22 International cooperation in advancing energy technologies for deep decarbonisation

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Climate change cannot be arrested without fundamental changes in the global energy system. Such a transformation will not be possible without major advances in a variety of low-carbon energy technologies. While carbon pricing can provide incentives for advancements in low-carbon energy technologies, more is needed to make deep cuts in global greenhouse gas (GHG) emissions in a cost-effective and politically feasible way. This is because the current state of the art for low-carbon technologies is such that they are significantly costlier than conventional fossil-based energy technologies if deployed at a larger scale. Bringing down the costs of low-carbon energy technologies will require substantial public sector investments not just in basic research, but also in pilot commercial-scale development of advanced energy technologies. Substantial gains in such efforts could be obtained from international agreement to coordinate national RD&D programmes for low-carbon energy and to share the fruits of discoveries. Such agreement promotes the provision of a public good versus negotiating over sharing the cost burden for curbing a global bad. International technology agreement can be complemented by coordinated efforts to raise international performance standards for energy efficiency and carbon intensity in key energy-using sectors.

The need for global energy system transformation

Global climate change cannot be arrested without fundamental changes in the global energy system. This can be seen from the following basic relationship explaining the influences the growth of greenhouse gas (GHG) emissions (the so-called Kaya identity):

[*% rate of change in global GHG emissions over time*] =

[*% rate of change in population*] +

[*% rate of change in income per capita*] +

[*% rate of change in energy utilised per unit of economic output (energy intensity)*] +

[*% rate of change in the embodied carbon per unit of energy utilised (carbon intensity)*]

The world's population will continue to grow over the remainder of the century, though the rate of growth will drop considerably over time. It is to be hoped that global average income per capita grows considerably over the coming decades, in order to sharply cut the percentage of individuals living in poverty and to achieve continued but more inclusive economic growth. Let us assume that population growth is about 1% per year over the next few decades, and that per capita income growth is about 3%.[1]

The growth in population and per capita income will be accompanied by considerable increases in energy use, in particular by the descendants of poor populations that today use little modern energy or even lack access to it altogether. Against these trends, energy efficiency is likely to continue to improve over time. However, annual rates of improvement in energy efficiency in the order of 4% would be needed to offset the growth in population and (hoped for) income growth. This is unrealistically high; 2% is a more realistic, albeit still ambitious figure. A rate of energy decarbonisation of 2% per year then would be needed to hold GHG emissions constant. In comparison, the global carbon intensity of energy use barely changed over the period 1990–2012 according to the IEA (2014, Figure 16), and the EIA's (2013) projection without major new policies internationally is for a decrease in carbon intensity of only 0.2% per year on average up to 2040.

These calculations illustrate only what would be needed to arrest growth in GHG emissions over the next few decades. In fact, global GHG emissions must not only peak fairly soon but also fall precipitously by the end of this century to limit the increase in the global average temperature to somewhere between 2°C and 3°C, a target range seen by many as needed to avoid unacceptably high risks from climate change. To

1 These are roughly the figures used in the Energy Information Administration's 2013 *International Energy Outlook* (EIA 2013).

accomplish this, the global energy system must be profoundly transformed into one that produces only a small fraction of the GHG emissions occurring today – even while average global income rises substantially from its current level. As shown in IPCC (2014a, Figure 7.16), low-carbon energy sources – renewables, nuclear, and fossil energy use with carbon capture and storage (CCS) – must increase from under 20% of total energy use to above 70% or even above 90% by 2100, depending on the stringency of the limit on temperature increase sought.

Such a transformation will not be possible without fundamental changes in energy technologies. The reason for this is that low-carbon energy technologies currently are not cost-competitive when implemented on a large scale. The lower 'energy density' of wind and solar resources per unit of capital expenditure, relative to conventional technologies, is one barrier (Kessides and Wade 2011). Even where direct costs of production are falling, as with solar photovoltaic (PV), the costs of large-scale PV use are increased by its intermittency and the challenges of coordinating such dispersed resources with the current power grid (Joskow 2011). While some very large hydroelectric resources remain to be developed, the number of economically attractive and environmentally manageable sites is inherently limited. Nuclear power remains dogged by cost overruns, public concerns, and the long time line that seems to be needed for 'next generation' reactors to become commercially available. 'Second-generation' biofuels that create fewer land-use tradeoffs and result in larger net carbon savings remain a number of years away (Cheng and Timilsina 2011). While plug-in vehicles are advancing quickly, they increase the pressure to decarbonise the power system.

All these potential pathways for decarbonisation of the energy system must bear fruit in terms of lower costs in order for dramatic decarbonisation to be economically manageable in practice. However, the ability to use carbon capture and storage appears to be especially urgent. Even some negative-emissions options are needed – in particular, growing biomass, which pulls CO_2 out of the atmosphere, and capturing the released CO_2 emissions when the biomass is burned to generate power. If CCS is not available in the portfolio of emissions mitigation options, the costs of constraining temperature increases are considerably larger (IPCC 2014b, Table SPM2). Yet, CCS remains an experimental technology, with very uncertain future prospects (see Tavoni 2015).

Challenges in achieving the transition

As it stands, the IPCC suggests that additional investments of around $150 billion per year may be needed to move forward on a path toward decarbonisation, as well as more than twice that amount for improvements in energy efficiency (IPCC 2014b, p. 27). The International Energy Agency has estimated that $44 trillion would be needed by 2050 in the effort to hold temperature change below 2°C (IEA, 2014), on top of the investments needed to meet growing energy demands.[2] Such added costs can limit the incentives for individual countries to launch programmes for energy decarbonisation, and exacerbate the debate over how the cost burden for drastically reducing global GHG emissions might be allocated.

Given that a profound change in the global energy system will be needed to reduce GHG emissions enough to stabilise the climate, and given that a high cost of decarbonisation acts as a serious barrier to unilateral and cooperative efforts to implement GHG-mitigating policies and measures, it stands to reason that technical progress in lowering the cost of decarbonisation needs to be a high priority. This is all the more important when one takes into account that the default for meeting rapidly growing energy demands in developing countries will include major increases in fossil energy, especially coal for electricity. Locking in high-carbon energy infrastructure only raises the opportunity cost of reducing emissions later, further deterring actions needed to stabilise the climate.

One way to stimulate such technical progress is by putting a price on GHG emissions. This creates powerful incentives for the development and diffusion of lower-cost, lower-carbon energy sources and technologies. With the development of such technologies, all GHG emitters can lower their costs of responding to policy (such as the need to buy allowances in the European Trading System (ETS) or to pay a carbon tax on residual emissions) by licensing the new technologies, and those who can provide cost-reducing GHG-mitigation technologies have a ready market in which they can recover their costs. Calel and Dechezleprêtre (forthcoming) show that carbon pricing in the ETS has

2 The IEA also estimates that fuel cost savings would be more than 2.5 times as large.

contributed to an increase in low-carbon innovation, though the effect is not that large given the relatively low carbon prices found in the ETS.

A key virtue of using carbon pricing to help induce development and diffusion of lower-carbon energy technologies is that it can foster competition among different approaches. Meanwhile, some of the cost disadvantages of large-scale low-carbon energy deployment will shrink through learning-by-doing as greater experience is gained with the operation of larger-scale solar photovoltaic and thermal power plants, different wind sites, and evolving technologies for growing and utilising biomass energy sources (as fuels and electricity feedstocks).

Beyond carbon pricing …

However, more will be needed to make deep cuts in global GHG emissions in a cost-effective and politically feasible way. There continues to be resistance in much of the world to setting carbon prices that are high enough to induce major energy technology transformations, despite mounting evidence of the threats posed by climate change. Moreover, some of the cost disadvantages of low-carbon energy systems may be persistent, requiring more fundamental advances in technology than might be induced through carbon pricing alone. These include the challenges of coordinating widely dispersed and intermittent renewable electricity sources for a stable power grid (and as part of that, the development of cost-competitive power storage technologies), and the development of a 'new generation' of nuclear power reactors that are cost-competitive and respond to public concerns about safety as well as nuclear proliferation. The technical challenges facing the development and widespread implementation of cost-competitive and publicly accepted CCS also are quite substantial. The more basic scientific research that seems necessary to overcome the cost barriers typically is undertaken on too small a scale, if at all, by the private sector, given both the risks from failure and the difficulties in appropriating economic benefits from a basic discovery.

…to disruptive innovation

The size and persistence of these sorts of challenges suggests that some 'disruptive' rather than just 'evolutionary' innovations in energy technologies will be needed to overcome them. While in principle such innovations could occur at any time and could come from a variety of sources, large and enduring increases in public sector R&D expenditures are likely needed in practice to raise the probability of achieving the necessary fundamental breakthroughs in low-carbon energy technology to an acceptable level. In addition, some public investment (or some other form of cost and risk sharing) will be needed in piloting commercial-scale applications of more fundamentally new technologies, in order to mitigate the economic risks of being an early mover with a new technology. For example, electricity grids that can successfully manage the integration of dispersed and intermittent resources are inherently large investments in technologies whose performance characteristics can only be fully understood once the technology has been scaled up. The same is true of large-scale CCS. Determining the economic performance of solar thermal technology on a large scale likely will require building a significant number of facilities using different specifications and operating conditions; yet each plant would cost some billions of dollars to build and would be likely deliver uneconomic power compared to alternatives while the technology is being refined.

The importance of international technology cooperation

The need for increased public sector R&D discussed above could be met by different governments funding a variety of different programmes, depending in part on their own comparative advantages (e.g. countries with high wind or solar potential, or geology favourable to CCS) as well as on their own reckonings of what technology paths may be more promising. There are, however, some significant limitations with this approach that point to the value of international cooperation in low-carbon RD&D.

One issue is the cost of greatly expanded national programmes for energy technology development. No one really knows how large these costs might be. According to figures from the IEA,[3] between 2005 and 2013, total energy-related RD&D in the OECD averaged about $15.3 billion per year. Of that amount, about 35% was for energy efficiency and renewable energy (in roughly equal parts), just under 30% was for nuclear, and only 15% was for fossil energy. On the other hand, the percentages for hydrogen and fuel cells and for storage technologies were only about 5% each. Funding for CCS is also minimal compared to its potential importance for decarbonisation in the medium to longer term.

As noted in IPCC (2014a, Section 7.12.4), energy R&D recently has been in the order of 5% of total R&D spending – less than half the level observed in 1980. With such a small share for total energy R&D, let alone low-carbon energy R&D, there are also concerns over the scope of international R&D for low-carbon energy. No one knows which of many possible technology pathways might be successful in lowering costs as well as emissions. Because of this, it would be highly desirable to pursue a number of them simultaneously, rather than picking a few 'winners' early on. However, many pathways can only be adequately explored through very substantial expenditures on both R&D and commercial-scale piloting, as noted above. Keeping open a range of options for technology development and diffusion, while very desirable, is costly.

At a time of limited fiscal space for many OECD and other countries, a significant absolute increase in RD&D spending for low-carbon energy will be challenging with or without international cooperation. Another difficulty, however, is the analogue of the problem with private R&D spending falling below the socially desirable level because of inherent problems in establishing adequate incentives for knowledge creation. Because fundamental knowledge coming from expanded public-sector R&D typically would not be possible to patent (though new devices based on that knowledge could be), a portion of the benefits of any R&D increase undertaken by a particular country will 'leak away' to others who can make use of the resulting knowledge without sharing in the costs. Yet, technology development and transfer to developing countries will be essential for a successful global climate regime (see Coninck et al. 2015). Understandably, individual governments considering major increases in low-carbon energy R&D programmes will

3 See http://www.oecd-ilibrary.org/energy/data/iea-energy-technology-r-d-statistics/rd-d-budget_data-00488-en.

be motivated by the benefits they can secure, not the benefits for the world as a whole. Moreover, the economic and political costs of unsuccessful programmes can create a bias in favour of pursuing technology options that appear more likely to succeed or easier to implement – even though success in decarbonisation may arise from what are seen today as 'fringe' possibilities. This may be easier to manage when one considers a global portfolio of R&D in which activities are coordinated and costs are at least implicitly shared for a range of options.

These points highlight the potential benefit from focusing substantial attention in upcoming international climate cooperation efforts on ways to greatly expand and coordinate global RD&D activity in low-carbon energy. Agreements on coordinating research programmes to share the costs of such RD&D investing, and on arranging for broad access to successes from the R&D, add to the global public good. This compares favourably with the politics of negotiation over allocating the cost of mitigating emissions (a global public bad) through negotiating over national emissions targets.[4]

That is not to say that arriving at an international agreement for low-carbon energy technology development would be easy. There would still need to be tough discussions over funding level commitments, the means for assuring that those commitments are carried out, and rights of participants to access discoveries coming from the programme. The details of programme administration would matter greatly. Trade barriers that limit the movement of international foreign-made green technologies today would remain an issue. Nevertheless, the promise of this approach suggests that it should receive much greater emphasis in international climate policy discussions.

4 Even with 'Intended Nationally Determined Contributions' (INDCs) for mitigating global GHG emissions, which are figuring prominently in the run-up to the Paris COP, there is still room to debate whether any one country's INDC is in some sense 'adequate'. Moreover, there is reason to believe that negotiations over INDCs will have to overcome the same basic challenge to international climate agreements that has been pointed out by numerous authors, namely, the fact that among many countries coming from diverse circumstances but with a common incentive to do less while hoping others will do more, the only feasible agreements may have limited impacts on the trajectory of global GHG emissions. The nature of this challenge is thoroughly reviewed in the various essays in Aldy and Stavins (2010).

A Global Apollo Programme?

The recent call by a number of prominent authors (including Lord Stern) for a 'Global Apollo Programme to Tackle Climate Change' (King et al. 2015) draws welcome attention to the need for expanding international RD&D for GHG mitigation, including low-carbon energy technologies.[5] The proposed programme calls for increased spending starting at $15 billion per year, or about 0.02% of global GDP, rising thereafter with growth in global income. Compared to the figures on recent energy RD&D expenditures presented above, this would represent somewhat more than double the recent levels of expenditure for non-fossil energy. However, it is an order of magnitude smaller than the amounts that the IPCC and IEA have suggested for effecting a low-carbon transition. Thus, the extent to which the proposed expenditures would lower the costs of new investments in low-carbon energy is open to question. The extent to which the expenditures would bring down the cost of low-carbon energy enough to stimulate earlier retirement of existing fossil energy production capacity is even more uncertain (Evans 2015).

On the other hand, is the international community prepared to spend something close to 0.02% of global GDP per year for some time on public and private RD&D in order to effect a deep and rapid reduction in GHG emissions? Only time and increased efforts to expand global RD&D cooperation will tell.

Complementary measures: Coordination of technology standards

A useful complement to creating a programme for internationally coordinated technology development for low-carbon energy would be international agreements on various performance standards for energy-using technologies, which could help spur demand for existing and new technologies (Barrett and Toman 2010). Even with current technologies, it could be possible to stimulate demand for more energy-efficient energy-using technologies and lower their cost of production through internationally

5 The analogy with the programme for successfully landing people on the moon is somewhat flawed, though, since it does not fully capture the diversity of technology initiatives needed to successfully accomplish drastic reductions in GHGs.

coordinated performance standards. The result could be significant reductions in emissions at relatively manageable costs (though the costs of energy efficiency programmes continue to be debated), and without the serious political economy challenges of carbon pricing.

More ambitious measures for stimulating new technology demand could involve international agreements on sector-specific carbon-intensity performance standards. For example, countries could agree that their national electricity systems would achieve targets for GHG emissions per unit of output by specified dates. Such agreements would obviously involve different costs for different countries, depending on the nature of the agreements. However, agreements over performance standards may be easier to negotiate than carbon-reduction targets per se, in that the performance standards can be framed in terms of technology modernisation and opportunities to compete internationally in the provision and utilisation of modern technologies. The ambition of any such agreements would depend on how countries perceive the prospects for declining costs of decarbonisation over time, in particular through shared efforts to reduce the cost of low-carbon energy technologies. They would not necessarily be a substitute for coordinated international carbon pricing, but they could play a valuable role en route to such coordination.

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