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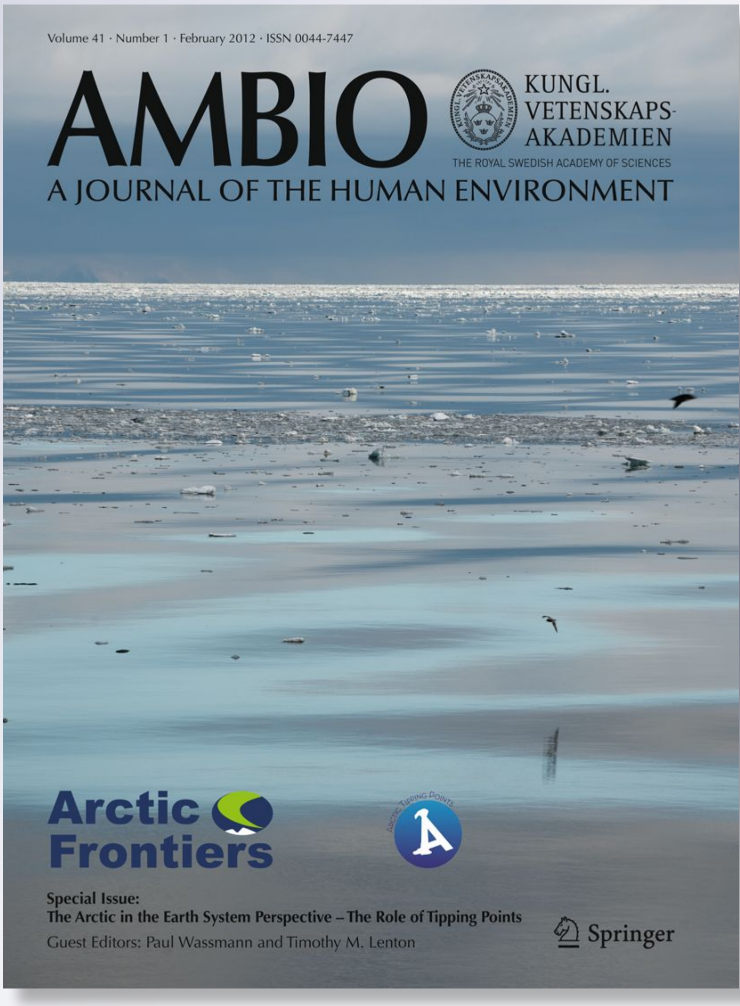

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How Should Support for Climate-Friendly Technologies Be Designed?

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Abstract Stabilizing global greenhouse gas concentrations at levels to avoid significant climate risks will require massive "decarbonization" of all the major economies over the next few decades, in addition to the reduced emissions from other GHGs and carbon sequestration. Achieving the necessary scale of emissions reductions will require a multifaceted policy effort to support a broad array of technological and behavioral changes. Change on this scale will require sound, well-thought-out strategies. In this article, we outline some core principles, drawn from recent social science research, for guiding the design of clean technology policies, with a focus on energy. The market should be encouraged to make good choices: pricing carbon emissions and other environmental damage, removing distorting subsidies and barriers to competition, and supporting RD&D broadly. More specific policies are required to address particular market failures and barriers. For those technologies identified as being particularly desirable, some narrower RD&D policies are available.

Keywords Climate-friendly technologies · Carbon pricing · Technology policies · Barriers

Many studies analyze the technological options for achieving deep reductions in greenhouse gas (GHG) emissions. For example, in a well-known *Science* article, Pacala and Socolow (2004) introduced a now-popular tool illustrating the "wedges" of potential reductions from available technologies to bring the emissions path to a stabilization target. These kinds of studies are informative, but they focus on the capacity of technologies, rather than the cost-effectiveness of reduction options (that is, meeting the policy target at lowest cost for the society), the possibilities for innovation over time, or the role of policies in getting there. Economists who model climate policies, on the other hand, tend to focus on cost-effective solutions, but often with less technological detail. All models have difficulty incorporating realistic representations of technological change, uncertainties, barriers, and non-market-based policies. It is important to remember that energy projections are difficult for proven technologies and even trickier for emerging ones.

In one word, a key challenge for meeting emissions and technology goals is *uncertainty*. We are not sure what emissions reductions will ultimately be needed or what the corresponding prices will be. We do not necessarily have a good idea of the costs of large-scale deployment of existing technologies, when breakthrough technologies might arrive, or to what degree the costs and quality of existing technologies will be improved. These kinds of uncertainties can create tension regarding how to choose among them. On the one hand, policies should be as neutral as possible to allow a broad range of technologies to emerge and compete and to avoid the problem of governments attempting to pick winners. On the other hand, we cannot be fully neutral, given that we are largely aware of the major technological options that will be available over the coming decades and that some technologies have specific barriers and potentials that may require targeted assistance. Two main challenges are to make certain that these decisions are based on best available knowledge that is regularly updated and on broad social interests, not the interests of narrow groups of stakeholders. Therefore, the first principle is not to pick technology winners, but to pick winning technology *policies*.

A second, related principle is thus for policies to address market and regulatory barriers, leaving technological barriers for scientists and the marketplace of ideas to focus on. In particular, economists are concerned with the problem of *market failures*, that is, when private actors do not reap the full social benefits or costs of their actions. By correcting these market failures and "getting the prices right," policies can better align private incentives with the public interest. The diffusion of environmentally friendly technologies relies not only on the technologies themselves, economic rationale, and specific policies, but also on support sectors (providing necessary capital, intermediary products, expertise, training, and so on), consumer choice (size of the market), and organizational constraints or managerial culture of a firm. All of these factors together determine the commercial viability of a technology, and ideal policies would ensure that all face appropriate market signals. In the next sections, we discuss a variety of market failures and related barriers for clean energy technologies, some of which are general and others of which are specific to certain technologies. In the end, we argue that a portfolio of policies and technologies is needed.

CARBON PRICING IS A TECHNOLOGY POLICY

The first step toward getting the prices right is to correct the fact that emitters do not bear the costs of the climate change risks they impose on the rest of society. Thus, the core of any cost-effective approach must be a strong price signal across the entire economy that carbon emissions are costly. This price signal should be increasing over time, since a climate policy could involve a budget on allowable GHG emissions, and increasing scarcity of allowable emissions is usually characterized by rising prices, because it is optimal to use less and less every year as less remains. Emissions pricing can be implemented through either a carbon tax or a broad-based cap-and-trade system. Studies indicate that emissions taxes provide stronger long-term incentives to invest in research, development, and deployment (RD&D) than does a cap-and-trade system (Requate 2005). Aiming at strong innovation incentives, policy uncertainty may favor taxing over cap-and-trade, given the variability of the allowance price in a cap-and-trade system and its sensitivity to policy changes, notwithstanding that politicians can change the tax level over time.

We underscore here that carbon pricing is not merely an emissions regulation, but also the single most important technology-neutral policy (Fischer and Newell 2008). The reason for a primary reliance on carbon pricing is twofold.

First, technologies are useful only if people want to use them. While social values may influence some to become early adopters of hybrid cars or compact fluorescent lightbulbs, financial self-interest is the primary driver for most participants in a market economy. Carbon pricing makes clean technologies more cost-competitive and provides "market pull" by encouraging their adoption. It also reduces some of the need for reliance on public innovation programs targeted specifically toward clean energy, as the market has more incentive to contribute. Furthermore, carbon pricing ensures that public spending on "market push" strategies of RD&D ultimately has greater impact, by increasing demand for these technologies.[1]

Second, many options are available for reducing emissions. Not only does a huge array of technological solutions exist for electricity generation, production processes, building materials, and consumer appliances, but a variety of behavioral changes also can contribute to smaller emissions footprints. No command-and-control regulation could efficiently prescribe all the appropriate activities that should be undertaken. Carbon pricing, on the other hand, creates incentives to do all these things: use less carbon-intensive fuels and fewer such products, conserve energy, and develop and deploy emissions-reducing technologies. Furthermore, when current technologies lead to cost-effective reductions in the near term, this lifts some pressure on the speed and depth of technological change needed in the future to reach a long-term cumulative emissions goal.[2]

Technological change and turnover will be essential for deep reductions; however, a lack of emissions pricing is not the only roadblock. A robust market for clean technology RD&D faces a host of other impediments such as financial, regulatory, behavioral, and network barriers; knowledge and innovation spillovers; and scale economies, among other challenges. In some cases, these impediments may be quite specific, depending on a particular technology, knowledge base, technological capability of the concerned region, or availability of alternative technologies (Shapira and Rosenfeld 1996; Shrivastava 2008, 2009).

Moreover, political realities may constrain the carbon price from being high enough to induce the necessary transformation and innovation. While many experts agree that a carbon price is necessary, few believe that a carbon price alone is sufficient to achieve these goals cost-effectively (Stern 2007; OECD and IEA 2008). A carbon price should be supported by complementary policies to address barriers to technological development and deployment.

In a sense, a carbon price addresses the primary barrier, which has been the lack of financial reward for climate-friendly behavior and technologies. However, additional

[1] For a broader discussion of the interaction among emissions pricing, spillovers, and public support for environmentally friendly technologies, see Fischer (2008).

[2] Fischer and Newell (2008) show that, even with knowledge spillovers, policy cost-effectiveness depends largely on the degree to which all options for reducing emissions are encouraged. While emissions pricing is the single most effective policy, an optimal portfolio also includes RD&D support, achieving emissions reductions at significantly lower cost than any single policy.

barriers or market failures may require additional policy tools, and many of these need not target specific technologies.

REMOVE DISTORTING POLICIES

In addition to a carbon price, other policies can ensure that the allocation of private RD&D better follows social (including environmental) values. For instance, distorting subsidies for fossil-based energy should be removed. In non-OECD countries, subsidies are primarily used to keep consumer prices artificially low, resulting in overconsumption. If major developing countries would wipe out all energy subsidies, global carbon dioxide (CO_2) emissions could fall by 4–5% (IEA 2002). Of course, energy subsidies often carry rationales of economic growth or income redistribution in developing countries. For instance, Sterner (2012) shows that the poor are not the main beneficiaries of such policies as cheap gasoline. On the contrary, the poor would benefit more if the same tax deduction were applied to food and other items they use intensely, instead of motor fuels, which they use relatively less. By contrast, in OECD countries, such as Germany, most of these subsidies are for fossil fuel production. In the United States, half of all energy subsidies go to fossil fuels, compared with just 5% for renewables (IEA 2006).[3] No doubt, beneficiaries of subsidies will resist reform. Therefore, removing subsidies may require a gradual phasing out (French coal subsidies were reduced in a 20-year program); transitioning to less distortionary forms of assistance (the United States replaced agricultural commodity price supports with a direct income support program); and educating the public about the benefits to rally support (IEA 2002).

Another kind of indirect subsidy is the lack of policy to reflect the cost of other environmental damages, besides GHG emissions. Regulating conventional air and water pollutants with market-based mechanisms will also help improve market signals and make clean energy sources relatively more competitive with their fossil fuel counterparts. This will not necessarily lead to lower GHG emissions, however, since there may be a trade-off between policy targets, such as increased biomass use favoring lower CO_2 emissions also leading to higher emissions of airborne particles.

[3] Many of these subsidies take the form of preferential tax treatment, relative to other sectors. The oil and gas industries in the United States and Canada have benefited from such provisions as accelerated depreciation, the expensing of exploration and development costs, and other investment tax breaks; direct expenditures on infrastructure and RD&D; and the incomplete capture of resource rents through royalties—many of which disproportionately support the development of the relatively dirty oil sands (Taylor et al. 2005).

Inefficient regulations, on the other hand, can impede technical progress. Unnecessary legal and regulatory barriers that favor incumbents should be removed to allow for better competition. Unfortunately, some of the energy sectors most relevant for GHG reductions also involve highly concentrated natural monopolies. For example, regulators of power generation, transmission, and delivery must keep an eye on the ability of new entrants to join and compete. Licensing, regulations, and interconnection procedures must be clear, not overly burdensome, and coordinated across jurisdictions, while allowing for appropriate oversight to balance potential trade-offs in economic and environmental costs. Often, streamlining regulations need not be technology-specific and can benefit all participants, not just new green entrants.

New technologies may also require explicit new policies to create regulatory certainty. For example, the long-term impacts of large-scale carbon capture and storage (CCS) remain uncertain, and relevant regulations, guidelines, and industry protocols are needed to assign liability and develop good practices.

REWARD THE SOCIAL VALUE OF INNOVATION

The social value of research and innovation often surpasses what the innovators can appropriate. These knowledge "spillovers" represent a kind of market failure, because by receiving only a fraction of the benefits, innovators have only a fraction of the incentive to engage in RD&D. Studies of commercial innovations suggest that, on average, less than half of the gains to RD&D return to the originator, although appropriation rates vary considerably over different types of innovations.[4] Basic research, in particular, is an excellent candidate for government support, as the commercial applications are often distant and unknown. Other technologies may become commercially viable, but only when the carbon price is high enough. Although greater stringency in climate policies may be expected in the future, patent lifetimes are still limited. Furthermore, in the case of innovations involving complex processes and interactions among many different actors (such as in process industries), it may be difficult to avoid large knowledge spillovers and thus also difficult to invoke patents. Consequently, the appropriation rates for climate-friendly technologies are likely to be relatively low, at least initially, but also likely to rise over time, meaning that some extra support during the transition can help clean technology development (Gerlagh et al. 2008). Even commercial innovations have spillovers; however, it is important to remember that spillovers are not the exclusive

[4] See, for example, Jones and Williams (1998).

domain of clean energy technologies.[5] With a carbon price in place, tax breaks and other public incentives for reflecting the additional social value of RD&D are most efficient when they are broadly based so that many technologies can emerge and compete.

PROMOTE LEARNING BY DOING

A sizable learning effect, by which costs fall as experience and cumulative production grow over time, is another form of innovation that the market alone may insufficiently reward. One reason may again be spillovers—if techniques can be replicated, later competitors can enjoy the benefits of the experience of the early movers without shouldering their higher costs. While the motivations are similar to those in RD&D policy, the instruments for learning must, by definition, focus on expanding the use of the technologies. Common deployment policies for renewable energy include direct production subsidies, such as the production tax credit in the United States; feed-in tariffs, which are widespread in Europe; and renewable portfolio standards, popular among US states.

In promoting learning, a key question is the degree to which one should differentiate among technologies. Learning rates are likely to differ among emerging technologies, in part depending on the degree of experience already accumulated, the innovation potential, as well as the geographic domain of learning, and therefore assumed learning spillovers (Lindman and Söderholm 2011). Technology-neutral production incentives, however, tend to promote the currently most commercial technologies. Consequently, there can be a significant cost-saving potential in choosing the technologies with highest learning potential—*if* they will ultimately become commercial as well. This argument, however, is complicated by the fact that learning rates are difficult to predict and can be known with some certainty only afterward. Furthermore, learning curves are ad hoc in the sense that the pure effect of accumulated knowledge and improved engineering is challenging to identify, since other effects, such as exogenous technological change, RD&D investments, changes in prices and market structure, economies of scale, and changes in government regulations, also contribute to a lower unit cost (McDonald and Schrattenholzer 2002; Rubin et al. 2007). Learning rates can be negative in an early phase and may change over time.

Our limited knowledge of learning effects related to emerging technologies and a number of attached uncertainties pull in the opposite direction—namely to support many technologies as part of a risk-hedging strategy. These opposing concerns must be balanced. Torvanger and Meadowcroft (2011) argue in this regard that the best government strategy is to support "a focused portfolio of emerging technologies."

OTHER BARRIERS MAY REQUIRE MORE SPECIFIC ATTENTION

Information

For markets to function, they require not only good property rights and competition, but also information. Some product characteristics are easily observable, but others, such as nutritional content or energy consumption rates, are not available or credible without government intervention. Improved availability and visibility of information, such as product-specific labels, credible reporting standards, and educational campaigns can allow better consumer and firm decision making, thus leading to lower costs.

Information barriers may also arise between the public and private sectors. Private actors have better information about their own costs and innovation potential, and they may have different perceptions about future policies and prices than policymakers. These asymmetries impede making correct choices in the design of efficient strategies (Stigson et al. 2009). Policymakers are concerned about investing scarce public dollars in the wrong technologies, while private actors seeking public support want to appear deserving of those dollars. A benefit of market-based policies like tradable credits is the revelation of information through the credit prices that emerge and the behavioral response to them. The private sector, on the other hand, worries about investing in RD&D when future financial support and policy commitments are unclear. Policy certainty is impossible to guarantee, as future governments can always alter policies, but certain instruments, such as loan guarantees and price collars, can help minimize financial uncertainty (Fell et al. 2009). Another policy instrument that may be considered in relation to information barriers is negotiated agreements, such as in a case with shared uncertainty about future abatement costs between the regulator (public authorities) and business. Stigson et al. (2010) point to the value of information exchange that occurs in negotiating agreements between public authorities and business. Through such negotiations, a dialog occurs on several issues (e.g., financial, technical, behavioral), where the regulator and business actors exchange opinions and may reach a mutual understanding of barriers and opportunities beyond mitigation costs, such as technical potentials in industry and investment

[5] In this regard, an opportunity cost is associated with government RD&D spending, since this money could be spent in other areas, where spillover effects could be equally large or larger.

willingness in case-specific situations. A concern associated with such agreements is their regulatory efficiency due to information asymmetries between regulator and company. This problem can be reduced through later verification and predetermined, agreed sanctions in case the company provides erroneous information or fails to meet the agreed target.

Standards

Still, perfect information may not be enough. Consumer uncertainty about energy prices and the quality and reliability of new technologies being offered can contribute to seemingly myopic behavior. Poor choices can also arise when those making decisions about energy-using appliances and building features are not the same people as those using or paying for the energy, such as in landlord–tenant relationships. Coping with short payback horizons and principal-agent problems can require product-specific interventions, such as building codes and standards for energy efficiency and fuel economy. While these standards generally are informed by technological options, they need not be prescriptive of particular ways to meet the standards. Indeed, they should be designed so as to allow cost-effective alternatives and ongoing incentives for improvement.

Intellectual property rights (IPRs)

IPRs play a critical and complex role in clean energy innovation and diffusion. On one hand, they provide an important vehicle for enabling innovators to gain financial returns on their investments. On the other hand, poorly designed and enforced IPRs can create obstacles to diffusion. For user firms, they slow down the diffusion process by adding to the costs, mostly through transaction and maintenance costs (GCN 2009; Shrivastava and Upadhyay 2009). In the case of producer firms, weak protection of IPRs adds to the hesitation in transferring or sharing technology among firms (Zhao 2006), which may slow down the overall process of diffusion, as well as advancement of the technological frontier.

Financing

Risk and payback horizons also influence investment decisions; if the private perceptions of these factors do not align with the public ones, then policies may be needed to assist financing and manage risks for publicly desirable projects. Technologies for which capital costs are very large (such as solar power, nuclear power, hydropower, and CCS) are more likely to need preferential financing or guarantees to reduce private investment risks. Even wind generation has high capital costs relative to operating costs; however, the capacity can be expanded more incrementally and policies to guarantee profitable production prices have typically been used to reduce investment risk, rather than finance guarantees, although investment tax credits are also common. Ultimately, greater certainty about the carbon pricing policy will also help reduce risks and raise returns for low-carbon technologies, and financing interventions should focus on narrowing the discrepancy between private and public payback horizons.

Developing country challenges

In developing countries, the finance sector often has been particularly hesitant to support projects with new and climate-friendly technologies because of the lack of capability to assess financial viability (especially in the case of energy-efficiency projects) and excessive reliance on the balance sheet as a criterion of credit-worthiness of project owners (GCN 2010). In this context, it is important to observe that multilateral financial institutions such as the World Bank, despite considerable growth in their support to renewable energy projects, still predominantly support nonrenewable energy projects (ADB 2009). In developing countries, high import dependency for intermediary goods as well as technology slows down the process of diffusion. For instance, realization of the full potential of efficiency gains by deploying the integrated gasification combined cycle (IGCC) is restricted in India because of the high ash content of Indian coal. The efficiency gain of the technology would require India to import high-quality coal, which would add to the cost of production, offsetting efficiency gains (Ockwell et al. 2008). In addition to carbon price, cheap availability of finance in the form of long-terms loans, subordinated equity, or carbon funds would not only reduce the immediate financial unattractiveness of such technologies, but also build confidence among financial institutions over time.

SOME BARRIERS ARE MORE RELEVANT FOR CERTAIN TECHNOLOGIES

Scale Economies

Economies of scale are an issue for many new technologies. Until enough units have penetrated the market, production costs are high and support services are scarce. Scale economies can also be driven by learning economies (Unruh 2000). Policies to address this barrier can legitimately help some new technologies gain acceptance and get off the ground, but they should be designed carefully to avoid extended support for uneconomic technologies. An example is the hybrid vehicle tax credits in the United

States, which phase out after a certain number of models are sold. Renewable energy portfolio standards also become easier to meet (and certificate prices fall) as scale economies are met.

Networks and Infrastructure

Some technological options require new infrastructure and support networks in order to function. However, private actors are reluctant to take on activities that supply public goods, and most would prefer to wait for someone else to do it. The resulting network externalities are an important cause of "path dependence" or "technological lock-in," and public intervention may be required to change paths. Important examples lie in the distribution of fuels for transport: biofuels, hydrogen, compressed natural gas, or plug-in electric vehicles would require new fuel (or battery) distribution and storage equipment, as well as new vehicle engines. Here, it may be costly to allow multiple new options and thereby difficult to avoid picking a winner, so the decision must be made deliberately. For costly network infrastructure investments, there is value to waiting for more information, in order to bet confidently on the technology.

Some infrastructure investments for carbon-free generation technologies may also have network externalities. Real-time energy metering can allow for time-of-use pricing to better manage electricity demand, for example, direct-current lines in buildings could allow solar cells to power many devices without inverters. Upgrades to "smart grid" transmission technologies can facilitate the incorporation of distributed generation and intermittent renewable energy sources. However, many infrastructure investments, such as transmission lines for remote renewable energy sources, are better viewed as an additional cost to developing more capacity in those resources, although there may be other barriers related to siting or entry. Expansion of nuclear generation would require central infrastructure in the form of a waste storage facility, which involves its own trade-offs.

Trade-Offs

Many technologies that reduce GHGs may instead cause other environmental damage and risks. For example, nuclear generation creates radioactive waste and security concerns. Hydropower affects aquatic ecosystems, fish spawning, and resource access rights for local people. Battery waste involves toxic chemicals; transmission lines can disturb other land uses; most power generation siting as well as CO_2 storage sites (as part of CCS projects) raise "not in my backyard" (NIMBY) issues—and the list goes on. Public assessment of the trade-offs is needed before allowing broad deployment. These assessments are also related to the regulatory regime for deploying technologies and assuring that the regime is appropriate but not unnecessarily long or cumbersome.

CERTAIN TECHNOLOGIES MAY DESERVE PREFERENTIAL TREATMENT

In addition to addressing important market failures and barriers, policymakers may want to direct extra attention and support to certain kinds of technologies that have special potential. Some examples of especially desirable technologies are those that expand options and lower costs of reaching deep reductions, those that may have additional spillover benefits at home, and those that may have spillover benefits abroad, further reducing global emissions and improving the likelihood of more globally stringent GHG agreements.

Backstop Technologies

As heavily emphasized in the Stern Review (Stern 2007), there is an important role for technology policies that focus on bringing down the costs of reducing carbon emissions. When the future emissions target is uncertain, as are the costs of reaching potential targets, both RD&D and early abatement activities can facilitate the adoption of more ambitious targets and thus help reduce the expected costs of future abatement, adaptation, and damages. However, certain kinds of RD&D may also help reduce the degree of uncertainty in these costs and thereby carry extra value (Fischer and Sterner, forthcoming).

In the climate policy case, the national or societal marginal abatement cost curve represents a sequence of technological options, each more costly than its predecessor. "Backstop" technologies are a particular kind of option. Conceptually, a true backstop technology is free to be replicated at a large scale without scarcity constraints, meaning that marginal costs, though relatively high, do not increase much as capacity is expanded. The presence of backstop technologies helps flatten out the upper portion of the overall marginal abatement curve, meaning that if stricter-than-expected emissions targets are necessary, carbon prices will not need to rise astronomically.

In other words, if it turns out that climate change is even more serious than we think, and we need to step up emissions reductions dramatically in the future, an affordable backstop that can be expanded to basically any scale would be invaluable. Therefore, given the uncertainty we face, there is an added value to bringing down the costs of technologies that help flatten the marginal abatement cost curve. Of course, another way to keep options open is by reducing emissions more aggressively in the near term. But if backstop technologies can keep costs lower in the worst-case scenarios, expected long-term costs are also lower, and that in turn reduces pressure to engage in deeper reductions in the near term.

In terms of true backstop technologies, the most discussed candidates are solar, biomass, wind power, and CCS (and theoretically, fusion) (OECD and IEA 2003). The flow of solar energy to earth is particularly large in comparison with societal needs. Each has the possibility of being used at large scales, though location (and risk management) could be a constraining factor. RD&D programs that can lower costs, expand capacities, and accelerate how rapidly these capacities can be tapped have an added insurance value, beyond the gains that would be realized at the expected levels of utilization laid out in road maps.

Comparative Advantage

Countries may have national RD&D deployment policies, but the development of new technologies is a global effort. Consequently, there may be opportunities for coordination (or free riding, for that matter) and for specialization. Technology-oriented agreements can be aimed at knowledge sharing and coordination, research, development or demonstration, and even deployment.[6] Such commitments can increase the technological effectiveness of an agreement over emissions reductions, although they are generally weak policies in terms of environmental effectiveness on their own. (Even at the international level, technology policies are complements to mitigation policies.) International agreements over technology standards can also be attractive from a competitiveness point of view, ensuring that trading partners have similar cost burdens.

On the other hand, technologies might become a source of competitiveness. Under different circumstances, some countries will enjoy a comparative advantage in certain technologies. In this case, not all countries will want to engage in the same RD&D deployment portfolio, but rather specialize to some extent. For example, countries with large availability of geological sequestration sites may prefer to invest more in CCS innovation.

Global Spillovers

Technology spillovers do not respect borders either and can inform priorities for dealing with global pollutants such as GHGs. Because of differences in national skills and opportunities, the large investments needed with uncertain payback, and positive spillover effects, international coordination and even collaboration make sense. In particular, technological advances that support international agreements and efforts have additional value beyond what is appropriated at home; for example, some technologies may have better potential to be adopted among emerging economies that lack direct carbon regulation. Indeed, the availability of low-cost abatement opportunities may help encourage these countries ultimately to take on hard emissions targets. As a result, developed countries will want to engage not only in technology transfer agreements, but also in RD&D deployment efforts that are likely to produce technologies to be transferred.[7]

The following table, based on a table in Torvanger and Meadowcroft (2011), offers a checklist of factors to consider when allocating government support for low-carbon energy technologies (Table 1).

REMAIN AWARE OF POLICY INTERACTIONS

Policymakers have enacted a variety of measures both to reduce emissions and to promote alternative energy sources. However, more policies do not always mean better outcomes or more clean energy technologies. In particular, when additional policies to promote renewable energy overlap with tradable quota mechanisms, the clean energy policies can instead benefit the dirty sources.

Fischer and Preonas (2010) review these policy interactions, distinguishing between fixed-price policies, such as most taxes and subsidies, and tradable credit programs, such as cap-and-trade or renewable portfolio standards (RPSs), in which the market determines the price. Importantly, credit prices respond to changes in the market context, including changes in other policies.

Once a binding cap on CO_2 emissions is established, it is important to remember that supplementary policies offer no increase in environmental benefits. Instead, clean energy subsidies allow the cap to be met more easily, driving down the price of emissions allowances, which enables other sources to expand and meet the cap. In fact, these supplementary policies tend to increase the overall costs of reducing emissions, while disproportionately lowering the compliance costs for the dirtiest fossil fuel producers.

In the presence of a binding RPS, supplementary policies may also have unintended effects. An RPS requires a certain percentage of electricity generation to come from qualifying clean generation. Renewable sources receive subsidies in the form of credits, whereas fossil sources pay to purchase those credits, until the standard is met. A binding standard thus links the fate of renewable and fossil sources. Additional subsidies that increase the supply of renewables

[6] For a discussion of technology-oriented agreements, see de Coninck et al. (2008).

[7] See also Popp (2011) for insights into technology transfer policies.

Table 1 A checklist of factors to be considered when allocating government support for low-carbon energy technologies (based on Torvanger and Meadowcroft 2011)

Important factors	Key questions	Considerations
Core potential		
Energy provision potential	How much energy can this provide? Is this a backstop technology?	An option that meets a large share of energy needs is generally desirable. Technologies that come in large units have large capital costs but fit centralized generation grids well.
Emissions mitigation potential	How much emissions reduction could this technology deliver?	Dependent on characteristics and scale of deployment. Higher life cycle reductions and larger scale of application are preferable
Timing	On what time scale would it become commercially deployable?	The sooner, the better. But the potential for large gains even on a long-time horizon can be attractive
Costs		
Present cost	What is the current cost of the technology?	Must be seen in relation to current capacity investment (experience curve stage)
Learning rate	How fast can costs come down?	Higher learning rates are desirable, but rates are uncertain
Learning potential	How far might costs eventually come down?	Higher learning potential is desirable but uncertain
Risk and payback	How are private perceptions of risk and payback period compared with public ones?	Deviations are an argument for assisting financing and managing risks for publicly desirable projects
Barriers		
Information failure	Is important information lacking?	Deployment may be negatively affected by information failures, for example, information barriers between the public and private sectors
Scale economies	Are there scale economies in deployment of an emerging technology? Can it be scaled down and yet be commercially viable?	Scale economics can impede deployment, but such problems can be reduced through suitable policies. Sometimes small and medium enterprises (SMEs) are important for developing countries, which require technologies that are efficient and viable at small or medium scale
Networks and infrastructure	Are there important network externalities?	Network externalities linked to infrastructure can cause "technological lock-in" that impedes deployment of emerging technologies, but this can be handled through a suitable regulatory regime
Subsidies	Are there sizable subsidies for competing energy sources and technologies?	Direct or indirect subsidies can be an important barrier to emerging technologies
Co-benefits and concerns		
Development potential	To what extent can the technology generate economic benefits: jobs, markets, profits, and taxes?	Investments are expected to generate economic benefits as well as energy/mitigation.
Energy security	Does it enhance energy security?	Relates to import dependence, diversity of supply, and robustness of infrastructure
Regional implications	Is it significant for regional energy, mitigation, or development interests?	Regional interests must be accommodated

Table 1 continued

Important factors	Key questions	Considerations
Environmental perspective	What are the associated environmental benefits/costs and opportunities/risks?	Fossil fuel CCS, nuclear power, hydropower, and new renewables have different cost–benefit profiles
Foreign markets and international competitiveness	What is the potential to develop export markets? How appealing would the technology be to other countries?	Technologies that appeal to other countries with growing energy and mitigation needs may represent important future markets
Compatibility	To what extent is this option compatible with other favored technologies?	Some energy/GHG mitigation options do not fit well with others
Pillars of support		
Technical, industrial, and resource foundations	Does it draw on existing strengths or potentials: resources, industries, innovation clusters?	The importance of exploiting existing knowledge/resource bases and relying on comparative advantages; protection of IPRs
Co-funding of RD&D	To what extent will private interests and firms and/or international partners contribute to funding RD&D?	Collaborative engagement can reduce development costs, spread risk, and cover more technological options
Public receptivity	To what extent is the public supportive/resistant to the technology?	Awareness of public and stakeholder groups; communications; familiarity; accidents
System perspectives		
Transition to carbon emissions-free energy system within half a century	How does the technology fit with transition pathways to a carbon emissions–free energy system?	The roles the technology might play; how its potential is distributed over time; potential interactions with other technologies; long-term visions; "backcasting"
Sustainable energy policy	How does it appear from the vantage of sustainable energy policy?	The provision of energy for sustainable development; economic, social, and environmental dimensions; holistic assessment

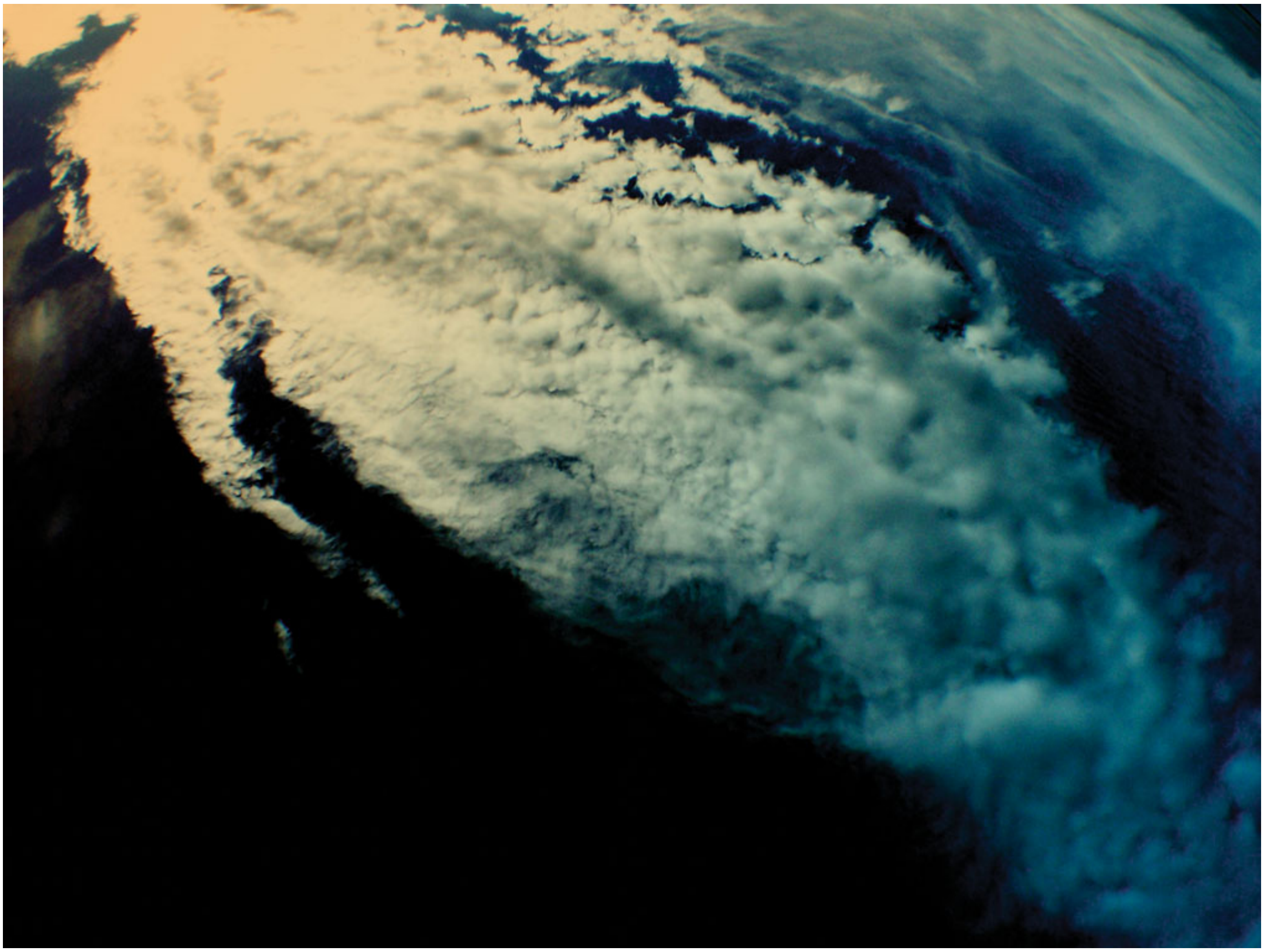

Fig. 1 How do we stabilize global GHG concentrations and design climate-friendly technologies? Photo by Kristin Smith (Stock.xchng)

drive down credit prices, making fossil sources more competitive, and allowing both sources, and emissions, to expand. Meanwhile, additional policies that disadvantage fossil energy sources reduce demand for renewable credits, thereby also discouraging renewable energy.

Relying on fixed-price policies has the advantage of making the effects of additional instruments more transparent. However, the real point is that once the cost of carbon is internalized, by either an emissions cap or a sufficiently stringent tax, technology subsidies are not needed to address that market failure. Instead, they should be focused on correcting the remaining barriers to innovation and diffusion. In other words, technology policies are most effective as technology policies, not emissions policies (Fig. 1).

SUMMARY AND OPTIONS

We should recognize that not all barriers to adoption are market failures. Cost, reliability and quality issues, and risk are all legitimate aspects that the market should be allowed to weigh in choosing cost-effective technologies. Furthermore, RD&D market failures are not exclusive to energy technologies, and once most energy-related market failures are addressed (as through carbon pricing), society must be wary of crowding out other legitimate innovation efforts.

As a result, the main tools for encouraging climate-friendly technologies should be those that encourage the market to make good choices more generally: pricing carbon emissions and other environmental damage, removing distorting subsidies and barriers to competition, and supporting RD&D broadly.[8]

Some technologies face particular barriers, requiring society to decide whether to support them, committing to major infrastructure investments or environmental risks.

[8] Researchers from other disciplines are commonly more in favor of supporting specific technologies than are economists. One example is Azar and Sandén (2011), who argue that a fully technology-neutral policy neither exists nor would be desirable when the aim is to achieve a large-scale transition of the global energy system. Instead, technology policies should be openly debated in society.

Other technologies may merit extra support, because they offer insurance against the possible need for deeper reductions or have greater potential for being adopted in other parts of the world.

Several policy options are available to support technological development. Broad-based policies include RD&D tax credits, funding universities and research institutions, and other public support for research through competitive grant processes. Scale economies can be supported through tax breaks, subsidies, performance standards (including tradable ones), or market-share mandates. While the last two policies also create an implicit subsidy to the targeted technology (such as renewable energy sources), paid for by the non-preferred sources, they have the advantage of not only requiring no public outlays, but also naturally phasing themselves out as the new technology becomes cost-competitive.

More specific policies are required to address particular market failures and barriers, including information requirements, energy-efficiency standards, building codes, and the like. In these cases, policies generally will be more effective the more closely they target the specific market failure rather than a specific technology. Standards perform better when they are flexible rather than prescriptive in terms of how the goal must be achieved.

Finally, for those technologies identified as being particularly desirable, some narrower RD&D policies are available. Traditionally, most policies subsidize inputs to research, through specific tax credits, grants or contracts, or directed research in publicly funded laboratories. If government lacks the expertise or impartiality, allocation of these research funds can also be outsourced to independent third-party managers given specific mandates.[9] Technology prizes, on the other hand, offer financial inducement to an output, such as being the first to develop a specific advance or the contestant having made the most progress by a deadline. Newell and Wilson (2005) indicate that such methods have been successful in the past and could play a supportive role in climate policy, although attention should be paid to the design features, including the technological target, the size and nature of the prize, and the method for selecting the winner. In some specific cases, demonstration projects may be necessary for potentially effective technologies that face doubts from investors.

International engagement is another component of technology policy. Recognizing that climate mitigation and technological advances are a global effort, countries can leverage their own RD&D resources with international partnerships and agreements to encourage knowledge sharing and broaden the markets for new technologies.

[9] An example is the Ontario Centres of Excellence, which operate somewhat like a publicly funded venture capital firm.

Ultimately, the biggest driver of technological adoption and change will be the mitigation policy, which determines the demand for the particular technologies. An additional advantage of emissions-pricing policies is their ability to generate revenue, which can help fund the complementary technology programs. However, that is not to say that all or even a particular share of those revenues should be explicitly earmarked for technology programs.

Indeed, just as technologies should compete in the marketplace for adoption, technology policies should compete in the budget among all the worthy causes. Supporting climate-friendly RD&D deployment is certainly one, but so are transitional assistance, adaptation, tax relief, foreign aid, and a host of other demands unrelated to climate, including other innovations. Priority should be given to policies that enhance overall economic efficiency, broadly supporting RD&D, removing distortions, addressing regulatory barriers, reducing tax burdens, improving information, and supporting fundamental research. Then policymakers can turn to more targeted programs, fully considering the benefits and the trade-offs.

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