CARBON TRUST

Making business sense
of climate change

Building options for UK renewable energy

Executive summary

The 2003 UK Energy White Paper set out an aspiration to cut carbon dioxide emissions by 60% and create a low carbon economy by 2050. These deep cuts will require both a doubling in the uptake of energy efficiency measures and significant new supplies of renewable energy.

As energy efficiency measures to reduce carbon emissions today are cheaper than renewable energy, Government could pursue its environmental goal at lowest cost by focusing on energy efficiency and "importing" renewable technologies once their cost has been driven down by development at scale elsewhere. An alternative would be to support the development of UK-based renewable technologies that could be globally competitive, creating economic value for UK plc as well as meeting the environmental challenge.

With both environmental and economic development objectives, the Carbon Trust carried out this study to better inform its investment decisions in this area. It reviewed five renewable technologies and assessed their cost reduction potential, market size and the competitive position of UK plc in terms of bringing them to market. These were on-shore wind, off-shore wind, wave, tidal stream and solar PV.

Taken globally, there is abundant renewable energy resource across each technology reviewed to meet growing energy demand. In addition, the cost of each technology could reduce significantly over time. On- and off-shore wind should become cost competitive with grid-connected fossil fuel electricity generation. Wave and tidal stream are at an earlier stage of development where costs are more difficult to estimate, but these technologies could also become cost competitive over time. Solar PV should become competitive with retail electricity in developed countries and off-grid developing country markets in the medium term.

While all the technologies reviewed could develop into significant global markets, the opportunities for UK plc vary greatly. The UK has the largest wind resource in Europe and, given wind's cost reduction potential, the market is expected to grow rapidly. In on-shore wind, UK plc has a relatively poor competitive position as Danish and German companies have a market share of over 80% in turbine manufacture. However, the UK could still build a significant domestic industry through local component manufacture, installation and operations in on-shore wind. In off-shore wind, UK plc could develop into a global leader as the industry is at an early stage of development, much of this development is in the UK itself and the UK has design, installation and operations experience in off-shore environments. Early estimates show that the UK has very significant wave and tidal resources, a strong competitive position and, therefore, the potential to become a global leader in the medium term if the technologies can become cost competitive. The potential for PV in the UK is constrained by the availability of natural resource, its cost and UK plc's weak competitive position. There is an opportunity to develop future generations of PV technology, leveraging the UK's relative strength in academic research.

To maximise the economic return to the UK, public support should be targeted at technologies where the UK has competitive strengths. Like private investors, public interest organisations like the Carbon Trust need to invest carefully, making funding available in support of specific objectives. To pursue our objectives cost effectively will require us to prioritise between technologies and follow differentiated investment strategies.

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Purpose of this research

Over the next three years, the Carbon Trust plans to invest a total of £75 million in selected technologies and businesses that can help the UK develop a low carbon economy.

The Low Carbon Technology Assessment, published in 2002, was commissioned to help the Carbon Trust make best use of its investment resource. It gives guidance on those technology groups with substantial potential for carbon emissions reduction and where investment by the Carbon Trust can make a material difference to the technology's progress towards commercialisation given other public/private sector funding.

Work undertaken this year developed the findings of the Low Carbon Technology Assessment in the specific area of renewable power technologies in order to inform the Carbon Trust's approach to investment in this area. This report summarises the key findings of this work.

Given the forward-looking nature of the study all forecasts and data should be considered to be rough estimates and any decisions based on this work should be taken accordingly.

"Work undertaken... in the specific area of renewable power technologies in order to inform the Carbon Trust's approach to investment in this area"

We would like to thank Chris Mottershead of BP and Professor Dennis Anderson of Imperial College for their input and acknowledge the support of management consultants LEK. It should be noted that this report does not necessarily reflect the views of these individuals or their organisations.

The case for renewable energy support

As the impact of climate change is recognised by Governments around the World, they are responding through framework agreements such as the Kyoto Protocol, regional agreements such as the EU Emissions Trading Scheme and national measures such as the UK's Climate Change Programme. These measures are driving the development and deployment of energy efficiency, reducing energy demand at the point of use and promoting clean low carbon energy supplies. Wide ranging Government regulation and incentives are creating substantial markets ahead, in many cases, of consumer and business demand.

The UK Government's 2003 Energy White Paper sets a long-term aspiration to create a low carbon economy in the UK. It has set the UK on a path to reduce carbon dioxide emissions by 60% by 2050. These deep cuts will require both a doubling in the uptake of energy efficiency measures and significant new supplies of renewable energy.

In the short term, energy efficiency, the most cost effective way of reducing carbon emissions today, is expected to deliver the biggest emission reductions. In the short to medium term, the EU Emissions Trading Scheme will be a major driver of energy efficiency and moves away from carbon intensive fossil fuels in power generation and should minimise the overall cost of carbon abatement across both the supply sector and for key industrial users.

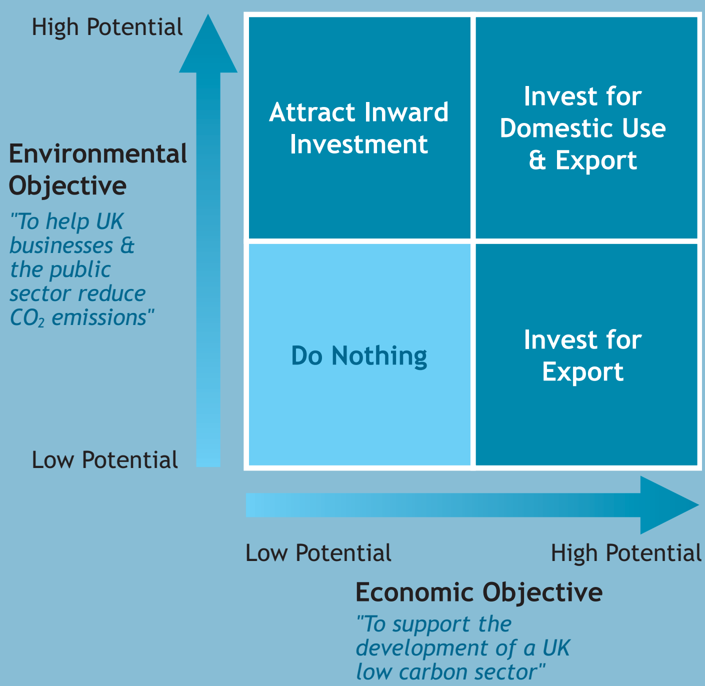
In the longer term, the UK Government recognises the need to increase the share of renewable power in the energy supply mix if a step change in emission reductions is to be achieved. In wholesale electricity generation, renewable power is more expensive than fossil fuel generation today but is expected to come down in cost through experience, increases in scale and technological improvement.

A dilemma facing many governments and public interest organisations is the degree to which they should support the development and deployment of renewable technologies today, given their cost premium over energy efficiency measures. The environmental objective of reducing carbon dioxide emissions is, in many cases, set alongside the need to address security of supply concerns by diversifying the energy base and economic development objectives of creating strong local and export industries.

Is the objective of public support environmental or economic?

The table shows how the Carbon Trust, which has both environmental and economic development objectives, assesses the appropriate support for a technology, given its potential to reduce carbon emissions and the potential for UK plc to benefit from its development. Government has similar but broader environmental and economic objectives.

- *If a technology has limited potential to reduce emissions in the UK and has limited scope to create value for UK plc, **Do Nothing**.*
- *If a technology has significant potential to reduce emissions in the UK but has limited scope to create value for UK plc because, for example, the value is in the intellectual property behind the technology and this is held overseas, a strategy to **Attract Inward Investment** makes sense.*
- *If a technology has limited potential to reduce emissions in the UK but has significant scope to create value for UK plc, an **Invest for Export** approach is appropriate. An example would be a small scale off-grid generation technology, more likely to reach industrial scale in developing countries without a power grid than in a developed economy.*
- *If a technology has strong potential to both reduce emissions in the UK and create value for UK plc through strong local and export markets, it is appropriate to **Invest for Domestic Use and Export**.*



The case for renewable energy support

The UK Government could pursue its environmental goal of reducing carbon dioxide emissions by supporting the deployment of "imported" renewable technologies. This would be achieved at lowest cost by waiting until these technologies have been commercialised elsewhere and their costs have decreased through experience and scale.

If, however, the environmental goal creates an economic opportunity, an alternative approach would be to support the development of one or more UK-based technologies that could be globally competitive and able to attract sustained private sector investment.

A number of countries are already investing in renewable power technologies to build potentially valuable stakes in global markets. In doing this they seek to leverage their productive potential, making good use of their natural, human and financial resources.

One example of this is the Japanese Government's involvement in promoting solar PV, capitalising on Japan's local manufacturing and high-tech skills base and addressing the need to diversify energy supplies. Market support and direct subsidies of around £1bn between 1994 and 2001 have led to the development of an industry with sales of over £2.4bn per annum.

As the value of renewable power markets are largely set by regulation and incentives and most renewable developers are multinational companies, the UK is competing for investment capital and renewable power capacity on the basis of its support for the sector. Beyond meeting environmental and security of supply objectives, the aim should be to maximise the economic value to UK plc of regulation and incentives in technology areas where the UK could build a globally competitive industry.

Case study

Japanese solar PV

Over the past decade, the Japanese Government has provided around £1bn of support to its solar PV industry. Over the same period, Japan has become the global market leader in PV manufacture, growing its market share from 20% in 1995 to around 50% in 2001 and current estimates predict that Japan will ship 70% of all units in 2003. The Japanese PV industry generates annual revenues of over £2.4bn (2001 estimates).

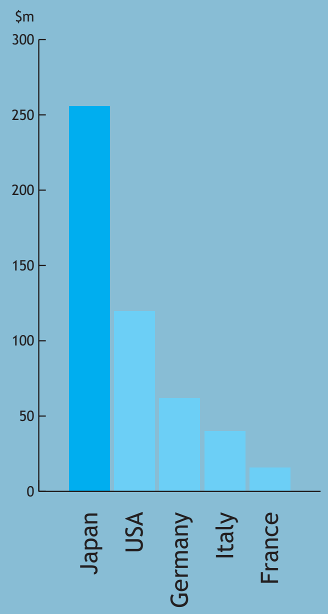
The Japanese Government has primarily used direct market subsidies to stimulate PV take-up, particularly in the domestic sector. In addition, it has funded a number of ongoing R&D and market demonstration programmes.

From an external perspective, Japan's support of PV is driven by three important considerations. Firstly, investing in PV creates economic value because it leverages Japan's expertise in high-tech manufacture i.e. it leverages a resource where Japan has a competitive advantage versus other countries. Secondly, given that Japan imports the vast majority of its energy requirements, its support for PV helps to grow an "indigenous" energy resource which can reduce Japan's acute security of supply issues. Finally, while PV is still relatively expensive versus other renewable energy technologies, the unit price of retail electricity in Japan is higher than many other developed countries and hence the unit price differential versus retail electricity is much lower.

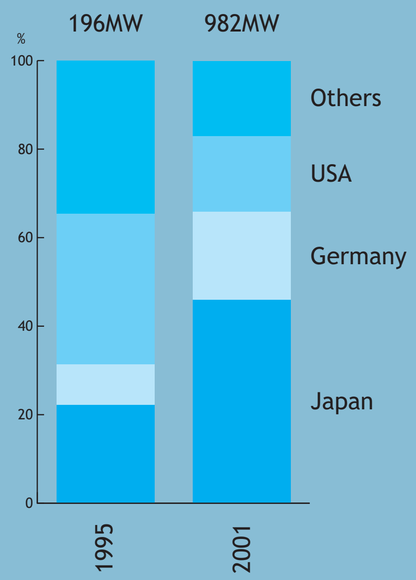
Looking to the future, the Japanese Government has a target to reach 4.8GW of installed PV capacity in 2010. Strong Government support is likely to continue, as is Japan's leading global position in conventional PV cell manufacture.

Japan has developed the most successful PV industry in the world

Public subsidies - Top 5 (2000)



Global market share*



*Note: * Based on cumulative installed capacity*

Source: IEA-PVPS

Case study

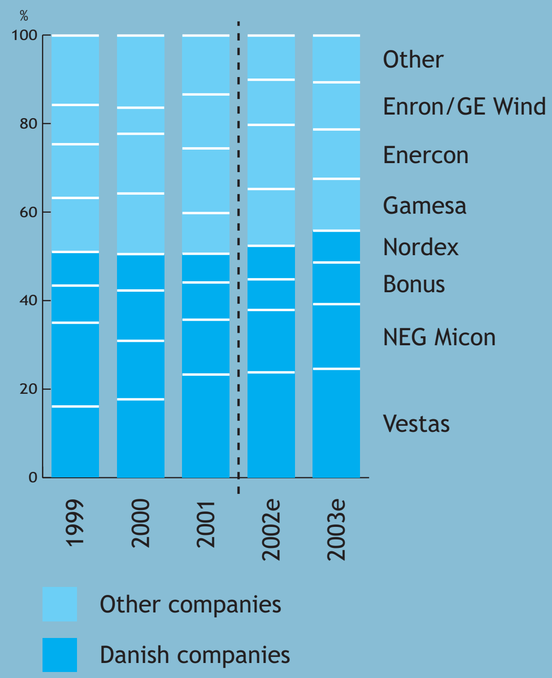
Danish wind

The Danish wind industry started its development in the 1970s during the energy supply crisis. Since 1993, the Danish Government has supported the development of its wind industry with measures worth over £1.3bn. This support has helped Danish companies to develop a global market share in the wind turbine market of greater than 50%. Annual revenues from this sector equate to some £2.7bn, with the vast majority of this revenue coming from export markets. The Danish Government has provided support for its wind industry through a combination of incentives (e.g. R&D funding, direct subsidies and export loans) and indirect measures (e.g. regulation on grid connection, agreements with utilities and liberal planning rules). While direct Government intervention has not been as systematic as in the case of PV in Japan, Government support has been instrumental in helping Danish companies develop a leading position in this area.

While political support for wind was initially driven by energy supply and environmental concerns, ongoing Government support has focused on capturing economic benefits. Denmark has been able to leverage its engineering experience to develop a wind technology sector. In addition, while the local market for wind technology was relatively small, Denmark could export its expertise and technology into rapidly growing global markets to develop the leadership position it holds today.

Danish wind turbine companies lead the global market

Global wind turbine market share



Source: Carnegic, April 2002

Where could the UK be globally competitive?

We have reviewed a number of renewable power technologies and assessed their relative value in terms of cost structure over time, potential market size, globally and in the UK, and the competitiveness of UK plc in terms of bringing these technologies to the market. This analysis provides the basis for determining what might be appropriate support for each technology.

The technologies reviewed were on-shore wind, off-shore wind, wave, tidal stream and solar PV. As the applications for biomass are broader than just electricity generation and include fuel for transport and heating, this will be the subject of a separate study.

The study addressed the following questions:

1. **What are the potential global and UK markets for each renewable technology?**
    1. Will there be demand for renewable energy?
    2. Is there enough renewable resource to meet demand?
    3. How might the cost of renewable technologies evolve?
    4. How might global and UK renewable power markets develop?
2. **What is the competitive position of UK plc?**

Data and information were gathered from a wide range of sources, many of which are in the public domain and are listed at the end of this document. Assessments were made based on this information by industry experts and analysts working with the Carbon Trust. It should be emphasised that, given the forward-looking nature of this work, all forecasts should be considered as rough estimates and decisions based on this work should be taken accordingly.

One important assumption, in relation to this work, is that grid connection and planning issues in the UK will be addressed and resolved as these would otherwise stall progress towards the 2010 renewable target and the development of renewable technologies at scale.

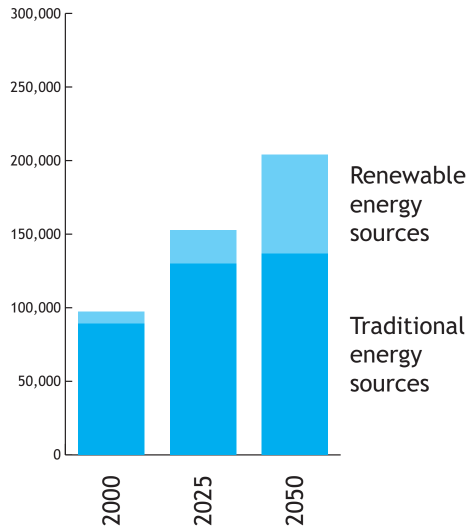
1.1 Will there be demand for renewable energy?

Demand for renewable energy will be driven by increasing global energy demand, potential increases in fossil fuel prices and increasing pressure for demand to be met from diverse and environmentally friendly sources. Most commentators, including the oil majors, see the markets for renewable power constrained not by demand but by our ability to develop and deploy renewable power technologies at a competitive cost.

Future energy scenarios assume significant renewable power

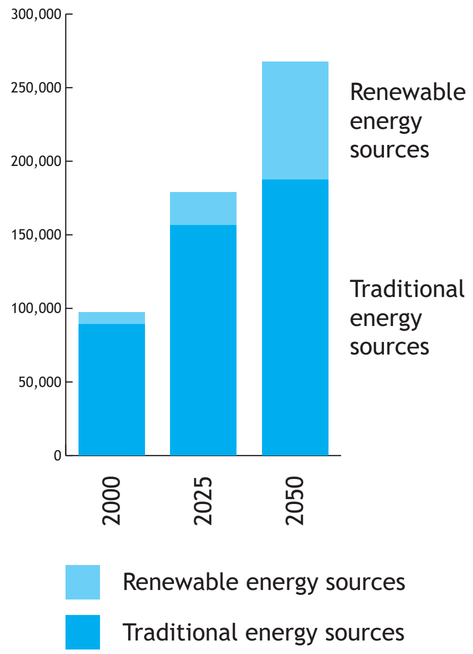
Scenario "Dynamics as usual"

Global energy demand (TWh/yr)



Scenario "Spirit of the coming age"

Global energy demand (TWh/yr)



Note: Renewable includes hydro, biofuels and other renewables. Traditional energy includes oil, coal, natural gas and nuclear

Source: Shell (2001)

Where could the UK be globally competitive?

1.2 Is there enough renewable resource to meet demand?

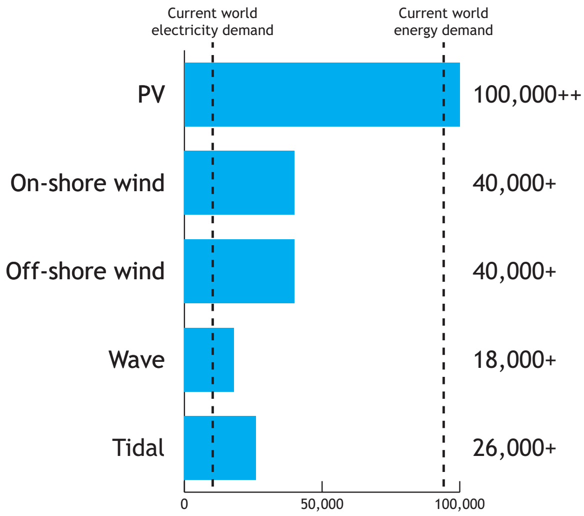
Renewable resource can be measured in two ways. The natural resource potential for a given technology is the total estimated resource relevant to the technology; for wind it would be the total wind power available without considering issues of site availability and economic constraints at low wind speeds. The practical resource potential reflects the constraints of site availability, technical development and the economic boundaries for development.

Compiling data from other studies, the charts opposite show that the resource available for renewable energy is huge. The top chart shows that for each technology considered, the natural resource available is significantly larger than current world electricity demand, despite using very conservative estimates for the natural resource potential of solar PV, in particular. The bottom chart applies site availability constraints and current technology conversion rates to the natural resource potential and shows a range of estimates of the practical resource potential for each technology.

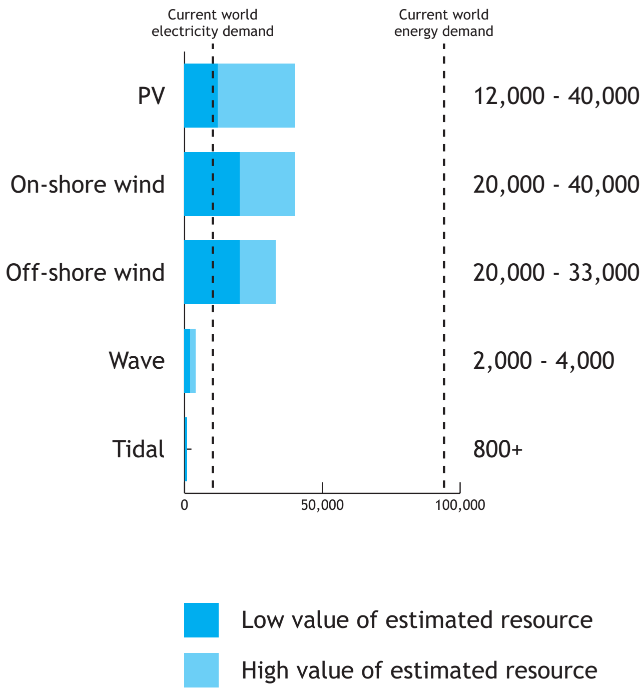
It is clear that there is sufficient renewable resource available to meet the world's current electricity demand several times over and enough to meet all forecast renewable demand this century. Taken globally, we have abundant renewable resource and the deployment of these technologies will be determined by technical, economic and social constraints.

Renewable resource could meet world electricity demand several times over

Global NATURAL resource potential (TWh/yr)



Global PRACTICAL resource potential (TWh/yr)



Note: 1. *Practical resource includes site availability and technical potential as defined by Gross, Leach, Bauen (2002)*

2. *Solar global resource is estimated as 2.5 times global practical resource as a very conservative estimate. Wave practical estimate is conservative, and could be up to three times as large as 4,000 TWh/yr. Tidal global potential estimates that only 3% of resource is "economic".*

3. *World electricity demand is given on an output basis.*

Source: WEC (2000) for global resource, global practical resource has been used from Gross, Leach and Bauen (2002) and World Off-shore Renewables Report (2002)

Where could the UK be globally competitive?

1.3 How might the cost of renewable technologies evolve?

Even in today's heavily subsidised markets, renewable technologies compete primarily on cost. Looking forward, as capacity grows to meet future demand for renewable power, the absolute cost of direct incentives will increase and then most likely fall, in unit terms at least, as Governments and consumers react to the spiralling cost of subsidies. Capital and operating costs will determine which technologies succeed at scale.

One can argue that the environmental cost of climate change will, through measures such as the EU Emissions Trading Scheme and its successors, be factored in to energy prices and that renewable power will, in future, compete with the cost of fossil fuel generation plus a premium for the "cost of carbon", reflecting the environmental benefits of renewables.

Whilst this would support the development of renewable technologies and could make a wider range of technologies cost competitive with fossil fuel generation, we believe that, with cost defined as the full cost of energy delivered to the consumer, the lowest cost renewable technologies will prevail and will be cost competitive with fossil fuels, without subsidy or a "cost of carbon" penalty on fossil fuels.

Renewable power technologies today are at very different stages of maturity, both in terms of technical development and market deployment at scale. Many studies have assessed the potential to reduce costs of specific technologies and, whilst in some cases the work is robust and offers investors some assurance, in others it is less well defined and leaves the investor with significant uncertainty and risk.

For on-grid applications, on-shore wind is currently the lowest cost renewable technology of those considered (ranging from 2.5-3.5p/kWh) followed by off-shore wind (costs ranging from 5-8p/kWh).

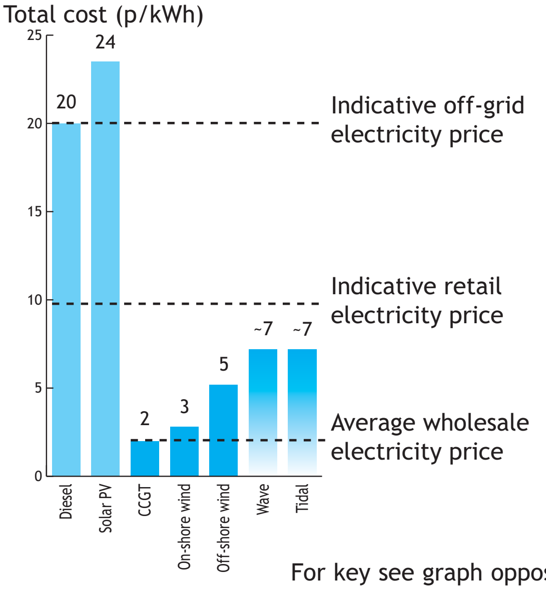
Crystalline solar PV is significantly higher in cost, but competes primarily in off-grid, developing country applications or in retail markets, where power is generated at the point of use and is not subject to heavy transmission and distribution costs.

Wave and tidal stream technologies are at the early stages of development; several competing devices exist and both their operating performance and ultimate cost at scale are unproven. Early estimates suggest that they are more expensive than wind but less expensive than solar PV.

The chart opposite shows the current costs for each of the renewable technologies considered.

Renewable power is not yet competitive without subsidy

Estimated cost of renewable & fossil fuel technologies in 2003



For key see graph opposite

Current cost estimates

We have compared crystalline solar PV costs to average retail electricity prices and off-grid diesel generation costs, as would apply to rural power generation in developing countries, assuming that solar PV will feed mostly into retail and off-grid markets. Currently, unsubsidised solar PV is slightly more expensive than diesel power generation and considerably more expensive than grid-connected retail prices.

In the on-grid wholesale markets, renewable technologies are compared to current Combined Cycle Gas Turbine (CCGT) costs. Available industry reports, those of the World Energy Council and the International Energy Agency and the UK's PIU, suggest that current estimates for on-shore wind costs are 3p/kWh, close to current CCGT costs of 2p/kWh. Off-shore wind is higher at an estimated 5p/kWh, although operating costs will need to be validated through experience.

Both wave and tidal stream costs are based on a model of generic wave and tidal devices, reflecting the predicted economics of a range of technologies currently being developed. The cost estimates around these technologies are less certain, given that few devices have actually been manufactured at full scale and tested under normal operating conditions.

Note 1. *Cost reductions based on experience curve and engineering cost reduction analysis from IEA, Gross and Redfield Consulting. Average and illustrative electricity costs from IEA, WEC, Credit Suisse First Boston*

2. *Average wholesale electricity price and retail price is expected to rise from DTI and McKinsey projections by 2020*

Source : Gross and Chapman (2001), IEA (2000) experience learning curves, WEC (2000), Credit Suisse First Boston (2003), Carbon Trust analysis

Where could the UK be globally competitive?

2020 cost estimates

All the technologies considered appear to have significant cost reduction potential.

IEA and PIU experience curve predictions suggest that, for a doubling of capacity, conventional solar PV costs will decrease by 18-20%. With these predictions by 2020, conventional solar PV should be competitive in retail as well as off-grid, developing country markets.

We have compared the future cost reduction potential of the renewable technologies against an illustrative CCGT total cost of 2.5p/kWh in on-grid markets. Gas prices are expected to rise, which would cause CCGT costs to increase above expected cost reductions from efficiency improvements.

Compiling IEA and the PIU experience curve estimates of cost-reductions for on-shore wind with estimates of installed capacity build rates to 2020, our analysis shows that on-shore wind could be competitive with a 2.5p/kWhr CCGT total cost. On-shore wind is a maturing technology and this forecast is more robust than those for off-shore wind and wave and tidal stream technologies.

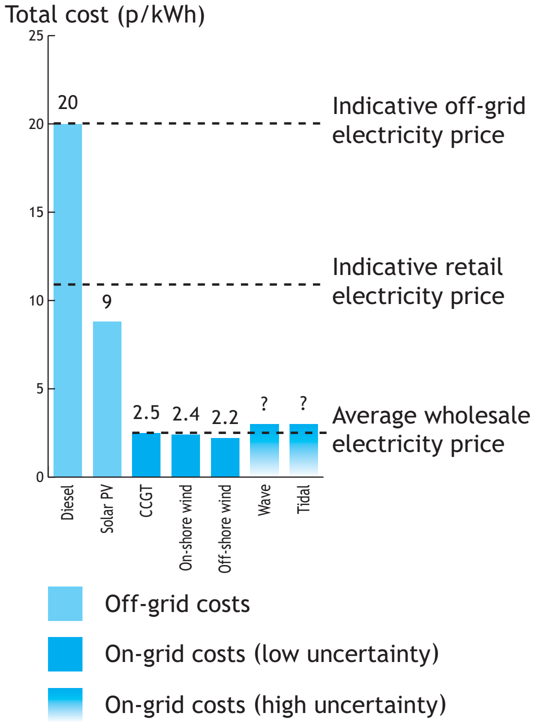
Off-shore wind is currently more expensive than on-shore wind. Significant cost reductions will depend on building very large installations of 1000MW or more, using standardised equipment to achieve economies of scale. If engineering constraints related to wind farm layout and location, foundation structures and off-shore operations and maintenance can be overcome, the overall cost of off-shore wind farms will decrease and, given their potential for scale, could be lower than on-shore wind farms despite additional grid connection and operating costs.

It is very difficult to assess the ultimate cost of wave and tidal stream technologies at scale. If they can become cost competitive with wind when manufactured and installed as standard low-cost modules, they should develop strongly, as their power off-take follows different intermittency patterns and, for tidal stream power, is more predictable. If their development is not supported or they cannot become cost competitive they may be relegated to niche applications and miss out on the large scale-up of renewable power.

We must also recognise the potential of even earlier stage technologies, such as so-called third generation solar PV that could see polymers absorb light and produce electricity. These could leapfrog today's technologies and offer even lower cost renewable power but their development paths are much less certain than the other technologies considered in this report.

Renewable power should be cost competitive without subsidy in the medium term

Estimated cost of renewable & fossil fuel technologies in 2020



Note 1. *Cost reductions based on experience curve and engineering cost reduction analysis from IEA, Gross and Redfield Consulting. Average and illustrative electricity costs from IEA, WEC, Credit Suisse First Boston*

2. *Average wholesale electricity price and retail price is expected to rise from DTI and McKinsey projections by 2020*

Source : Gross and Chapman (2001), IEA (2000) experience learning curves, WEC (2000), Credit Suisse First Boston (2003), Carbon Trust analysis

Where could the UK be globally competitive?

1.4 How might global and UK renewable power markets develop?

Many studies have estimated the ramp up in scale of renewable power technologies over time. We have reviewed a number of these studies and made an assessment based on factors including the available practical resource, the evolution of cost over time and the momentum in key markets provided by regulation and incentives.

The chart opposite shows one view of the development of global renewable power to 2050, whilst the chart on page 14 shows a view of the development of UK renewable power to 2050.

Global renewable power to 2050

The overall estimates are conservative with solar PV, on-shore wind and off-shore wind each showing approximately 250GW of installed capacity by 2050. The rate of deployment in the next 25 years is more significant to investors than the estimated potential in 2050 and this differs between the technologies considered.

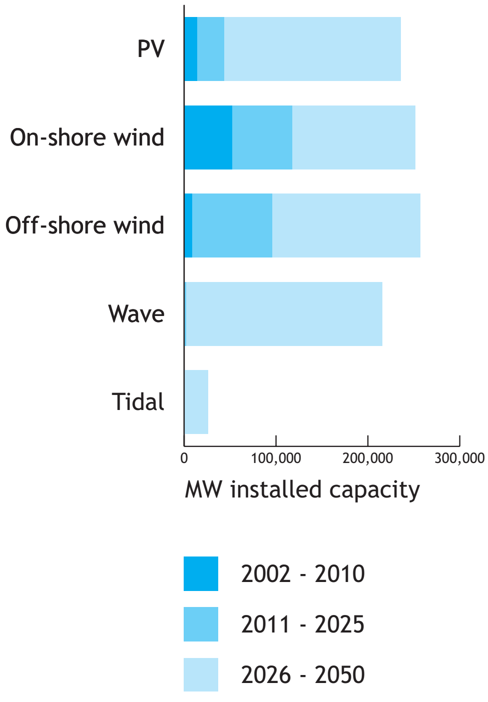
Solar PV is assumed to have a slower initial take-up than the more cost competitive wind technologies. The three largest markets today, Japan, Germany and the US, all offer heavy support through regulation and incentives. Whilst sales into off-grid applications will increase, particularly in developing countries, the trigger to solar PV taking off at scale would be unsubsidised cost competitiveness with retail electricity prices in major markets. Future generations of solar PV technology should have significantly increased conversion efficiencies and offer this prospect in the medium term.

On-shore wind is close to being cost competitive today and is likely to be a major contributor to the build up of renewable power capacity over the next ten years. The main barriers to its deployment are grid-connection and public acceptability. Grid-connection, gaining local access at reasonable cost to transmission and distribution networks, is an issue shared with other renewable technologies where power is generated away from the point of use and can be addressed by regulation or incentives. Public acceptability is an issue more specific to on-shore wind and less easy to address. Opinions regarding the visual intrusion of wind farms vary widely but local influence on planning decisions gives opponents of on-shore wind farms a strong voice. This, more than cost or operational issues, may ultimately constrain the growth of on-shore wind.

Off-shore wind is expected to develop more slowly than on-shore wind but much faster than solar PV and early stage technologies including wave and tidal stream. Unlike solar PV and on-shore wind, which rely to some extent on community engagement, off-shore wind can be developed as a purely industrial activity with fewer planning constraints. Support regimes in a number of countries, including Germany and the UK, will be needed to build both scale and experience and bring down costs, with the prospect of off-shore wind being cost-competitive in the medium term.

Given the relatively early stage of development of wave and tidal stream technologies, the deployment of both is expected to lag behind that of solar PV and wind. The significant wave and tidal stream resource potential will ensure that, if one or more of these technologies proves to be cost competitive, there should be significant take up at scale.

A view of global renewable electricity market in 2050



Note: *Estimates for global capacity installations from IEA, BTM, WEC, DTI estimates.*

Source: *IEA (2000), BTM Consult (2003), Gross, Leach and Bauen (2002), WEC (2000), Carbon Trust analysis*

Where could the UK be globally competitive?

UK renewable power to 2050

The UK renewables market is likely to reflect domestic resource, local cost effectiveness and momentum in the key markets. It is unlikely, therefore, to mirror the global market, as shown in the chart on page 12.

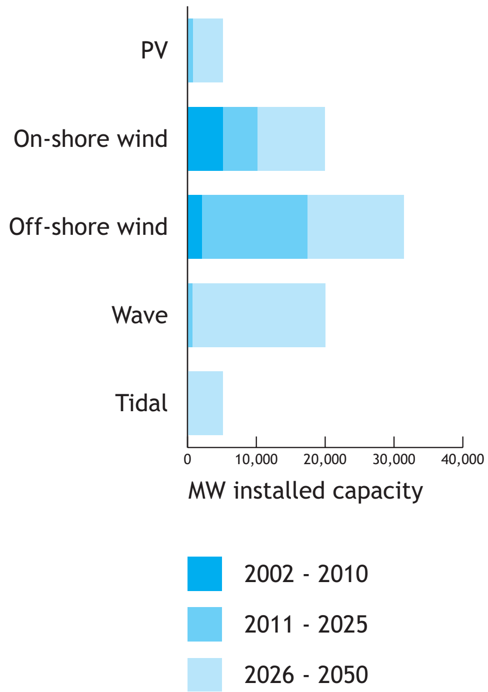
Without massive subsidy, the development of solar PV in the UK will be constrained by available natural resource and cost. In terms of solar insolation, the UK compares badly with more tropical climes, both in terms of average insolation and its availability through the year to meet demand. This increases the installed capacity required to meet a given level of demand and, coupled with the high cost of solar PV, drives development in more limited building integrated or off-grid applications where other elements of value are considered.

The UK has one of the largest on-shore wind resources in Europe and, given its cost competitiveness and the Renewables Obligation support regime, on-shore wind development is rapidly scaling up. Site availability and public concern over visual intrusion may ultimately curb the growth of on-shore wind in the UK but installed capacity of 20GW is seen as realistic by 2050.

The UK has the largest off-shore wind resource in Europe. If a number of issues relating to the stability of the UK incentive regime, grid connection and consents can be addressed, the UK could also establish the most significant market for off-shore wind in Europe with over 30GW of installed capacity by 2050.

Estimates suggest that the UK also has the greatest potential resource for wave and tidal stream power generation in addition to a large number of UK-based technologies under development. With competitive costs, wave and tidal stream technologies could add another 10-20GW of installed capacity by 2050.

A view of UK renewable electricity market in 2050



2 What is the competitive position of UK plc?

Solar PV

In solar PV, module manufacturing costs represent about two thirds of the total system cost, the balance being made up of a mounting structure, an inverter and labour to install the system. As the unit cost of modules is heavily dependent on the scale of the manufacturing plant, the industry is concentrated and starting to consolidate – the top five manufacturers have a market share of about 65% and the top ten about 85%, dominated by Japanese, US and German companies.

Given this context and UK plc's very weak competitive position (we exclude BP and Shell's overseas operations) it is unlikely that UK plc could establish a local manufacturing base for PV modules, although inward investment by an existing manufacturer might be possible. The potential for UK plc would appear to be in marketing, installing and operating solar PV systems in building integrated and off-grid applications, building a market share by value for UK plc of maybe 15-20% in the UK and 1-3% globally.

Note: Estimates for UK capacity installations from IEA, BTM, WEC, DTI estimates.

Source: IEA (2000), BTM Consult (2003), Gross (2002), WEC (2000), Carbon Trust analysis

Where could the UK be globally competitive?

Where significant potential still exists for UK plc is in supporting the development of the next but one generation of PV technology, sometimes referred to as 3rd generation PV, such as "solar polymers" for buildings. In this area, basic research and development is already being undertaken in a number of countries, including Japan. Given the UK's relative strength in University-based research and development, it could develop and enhance current research programmes, aiming to position UK plc as a future leader in this area.

On-shore wind

In on-shore wind, suppliers of gearboxes, generators, control systems and other components and the manufacture of wind turbines themselves account for between half and two thirds of the system cost, the balance being made up of installation and operating costs. As in solar PV, the industry is already concentrated with over 80% market share held by Danish and German wind turbine manufacturers.

There are no major UK-based manufacturers and relatively high barriers to entry. A strong global network is required to cover a growing international market, financial capacity is needed to deal with the growing size of orders and critical mass is needed to achieve economies of scale.

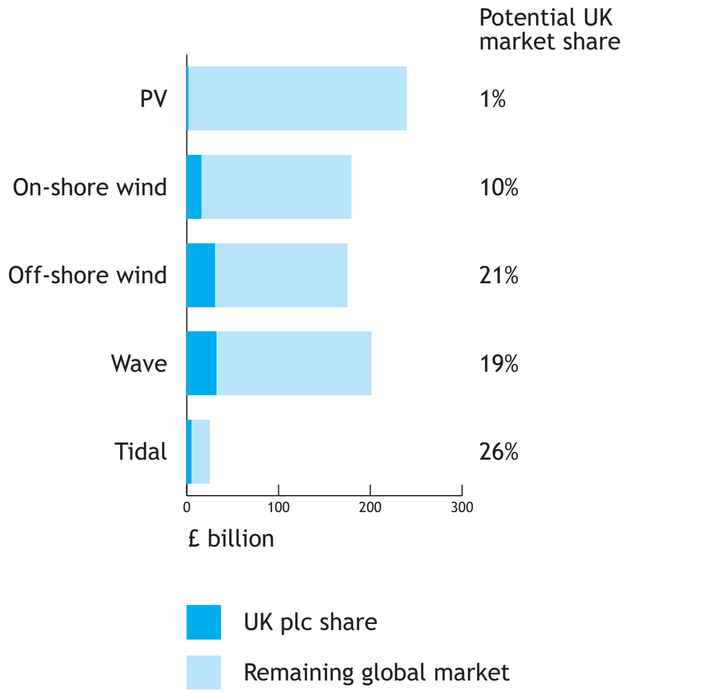
UK plc could still build a significant domestic industry by encouraging foreign manufacturers to build manufacturing and assembly plants in the UK, as is starting to happen, and by taking a major share, maybe up to two thirds, of the installation, operations and maintenance activities. These service markets and specialised component manufacture could provide some potential for export but the global market share for UK plc is unlikely to exceed 10%.

Off-shore wind

In off-shore wind, the turbines account for a smaller proportion of the total system cost than in on-shore wind. There are significant off-shore engineering activities related to the installation and anchoring of the turbines, cabling and power management and ongoing operations and maintenance.

Beyond turbine manufacture, the industry is in its very early stages of development and very fragmented. About half the schemes currently being developed are in the UK or Germany and few companies have established clear leadership positions. UK plc has experience in design, installation and operations in off-shore environments and could convert its oil and gas experience to create a globally-competitive position in off-shore wind.

Indicative value of renewable electricity markets in 2050 and UK plc's potential market share



If the UK invests aggressively now in developing off-shore wind capacity, UK plc could secure positions across much of the value chain and aim to achieve a market share of 80% by value. By establishing strong positions in one of the World's leading markets for off-shore wind development, UK companies would be well positioned for export growth in areas including the provision of installation and maintenance vessels and off-shore operations and maintenance services overseas.

Wave and tidal stream

It is too early to talk about a value chain for wave and tidal stream technologies. A number of devices and approaches are under development and a majority of these, though by no means all, are UK based.

Unlike solar PV and on-shore wind, where foreign companies dominate high value elements of an established supply chain, UK plc has the opportunity and potential to create competitive positions in all areas of design, manufacture, installation and operation.

If the cost of wave or tidal stream power generation becomes competitive at scale, the sector has great potential to create value for UK plc with estimates of market share as high as 90% for the UK market and 20% globally by value.

Note: *Based on undiscounted cumulated installed capex and opex revenues, taking into account IEA and PIU experience cost curve predictions. Estimates of UK share are from Carbon Trust workshops with industry experts.*

Source: *IEA (2000), BTM Consult (2003), Gross (2002), WEC (2000), Carbon Trust analysis*

Differentiated investment strategies

There is no single market for renewable energy. The renewable technologies discussed in this report have very different cost structures and are at different stages of development. Of the technologies that we have considered, some are commercial in niche markets, others are close to being commercial in mainstream markets, but most are still some way from being cost competitive with fossil fuel power generation. For investors, this translates into very different levels of investment risk reflecting the uncertainties related to both technical development and ongoing public support through regulation and incentives.

Opportunities for UK plc vary significantly between technologies. The UK has exceptional natural resources for wind, wave and tidal stream development. It has arguably "missed the boat" in conventional solar PV and wind turbine manufacture but Government targets and incentives are building momentum in off-shore wind where UK plc capacity in off-shore engineering and operations could be leveraged.

If economic development is the objective, public support should be targeted at technologies where the UK has competitive strengths. It would be inefficient for scarce public resource to provide support for the development of every low carbon technology, particularly where other countries have a significant advantage in terms of natural or human resource or progress already made. If, in addition, there is significant technical uncertainty and the UK has the potential to become a leading player, there is value in investing to build options for the future. This is particularly true for early-stage technologies, for example, wave and tidal stream power and third generation PV.

Like private investors, public interest organisations like the Carbon Trust need to invest carefully, making funding available in support of specific objectives. In our case, we seek to reduce carbon dioxide emissions in the UK and support the development of a UK-based low carbon industry sector. We therefore need to estimate the potential environmental and economic development benefits of each technology as the basis for our support. To pursue our objectives cost effectively will require us to prioritise between technologies and follow differentiated investment strategies.

Solar PV

Given the limited potential for UK plc in solar PV, we assess our support largely in terms of the environmental benefits that it offers. We believe that these will be primarily in building integrated applications.

We are also working with EPSRC through our Carbon Vision joint venture looking to support UK research into 3rd generation PV.

On-shore wind

We assess our support in terms of the potential for UK plc to develop local assembly, installation and operations businesses, the environmental benefits of wind and the materiality of our funding. Given the scale and maturity of on-shore development and, in particular, the materiality of our funding, it is unlikely that we will invest directly in technology development.

We will continue to focus our support in this area on project work that addresses barriers to deployment, including how to make private sector finance available at scale and ensuring that issues relating to grid connection are fully understood. We commissioned and published an independent study for the Renewables Advisory Board on investor perceptions of the UK renewable energy market and related financial incentives.

Off-shore wind

Of the technologies considered, off-shore wind offers the greatest economic development potential for UK plc. To capture this potential, the UK policy framework must attract private investment at scale to support the rapid development of the sector.

As with on-shore wind, given the materiality of our funding, we will focus our support on project work that addresses key barriers to deployment and early stage developments.

Wave and tidal stream

We assess our support in terms of the significant economic potential for UK plc in the medium term and the longer-term environmental benefits. In order to attract development capital and accelerate commercialisation, the sector must establish whether emerging technologies can become cost competitive without subsidy and are durable in service.

Given the scale of funding required at this stage of development, Carbon Trust funding can be material and we have put in place dedicated resource to develop and take forward our support for these technologies through direct investment in companies developing wave and tidal stream technologies, a programme of engineering support for the sector, research and development through Carbon Vision and funding for the European Marine Energy Centre in Orkney.

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Making business sense of climate change