Mainstreaming New Renewable Energy Technologies

Karsten Neuhoff and Rick Sellers

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Mainstreaming New Renewable Energy Technologies:

Enhancing Market Learning

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Karsten Neuhoff and Rick Sellers[1]

This paper outlines the benefits, obstacles and options for governments to support international markets for technology development. International markets for new energy technologies offer greater scope, thereby increasing the incentives and opportunities for technology improvements. As the market is supported by more independent governments, the confidence of technology developers and producers that future markets for their products will exist is increasing, thus enabling capital access and inducing R&D investment and exploration of improved production processes. The bigger markets also allows for international competition, thus allowing for the application of the best available technology. The government challenge to induce sufficient RD&D remains and with international markets the benefits and costs of national governments freeriding on international effort needs to be considered and addressed with appropriate mechanisms. Finally, we discuss how international co-operation can be used to evolve the energy system in such a way that it can integrate new technologies with their specific characteristics like intermittency, volatility and geographically-varying resource potential at minimum cost.

Key words: Energy technology, Research and development, Deployment
JEL classificaiton: 038, Q42, L94, D92

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Contact details: karsten.neuhoff@econ.cam.ac.uk, Faculty of Economics, University of Cambridge, Cambridge, CB3 9DE, UK, and rick.sellers@cegetel.net.

1 Introduction

Various studies have identified barriers that restrict the market growth of new renewable technologies. Most of these studies are oriented towards the barriers to market uptake in specific applications, or specific technologies, some addressing barriers in OECD countries and some in developing countries.[2] Several studies have addressed the larger question of barriers to renewables from the global market context[3]. These studies, too, generally focus on the barriers to project or market development.

These studies, while helpful to improving understanding of the barriers to the execution of projects and functioning of markets, fail to inform us as to the most efficient way to advance the competitiveness of the technologies, specifically their technical performance and cost. Renewable energy technologies, like virtually all other manufactured goods, become competitive in the market through a complex process, involving research and development, as well as through improvements made via the learning gained by installing the systems in operation in the market. Therefore, just as there are strategies to lower the cost and accelerate the pace of R&D, so there may be strategies to improve the efficiency and efficacy of technology advancement in the market learning cycle.

2. Benefit of an international market - size

To show the benefit of a growing international market, we briefly describe our model of technology improvement.

Simply stated, the process of developing a technology typically starts with a “bright idea” or some “blue skies” research. Through this, a concept is born, which then goes through several stages of research and development. At some point, bench models are developed to prove the concept, and then scale models are produced to prove the viability of the future product. At this stage, manufacturing technology is developed to begin mass production, and larger scale demonstrations are required to refine the technology for deployment in the market and to prove the viability of the target market.

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[2] See bibliography of barriers studies in Annex 1.

[3] See, for example, the G8 Renewable Energy Task Force Co-Chairmen’s Report.

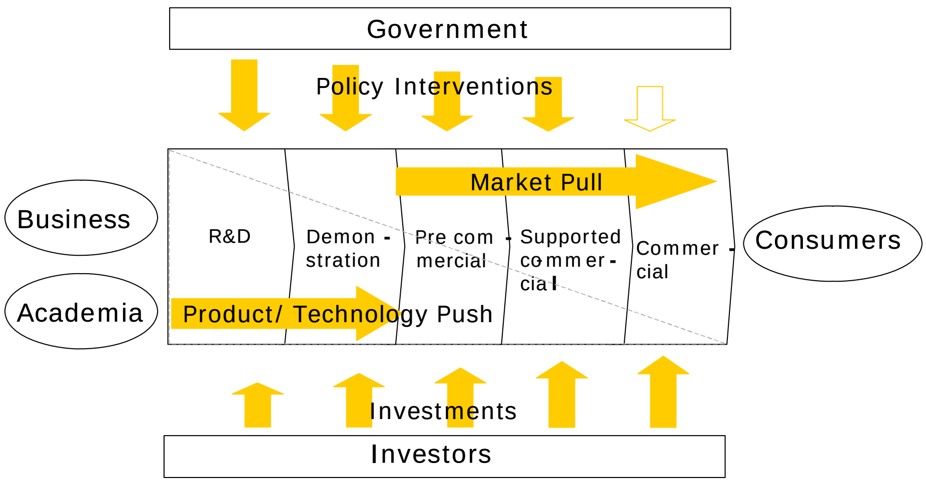

Figure 1 Stages of technology development (Foxon and René)

The funding for these stages of the RD&D process is sourced from both governments and from the private sector. There are few reliable assessments of the investment made by industry in RD&D, but recent studies by the IEA have illuminated the funding provided by IEA governments, which is thought to constitute the vast majority of global government investments. See Annex 1 for a brief review of IEA government RD&D investments.

During this RD&D process, market studies reveal the customers for the technology and the costs that they will be willing to pay, and the technology developers align their product to these expectations. Large-scale demonstrations are considered to be the crossover point to the market.

To complement the investments in RD&D, governments also encourage technology development through support for deployment of technologies into the market. These deployment supports are intended to ensure that technology costs will continue to decline as a result of "market learning." Market learning that results from early deployment experience is a necessary step in commercialisation and to reduce costs. In principle, market learning provides a complementary feedback loop to manufacturers as they refine products.

Case studies for various technologies and industries have shown that technologies exhibit a "learning ratio" that usually stays constant for a technology for large periods of time. This learning ratio is calculated by comparing production costs of a technology each time there is a doubling of manufacturing capacity. Typical learning ratios for energy technologies are between 10% and 20%. Therefore, each time installed capacity of a technology is doubled, the costs of energy produced with the technology fall by between 10% and 20%. The concept of learning ratio is a heuristic concept, which does not identify the specific aspect where the improvement was or might be achieved, but observes that costs fall as experience with a technology is fed back into the manufacturing process and in research in better technology, operation, installation and maintenance.[4] Given the heuristic nature of the concept of market learning, it can provide insights about likely evolutions of a technology. As such, it should be used for long-range strategic rather than short-range tactical decisions.

This is particularly important for new energy technologies, as they reflect cost improvements from early experience more than more mature technologies, simply due to the scale of the market. For example, for a very new technology with a 20% learning ratio, one would expect to see a 20% improvement when the installed capacity doubles from 10 MW to 20 MW, requiring only 10 MW to see the effect. At the same time, an emerging technology will reduce costs when installations double from 1000 to 2000 MW, requiring 1000 MW for the effect. Similarly, a more mature technology may require 40,000 MW to double from its present installed capacity, as is the case for wind power today.

This is the point at which the international market argument becomes relevant. In order to achieve the increased market volume, the limited size of a national market might no longer suffice. Furthermore, as all new energy technologies enter the market at costs above those of established technologies, they initially require some financial support from government or the collective energy consumers. As the market volume increases, the amount of support is initially also increased. Only gradually will the effect of falling technology costs dominate this effect, so that the amount of required financial support will decrease again. Figure 2 shows this in the example of a projection for photovoltaic technology (P.V.). As the global market volume is expected to increase at 25% growth rate per year, the amount of required investment subsidy also increases.[5] Only as the P.V. costs become competitive with existing technologies, towards the early 2020s, will the investment support also decrease again. While it might be difficult to convince an individual government to shoulder the annual costs, this should be far easier if shouldered by many countries.

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[4] IEA, (Wene, Clas Otto) Experience Curves for Energy Technology Policy, Paris, 2000.

[5] In some off-grid applications, P.V. is already cost competitive with conventional technologies. The off-grid market is growing at 16% per year (1992-2002) but is too small to support large P.V. production increases. By 2002, less than 10% PV capacity was installed off-grid. Significant sales increases require a grid-connected market. (Source PVPS, 2003).

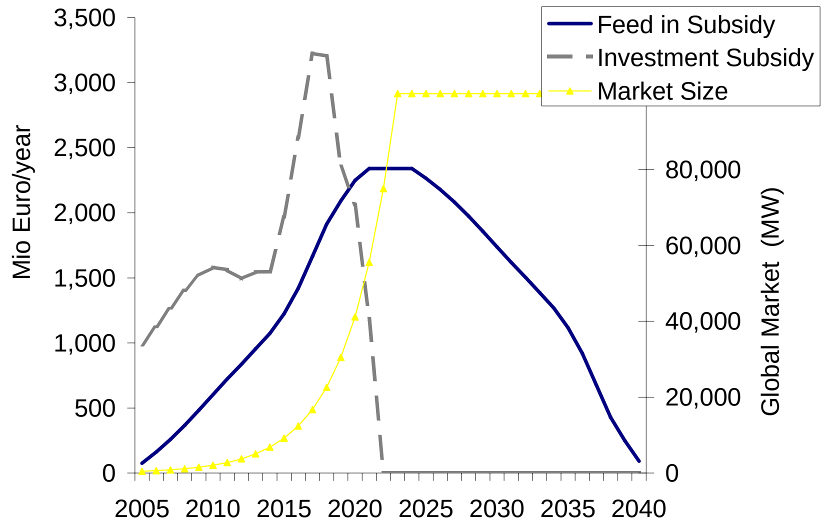

Figure 2 Projected P.V. market size and required subsidies, either as feed in subsidy over project life-time or investment subsidy at time of investment (Neuhoff, 2005).

There are many examples that support the idea that an increasing number of countries can participate in the application of a technology, thus providing the required increase in market size, and as with the example of wind energy, can also increase the amount of financial support, to enable it to compete against existing technologies.

While in the 1980s the largest market for wind turbines was California, over time demand has shifted towards Denmark and Germany and in recent years additional countries have implemented support policies that have resulted in an increase in wind turbine demand.

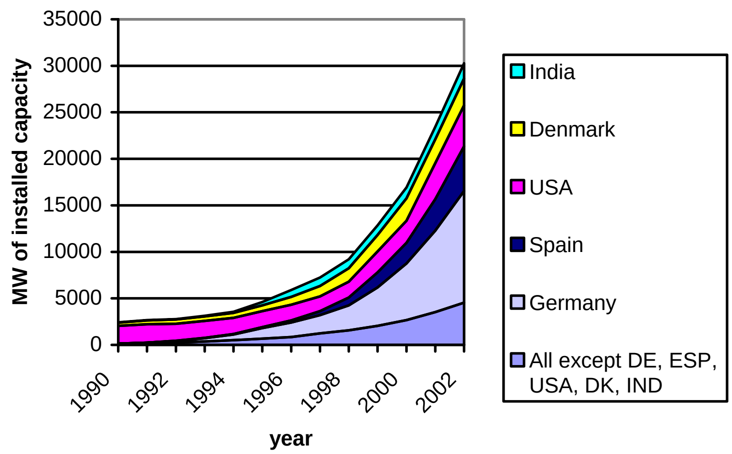

Figure 3 Wind Power Comparison of Top 5 – Rest of World, Sources: IEA, WindPowerIndia, Innovation Norway, Windicator, EFChina

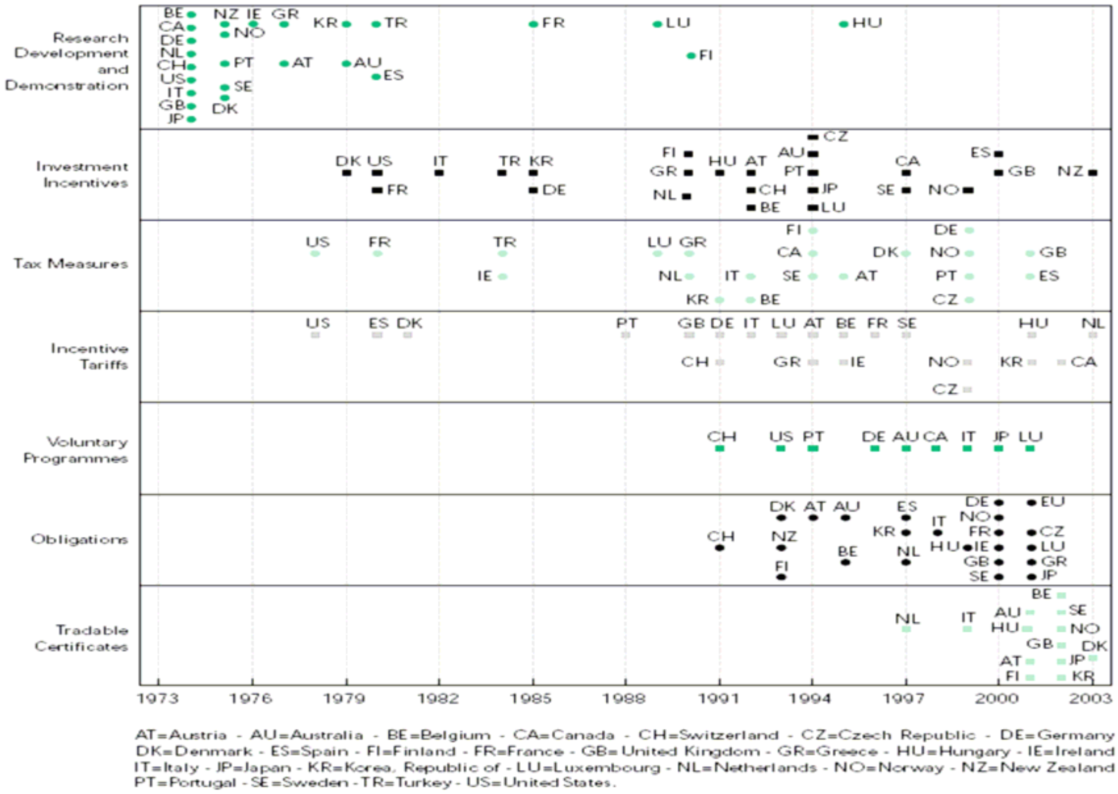

Figure 4 The introduction of renewable energy policy by country. (Source: IEA, 2004)

The table notes for each type of policy the first year that it was promulgated in any country. Although policies evolve over time, the chart reflects only the first instance of the enactment of that type policy in a country.

3. Benefit of an international market – investors' confidence

In liberalised energy markets energy technologies are typically neither developed by the consumers nor by the companies that deliver energy services but by technology companies. We need to take this separation into consideration when analysing policy options to support technology development.

Electricity generation technologies, just like heating installations for houses or industrial places, are acquired by energy companies or project developers at the last stage illustrated in Figure 5. If new energy technologies, like off-shore wind or solar photovoltaics are more expensive than existing technologies, like e.g. combined cycle gas turbines, then support -mechanisms like feed-in tariffs or renewable obligation certificates are required to ensure their application. Experience so far suggests, that feed-in mechanisms achieve larger deployment at lower costs, as they provide assurance of legally guaranteed revenue streams for up to twenty years if the technology remains functional (Butler, Neuhoff 2005).

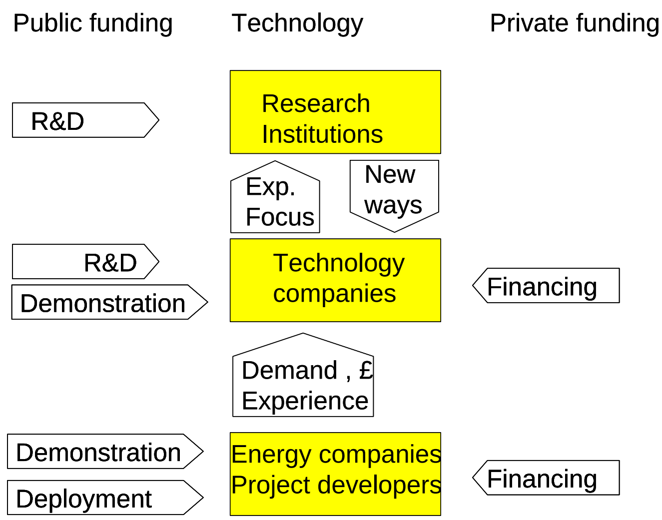

Figure 5 Illustration between policy links. Stable deployment policy required to provide stable demand from technology companies (enhancing their research activities).

For our purposes, it is of more relevance that both feed-in tariffs and quota systems can be replaced given any change in political mood. In the case of such a change, legal guarantees would safeguard the position of existing turbines, and aspects of government credibility – or, in the European context, possibly the EU - would ensure the ongoing support for owners of existing projects. However, such a change in national policy would effectively stop any new investment for specific technologies. If a technology fails to deliver cost improvements and it becomes clear that it will not contribute to energy supplies, there should be an opportunity to stop strategic deployment programmes. However, technology companies are concerned that such programmes could be stopped based on regulatory/policy discretion outside of their control and independent of the technology's performance.

This might be one of the reasons why little investment is provided by venture capital firms to support technology development in the energy sector, as Figure 6 illustrates, in the German example.

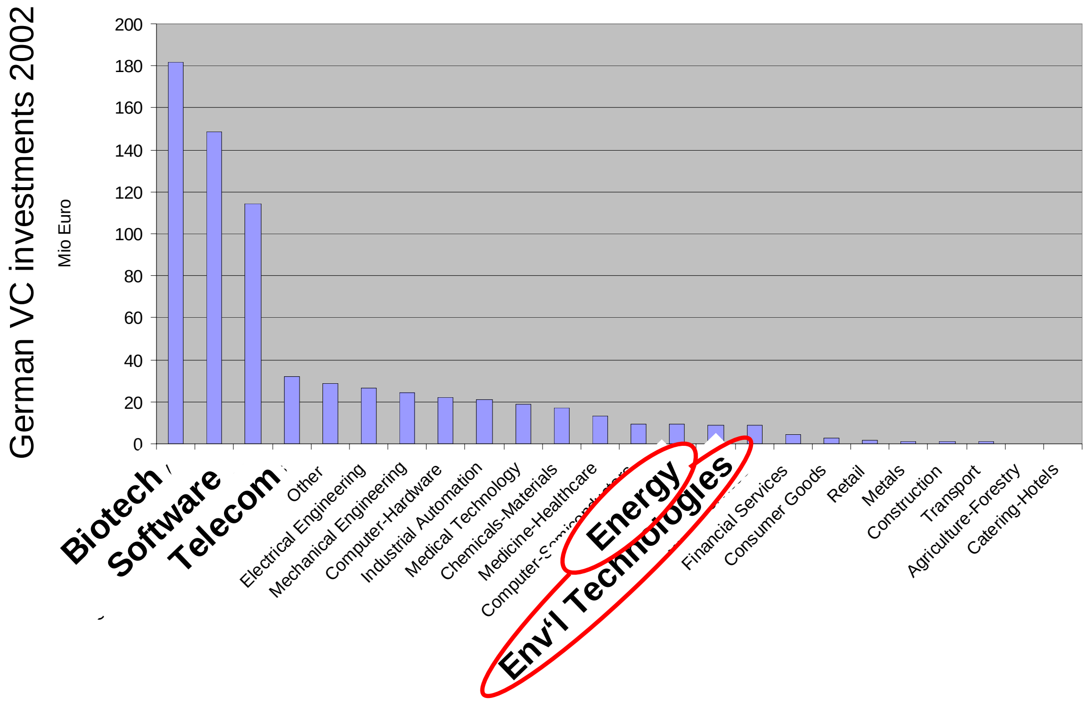

Figure 6 Venture Capital Investment in various technologies, Germany, Source: Sustainable energy venture capital ETAP conference "Financial instruments for sustainable innovations" Amsterdam 21-22.10 2004, Tarja Teppo Helsinki University of Technology, Finland and Rolf Wuestenhagen, University of St. Gallen, Switzerland.

To ensure investment in product and process innovation of technology, companies need to be reassured about the future size of the market into which they can sell their product. However, sudden changes of national support programmes, frequently associated with changes in government, undermine this confidence. If multiple countries implement support programs and their markets are open for power technologies from other countries, the policy change within an individual country will only have limited impact on the overall demand, thereby reducing uncertainty.

Well-defined processes towards the internalisation of environmental externalities of existing technologies – e.g. ensuring an increasing CO^2 price - not only increase future demand for renewable energy technologies, but also make investors more confident about this future demand and profit opportunity. Thus, international cooperation on internalisation of externalities might direct private money and expertise into improving renewable energy technologies. It might also be easier to advance internalisation of environmental externality costs if parallel movements in other countries addressed concerns about competitive disadvantages of national industry (e.g. move towards effective CO^2, SO^2, NOx programs).

4. Benefit of an international market – choosing the best technology option

Process and product improvements and innovation are built on experimenting with different options. The objective of technology policy should therefore be to create an environment that motivates experimentation and ensures that insights are then widely applied. We use Figure 7 to illustrate the implications. If multiple companies produce individual components of an energy system, then there exists competition for the best option to provide any one of the components, and it is likely that a effective solution will be identified. If companies can focus on the development of individual components, it will also be easier for new companies to enter the market, thus increasing competition, specialisation and focus on core capabilities, incentives for innovation and the ability to include new insights into our experience. The model of the computer industry is illustrative. Initially, IBM developed the entire PC including all components, while competitors like Apple, too, had to produce the entire system, including software, storage, processor and system architecture. Then IBM introduced an open standard for its PC architecture, allowing component manufacturers to gain economies of scale, thus ensuring rapid cost reductions. This might be the main explanation of IBM's success relative to that of Apple.[6]

To aid the final consumer, many technology companies have evolved, still offering the integration of the components, and delivering a ready-made PC. Similarly, one would expect project developers to continue to buy their wind turbines from one company which integrates the different components.

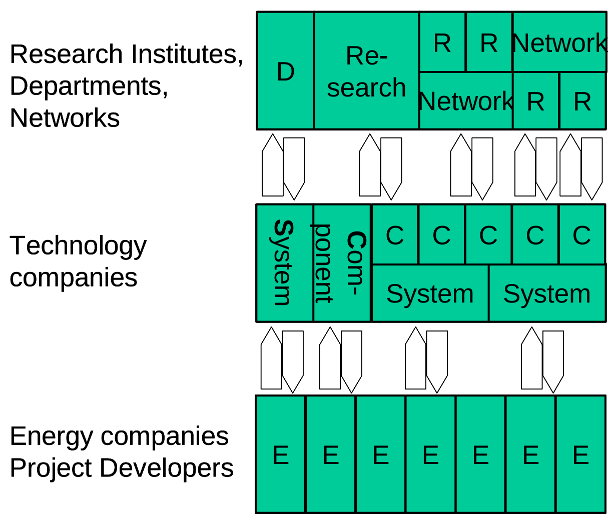

Figure 7 Disaggregating the learning effect within companies

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[6] The PC industry in the early 1990s saw a 'competitive crash', whereby firms previously operating in different market segments began competing for the same customers. IBM, which had previously maintained control of the operating system platform and also the hardware used to operate this software, began to facilitate the vertical disintegration of component production and invention. This process was amplified by the advent of 'Wintel' platform dominance. In this case, the platform was no longer sponsored by IBM but instead represented merely an 'industry standard architecture', around which hardware manufacturers could compete and innovate. (Bresnahan & Greenstein, 1999) Economics.

The success of this model in the IT industry suggests that we should facilitate international **competition for individual components** – thus offering a large market for producers of individual components, ensuring strong incentives for innovation with regard to all individual components.[7]

One core aspect for the success of the model in the PC industry was development of *platform* standards to **ensure compatibility** of components from different producers.[8] Platforms share interchangeable components, allowing customers and suppliers to benefit from the same technical advances, and advances can diffuse through such a market more rapidly. This has facilitated competition and innovation in component markets even where platform monopolies have developed (e.g. 'Wintel': Microsoft Windows and Intel).

Overall, energy technologies might benefit if **operational experiences were mutually shared**, thus allowing a wide group of companies and people to address these in subsequent product and process developments. More information on the performance of new renewable energy technologies will also reduce the costs of insurance. Financial markets currently face difficulties in providing risk management instruments for new renewable technologies (United Nations Environment Programme, 2004). For a start, historical actuarial data are not available to assess risk (Sonntag-O'Brien and Usher, 2004).

To support this process, it is important for companies to be able to both sell their products on international markets and compete for resources on international markets. This allows both for sufficient market size for companies, but also **accelerates technology diffusion**. There might, for example, be grounds to ensure that government support for venture capital should be made broadly available.[9]

In this discussion, one needs to keep in mind the challenge of balancing the benefits of accelerated industry development if information is shared, and the benefit of increased incentives to invest in innovation and product improvements if companies gain competitive advantage from their experiences

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[7] Internationally accepted requirements for power performance, safety, noise and other environment-related conditions should be developed, in order to reduce trade barriers and administrative and installation costs. (p. 172, IEA, 2003a). This is a movement we are starting to observe, e.g. LM Glasfiber provides blades to various turbine producers.

[8] Sutton (pg390-1, 1999) highlights the importance of IBM's 360 series (in mainframes during the 1960s and 70s) in defining an industry standard, making software transferable across a wide range of machines, but also in widening the market for a single software package. More recent evidence suggests that the dominant Microsoft operating system standard, at least, has allowed the development of a competitive industry for component parts built around the central issue of compatibility with the Windows software.

[9] One might envisage a global Innovation Fund for renewables, that would work in similar ways to the Gates Foundation/WHO Global Fund for TB, Aids, Malaria, but with weaker commercial criteria (i.e. no exit/lower exit requirements), and would work in conjunction with industry, corporates, IEA, private sector VCs and national governments.

and developments. There is an argument that a medium level of competition is associated with the highest level of R&D investment of companies. It is a tricky balance, ensuring that strategic deployment can create markets for individual technologies (e.g. crystalline, thin film PV) while not excluding (foreign) competition by artificial detailled specifications of a technology qualifying within a support scheme.

There might be a case for supporting a broad set of approaches during the early stages of a technology in order to explore the different options, and then gradually shifting to a clear set of standards to ensure compatibility of components provided by specialised companies (example Iliev 2005).

5. RD&D in an international environment

Private companies cannot appropriate all the benefits of their innovation, product and process improvement.[10] Therefore, it is widely accepted that governments need to support RD&D. RD&D support should assist (a) early-stage renewable energy technologies, e.g. solar concentration, (b) fundamentally new design approaches for other energy technologies, e.g. wind turbines with more flexible blades and (c) development of improvements of components of energy technologies, e.g. materials for turbine blades and power electronics.

[10] Margolis and Kammen (1999b) estimate that private returns on R&D across various sectors are between 20-30%, while social rates of return are around 50%. This suggests that private investors only appropriate a fraction of social returns because technology 'spillover' in the energy sector is large. Investors also face difficulties in evaluating intangible research and development output (Alic et al., 2003) and are likely to under-invest in R&D (Azar and Dowlatabadi, 1999). This suggests that research and development intensive companies are systematically under-priced by the market, likely reducing the incentive to perform basic research. Lev (2004) observed that companies, which are members of an industrial research institute, reduced the allocation of R&D funds to basic research every year from 1993 to 2003, in favour of modifications and extensions of current products. Furthermore, energy technologies are usually sold to markets that are closely regulated. A path-breaking research success is likely to induce a change in the market design or regulation, so that the public appropriates the profits, not the private innovator. This might further reduce the incentive to privately fund R&D. Therefore, it is generally accepted that public support is required to achieve an optimal R&D level.
The importance of R&D is also supported by macro-economic analysis. Jorgenson and Wilcoxen (1990) attribute about 50% of economic growth to technology change. Goulder and Schneider (1999) argue that increasing R&D expenditures in carbon-free technologies could crowd out R&D in the rest of the economy and therefore reduce overall growth rates. However, Azar and Dowlatabadi (1999) refer to Mansfield's (1968) counter-argument: radical technological change will trigger more research overall and therefore increase economy-wide productivity rates.
Industry-funded R&D focuses on the areas of existing activity of a company. Jelen and Black (1983) observed that companies fund internal research, development and demonstration in rough proportion to sales revenues. The market volume of renewable energy technologies is still small, and therefore industry R&D is likely to be small. Furthermore, even forward-looking companies do not plan for more than a decade and are therefore likely to focus on improvements that can be leveraged in the short term (Anderson and Bird, 1992).

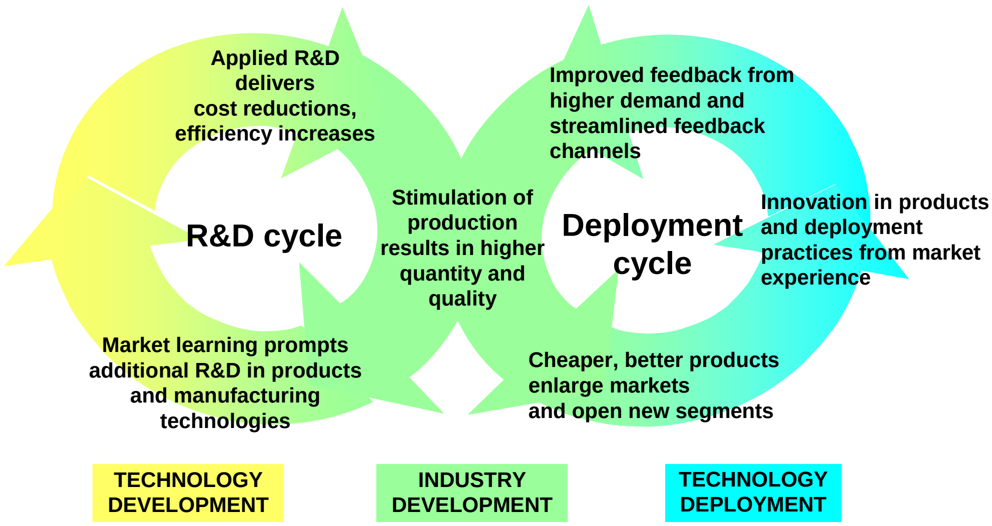

Figure 8 The interaction between research and deployment

By its very nature, RD&D support is typically aimed at very specific technological solutions, which usually are not yet competitive in the market. This should, however, not preclude a more international competition for these funds, thus ensuring that the most effective solution to a given RD&D problem is identified. While national governments can define the RD&D challenges more narrowly in order to enhance the chances of success of their national industry, we should aim to eliminate administrative and other barriers that might be used to guarantee the success of national initiatives even if better solutions are available in the international marketplace.

As with deployment support programmes, the RD&D for individual technologies tend to be extremely volatile, differing from nation to nation, thus obstructing the development of human resources and risking the loss of tacit knowledge.[11] This provides an argument to retain individual national R&D&D programmes in such a way that their individual volatility is smoothed out on the international level. A further argument for retaining some decentralised structure of RD&D support is that there is no consensus on what criteria and instruments to use to allocate these funds. Diverse approaches, therefore, might hedge against the risk of using inappropriate approaches and might, furthermore, provide insights about the performance of individual approaches.

[11] Funding levels for individual technologies in individual countries have changed by more than 30% in about half the observation years (based on R&D data provided by IEA). Kamman (2004) concludes that national research and development programmes have frequently have exhibited “roller-coaster funding cycles.”

6. The free rider challenge

Not only companies but also countries fail to reap all the benefits from innovation and product and process improvements, which they support with their national programmes. Straightforward economic rationale suggests that governments will, in response, limit their support for technology development.[12] Figure 9 of public R&D expenditure on energy technologies reflects this expectation.[13] While the oil shock in the 1970s added the argument of energy autonomy to the strategic motivation of funding national nuclear research, the subsequent inertia of these established large interest groups meant only the nuclear and coal industries managed to secure significant funding for research and development. Despite the extensive rhetoric on the side of politicians, the renewable energy side so far has not achieved sufficient leverage to increase its share of research funding.

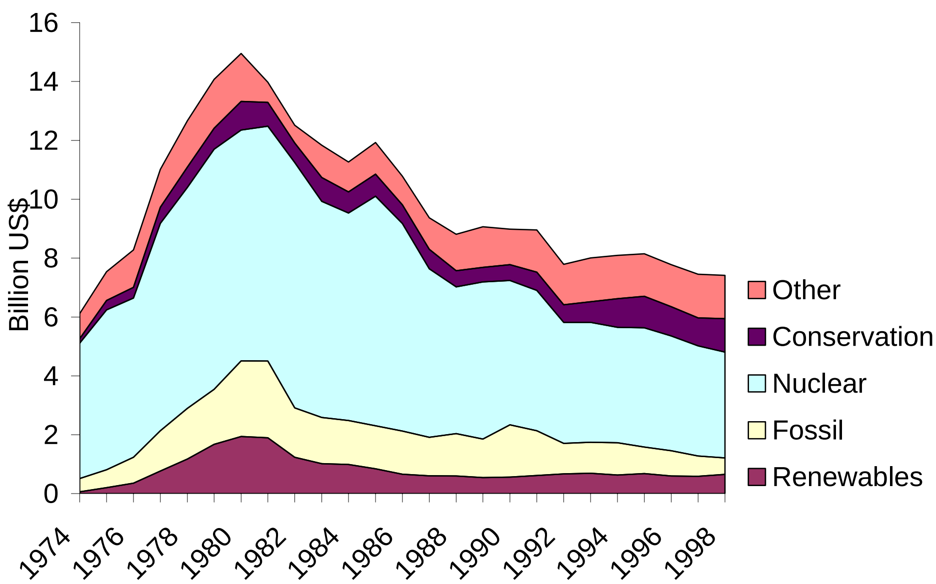

Figure 9 IEA country public R&D expenditure on energy technologies (IEA database of R&D)

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[12] Barreto and Klaassen (2004) (p. 74) suggest that learning spill-over could result in a lack of incentives for [individual] countries to pay for the 'learning investments', because other countries could be free riding. It is not clear to what extent technology 'spill-over' prevents public investment into energy technologies. For example, US federal and state governments and some industrial corporations spent US$5.6bn on research and development in the Clean Coal Technology Demonstration Program. (IEA, 2003).

[13] This picture is even more disturbing if we consider that private R&D expenditure in the energy sector is extremely low. In the US, as a typical example, 0.5% of sales revenue in the electricity sector is devoted to R&D, compared to 3.3% in the car industry, 8% in electronics and 15% in pharmaceuticals (based on Alic et al., 2003).

A strong motivation for national technology support programmes are the benefits for national industry, especially as early adopters expect that early support will move their national industries into a leading position on international markets. Strategic deployment of wind energy cost Denmark an estimated US$1.4bn subsidies over 1993-2001; annual revenues of Danish wind companies by 2001 were US$2.7bn, the vast majority from its dominant position in export markets (Carbon Trust, 2003).

Renewable energy technologies offer a new benefit that should justify additional national support. With increasing application of these technologies in foreign countries, both their emissions and their requirement for scarce natural resources will be reduced. Thus, even technology spillover that does not benefit national industry offers benefits for the population of countries thus strenghthening the case for public support.

However, the low level of support from national governments for new energy technologies suggests that we need to align national interests with global interests. The example of the EU renewables objective does offer some insights. Member states are committed to increasing the share of renewable technologies in their electricity supply by about 10% between 2003 and 2010 (to 22% by 2010).[14] While the process of coming to this agreement was difficult[15] and the level of compliance, and possible sanctions are still being debated (COM/2004/0366 final), the commitment was a driving force for the implementation and continuation of national support programmes. The EU-programme does not define targets for individual technologies, and thus most countries devote most investment to the cheapest energy technology, typically on-shore wind and biomass. Thus, additional efforts are required to ensure that technologies that are, like photovoltaics, at their current stage of development more expensive, also receive sufficient support.

On an international basis, the following approaches might be considered, to internalise some of the positive externalities from technology spill-over.

National politicians or administrations will be more successful in pursuing strategic deployment programmes if these programmes are coherent, with similar initiatives in other countries.[16] A joint public declaration or credible but even so not legally binding tatement made by the Johannesburg Renewable Energy Coalition, the G-8[17], or any similar institution could express support for stretching targets for increases in research and development budgets or strategic deployment funding. This could

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[14] http://org.eea.eu.int/documents/newsreleases/bonn_renewables-en

[15] Rowlands (2004) describes the European debate about the definition of renewables. During the debate, the scope was first broadened, e.g. keeping the option for large-scale hydro plants open, and yielding to pressure from Italy, the Netherlands and the UK to include municipal and industrial waste. Subsequently, the definition of renewables was broadened to allow directly combusted, and not digested, waste to contribute to the renewable quota.

[16] Barreto and Klaassen (2004) suggest forging sound international co-operation on research, development, demonstration and deployment activities for technologies that could contribute to mitigate greenhouse gas emissions.

[17] The G8 Renewable Energy Task Force (G8, 2001) provided a comprehensive set of policy recommendations.

provide a reference point for national policy debate and focus the attention of national administrations on energy technology policy.

An international agreement that supports the strategic deployment of several renewable energy technologies would have the advantage that that the nationally championed technology of each country could be included. This is likely to increase the number of participating countries. However, it would require a lengthy international process to foster such an agreement, as demonstrated by negotiations of the Kyoto Protocol.

Rather than fostering a broad agreement among many countries, one might consider developing 'clubs' of countries that support a new energy technology. A club of countries already covers a larger fraction of global population and industry than a single country. If the members decide jointly on their technology support programmes, they will internalise more of the positive externality and hence provide stronger support than if they were to make individually optimal decisions. This would be particularly successful if such a group of countries already represent a large fraction of the global natural resource-base for a technology, e.g. occupying the coastline with strong tidal streams. Another motivation for the formation of such a club could be that its members can capture a large share of the human, technological and financial resources required to advance a specific new energy technology.

Following the discussion on the benefits of larger markets, the success of such a club is likely to multiply if the members of the club fully open their RD&D and deployment programmes to participants from other countries. If this is not be possible due to fear of free-riding third countries – whether a justified fear or political posturing - a reciprocity clause might be considered. Only companies from countries that also implement RD&D programmes and open these for international participation may participate in the public tenders. We are currently investigating the compatibility of such an approach with the WTO framework.[18]

Any barriers to entry to support programmes for the development of new technology, firstly are best formulated in a direct and transparent way. In particular, the environmental raison d'etre for a reciprocity clause needs to be spelled out, so as to maximise chances of WTO-compatibility.

The precise form, which a reciprocity clause would have to take to pass the tests of the Agreement on Subsidies and Countervailing Measures (SCM), would require ad hoc analysis of that agreement. However in general the agreement does provide for a fair amount of flexibility for R&D as well as (more limited) environmental funding.

The case for a reciprocity clause under EU law, could be simultaneously more complicated as well as

[18] WTO/EU aspects will be addressed in a paragraph from Prof Dr Geert van Calster, Co-director, IMER - Collegium Falconis, K.U. Leuven, P +32(0)16 32 5132, gavc@law.kuleuven.be by 6/10/2005.

more feasible. More complicated, given the deep integration model of the EU which would rule out discrimination amongst Member States; more feasible, in that the EU Instituttions generally are more prone towards accepting the type of environmental rguments which could underpin this scheme.

It might be easier to foster agreements for individual technologies. For example, the Concentrating Solar Power Global Market Initiative (GMI) of several European, North American and North African countries aims at deploying 5GW of solar concentration in the next 10 years. The resulting learning-by-doing is expected to reduce costs and allow for competition with mid-range generation capacity.[19]

Partnerships with developing countries could provide mutual benefits. OECD countries would benefit from larger markets and lower production costs, while developing countries would obtain access to new technologies, new employment opportunities and reduced fossil fuel costs. All participants would benefit from reduced emissions. One step towards facilitating such co-operation would be the expansion of export credit guarantees for renewable energy technologies.[20] A more far-reaching approach would be to provide direct subsidies for the application of new energy technologies in developing countries. For example, a fund could cover the price difference between the electricity costs based on diesel generation and the electricity costs for generation using P.V. This should allow for a clear separation of development objectives and technology objectives, thus making both processes more transparent and all parties more accountable for the achievement of their specific objectives. Finally, one might consider allowing developing countries to build and develop renewable energy technologies while granting them the relevant IP rights for free, and providing initial transfer of the technology know-how. This would be a process similar to the process observed in the pharmaceutical industry, with the additional benefit that inappropriate usage of renewable energy technologies does not create negative externalities on other countries (e.g. no development of resistant bacteria, nuclear accidents or nuclear proliferation).

7. System integration of new technologies

While there are no fundamental barriers to the delivery of large shares of energy from renewables (See Annex 3), the costs of operating the system with increasing shares of renewables are increasing. Most engineering 'constraints' translate into additional costs. However, several of these constraints can be relaxed, thereby reducing the costs of renewables for the system, as will be discussed in this section.

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[19] See http://www.solarpaces.org.

[20] UNEP suggests an extension of the repayment period to 15 years instead of 12, given the longer lifetime of energy projects. Micro-credit linked to micro-enterprises can have considerable success in both promoting renewable energy use and meeting poverty reduction goals (Johansson et al., 2004). Strategies to include renewables in non-energy sectors, such as water supply, health, education, and communication, can significantly enhance energy access (Johansson et al., 2004b).

7.1 Short-term weather forecasts

The electricity system requires a permanent match between demand and supply. It must keep sufficient generation resources at various levels of standby, in order to complement unexpected output changes. Increasing penetration of wind and solar energy does require additional resources to stand by and compensate for their output deviations. This additional cost could be limited, however, if better short-term weather forecasts reduced uncertainty about their output. Improvements of short-term weather forecasting do require an increased frequency of large-range weather predictions.

7.2 Flexible system operation and flexible transmission use

The main market concern for renewable energy technologies is that wind, solar and wave output cannot be predicted with sufficient accuracy at the time of the liquid day-ahead market. By the time prediction accuracy improves (about four hours before final production), most international electricity transmissions have been allocated and liquidity in energy markets is low. This is despite the fact that transmission flows can be adjusted within seconds, most power plants can be started and stopped and all power plants can change their output within this timeframe.[21] As a result, the electricity system is operated inefficiently, and wind, solar and wave output sold on the open energy market receive lower than efficient prices.

An internationally compatible market framework would allow for the flexible use of transmission capacity.[22] Flexible generation plants in the entire national or international system can then jointly adjust to changes from demand, conventional or intermittent generation. Such increased efficiency in the operation of the system reduces the costs of intermittent generation. This would, however, require a strong representation of the interests of intermittent generation in the negotiation processes, as many conventional generators benefit from selling expensive balancing services and strong lobby groups for industrial consumers focus on the average wholesale price level rather than complex balancing arrangements.

7.3 Possible lack of transmission investment

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[21] This effect is enhanced if, in systems like the English and Welsh NETA, renewables generators balance their output in order to avoid high imbalance prices. As individual output is relatively more volatile than aggregate output, this results in higher levels of flexible plant that must be kept running, creating energy and capital costs.

[22] More effective and flexible use of the network would require closer co-operation among TSOs, sharing realtime information and supporting an integration of balancing markets. The co-operation of PJM with neighbouring TSOs in the US is a successful example.

Most energy from new renewable energy sources is delivered as electricity, apart from biomass, solar and geothermal heat. Transformation of electricity into other fuel involves high efficiency losses (hydrogen); therefore, it is preferable if it can be directly used in the form of electricity. However, renewable energy resources have lower energy intensity, therefore requiring more space to capture the energy required in areas with high concentration of population or industry. They are volatile and frequently intermittent, but some of this volatility is averaged over large areas. There can therefore be significant benefit from increasing transmission infrastructure to complement the development of renewables. This raises various issues: Open Access Requirement as part of EU/other regulation, financial viability of merchant transmission investment and incentives for regulated transmission investment).

7.4 Planning permission

Administrative frameworks were developed for existing technologies and are not yet tailored to the needs of renewables. While spatial planning traditionally envisages specific zones for industrial development, local plans must frequently be revised, to allow for the location of wind or bioenergy plants. This creates uncertainty and costly delays for project developers, for European wind projects between 1.5 and 4.5 years (Admire Rebus, 2003, situation improved in the meantime in various countries). The small scale of renewable energy projects multiplies the relative costs incurred through multiple administrative processes. For example, biogas plants in Germany require several parallel permit processes designed to address issues such as EU regulations aimed at preventing the spread of BSE, while large power plants only require a single general permit process (Klinski, 2004).
While most administrative hurdles are based on a national and local level, international co-operation might aim at providing a best practice planning procedure, which could then be used as guideline for national implementation.

7.5 Invest in RD&D on storage, transmission and power electronics

The value of new technologies to operate energy systems will increase with the share of intermittent generation technologies in the system. In the meantime the value of such new technologies is low. It is for example currently cheaper to run existing power stations in part load rather than to invest in new storage technologies. In absence of current market demand for these technologies it is unlikely that private investors will invest in their development – suggesting that government support is required to induce research, development, demonstration and to create market experience for these technologies. This will both ensure their availability once the market share of new energy technologies is higher and will also provide information about their capability to guide today's decisions on energy policy.

8. Conclusion

International co-operation can advance renewable energy technologies by supporting a learning architecture to capture the synergies of ideas and experiences from all people, organisations and countries involved in technology development. We envisage international markets facilitating the co-ordination, offering the incentives and allowing for the diffusion of innovations and product and process improvements. We discussed the benefits for acceleration of technology development from such an opening of markets for early technology exchange. Government should use the leverage they gain from their financial support for early stage energy technologies to ensure that competition can arise for individual components of technologies, for example by ensuring compatibility, sharing operational experience and facilitating technology diffusion. Support for international VC funds, in line with similar developments in the pharmaceutical sector, might offer an additional option.

The positive experience from market-based learning shows the benefits of projects at a significant scale; merely doing studies is not sufficient to have any effect on the learning curve. International co-operation can complement national support strategies in enhancing investors' confidence in future markets for their renewable energy technologies, in order to allow for privately funded innovation and technology companies to explore new solutions to technology and component challenges. If not only national deployment but also demonstration support programmes are opened up to international competition, this might allow for more focus on effective technology solutions, induce earlier standardisation and increase market size and incentives to provide technology solutions.

However, we acknowledge that it is currently unclear whether governments will provide financial support on the required scale, both on the deployment and the R&D side. While the motivation to be the first mover in the market has motivated some successful national programmes, the increasing scale of support required can only be achieved with wider international participation. We discuss various options of international strategies to motivate national governments to increase their support for new energy technologies.

Most new energy technologies have different characteristics from existing technologies. While this does not create insuperable hurdles, the cost of system integration can be reduced if 'artificial' barriers from energy market designs are reduced and if complementary technologies for transmission, storage and system management are advanced more rapidly than envisaged under current programmes.

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ANNEX 1 Review of Barrier Studies

Study Abbreviation	Technologies covered general	wind	solar	marine	biomass	geothermal	Barriers considered Technological barriers	Uneven Playing field	Market Place Barriers	Non-Marketplace Barriers	Technology Lock-Out	Barriers Caused/ Addressed Internat.
Alsema, 1998			Y				Y					
Barton, 2003	Y							Y	Y	Y		Y
Biewald et al, 1998		Y	Y					Y	Y			
Cabraal et al (1996)								Y	Y	Y		
Callaway et al (1999)												
Chino, 2002	Y							Y	Y	Y		Y
Clemmer et al, 1999	Y								Y	Y		Y
Foxon et al, 2003		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Friedman, 2001	Y						Y			Y		Y
Glockner, 2001	Y						Y		Y			Y
Hetherington et al, 2004	Y						Y	Y	Y	Y		Y
IISD (2004)	Y						Y	Y	Y	Y		Y
Kirby-Harris, 2005	Y						Y	Y	Y	Y		Y
Main, 2003	Y						Y	Y	Y	Y	Y	Y
Martinot et al (1999)	Y						Y	Y	Y	Y	Y	Y
MRC (2004)		Y	Y	Y	Y	Y	Y			Y		
Nogee et al, 1999	Y							Y	Y	Y		Y
Painuly, 2001	Y						Y	Y	Y	Y	Y	Y
Papay, 2003	Y						Y		Y	Y		Y
Rader et al, 1996	Y							Y	Y	Y		Y
REBT, 2002	Y						Y	Y	Y	Y		Y
Sellers, 2004	Y									Y		Y
Tayati, 2004	Y						Y			Y		Y
UNEP, 1998							Y	Y	Y	Y		
USDI, 2005		Y	Y	Y	Y	Y	Y		Y	Y		
Wooley et al, 2001		Y	Y	Y	Y	Y				Y		

Study	Main Findings
Alsema, 1998	No significant technological barriers; An improvement is needed in the electricity storage technologies. PV delivers significant mitigation of CO2 emissions
Barton, 2003	Concerned with the public perception of renewable energy.
Biewald et al, 1998	A number of policies are needed for promoting zero carbon resources
Cabraal et al (1996)	The need to overcome the first cost barrier is a sine qua non in any country context.
Callaway et al (1999)	
Chino, 2002	
Clemmer et al, 1999	The report examines the costs and benefits of achieving renewable portfolio standards (RPS) targets: they conclude that the minimum national renewable generation requirement would accomplish: (1) considerable environmental benefits; (2) Reduce CO2 emissions at a low cost; (3) Diversify the nation's electricity mix; (4) Expand renewable energy development throughout the nation; (5) Have only a modest impact on electricity prices; (6) Lower natural gas prices.

Foxon et al, 2003	There is a strong case for policy support to keep early stage options open.
Friedman, 2001	Pricing & Reliability Still Need Attention; Need Other Applications (e.g., transportation) to Build Volume and Establish Service Infrastructure
Glockner, 2001	Importance of capital investment, storage capacity, start-up time, control strategy
Hetherington et al, 2004	The 2010 renewable electricity target can still be met if barriers to winds deployment can be eliminated, 3rd generation solar research focussed on collaborative efforts with nations with complementary scientific skills and industrial capabilities to exploit solutions.
IISD (2004)	It is a summary report of the International Conference for Renewable Energies: 2004
Kirby-Harris, 2005	There appears to be a funding gap in moving renewables to the pre-commercial stage. Renewables seem to have developed a 'low cost' view of their implementation, which will not drive the actual costs of developing energy sources on the scale needed.
Main, 2003	Renewables presently suffer from various barriers to exploitation, which demand greater R&D.
Martinot et al (1999)	Many of the opportunities for energy efficiency and renewable energy are not being realized fully because barriers of many types limit or prevent technology diffusion and investment
MRC (2004)	The implemented Ecological Fiscal Reform in Canada is one of the most powerful means at the government's disposal to influence outcomes in the economy. The second phase of the EFR program focuses on the potential contribution of EFR to reducing carbon dioxide (CO2) emissions from energy. The program includes development of case studies on three sectors that can contribute significantly to "decarbonization" of Canada's energy sector, namely: renewable energy, hydrogen and energy efficiency.
Nogee et al, 1999	There are significant market barriers and market failures that will limit the development of renewables unless special policy measures are inacted to encourage that development.
Painuly, 2001	RETs are cost-competitive with conventional energy sources in several applications. Develops a framework for identifying and overcoming barriers.
Papay, 2003	Domestic introduction of technologies requires incentive mechanisms
Rader et al, 1996	The existence of market imperfections clearly justifies renewables policy
REBT, 2002	Adoption of Generation Information System and RPS
Sellers, 2004	
Tayati, 2004	The reliability, power losses and voltage profile are identified as possible barriers to implementation of VSPP. It was found that if the system has power balance between power generation and local demand, the power losses and voltage profile impacts will be optimised. In addition, if the system is not dependent on the grid

	sources e.g. a micro-grid system, the reliability will be greatly improved.
UNEP, 1998	
USDI, 2005	The Department of Interior has developed and is implementing new policies to promote increased development of wind, geothermal, solar and biomass energy resources on the public lands. A significant part of this effort involves removing administrative and other process barriers to reduce permitting backlogs while providing careful oversight to ensure these energy resources ardeveloped in full compliance with existing laws and regulations and in an environmentally sound and economically feasible manner.
Wooley et al, 2001	Integration of renewables into the fabric of clean air programms is an important policy objective, Coordinated Effort By Government, States, Renewable Industries And Environmental Groups To Popularize And Support The Concept

Study	Policy Recommendations
Alsema, 1998	No policy recommendation.
Barton, 2003	More detailed social research is needed.
Biewald et al, 1998	1) System benefits charge; 2) Renewable Portfolio Standard; 3) Regulatory support for Green power; 4) Further Research
Cabraal et al (1996)	The findings emphasize the need to: (1) Overcome the first cost barrier; (2) Establish responsive and sustainable infrastructure to deliver PV services, and (3) Provide quality products and services.
Callaway et al (1999)	
Chino, 2002	Provision of financing for renewable projects
Clemmer et al, 1999	Designing an effective RPS policy: (1) RPS targets should be set near the high end of the range of proposals studied; (2) RPS targets should increase gradually over a long period of time; (3) If a cost cap is desired, it should be set just above the expected market price of renewable energy credits; (4) existing hydropower and municipal solid waste incineration should not be eligible for credits under an RPS.

Foxon et al, 2003	Agree strategic goals for the medium term; set out transition paths or 'route maps' for how these might be achieved; agree support for the initial steps or 'learning experiments' along these paths. The simplest and most effective means to create a small niche market to allow early stage technologies move into pre-commercial trials would be to combine a capital grants programme with a fixed premium price scheme. It is recommended that policymakers improve long term risk/reward ratios by creating a framework for investments that encourages long term contracts. Where appropriate, eg in the case of offshore wind, larger returns could also be encouraged through licensing rules that encourage larger projects.
Friedman, 2001	
Glockner, 2001	Models with less stringent requirements should be developed. Cost models should be included in the model library to enable users to identify break-even points with regard to control strategies and type of technology installed. The potential for hydrogen energy systems for load levelling in weak grids should also be investigated.
Hetherington et al, 2004	Timely incentivisation of necessary grid upgrades, addressing other institutional barriers and an appropriate financial framework will be important. Longer term, the UK should develop technology and market options to achieve 2020 and 2050 aspirations and generate UK benefit. Wave/tidal - accelerated staged trials to discover whether a feasible cost-effective solution can be developed. Biomass - develop energy crops option and exploit heat markets to kickstart fuel chains. Fuel cells - R&D and niche market development in the stationary sector. Technology blind programme to support building integrated renewables (including solar) and energy efficiency technologies.
IISD (2004)	It stresses the need to overcome a number of barriers to implement renewables.
Kirby-Harris, 2005	
Main, 2003	Establishment of National Energy Research Centre.
Martinot et al (1999)	GEF adopted an operational strategy/ and long-term operational programs to promote energy efficiency and renewable energy by (1) Removing Barriers to Energy Conservation and Energy Efficiency; (2) Promoting the Adoption of Renewable Energy by Removing Barriers and Reducing Implementation Costs; (3) Reducing the Long-Term Costs of Low-Greenhouse-Gas-Emitting Technologies.
MRC (2004)	As a general rule, an EFR instrument will be more efficient and effective if it signals to multiple agents in the electricity market that carbon is more expensive. While cost reductions can be expected to occur from R&D spending, the scope and scale of the cost reductions is questionable, thus increasing the overall uncertainty if using a single instrument, namely promoting R&D investments.

Nogee et al, 1999	The report describes seven practical measures that would increase the contribution of renewables to electricity sypply: (1) Renewables portfolio standards; (2) Public benefits funding; (3) Net metering; (4) Fair transmission & distribution rules; (5) Fair pollution rules; (6) Customer Information; (7) Putting green customer demand to work;
Painuly, 2001	Measures to overcome the barriers may be unique to a country/region…
Papay, 2003	International opportunities exist, but cooperative mechanisms are needed. Develop technological options for future demand. Use a "Spiral Development Approach" to insert advanced technologies as they become available.
Rader et al, 1996	Renewables Portfolio Standards ; Green Marketing; System benefits charge
REBT, 2002	Create a Certificate Market to link environmental attributes with electric generation and then use the market for those attributes to create energy products at the retail level as well as allow for the consumer disclosure and RPS rules to be implemented at low cost to the consumer. Secure the enactment of an RPS system and the incorporation of SBTM resources into the rules.
Sellers, 2004	Assess the political viability of reducing or eliminating customs rates for renewables until a global market is assured.
Tayati, 2004	Possible technical barriers can be overcome with investment cost. Whether the utility and/or the power producers are willing to share this cost, is an important issue to be resolved. Further study is also required to look into an impact on distribution system protection which is one of major issues as far as the utility is concerned.
UNEP, 1998	A number of policies are proposed for achieving the desired mitigation and adaptation…
USDI, 2005	
Wooley et al, 2001	Tighten the existing SO2 cap and establish an improved allowance set-aside program to replace the CRER. Encourage renewables under state programs developed under NOx SIP call or Northeast OTC MOU. Pursue a mandatory state set aside for renewables in regional or national cap-and-trade programs for NOx and pursue multi-polutant programs.

ANNEX 2 Review of RD&D Investments by IEA Governments[23]

Today, renewable energy sources account for some 13.5% of total global energy supply. Against the backdrop of rapidly rising energy consumption and prices, several scenarios have suggested that renewable energy sources could meet over 20% of energy demand in 2030 and significantly more in 2050. The projected growth in renewable energy markets is based on a competitive environment for all energy sources. Within those projections, three factors affect renewables' cost and market growth: the intensity and availability of the natural energy resource, the maturity of each renewable technology and the market rules set by governments.

To encourage a larger renewables share, governments are investing in research, development and demonstration (RD&D) and are establishing a range of policies to support market deployment. These investments are underpinning a shift from the first generation of competitive renewable energy technologies to a second generation. These newer technologies have strong and growing markets, but in just a few countries, and the challenge is to broaden the base of the market to assure continued rapid growth. The key to achieving a high penetration of renewables over the longer term is to foster the development of a third generation of technologies. These technologies are on the horizon, but are not yet receiving sufficient RD&D funding.

In terms of potential business opportunities, if renewable energy technologies succeed in accelerating their market acceptance through technology and market cycles, it is conceivable that they could capture a significant share of the projected US$16 trillion of investments for the global energy supply infrastructure over the next three decades (IEA World Energy Investment Outlook 2003).

Renewable Energy Status

At the time of the first oil crisis in 1973, the commercial portfolio of renewable energy technologies included hydropower, electricity from the combustion of biomass fuel, and geothermal heat and power. These technologies entered the market as early as the Industrial Revolution in the late 1800s. Hydropower sprang from the adaptation of water mills to drive electric generators. Biomass combustion was an evolution of mankind's longstanding use of fuel wood: combustion chambers were improved, heat recovery was enhanced, and electricity

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[23] Extract from Renewable Energy Markets: Past and Future Trends, Rick Sellers, Paris, France, 2005

was generated. Geothermal heat and power was an offshoot of mineral mining from volcanic effluent. All these technologies became competitive in locations where the resource was strong, and where there was local demand for their energy. These technologies moved into developing countries as they became competitive, and as industrial demand in those countries developed.
Growth of these three technologies in the late 1970s and early 1980s was largely the result of their improved competitiveness in the aftermath of the oil price crises. Hydropower production in IEA countries increased from 71 Mtoe in 1970 to 91 Mtoe in 1980. Growth in hydropower production, however, slowed considerably in the late 1980s and 1990s. Production actually declined from 1995 to 2001, primarily due to a decrease of 9.7 Mtoe in hydropower production in the United States. Bioenergy supply nearly doubled from 1970 to 1990, but growth also slowed in the 1990s. Growth in geothermal supply also slowed in the 1990s. These more mature renewable technologies have not been a main focus of the policy support that benefited new renewables in the 1990s. Growth in these first generation technologies reached a plateau in IEA countries [when?], at about 5% of TPES. While there is some additional potential there, the greatest potential is in those developing countries with abundant resources and growing energy demand.

Table 1. Average Annual Growth Rates of Renewable Energy Sources

	1970-1980	1980-1990	1990-2001
Renewables	3.2%	2.4%	1.2%
Biomass	3.5%	3.0%	1.6%
Hydro	2.6%	0.7%	0.4%
Geothermal	8.3%	9.4%	0.4%
Wind/Solar	6.4%	23.5%	23.1%

Source: IEA (2004)

Albeit from a very low base, the second generation of renewables - solar electric, wind power, and some advanced biomass technologies - have grown at impressive rates over the past three decades, by about 23% per year from 1980 to 2001. For some technologies, this pace is estimated to have accelerated considerably in the past several years. For example, PV growth in 2004 was over 65%. Yet despite rapid growth, total production from second-generation renewables was only 6.4 Mtoe in 2001, a tiny fraction of the contribution from first generation renewable energy technologies.

Growth in this second generation of technologies is the result of substantial investment by IEA governments in RD&D and support for market deployment policies. As far as we know, there was no RD&D funding for renewable energy technologies prior to 1974. In that first year of funding, geothermal, solar heating & cooling and solar thermal electric accounted for over 80% of renewable energy RD&D, although the total was only about US$65million across all IEA countries. The focus on those technologies remained strong up until about 1978, when a rapid shift in priorities can be seen, toward wind, solar PV and advanced forms of bioenergy. By 2002, these second generation technologies accounted for almost 80% of RD&D funding, while the former leaders received the balance.

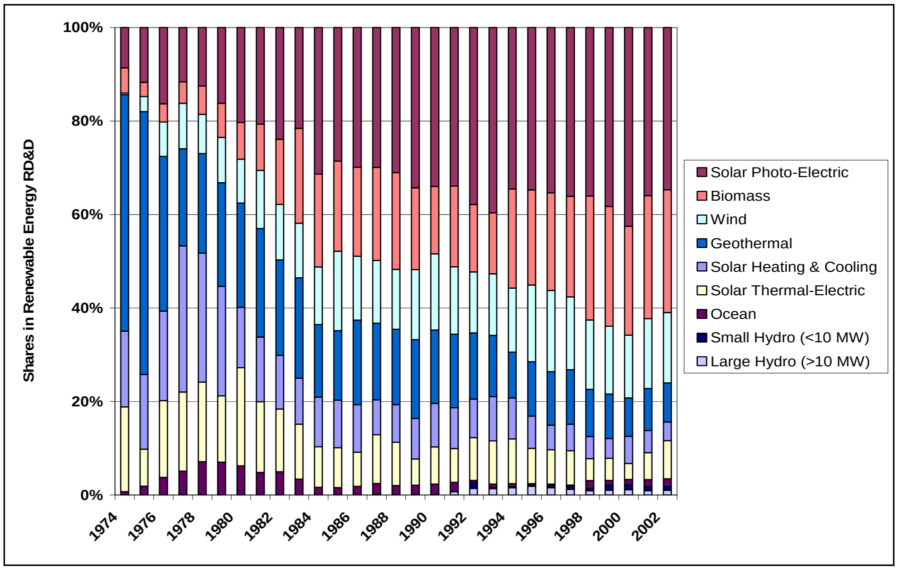

Figure 10 Shares of Renewable Energy Technology RD&D, (IEA, 2004)

At the same time, the overall level of renewables RD&D funding has been very erratic. From the first year in 1974 at ~US$65 million, renewables RD&D peaked at just under US$2bn in 1980, and then collapsed to less than a third of that, to ~US$600 million in 1987. This follows, but is more extreme than, the pattern of total government energy RD&D budgets that increased sharply after the oil price shocks in the 1970s, but then declined to about half of their peak levels by 1987, where they remained relatively stable until 2002.

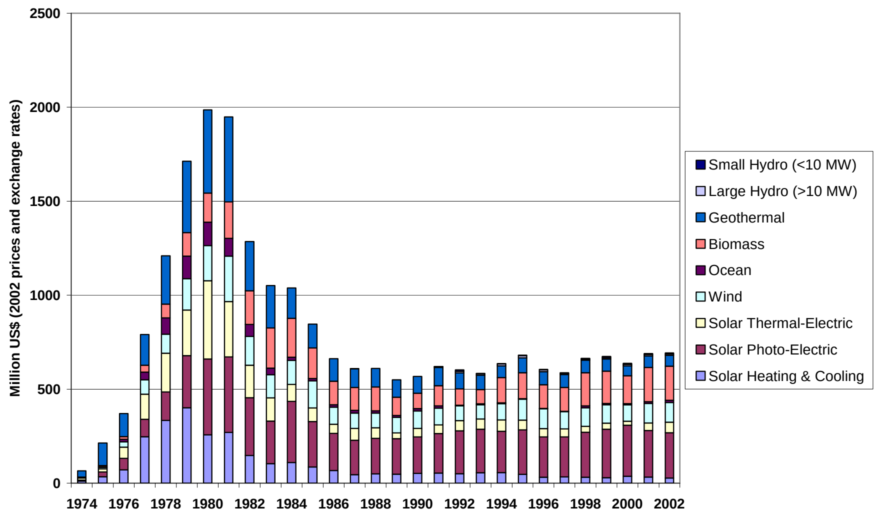

Figure 11 Renewable Energy Technology RD&D (IEA, 2004)

As a percentage of total RD&D funding, RD&D funding for renewables was higher from 1974 through 1986 than in the period since 1987. Taken together, renewable energy technologies accounted for just 7.7% of total government energy RD&D funding from 1987 to 2002. The shares of renewable energy technologies out of total energy RD&D funding over the entire period, can be seen in this table. The United States, Japan, and Germany accounted for 70.4% of government renewable energy RD&D funding in the 1974-2002 period among IEA countries.

Table 2. Renewable Energy RD&D in IEA countries	
solar photovoltaics	2.7%
geothermal	0.9%
solar heating and cooling	0.7%
biomass	1.6%
wind energy	1.1%
solar thermal electric	0.5%
ocean energy	0.1%
large hydro	0.1%
small hydro	0.04%

Source: IEA (2004)

Given public expectations and policy commitments, it is surprising that renewable energy technologies continue to be funded at a low level relative to nuclear and fossil energy. This picture is even more disturbing if we consider that overall RD&D expenditure in the energy sector is extremely low. In the US, as a typical example, 0.5% of revenue in the electricity sector is devoted to RD&D, compared to 3.3% in the car industry, 8% in electronics and 15% in pharmaceuticals.

ANNEX 3 No fundamental barriers to system integration

Typical concerns about renewable energy relate to their intermittency. This can be assessed in the following three time frames:

First, three to four hours before production, average regional output can be predicted with a high degree of accuracy. Remaining uncertainty is mainly due to sudden wind bursts shutting down turbines or cloud fronts covering solar panels. Transmission networks are already designed to cope with larger output changes caused by sudden shutdowns of large fossil or nuclear power stations (Grubb and Vigotti, 1997). Currently, the heavy and fast rotating conventional generators provide the inertia to drive the system through the critical first moment after a failure. If wind and solar replace most or all conventional generation, their power electronics will have to be improved so they can drive the system through the critical moment. Network tariffs do not (yet) reward such capabilities. At the distribution level, sudden output changes from large shares of renewable generation capacity can result in voltage-swings. Recent developments of power electronics or active management of distributed generation offer solutions.[24]

Second, during the 24 hours prior to production, the accuracy of output predictions for wind, solar and wave increases. With improving predictions, the operational schedule for power plants and the transmission network must be adjusted to make efficient use of all resources. Current electricity market designs do not provide the flexibility or trading liquidity for such adjustments. For example, in Germany deviations from the rather inaccurate 24h predictions of wind output are compensated for with last-minute balancing activities. This requires flexible and therefore expensive plant operation. Germany's system operators have an incentive to retain this scheme because they own most of the generation assets and therefore benefit from selling balancing services. Furthermore, they can reduce political support for further wind deployment by pointing to (artificially) high balancing costs[25] and thereby reduce competition for their existing fossil and nuclear generation.

Third, for system-planning purposes, no power plant can be assumed to produce with 100% availability. Repair, maintenance, constraints on fuel and cooling water and availability of wind

[24] See recent EU research projects: www.sustelnet.net, www.dispower.org, www.clusterintegration.org and http://www.ecn.nl/docs/library/report/2004/rx04078.pdf.
[25] Wind report 2004, at www.eon-netz.com.

and solar can reduce or inhibit production by all technologies. Statistical models are used to calculate the risk that multiple plants will not be available simultaneously. This determines how much back-up capacity is required to ensure reliable electricity supply. The availability of wind, solar, wave and tidal is far lower than that of conventional power stations. If these technologies contribute only a small share of total electricity generation (< 5%), the system benefits from the increased diversity, and renewable output is of similar value to conventional generation output.

However, with increasing market shares, the lower availability implies that individual renewable technologies contribute less towards peak demand and therefore that wholesale value of their output is reduced (with market shares below 20% by approx. 10% according to Smith et al., 2004; see also Strbac, 2002). If individual intermittent renewables contribute large shares of electricity, they require significantly more back up and storage capacity than conventional power stations. Retaining old power plants was historically the cheapest option for provision of backup capacity for periods of peak demand or power station outages. This could also prove a low-cost way for initial support of larger market shares of intermittent renewables. In the long term, if intermittent renewable resources dominate electricity generation, new backup capacity or storage technologies must play an important part.

The 20% quoted above is not a fixed number; it is subject to current research and a function of at least four system characteristics. (1) Spatial diversity reduces the correlation of output of renewable generation at different locations and therefore increases renewables' value. This provides a strong argument for closely co-ordinated operation of these networks, and for integrated networks rather than micro-grids. (2) Mixing different renewable technologies provides uncorrelated output, once again increasing the value.[26] (3) PV output is, in many regions, correlated with peak demand from air conditioning and can therefore significantly reduce system costs (Herig, 2000). (4) Demand-side response and demand-shifting reduce the need for peak demand and increase the value of intermittent generation.

The discussion shows that individual renewable energy technologies can contribute a significant share of electricity production. This makes them valuable for our electricity systems. However, uncertainty about availability and costs of generation, network, storage and control technologies makes it difficult to predict the maximum market share or optimal future mix of individual renewable energy technologies.

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[26] See http://www.eci.ox.ac.uk/lowercf/intermittency/summary.html.