate mitigation technologies, such as renewables and energy efficiency, has risen significantly. In contrast, the shares devoted to nuclear and fossil fuels have fallen substantially.
- Government R&D budgets for climate-relevant energy technologies (energy efficiency, renewables, hydrogen fuel cells, energy storage and carbon capture and storage) have fluctuated over time.
- The United States of America, Japan and a few other countries dominate government R&D funding for key climate technologies. Figure 4.3 provides further information on this trend.

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[31] Data available at https://stats.oecd.org/Index.aspx?DataSetCode=MSTI_PUB Retrieved November 16, 2016.
[32] While OECD uses the term "industry", "business" is used in this paper for consistency.
[33] Kaplan, Steven N. and Josh Lerner, 2016. Venture Capital Data: Opportunities and Challenges, National Bureau of Economic Research, Washington, D.C. Retrieved from www.nber.org/chapters/c13495.pdf November 9, 2016.
[34] Preqin data, current dollars. www.preqin.com. Retrieved November 18, 2016.
[35] National Venture Capital Association (NVCA), 2016, Figure 6.0, p. 13.
[36] The 2015 figures reported by NVCA for the US – 4,380 deals worth almost USD 60 billion – represent 41% of all deals and 43% of total commitments.
[37] IEA Energy Technology RD&D Database http://www.iea.org/statistics/RDDonlinedataservice/. Rhodes, A., Skea, J., and Hannon, M., 2014, p. 5611 notes a strong correlation between the price of oil and public RD&D funding although a direct causal relationship should not be inferred.
[38] IEA Energy Technology RD&D Database http://www.iea.org/statistics/RDDonlinedataservice/
[39] The 2009 spike reflects a large increase in energy RD&D spending as part of post-financial crisis stimulus package in the United States.

Figure 4.2 Public energy research and development budgets of IEA member countries[40]

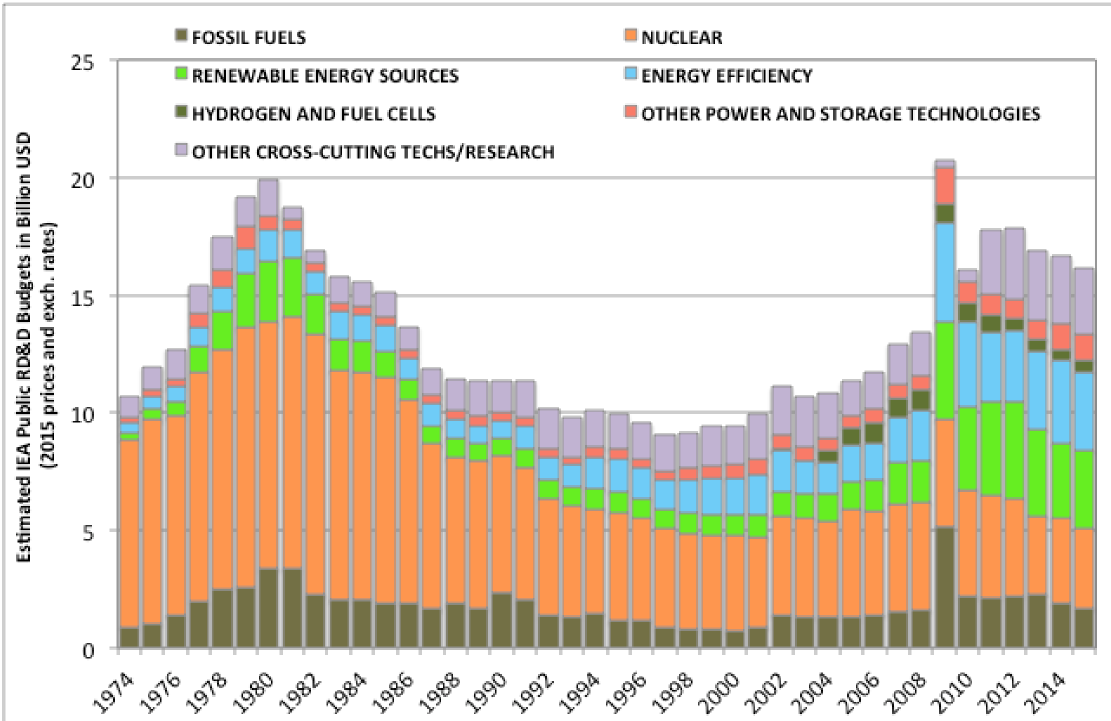
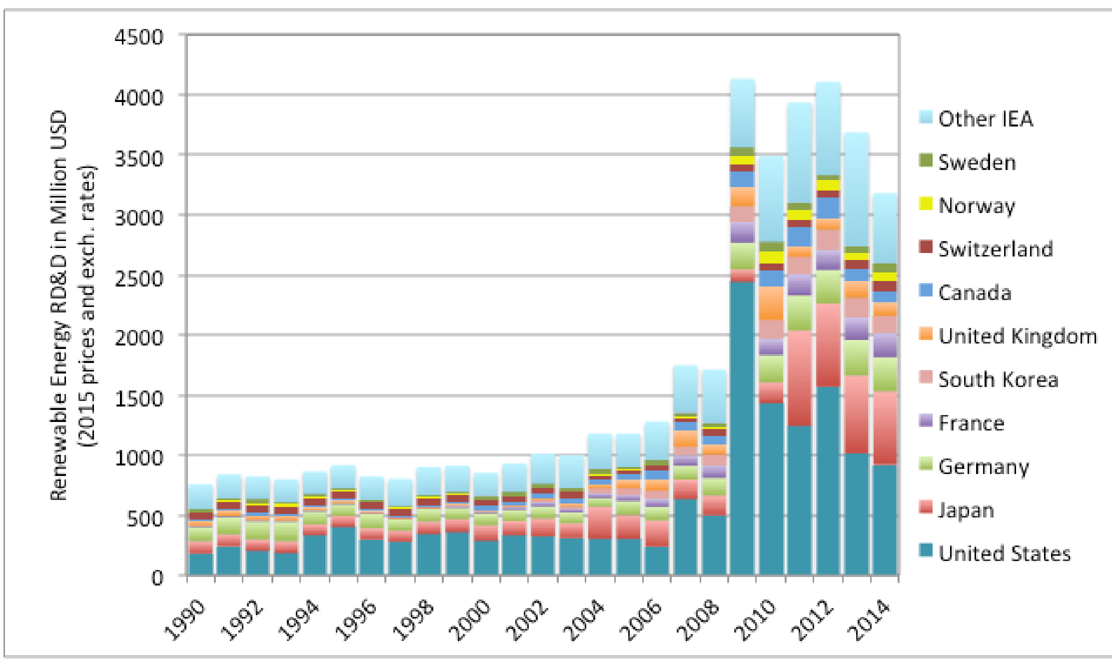


Figure 4.3 Top ten funders (in 2014) of public renewable energy R&D among IEA member countries[41]

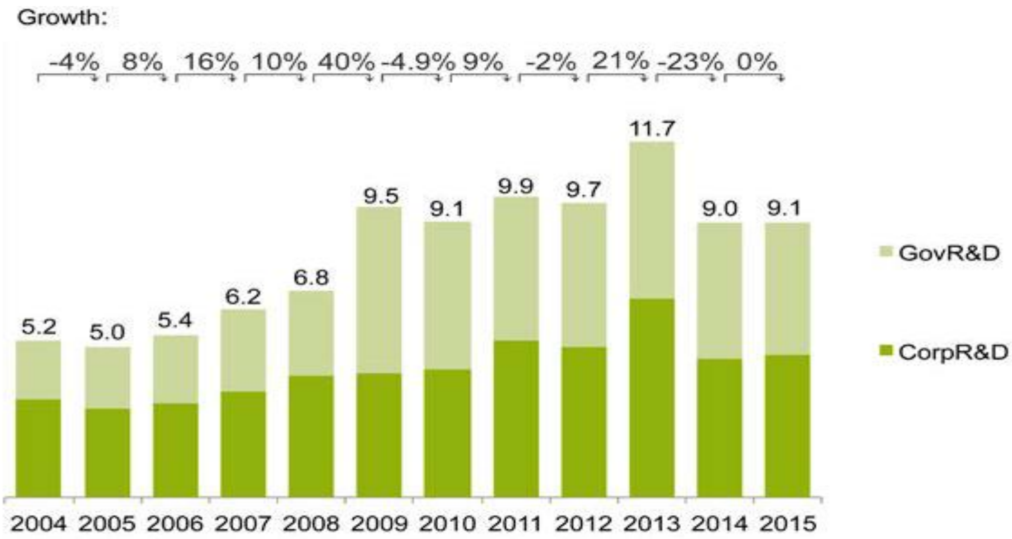


The Frankfurt School-UNEP Centre and Bloomberg New Energy Finance (BNEF) reports are another source of information on R&D spending on renewable energy technologies. In their annual report, they note that global R&D for renewable energy grew from more than USD 5 billion in 2004 to almost USD 12 billion in 2013, before declining

[40] IEA Energy Technology RD&D Database http://www.iea.org/statistics/RDDonlinedataservice/
[41] IEA Energy Technology RD&D Database http://www.iea.org/statistics/RDDonlinedataservice/

to around USD 9 billion in 2015 (current dollars) (see Figure 4.4). This represents less than 1% of global GERD. The annual growth rate between 2004 and 2014 was 8.7%, well above the rate of inflation thus indicating real increases in R&D spending.

Figure 4.4 R&D spending on renewable energy (USD billion)[42]



Data on developing country public energy R&D expenditures is scarce. While some of the major developing countries have significant expenditures, most are by public-sector enterprises.[43] Direct government R&D support may be quite skewed, with a few sectors receiving most of the funds.[44] In recent years China has made significant public investments in renewables R&D (consonant with its sharp rise in overall R&D). The BNEF/Frankfurt School estimates that in 2015 China invested USD 1.8 billion in public R&D funding for renewables.[45]

Data on private sector expenditures on R&D for energy technologies is not systematically compiled and published, in part because of the wide-ranging scope of energy technologies and the diverse nature of the firms that engage in energy-relevant R&D.[46] Box 1 below provides an insight into how one may approximate R&D energy expenditure for large private sector enterprises, however it is noted that much private sector innovation is not undertaken by traditional energy companies.[47] For renewable energy technologies, the BNEF/Frankfurt School estimates that the corporate share of total R&D spending is around 55% (see figure 4.4). For 2015, this equates to USD 5 billion (see figure 4.4). Although R&D spending has risen rapidly, private sector renewables investment has grown even faster thus causing R&D spending as a percent of investment to decline. Private R&D expenditure for renewables is about

[42] Frankfurt School-UNEP Centre/BNEF. 2016. Global Trends in Renewable Energy Investment 2016. Retrieved from http://www.fs-unep-centre.org March 29, 2016. Figure 54, p. 72.

[43] Kempener, R, Anadon, L.D., and Condor, J. "Governmental Energy Innovation Investments, Policies and Institutions in the Major Emerging Economies: Brazil, Russia, India, Mexico, China, and South Africa." Discussion Paper, 2010-16, Energy Technology Innovation Policy Project, Belfer Center, November 2010.

[44] Sagar, A. "India's Energy R&D Landscape: A Critical Assessment." Economic and Political Weekly, vol. 37. no. 38. (September 21 - September 27, 2002): 3925-3934

[45] Frankfurt School-UNEP Centre/BNEF. 2016. Global Trends in Renewable Energy Investment 2016. Retrieved from http://www.fs-unep-centre.org March 29, 2016. Figure 55, p. 73.

[46] Sagar, A. and Holdren J.P. 2002, "Assessing the global energy innovation system: some key issues," Energy Policy, 30(6):465-469.

[47] IEA, 2010, p. 9.

3% of sales revenue. This compares with an overall industrial average of 3.2%. For oil and gas producers the average is 0.3% and electricity producers 0.5%.[48]

Box 1: Private sector expenditures on research and development for energy technologies

Diversified industrials that have a large presence in the energy sector often have significant R&D energy expenditures. Let us look at three such companies. Based on publicly available data published for the 2016 financial year, 40% to 60% of total revenues of Siemens, Hitachi, and ABB are energy related.[49] These enterprises also reported total research and development (R&D) expenditure for the 2016 financial year of USD 5.2 billion, USD 3.0 billion and USD 1.4 billion respectively. While we do not have information on the share of their R&D devoted to energy, the sheer magnitude of these R&D investments and the significant presence of the energy sector in these firms' turnovers suggests their energy R&D investment will be a significant fraction of their overall R&D investments and therefore a sizable amount in absolute terms

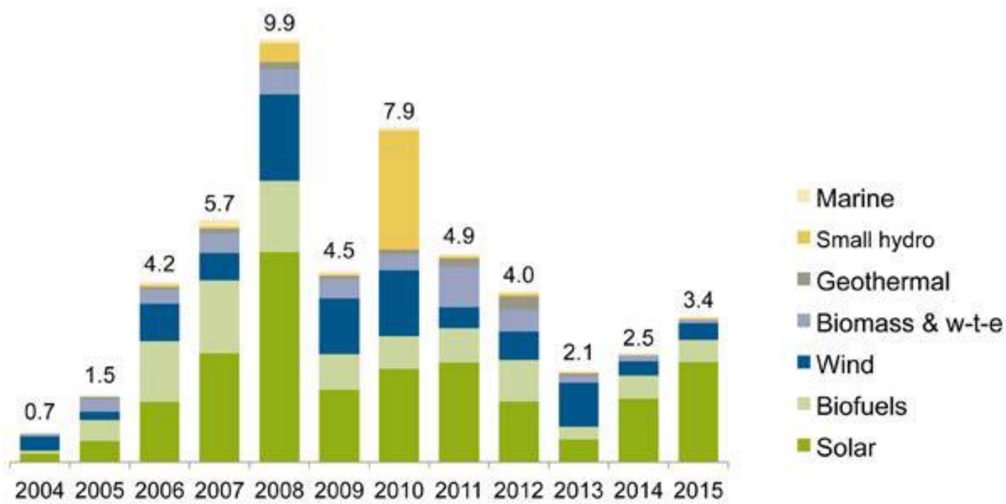
Finally, on venture capital, the United States of America's National Venture Capital Association reports on investments for 17 sectors, including industrial/energy. Since 2005, annual investment in this sector has fluctuated between USD 1.5 and USD 4.5 billion. In this time, the sector's share has been between 2.5% and 6.0% of total venture capital investment. Global investments in the industrial/energy sector are estimated to be of the order of USD 7.5 billion, which is just over 5% of the USD 140 billion of total venture capital finance. The pattern for venture capital investments is thus like the IEA reported energy R&D expenditures as noted above; energy technologies receive around 5% of the total investment. Strikingly, the BNEF/Frankfurt School Venture estimates that venture capital investment in renewable energy technologies annually exceeds 25% of the R&D spending,[50] well above the overall energy investment share. Solar has attracted the largest share of the renewable energy venture capital investment (see Figure 4.5).

[48] Rhodes et al, 2014, p. 5602.

[49] In the 2016 financial year, Siemens had total orders of USD 86.480 billion, of which power and gas was USD 19.454 billion; wind power and renewables USD 7.973 billion; energy management USD 12.963 billion; building technologies USD 6.435 billion; and process industries and drives USD 8.939 billion. This gives an approximate energy related total of USD 55.764 billion euro, which is 64.5% of total orders. Hitachi Ltd. had annual revenue of USD 88.799 billion of which social infrastructure and industrial systems was USD 20.647 billion; automotive systems USD 8.860 billion; and smart life and ecofriendly systems USD 6.027 billion for an approximate energy related total of USD 35.534 billion, or 40.0% of total revenue. The ABB Group had total orders of USD 39.100 billion of which low voltage products was US 6.581 billion; power products USD 10.033 billion; and power systems USD 6.800 billion for an approximate energy related total of USD 23.414 billion, or 59.9% of total revenue.

[50] Frankfurt School-UNEP Centre/BNEF. 2016. Global Trends in Renewable Energy Investment 2016. Retrieved from http://www.fs-unep-centre.org March 29, 2016. Figure 50, p. 68.

Figure 4.5 Venture capital investment in renewable energy (USD billion)[51]



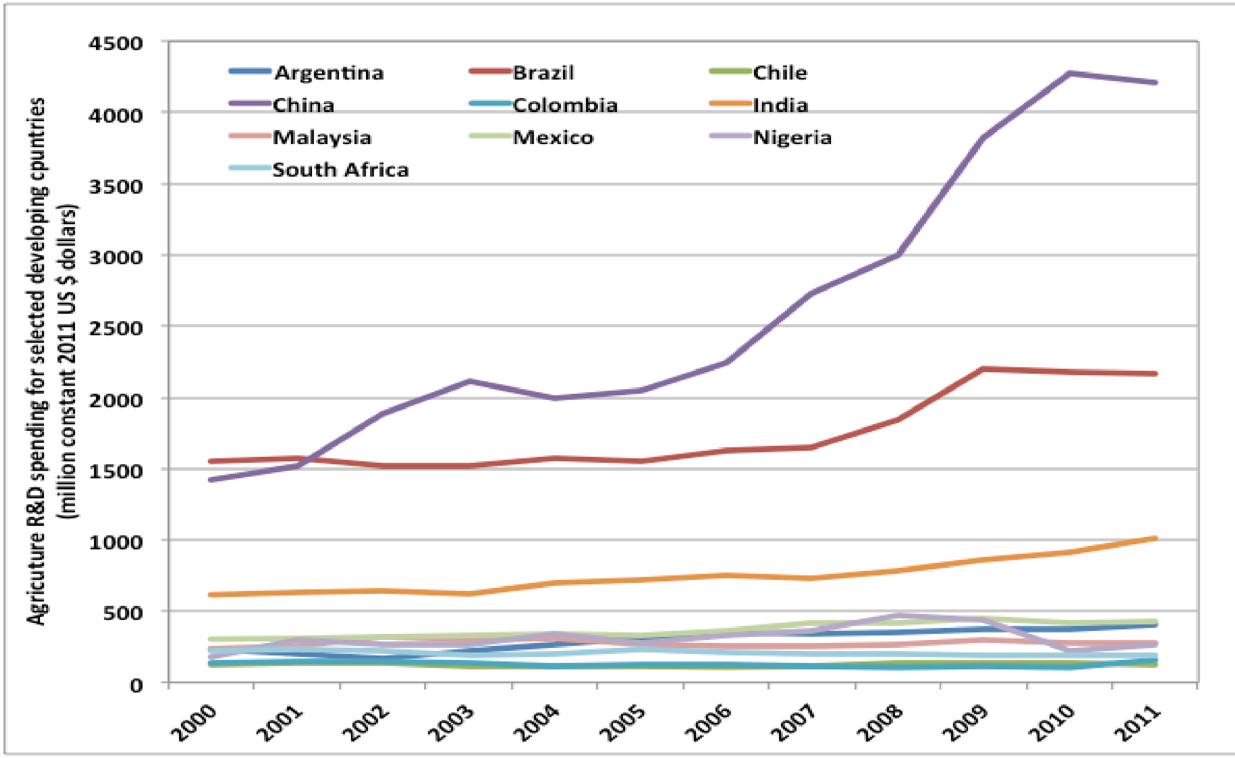
4.3 Expenditures for the research and development of agriculture technologies

Less data is available on agricultural R&D spending. Interestingly, the data for agriculture focus more on developing country R&D expenditures. They have been the main drivers of the growth in global public R&D spending for agriculture (from PPP USD 26.1 billion to PPP USD 31.7 billion between 2000 and 2008).[52] During that period, the growth in public R&D in developed countries slowed with the result that they were responsible for 51% of the global total in 2008. The United States of America and Japan were the top public agriculture R&D funders and accounted for almost half of the developed country total. Among developing countries, China, Brazil and India dominate (see figure 4.6).

[51] Frankfurt School-UNEP Centre/BNEF. 2016. Global Trends in Renewable Energy Investment 2016. Retrieved from http://www.fs-unep-centre.org March 29, 2016. Figure 54, p. 72.

[52] Beintema, N., Stads, G., Fugtie, K., and Heisey, P. 2012. ASTI Global Assessment of Agricultural R&D Spending. Washington, D.C.: International Food Policy Research Institute.

Figure 4.6 Public agriculture R&D spending by ten developing countries with largest budgets 2000-2011[53]



Over the period 2000-2008, private R&D on agriculture and food processing grew from USD 14.4 billion to USD 18.2 billion (of which food processing accounted for 54%).[54] Thus for agriculture technologies it can be observed that public R&D spending is larger than private R&D spending, a contrast to the public-private ratio for energy investments. In fact, public funding accounts for roughly 80% of the agriculture R&D. The data in Table 4.1 also shows a clear trend that middle-income countries are undertaking a growing portion of agriculture and food processing R&D, both government and private. While data is not available on the fraction of agriculture R&D that is targeted towards climate mitigation or adaptation, many of the agriculture R&D's goals contribute to climate resilience, including increasing agricultural productivity and food security, reducing poverty and increasing economic growth.

Table 4.1: Food and agricultural R&D by country income groups, 1980 and 2011 [55]

	Private ag R&D				Public ag R&D			
	1980		2011		1980		2011	
	Amount	Per capita	Amount	Per capita	Amount	Per capita	Amount	Per capita
	(million 2009 PPP$)	*(2009 PPP$)*	*(million 2009 PPP$)*	*(2009 PPP$)*	*(million 2009 PPP$)*	*(2009 PPP$)*	*(million 2009 PPP$)*	*(2009 PPP$)*
Low income	63	0.18	165	0.22	593	1.73	1,112	1.51
Middle	1,498	0.54	11,065	2.41	6,374	2.30	18,995	4.14
High income	7,992	9.75	19,899	19.58	10,863	13.25	18,022	17.73
Total	9,553	2.43	31,129	4.91	17,830	4.53	38,129	6.02

[53] ASTI (Agricultural Science and Technology Indicators). ASTI database. International Food Policy Research Institute (IFPRI). Accessed Jan 14, 2017

[54] Beintema, N., Stads, G., Fugtie, K., and Heisey, P. 2012. ASTI Global Assessment of Agricultural R&D Spending. Washington, D.C.: International Food Policy Research Institute. Within this, agriculture R&D grew from USD 7.5 to USD 8.3 billion.

[55] Pardey, P.G., Chan-Kang, C., Beddow, J.M. and Dehmer, S.P., 2016. Shifting Ground: Food and Agricultural R&D Spending Worldwide, 1960-2011. St Paul: University of Minnesota, International Science and Technology Practice and Policy center.

4.4 International collaboration on research and development for climate technology

A recent study notes that at least 90% of all low-carbon R&D activity is funded and undertaken within the same country.[56] International R&D collaboration has received relatively limited attention, but it can improve the effectiveness of R&D spending by leveraging synergies, avoiding duplication, and filling key gaps.[57] At least two major platforms for international R&D collaboration already exist for climate technologies – CGIAR for agriculture and the IEA Technology Collaboration Programmes (TCPs, formerly implementing agreements) for energy. The CTCN also offers the potential for contributing significantly on this front.

For four decades CGIAR has fostered collaboration among 15 independent, non-profit research centres on sustainable crop and animal agriculture, forestry and fisheries. Funds are provided by over 30 developed and developing countries, international organizations and philanthropic organizations. The centres perform the research, with many having facilities in developing countries. The CGIAR's efforts are particularly targeted at helping developing countries meet their agricultural technology needs. The CGIAR system is a major funder and performer of international agriculture R&D. Its total revenue is currently approximately USD 1 billion per year, which means that it represents approximately 3% of global agriculture R&D spending (see section 4.3 above).[58] CGIAR sees climate mitigation and adaptation as key goals and has committed to devote at least 60% of its budget towards these goals by 2030.[59]

The IEA TCPs have facilitated collaborative energy R&D for over 40 years.[60] At present there are 39 TCPs related to R&D, covering: end-use for buildings, electricity, industry and transport; fossil fuels; fusion power; and renewable energy and hydrogen. Participants include governments, industry and research organisations in 26 developed and 25 developing countries as well as 8 international organizations. Most of the participants are in IEA member countries.[61] However, a country does not have to be an IEA member to participate in TCPs and emerging economies (such as China for example) participate actively. The strategic direction of each TCP is determined by the members of the IEA Committee on Energy Research and Technology and include activities ranging from research in selected areas, construction of pilot plants, demonstration projects, and measures to facilitate deployment. The participants provide the funds and often undertake the research.

There also are examples of bilateral programs such as the US-China and US-India joint clean energy R&D centres. For example, the India-US Joint Clean Energy R&D Center (JCERDC) was established through a joint agreement in 2010, with each country providing USD 25 million. The objective is joint R&D on clean energy technologies that could be deployed quickly, resulting in significant impact. The JCERDC's three initial areas of focus were solar energy, energy-efficient buildings, and second-generation biofuels. The JCERDC funded, after an open call, a joint US-India consortium of research organizations that have developed tools to facilitate deployment of clean energy technologies (such as building design assistance tools) as well as deployable technologies. The JCERDC was extended in 2015 and expanded to include smart grids and grid storage.

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[56] Eis, J., Bishop, R. and Gradwell, P. 2016. Galvanising Low-Carbon Innovation. A New Climate Economy working paper for Seizing the Global Opportunity: Partnerships for Better Growth and a Better Climate. Retrieved from: http://newclimateeconomy.report/misc/working-papers.

[57] Ockwell, David G and Mallett, Alexandra (2012) Introduction: low-carbon technology transfer: from rhetoric to reality. In: Ockwell, David G and Mallett, Alexandra (eds.) Low-Carbon Technology Transfer: From Rhetoric to Reality. Routledge, New York and Oxon, pp. 3-19. ISBN 9781849712699

[58] CGIAR, 2016, 2015 CGIAR Financial Report, June 2016. Retrieved from <http://www.cgiar.org/resources/cgiar-financial-reports/> 23 January 2017.

[59] http://www.cgiar.org/our-strategy/

[60] IEA, 2016. Accelerating technology innovation worldwide. Retrieved from <https://www.iea.org/tcp/> 20 January 2017.

[61] 203 of 280 distinct entities and 474 of 594 entity-TCPs are from IEA member countries. IEA, 2016 p. 61.

Although platforms for international R&D collaboration already exist for agriculture and energy, the scale of the collaboration for climate technologies is limited. Approximately 30 developing countries are involved in CGIAR (out of a total of 45 participating countries) or the TCPs (49 participating countries). The CGIAR budget is approximately 3% of global agriculture R&D spending and currently less than 10% of the budget directly goes to the Climate Change, Agriculture, and Food Security (CCAFS) programme. Most of the TCPs cover renewable energy, energy efficiency and energy storage technologies but the budgets for those programmes are not available.

4.5 Summary

Developing a clear picture of RD&D expenditures for climate technologies and related trends is not an easy task. Systematic data on R&D expenditures for climate technologies exists only for a few sectors (energy and agriculture), and even these have gaps. No data are available on R&D spending for adaptation technologies. Data on government R&D funding are more comprehensive than on private R&D expenditures. There is a need to compile systematic data on public and private RD&D expenditures for climate technologies, as such efforts would help identify potential overlaps and gaps in such RD&D.[62]

The limited data available suggest that funding for energy and agriculture R&D increased as a share of GDP from the mid 1990s to 2011. Since then, public funding for energy R&D has declined and recent trends for private funding for energy and agriculture R&D are not known. R&D investment in each of these sectors currently accounts for around 5% of total global R&D. While data on private sector R&D spending is incomplete, it appears that it exceeds public funding for energy while in agriculture the opposite is true. The share of government energy R&D budgets allocated to renewables and energy efficiency has risen significantly while those devoted to nuclear and fossil fuels have fallen substantially. R&D activities for climate technologies, like all R&D, is concentrated in relatively few developed countries. Over the past two decades China and India have joined this group for energy. Developing countries play a larger role in agriculture R&D. Venture capital can play an important role in commercializing new technologies. Overall venture capital investments equal roughly 5% of R&D spending for energy, but renewables, especially solar, have attracted much higher levels over the past decade.

Platforms for international R&D collaboration involving developing countries already exist – CGIAR for agriculture and the IEA TCPs for energy. However, the current scale of international R&D collaboration for climate technologies is limited, about 30 developing countries and less than 1% of the global R&D expenditures for agriculture.[63]

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[62] This is also highlighted by others, e.g., IEA, 2010, p. 33.

[63] The CGIAR budget is about 3% of global agriculture R&D spending and less than 10% of the CGIAR budget goes to climate change at present.

5 ENHANCING THE FINANCING OF CLIMATE TECHNOLOGY RD&D

Section 3 highlighted the significant value of R&D and its outputs. Section 4 that trends indicate that public R&D finance for the energy and agriculture sectors is a relatively small part of global public R&D spending (around 5%, as noted above). It also noted that in the energy sector public R&D funding has declined in recent years. In other sectors, we do not know the level of R&D spending. This section builds on those two sections to identify ways to enhance RD&D finance for climate technologies.

The importance of RD&D financing for climate technology is noted in recent reports. For instance, the IEA, in its report *Energy Technology Perspectives 2016*, notes that "current RD&D investment falls well short of the levels required to meet this long-term climate goal."[64] Similarly, the Global Commission on the Economy and Climate in its report *The New Climate Economy 2016: The Sustainable Infrastructure Imperative* notes that "we must ramp up investments in clean technology R&D and deployment to reduce the costs and enhance the accessibility of more sustainable technologies."[65]

This section develops an understanding of (1) how to scale-up RD&D finance and (2) how to generate the best possible results from the limited RD&D financing available. It also describes (3) how the UNFCCC process can support enhanced RD&D financing.

5.1 Enhancing the research, development and demonstration of climate technologies

Before considering how to enhance RD&D financing, it is important to note that enhancing RD&D goes beyond RD&D financing. While beyond the scope of this paper, it is understood that innovation is a systemic process in which a range of interacting actors and resources together underpin successful technology development and deployment. Thus, effective technological change requires paying attention to all components and key functions of this system. Public policy and other efforts aimed at developing a well-functioning innovation system at the national (or sectoral level) can be effective in overcoming innovation gaps that might exist not only for developing countries but also for developed countries. Organizational forms such as climate innovation centers and partnership models may provide support for activities and aim to fill gaps in the local innovation ecosystem.

To accelerate climate technology innovation, it is important for the government to establish an enabling environment for and stimulate private sector participation in these innovation activities. Achieving this requires a mix of policy and financing instruments and includes both technology 'push' and technology 'pull' actions. Technology push involves implementing public policies and direct public funding[66] on climate technology RD&D in a way that drives both public and private actors to undertake RD&D activities with the aim of achieving identified objectives. Such policies may include: fiscal incentives such as reduced taxes; technology mandates; capital grants for demonstration projects and programs; direct subsidies; and loan guarantees. Technology pull involves policies, market creation and incentives to draw the private sector to climate technology markets. This may include: market based approaches and incentives, such as carbon pricing and carbon taxes; standards; regulations; consumer education and labelling; quota-based schemes like renewable portfolio standards and vehicle fleet efficiency standards; tenders for tranches of output; and public procurement policies.

In addition to these efforts, enhanced international cooperation can share the cost of public investment, facilitate economies of scale, increase the sharing of knowledge and foster technology development and dissemination. And last, but not least, building capacity – technical, institutional, policy, and coordination – to support both RD&D

[64] IEA, 2016, p. 69 [IEA Energy Technology Perspectives 2016].
[65] Global Commission on the Economy and Climate, 2016, The New Climate Economy 2016: The Sustainable Infrastructure Imperative, Key messages and Executive Summary, p. 2. Retrieved from: http://newclimateeconomy.report/2016.
[66] IEA, 2010, p. 9.

as well as other stages of the technology cycle is absolutely key to support the climate technology transition in developing countries.

The UNFCCC Technology Mechanism, and particularly the CTCN, may play a key role to support developing countries with the actions noted previously. The CTCN provides technical assistance to accelerate the transfer of climate technologies at the request of developing countries, creates access to information and knowledge on climate technologies, and fosters collaboration among climate technology stakeholders. The CTCN is now exploring its role in facilitating RD&D, in response to the COP 21 mandate.[67]

5.2 Increasing finance for research, development and demonstration

Essentially, increasing RD&D financing for climate technologies involves combining public RD&D funds with a suite of policy tools to catalyse private sector investment.[68] As section 4 points out, public climate-relevant R&D finance has increased in the last decade or so in response to climate (and related) challenges, although with a recent plateau for renewables. There also have been some more recent efforts to increase public climate R&D finance. A major initiative, Mission Innovation, was launched in Paris in November 2015 by twenty major energy economies to "reinvigorate and accelerate public and private global clean energy innovation with the objective of making clean energy widely affordable".[69] To support this objective, the governments of the member countries seek to double their public clean energy R&D expenditures, which should result in an additional USD 15 billion in R&D spending by 2021. Similarly, CGIAR has declared its intention to expand it climate-relevant RD&D efforts.[70] Yet there may be other areas, especially those relating to adaptation, where greater public R&D spending may be useful.[71] Further RD&D investment on energy efficiency technologies may also reap significant benefits.[72] In general, it is important for countries to consider how they may be able to allocate additional financial resources to public R&D for climate technologies, including possibly by reducing funds allocated to R&D for fossil fuels.

Another possible source of additional R&D finance for climate technologies may be non-traditional funders, such as philanthropies, that have been quite active and successful in other arenas (such as health) in providing catalytic funding as well as supporting innovative organizational forms (such as multi-actor partnerships). Some philanthropies are already involved in agriculture R&D through their participation in CGIAR, along with bilateral and multilateral development agencies. This may be of particular importance in areas such as disaster risk management that might fall outside traditional public R&D efforts.

The private sector must be an active partner in accelerating climate technology RD&D. Private RD&D efforts are at the heart of any attempt to achieve widespread real-world application of a technology. While firms make their RD&D spending decisions based on internal decisions, there is much that can be done to both stimulate private RD&D efforts and ensure that the results of such RD&D are successfully translated into real-world impact. Suitable policies and markets are central elements of these complementary efforts.

Providing a clear signal, thorough appropriate policies, about the existence of a market for climate technologies is key to ensuring that there is incentive for private firms to increase their R&D spending and to take technologies forward to market. A weak or fluctuating signal will lead either to insufficient RD&D efforts or wasted resources due to cycles of withdrawal and re-entry, as in the case of venture capital investment for clean technologies (see Figure 4.5). There is thus widespread agreement about the importance of governments providing clear and

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[67] See page 4 above.
[68] IEA, 2010, p. 9.
[69] Mission Innovation has now expanded to 22 countries and the European Union.
[70] http://www.cgiar.org/our-strategy/
[71] Although this itself will require developing a better understanding of current state of adaptation RD&D and needs, as noted in Section 3.
[72] OECD/IEA, 2016, Tracking Clean Energy Progress 2016, Paris, p. 13.

sustained policy signals of their long-term commitments to mitigate GHGs and adapt to climate change. Such signals drive private RD&D efforts to develop and deploy climate technologies.

Which combination of policies provides the best incentive for low-carbon technology development? Environmental policies, science, technology and innovation policies, and trade policies all may play key roles. Price-based instruments, such as carbon markets, and quantity-based instruments, such as renewable energy targets, tend to favour innovation in technologies that are closest to the market.[73] A signal of long-term stability in policy can stimulate R&D that will yield results further down the line. Research has also shown that volatility in public RD&D can adversely affect innovation rates[74], thereby suggesting that it is not only important to enhance climate public RD&D but also shield it from fluctuations (or which have seen many in recent years, as the data Section 4 has shown).

For example, research suggests that patent filings are closely related to the stringency of policy[75] in OECD countries.[76] Other work suggests that the European Union Emission Trading System (EU ETS) contributed to the increase in low-carbon technology patenting by participating companies. Participants and similar non-participants had roughly comparable innovation activity before the EU ETS began, but participants quickly increased their innovation activity relative to non-participants afterwards.[77] Climate change policies, based on market signals or regulations, have tended to shift innovation efforts from polluting to low-carbon technologies. Recent research in two sectors – alternative energy and automotive manufacturing – indicates that low-carbon R&D funding comes at the expense of R&D funding for more polluting technologies.[78] Other policy instruments such innovation prizes also can stimulate substantial private R&D spending. In the case of the Ansari X-Prize for suborbital space flight, a USD 10 million prize purse led to total expenditures of over USD 100 million in R&D by the 26 participating teams.[79] Some governments have already begun to incorporate this instrument into their overall innovation toolkit.[80]

Lastly, public RD&D funding can stimulate private sector RD&D funding by sharing the cost of private sector RD&D activities and by generating results with commercial potential. Some research suggests that increased public R&D

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[73] Regulatory standards likewise tend to favour technologies that are almost commercial. But they can bias the technology development. Regulations to limit SO_2 emissions by electric utilities specified removal rates (95%) and reliability levels (95% operation) for scrubbers. The reliability requirement led to designs with back-up capacity. When the SO_2 trading system was adopted, the reliability requirement no longer mattered because allowances were needed for all emissions. In effect allowances replaced the back-up capacity. Costs of new scrubbers were substantially lower because they had no back-up capacity. And scrubbers tended to operate more than 95% because this reduced the number of allowances needed for compliance.

[74] Johnstone, N. Haščič, I. and Kalamova, M. 2011, Environmental Policy Design Characteristics and Innovation," in Invention and Transfer of Environmental Technologies, OECD.

[75] Dechezleprêtre, et al., 2016, p. 6, footnote 2: "The indicator of environmental policy stringency is a composite index of various environmental policy instruments, primarily related to climate and air pollution." For details on the construction of the indicator, see Botta, E., and Kozluk, T., 2014. Measuring environmental policy stringency in OECD countries. A composite index approach. OECD Economics Department Working Papers No. 1177. [pdf] Available at: http://www. oecd-ilibrary.org/docserver/download/5jxrjnc45gvg.pdf?expires=1452603396&id=id&accname=guest&checksum=82CA61FB36402F2CE8BC745EB0AAC716.

[76] Dechezleprêtre, et al., 2016, Figure 1, pp. 6-7.

[77] Dechezleprêtre, et al., 2016, Figure 2, p. 8. Calel, R. and Dechezleprêtre, A., 2014. Environmental policy and directed technological change: Evidence from the European carbon market. *Review of Economics and Statistics*. [online] Available at: http://www.mitpressjournals.org/doi/abs/10.1162/REST_a_00470#.Vo-mjvmLSHs

[78] Dechezleprêtre, et al., 2016, p. 9. Popp, D. and Newell, R., 2012. Where does energy R&D come from? Examining crowding out from energy R&D. *Energy Economics*, 34(4), pp.980–991.

[79] http://ansari.xprize.org/teams

[80] See, for example, https://www.challenge.gov/list/ in the United States and http://www.nesta.org.uk/challenge-prize-centre in the United Kingdom.

funding stimulates private R&D,[81] although others suggest that it may be a more mixed answer.[82] Therefore, increased public R&D may have a multiplier effect, although greater clarity on this issue would be of value. To highlight a recent example, the Mission Innovation governments, in addition to boosting their clean energy R&D, have explicitly stated their intent to work with the private sector and business leaders to promote private investments in clean energy technologies. In return, a group of investors have formed the Breakthrough Energy Coalition to advance the translation of technologies from lab to market through support for early-stage technology development for breakthroughs emerging from Mission Innovation countries. The members of the coalition intend to invest individually, through partnerships, directly in companies, or through pooled capital vehicles.[83] This is an example of where an intention to increase public R&D spending has also stimulated additional early-stage investments by private investors (see Box 2 below for further detail). Similarly, on a smaller scale it has been noted that business models where public R&D funding provides early-stage grants to private sector firms may be effective in stimulating effective innovation.[84]

Finally, while a specific discussion on venture capital goes beyond the scope of this paper, to support such investments on climate technologies in developing countries it may be necessary to further develop insurance coverage in this area.

Box 2: Breakthrough Energy Coalition

The Breakthrough Energy Coalition encourages broad public and private investment on innovation focused on developing new clean technologies for providing access to reliable and affordable energy, food, goods, and services. It notes that to provide reliable and affordable power without contributing to climate change we need to address emissions in five key areas: electricity, transportation, agriculture, manufacturing, and buildings. The coalition maps out a landscape of innovation to help meet those challenges.[85]

5.3 Enhancing the effectiveness of finance for research, development and demonstration

It is also important to improve the effectiveness of R&D spending, i.e., get a greater output (new knowledge, enhanced capacity, stronger networks and more effective technologies) from the available funds. Maximizing cost-effectiveness is an important issue for any technology-based sector[86] and any organization that funds or performs R&D. This is as true of the business sector as the public sector. Enhancing effectiveness of R&D finance involves several factors.[87]

At the broadest level, national R&D funding agencies consider the effectiveness of R&D finance in terms of getting the best results from their expenditures. There are two key issues here. Firstly, governments have to consider how to develop funding strategies, which combine public investments with policies that catalyse corporate

[81] Guellec, D. and B. van Pottelsberghe de la Potterie (2000), "The Impact of Public R&D Expenditure on Business R&D", OECD Science, Technology and Industry Working Papers, No. 2000/04, OECD Publishing, Paris.
[82] David, P.A., Hall, B.H. and Toole, A.A., 2000. Is public R&D a complement or substitute for private R&D? A review of the econometric evidence. *Research policy*, 29(4), pp.497-529.
[83] http://www.b-t.energy/faq/
[84] Howell, S.T., 2017, "Financing Innovation: Evidence from R&D Grants", American Economic Review, 107(4): 1136–1164.
[85] <http://www.b-t.energy/landscape/> and <http://www.b-t.energy/wp-content/uploads/2016/10/BreakthroughEnergyCoalition_Landscape.pdf>.
[86] See, for example, Paul, S.M., Mytelka, D.S., Dunwiddie, C.T., Persinger, C.C., Munos, B.H., Lindborg, S.R. and Schacht, A.L., 2010. How to improve R&D productivity: the pharmaceutical industry's grand challenge. Nature Reviews Drug Discovery, 9(3), pp.203-214. Knott, A.M., 2012, The Trillion-Dollar R&D Fix, Harvard Business Review.
[87] Alene, A, Yigezu, Y, Ndjeunga, J, Labarta, R, Andrade, R, Diagne, A, Muthoni, R, Simtowe, F, and Walker T., 2011. Measuring the effectiveness of agricultural R&D in Sub-Saharan Africa from the perspectives of varietal output and adoption, IFPRI: Washington DC.

investment.[88] This involves a consideration of the amount of funding and how that is allocated among various options, i.e., the R&D portfolio. Secondly, funders have to consider how to enhance the organization of R&D efforts and the available human resources to improve the performance of this R&D. Monitoring and evaluation will also play important roles in enhancing the effectiveness of RD&D efforts.

On the first issue, a number of analytical efforts have attempted to elucidate insights about RD&D funding strategies and suitable levels of R&D spending in areas such as energy and agriculture.[89] There are analyses of how to better assess the scale and suitability of R&D spending[90] as well as on how to improve allocations of R&D funding from amongst a variety of options by using approaches such as real-options,[91] fuzzy approaches,[92] and expert elicitations.[93] Notably, public investments in demonstration projects may play a key role in advancing RD&D.[94] Thus a better understanding of how to best allocate funds between R&D and demonstration may benefit from greater analytical effort. It also should be noted that stability of R&D funding is key to ensuring sustained returns from R&D.

On the second issue, a few governments have adopted new institutional models aimed at improving the effectiveness of the R&D process. These include ARPA-E in the United States of America and the Catapult Centers

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[88] IEA, 2010, p. 32.

[89] See, for example, PCAST, 1997. Federal Energy Research and Development for the Challenges of the 21st Century, The White House: Washington DC.; Margolis, R.M. and Kammen, D.M., 1999. "Evidence of Under-investment in Energy R&D in the United States and the Impact of Federal Policy," *Energy Policy*, 27(10): 575-584; Nemet, G.F. and Kammen, D.M., 2007. "US energy research and development: Declining investment, increasing need, and the feasibility of expansion," *Energy Policy*, *35*(1): 746-755; Jamasb, T., Nuttall, W.J. and Pollitt, M., 2008. The case for a new energy research, development and promotion policy for the UK. *Energy Policy*, 36(12), pp.4610-4614; Beintema, N. and Elliott, H., 2009. Setting meaningful investment targets in agricultural research and development: challenges, opportunities and fiscal realities. In How to feed the World in 2050. Proceedings of a technical meeting of experts, Rome, Italy, 24-26 June 2009 (pp. 1-29). Food and Agriculture Organization of the United Nations (FAO); Baldos, U.L.C., Hertel, T.W. and Fuglie, K.O., 2015. Climate change adaptation through agricultural R&D investments: Implications for food security and the environment. In 2015 *AAEA & WAEA Joint Annual Meeting*, July 26-28, San Francisco, California.

[90] Wiesenthal, T., Leduc, G., Haegeman, K. and Schwarz, H.G., 2012. Bottom-up estimation of industrial and public R&D investment by technology in support of policy-making: The case of selected low-carbon energy technologies. *Research Policy*, 41(1): 116-131; Nin-Pratt, A., 2016. Comparing apples to apples: A new indicator of research and development investment intensity in agriculture (Vol. 1559). Intl Food Policy Res Inst.

[91] Grubler, A. and Riahi, K., 2010. Do governments have the right mix in their energy R&D portfolios? *Carbon Management*, 1(1), pp.79-87; Bosetti, V., Carraro, C., Massetti, E., Sgobbi, A. and Tavoni, M., 2009. Optimal energy investment and R&D strategies to stabilize atmospheric greenhouse gas concentrations. *Resource and Energy Economics*, 31(2), pp.123-137; Davis, G.A. and Owens, B., 2003. Optimizing the level of renewable electric R&D expenditures using real options analysis. *Energy Policy*, 31(15), pp.1589-1608.

[92] Lee, S., Mogi, G., Lee, S. and Kim, J., 2011. Prioritizing the weights of hydrogen energy technologies in the sector of the hydrogen economy by using a fuzzy AHP approach. *International Journal of Hydrogen Energy*, 36(2), pp.1897-1902.

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in the United Kingdom of Great Britain and Northern Ireland, which take different approaches to strengthening the RD&D process. The ARPA-E model is a project-based approach, focusing on transformational advanced energy technologies. The projects are envisioned in relation to specific end-objectives. Project directors aim to shepherd the projects forward by providing technical and other advice to the researchers. In addition, technology-to-market advisors provide market and business advice to help ensure that both technical and market dimensions are addressed by the teams. ARPA-E has also built linkages to US Department of Energy (DOE) programs to facilitate up take of technologies through DOE initiatives with the Department of Defense.[95]

Another example is the UK Catapult centers, which are designed around specific technologies.[96] The centers bring together business and academic personnel to work on late-stage R&D on high-potential ideas, with the intention of developing new products and services that contribute to the UK's innovativeness and competitiveness. Each catapult center is unique but serves the purpose of creating a critical mass of highly-skilled researchers and engineers. The centers also provide specialist facilities, technical advisory services, and supporting activities such as pre-competitive R&D and systems integration.[97] This allows the centers to move the technology forward in a way that individual firms or academia would not likely do otherwise.

While these examples illustrate initiatives which aim to enhance RD&D performance, others have suggested that a wide-ranging reform of R&D institutions and systems is needed to make them more effective at R&D performance, especially for the kind of transformational breakthroughs that are needed to address the climate challenge.[98] Equally, much thinking is needed on how to best organize international collaborative RD&D to help accelerate the global climate technology transition (see box 3 below).

Box 3: Strengthening collaborative research, development and demonstration for climate technologies

Collaborative research, development and demonstration (RD&D) may play a productive role in helping developing countries accelerate their action on climate change. Benefits of international collaboration on RD&D may include cost savings, accelerated learning, harmonization of standards and approaches and elimination of duplication.[99]

Platforms for international R&D collaboration between developed and developing countries already exist for agriculture (CGIAR) and energy (IEA technology collaboration programmes (TCPs)) on a plurilateral basis; there also are institutionalized examples of bilateral R&D collaboration. But the scale of the collaboration for climate technologies is limited. Approximately 30 developing countries (of a total of approximately 50 countries) are involved in CGIAR or the TCPs. And the share of the resources devoted to climate technologies is small. The CGIAR budget is approximately 3% of global agriculture R&D spending and currently less than 10% of the budget directly goes to the Climate Change, Agriculture, and Food Security (CCAFS) programme. An unknown percentage of the TCPs is focused on climate technologies.

There has been some exploration of other options for RD&D collaboration involving public and private actors (see

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[95] Bonvillian, W.B., 2014. The new model innovation agencies: An overview. *Science and Public Policy*, 41(4), pp.425-437; Bonvillian, W.B. and Van Atta, R., 2011. ARPA-E and DARPA: Applying the DARPA model to energy innovation. *The Journal of Technology Transfer*, 36(5), p.469. Anadón, L.D., 2012. Missions-oriented RD&D institutions in energy between 2000 and 2010: A comparative analysis of China, the United Kingdom, and the United States. *Research Policy*, 41(10), pp.1742-1756.
[96] Including energy systems, offshore renewable energy, and transport systems.
[97] Review of the Catapult network: recommendations on the future shape, scope and ambition of the programme,
[98] Narayanamurti, V., Anadon, L.D. and Sagar, A.D., 2009. Transforming energy innovation. *Issues in Science and Technology*, 26(1), pp.57-64; Anadon, L.D., Chan, G., Bin-Nun, A.Y. and Narayanamurti, V., 2016. The pressing energy innovation challenge of the US National Laboratories. *Nature Energy*, 1, p.16117; Foxon, T.J., Gross, R., Chase, A., Howes, J., Arnall, A. and Anderson, D., 2005. UK innovation systems for new and renewable energy technologies: drivers, barriers and systems failures. *Energy policy*, 33(16), pp.2123-2137.
[99] IEA, 2010, p. 32.

Annex C) but given the importance of this topic – and its specific mention in the Paris Agreement – a better understanding of the gaps and opportunities on this front is needed. Notably, collaborative R&D has both North-South as well as South-South dimensions, and requires an understanding of the comparative advantages of countries and their investment capacities. And international collaboration on RD&D may be easier during the early stages of the technology cycle because the competitiveness concerns related to commercial products are more remote.

5.4 The role of the UNFCCC process in enhancing RD&D financing

UNFCCC mechanisms and bodies can support developing countries both in developing policies and implementing actions to enhance such efforts. Cooperation between these bodies is necessary to build on their comparative strengths and make practical and comprehensive decisions. On policies, the TEC, the CTCN, the Standing Committee on Finance (SCF), the Green Climate Fund (GCF) and the Global Environment Facility (GEF) have a wealth of policy knowledge on both climate technology and climate finance. In accordance with their mandates, the TEC and SCF focus more on global policy considerations while the CTCN, GCF and GEF focus primarily on supporting developing countries with the implementation of action. Bringing together these complementary sets of knowledge and experiences, these bodies could collaborate to develop recommendations on RD&D financing policies that could support developing countries to enhance their RD&D efforts.

On a practical level, the CTCN could support developing countries at their request on issues related to RD&D for climate technologies. The GCF and GEF could also play important roles. There is also a need to understand what collaborative arrangements may be most effective. The CTCN could collaborate with the TEC in promoting existing and identifying new collaborative RD&D arrangements, including public-private partnerships, which may support developing countries to scale up NDC technology implementation to 2030, and develop broader innovation capabilities up to and beyond 2030. In addition to identifying such arrangements, the TEC and the CTCN could also have a role in supporting developing countries to build their capacity for engaging in such activities.

6 Conclusions

RD&D programmes enhance the performance and reduce the cost of climate technologies. They can also develop completely new innovative technologies. There is general agreement that the economic, environmental and social benefits of RD&D activities can be significant. The rate of return on investment can also be substantial, and it can also increase a country's competitiveness. Global RD&D investments in the energy and agriculture sectors each account for less than 5% of global R&D. And since 2011, public funding for energy R&D has declined. Countries may consider increasing these percentages and reversing these trends to achieve the Paris Agreement objectives.

Enhancing RD&D finance for climate technologies will require increasing its scale. However, it will be imperative to do so in a manner that ensures both public and private RD&D are increased. It will also be important to ensure that such increases cover different climate sectors rather than only a few (such as energy and agriculture), and that there is an effective allotment of spending for R&D and demonstration. In doing so, it will be important to ensure that the needs of all developing countries are addressed. Collaborative RD&D (both North-South and South-South) may play an important role here and therefore needs particular attention.

Enhancing RD&D finance for climate technologies will also require enhancing its effectiveness through a suite of activities. These include improving the allocation of the RD&D portfolio and taking steps to improve the performance of RD&D activities and organizations. These will help enhance the output of RD&D activities for the available resources. Furthermore, complementary activities that focus on downstream stages of the technology cycle (such as market creation and deployment-enhancing activities), are key to ensuring that RD&D outputs – new technologies and services – find commercial application.

The UNFCCC and its constituted bodies can play a key role in supporting transformative financing for RD&D activities. The TEC, CTCN, SCF, GCF and GEF have the knowledge and experience to enhance RD&D financing in developing countries, within their existing mandates. These bodies can stimulate and catalyse the global action that is desperately needed.

Annexes

Annexes are available online:

Annex A – What are climate technologies?
https://goo.gl/t7M7sa

Annex B – What are the outcomes of RD&D programmes?
https://goo.gl/PvEzpO

Annex C – Illustrative set of collaborative RD&D options to meet developing country needs
https://goo.gl/y2j0Hv

The Technology Executive Committee would like to thank Ambuj Sagar and Erik Haites for their contributions to this paper.