16 Accelerating Technological Innovation

Key Messages

Effective action on the scale required to tackle climate change requires a widespread shift to new or improved technology in key sectors such as power generation, transport and energy use. Technological progress can also help reduce emissions from agriculture and other sources and improve adaptation capacity.

The private sector plays the major role in R&D and technology diffusion. But closer collaboration between government and industry will further stimulate the development of a broad portfolio of low carbon technologies and reduce costs. Co-operation can also help overcome longer-term problems, such as the need for energy storage systems, for both stationary applications and transport, to enable the market shares of low-carbon supply technologies to be increased substantially.

Carbon pricing alone will not be sufficient to reduce emissions on the scale and pace required as:

- Future pricing policies of governments and international agreements should be made as credible as possible but cannot be 100% credible.
- The uncertainties and risks both of climate change, and the development and deployment of the technologies to address it, are of such scale and urgency that the economics of risk points to policies to support the development and use of a portfolio of low-carbon technology options.
- The positive externalities of efforts to develop them will be appreciable, and the time periods and uncertainties are such that there can be major difficulties in financing through capital markets.

Governments can help foster change in industry and the research community through a range of instruments:

- **Carbon pricing**, through carbon taxes, tradable carbon permits, carbon contracts and/or implicitly through regulation will itself directly support the research for new ways to reduce emissions;
- **Raising the level of support for R&D** and demonstration projects, both in public research institutions and the private sector;
- **Support for early stage commercialisation investments in some sectors.**

Such policies should be complemented by tackling institutional and other non-market barriers to the deployment of new technologies.

These issues will vary across sectors with some, such as electricity generation and transport, requiring more attention than others.

Governments are already using a combination of market-based incentives, regulations and standards to develop new technologies. These efforts should increase in the coming decades.

Our modelling suggests that, in addition to a carbon price, **deployment incentives for low-emission technologies should increase two to five times globally** from current levels of around $33billion.

Global public energy R&D funding should double, to around $20 billion, for the development of a diverse portfolio of technologies.

16.1 Introduction

Stabilisation of greenhouse gases in the atmosphere will require the deployment of low-carbon and high-efficiency technologies on a large scale. A range of technologies is already available, but most have higher costs than existing fossil-fuel-based options. Others are yet to be developed. Bringing forward a range of technologies that are competitive enough, with a carbon price, for firms to adopt is an urgent priority.

In the absence of any other market failures, introducing a fully credible carbon price path for applying over the whole time horizon relevant for investment would theoretically be enough to encourage suitable technologies to develop. Profit-maximising firms would respond to the creation of the path of carbon prices by adjusting their research and development efforts in order to reap returns in the future. This chapter sets out why this is unlikely to be sufficient in practice, why other supporting measures will be required, and what form they could take.

This chapter starts by examining the process of innovation and how it relates to the challenge of climate change mitigation, exploring how market failures may lead to innovation being under-delivered in the economy as a whole. Section 16.3 looks more closely at the drivers for technology development in key sectors related to climate change. It finds that clean energy technologies face particularly strong barriers – which, combined with the urgency of the challenge, supports the case for governments to set a strong technology policy framework that drives action by the private sector.

Section 16.4 outlines the policy framework required to encourage climate related technologies. Section 16.5 discusses one element of this framework – policies to encourage research, development and demonstration. Such policies are often funded directly by government, but it is critical that they leverage in private sector expertise and funding.

Investment in Research and Development (R&D) should be complemented by policies to create markets and drive deployment, which is discussed in Section 16.6. A wide range of policies already exist in this area; this section draws together evidence on what works best in delivering a response from business.

A range of complementary policies, including patenting, regulatory measures and network issues are also important; these issues are examined in Section 16.7. Regulation is discussed in the context of mitigation more generally, and in particular in relation to energy efficiency in Chapter 17.

Overall, an ambitious and sustained increase in the global scale of effort on technology development is required if technologies are to be delivered within the timescales required. The decline in global public and private sector R&D spending should be reversed. And deployment incentives will have to increase two to five-fold worldwide in order to support the scale of uptake required to drive cost reductions in technologies and, with the carbon price, make them competitive with existing fossil fuel options. In Chapter 24, we return to the issue of technological development, considering what forms of international co-operation can help to reduce the costs and accelerate the process of innovation.

16.2 The innovation process

Innovation is crucial in reducing costs of technologies. A better understanding of this complex process is required to work out what policies may be required to encourage firms to deliver the low-emission technologies of the future.

Defining innovation

Innovation is the successful exploitation of new ideas[1]. Freeman identified four types of innovation in relation to technological change[2]:

- Incremental innovations represent the continuous improvements of existing products through improved quality, design and performance, as has occurred with car engines;
- Radical innovations are new inventions that lead to a significant departure from previous production methods, such as hybrid cars;
- Changes in the technological systems occur at the system level when a cluster of radical innovations impact on several branches of the economy, as would take place in a shift to a low-emission economy;
- Changes of techno-economic paradigm occur when technology change impacts on every other branch of the economy, the internet is an example.

[1] DTI (2003)
[2] Freeman (1992)

Many of the incentives and barriers to progress for these different types of technological change are very different from each other.

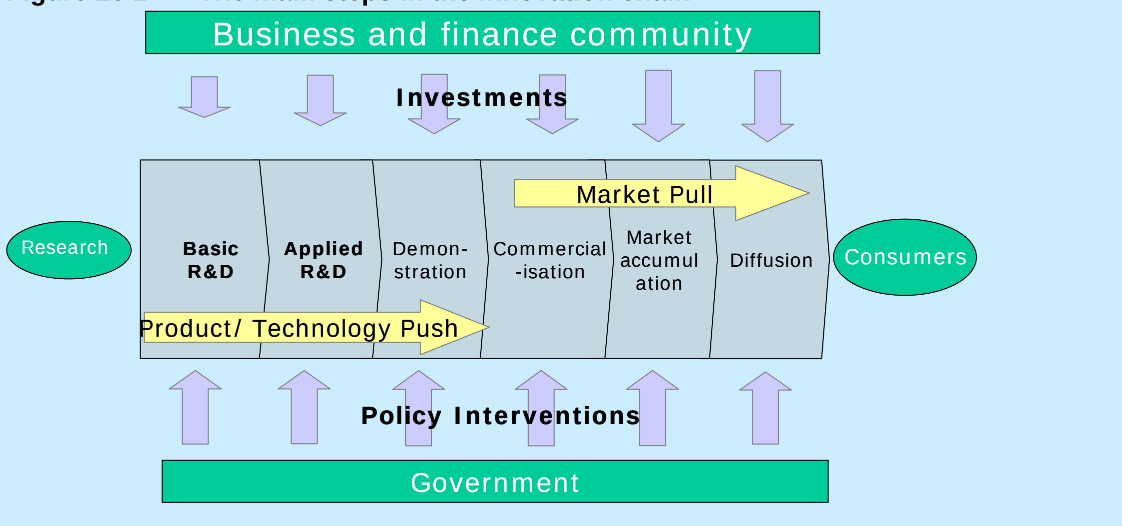
Innovation is about much more than invention: it is a process over time

Joseph Schumpeter identified three stages of the innovation process: invention as the first practical demonstration of an idea; innovation as the first commercial application; and diffusion as the spreading of the technology or process throughout the market. The traditional representation of the diffusion process is by an S-shaped curve, in which the take-up of the new technology begins slowly, then 'takes off' and achieves a period of rapid diffusion, before gradually slowing down as saturation levels are reached. He proposed the idea of 'creative destruction' to describe the process of replacement of old firms and old products by innovative new firms and products.

There is an opportunity for significant profits for firms as the new product takes off and this drives investment in the earlier stages. High profits, coupled with the risk of being left behind, can drive several other firms to invest through a competitive process of keeping up. As incumbent firms have an incentive to innovate in order to gain a competitive advantage, and recognising that innovation is typically a cumulative process that builds on existing progress, market competition can stimulate innovation[3]. As competition increases, and more firms move closer to the existing technological frontier of incumbents, the expected future profits of the incumbents are diminished unless they innovate further. Such models imply a hump-shaped relationship between the degree of product market competition and innovation, as originally suggested by Schumpeter.

An expanded version of this 'stages' model of innovation that broadens the invention stage into basic R&D, applied R&D and demonstration is shown in the subsequent figure. In this chapter the term R&D will be used but this will also cover the demonstration stage[4]. The commercialisation and market accumulation phases represent early deployment in the market place, where high initial cost or other factors may mean quite low levels of uptake.

Figure 16.1 The main steps in the innovation chain[5]



This model is useful for characterising stages of development, but it fails to capture many complexities of the innovation process, so it should be recognised as a useful simplification. A more detailed characterisation of innovation in each market can be applied to particular markets using a systems approach[6]. The transition between the stages is not automatic; many products fail at each stage of development. There are also further linkages between

[3] Aghion et al (2002): Monopolists do not have competitive pressures to innovate while intense competition means firms may lack the resource or extra profit for the innovator may be competed away too quickly to be worthwhile.
[4] R,D&D (Research, Development and Demonstration) can be used for this but it can lead to confusion over the final D as some of the literature uses deployment or diffusion in the same acronym.
[5] Grubb (2004)
[6] For an excellent overview of innovation theory see Foxon (2003)

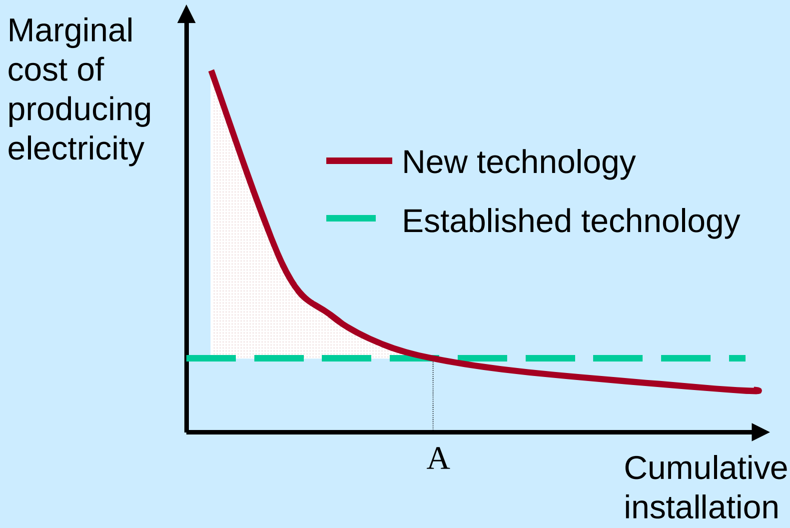
stages, with further progress in basic and applied R&D affecting products already in the market and learning also having an impact on R&D.

Experience curves can lead to lock-in to existing technologies

As outlined in Section 9.7 dynamic increasing returns, such as economies of scale and learning effects, can arise during production and lead to costs falling as production increases. These vary by sector with some, such as pharmaceuticals, experiencing minimal cost reductions while others fall by several orders of magnitude. These benefits lead to experience curves as shown in Box 9.4.

Experience curves illustrate that new technologies may not become cost effective until significant investment has been made and experience developed. Significant learning effects may reduce the incentive to invest in innovation, if companies wait until the innovator has already proven a market for a new cost effective technology. This is an industry version of a collective action problem with its associated free-rider issues.

Figure 16.2 Illustrative experience curve for a new technology



Dynamic increasing returns can also lead to path dependency and 'lock-in' of established technologies. In this diagram, the market dominant technology (turquoise line) has already been through a process of learning. The red line represents a new technology, which has the potential to compete. As production increases the cost of the new technology falls because of dynamic increasing returns, shown by the red line above. In this case, the price of the new technology does ultimately fall below the level of the dominant technology. Some technological progress can also be expected for incumbent dominant technologies but existing deployment will have realised much of the learning[7].

The learning cost of the new technology is how much more the new technology costs than the existing technology; shown by the dotted area where the red line is above the blue. During this period, the incumbent technology remains cheaper, and the company either has to sell at a loss, or find consumers willing to pay a premium price for its new product. So, for products such as new consumer electronics, niche markets of "early adopters" exist. These consumers are willing to pay the higher price as they place a high value on the function or image of the product.

The learning cost must be borne upfront; the benefits are uncertain, because of uncertainty about future product prices and technological development, and come only after point A when, in this case, the technology becomes cheaper than the old alternative. If, as is the case in some sectors, the time before the technology becomes competitive might span decades and the learning costs are high, private sector firms and capital markets may be unwilling to

[7] The learning rate is the cost reduction for a doubling of production and this requires much more deployment after significant levels of investment.

take the risk and the technology will not be developed, especially if there is a potential free-rider problem.

Innovation produces benefits above and beyond those enjoyed by the individual firm ('knowledge spillovers'); this means that it will be undersupplied

Information is a public good. Once new information has been created, it is virtually costless to pass on. This means that an individual company may be unable to capture the full economic benefit of its investment in innovation. These knowledge externalities (or spillovers) from technological development will tend to limit innovation.

There are two types of policy response to spillovers. The first is the enforcement of private property rights through patenting and other forms of protection for the innovator. This is likely to be more useful for individual products than for breakthroughs in processes or know-how, or in basic science. The disadvantage of rigid patent protection is that it may slow the process of innovation, by preventing competing firms from building on each others' progress. Designing intellectual property systems becomes especially difficult in fields where the research process is cumulative, as in information technology[8]. Innovation often builds on a number of existing ideas. Strong protection for the innovators of first generation products can easily be counterproductive if it limits access to necessary knowledge or research tools for follow-on innovators, or allows patenting to be used as a strategic barrier to potential competitors. Transaction costs, the equity implications of giving firms monopoly rights (and profits) and further barriers such as regulation may prevent the use of property rights as the sole incentive to innovate. Also much of value may be in tacit knowledge ('know-how' and 'gardeners' craft') rather than patentable ideas and techniques.

Another broad category of support is direct government funding of innovation, particularly at the level of basic science. This can take many forms, such as funding university research, tax breaks and ensuring a supply of trained scientists.

Significant cross-border spillovers and a globalised market for most technologies offer an incentive for countries to free-ride on others who incur the learning cost and then simply import the technology at a later date[9]. The basic scientific and technical knowledge created by a public R&D programme in one country can spillover to other countries with the capacity to utilise this progress. While some of the leaning by doing will be captured in local skills and within local firms, this may not be enough to justify the learning costs incurred nationally.

International patent arrangements, such as the Trade Related International Property Rights agreement (TRIPs[10]), provides some protection, but intellectual property rights can be hard to enforce internationally. Knowledge is cheap to copy if not embodied in human capital, physical capital or networks, so R&D spillovers are potentially large. A country that introduces a deployment support mechanism and successfully reduces the cost of that technology also delivers benefits to other countries. Intellectual property right issues are discussed in more detail in Section 23.4.

International co-operation can also help to address this by supporting formal or informal reciprocity between RD&D programmes. This is explored in Chapter 24.

Where there are long-term social returns from innovation, it may also be undersupplied

Government intervention is justified when there is a departure between social and private cost, for example, when private firms do not consider an environmental externality in their investment decisions, or when the benefits are very long-term (as with climate change mitigation) and outside the planning horizons of private investments. Private firms focus on private costs and benefits and private discount rates to satisfy their shareholders. But this can lead to a greater emphasis on short-term profit and reduce the emphasis on innovations and other low-carbon investments that would lead to long-term environmental improvements.

[8] Scotchmer (1991)
[9] Barreto and Klaassen (2004)
[10] The agreement on Trade Related Intellectual Property Rights (TRIPs) is an international treaty administered by the World Trade Organization which sets down minimum standards for most forms of intellectual property regulation within all WTO member countries.

16.3 Innovation for low-emission technologies

The factors described above are common to innovation in any sector of the economy. The key question is whether there are reasons to expect the barriers to innovation in low-emission technologies to be higher than other sectors, justifying more active policies. This section discusses factors specific to environmental innovation and in particular two key climate change sectors – power generation and transport.

Lack of certainty over the future pricing of the carbon externality will reduce the incentive to innovate

Environmental innovation can be defined[11] as innovation that occurs in environmental technologies or processes that either control pollutant emissions or alter the production processes to reduce or prevent emissions. These technologies are distinguished by their vital role in maintaining the 'public good' of a clean environment. Failure to take account of an environmental externality ensures that there will be under-provision or slower innovation[12].

In the case of climate change, a robust expectation of a carbon price in the long term is required to encourage investments in developing low-carbon technologies. As the preceding two chapters have discussed, carbon pricing is only in its infancy, and even where implemented, uncertainties remain over the durability of the signal over the long term. The next chapter outlines instances in which regulation may be an appropriate response to lack of certainty. This means there will tend to be under-investment in low-carbon technologies. The urgency of the problem (as outlined in Chapter 13) means that technology development may not be able to wait for robust global carbon pricing. Without appropriate incentives private firms and capital markets are less likely to invest in developing low-emission technologies.

There are additional market failures and barriers to innovation in the power generation sector

Innovation in the power generation sector is key to decarbonising the global economy. As shown in Chapter 10, the power sector will need to be at least 60% decarbonised by 2050[13] to keep on track for greenhouse gas stabilisation trajectories at or below 550ppm CO_2e.

For reasons that this section will explore the sector is characterised by low levels of research and development expenditure by firms. In the USA, the R&D intensity (R&D as a share of total turnover) of the power sector was 0.5% compared to 3.3% in the car industry, 8% in the electronics industry and 15% in the pharmaceutical sector[14]. OECD figures for 2002 found an R&D intensity of 0.33% compared to 2.65% for the overall manufacturing sector[15]. Unlike in many other sectors, public R&D represents a significant proportion, around two thirds of the total R&D investment[16].

The available data[17] on energy R&D expenditure show a downward trend in both the public and private sector, despite the increased prominence of energy security and climate change. Public support for energy R&D has declined despite a rising trend in total public R&D. In the early 1980s, energy R&D budgets were, in real terms, twice as high as now, largely in response to the oil crises of the 1970s.

[11] Taylor, Rubin and Nemet (2006)
[12] Anderson et al (2001); Jaffe, Newell and Stavins (2004) and (2003)
[13] This is consistent with the ACT scenarios p86 IEA, 2006 which would also require eliminating land use change emissions to put us on a path to stabilising at 550ppm CO_2e
[14] Alic, Mowery and Rubin (2003)
[15] Page 35: OECD, (2006)
[16] There are doubts as to the accuracy of the data and the IEA's general view is that private energy R&D is considerably higher than public energy R&D (though this still represents a significant share).
[17] Page 33-37: OECD (2006)

Figure 16.3 Public energy R&D investments as a share of GDP[18]

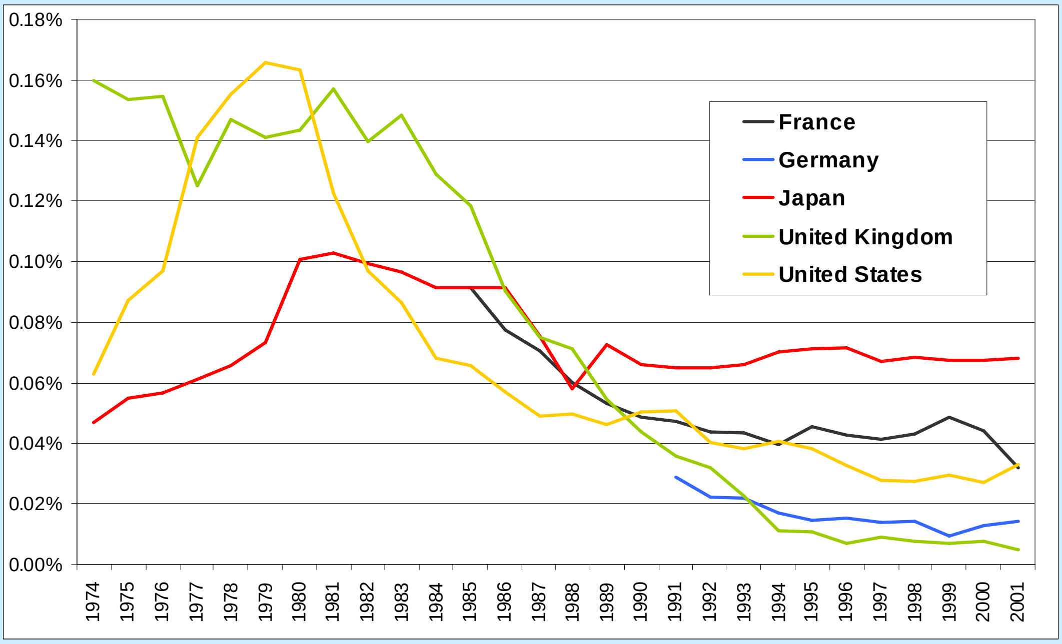
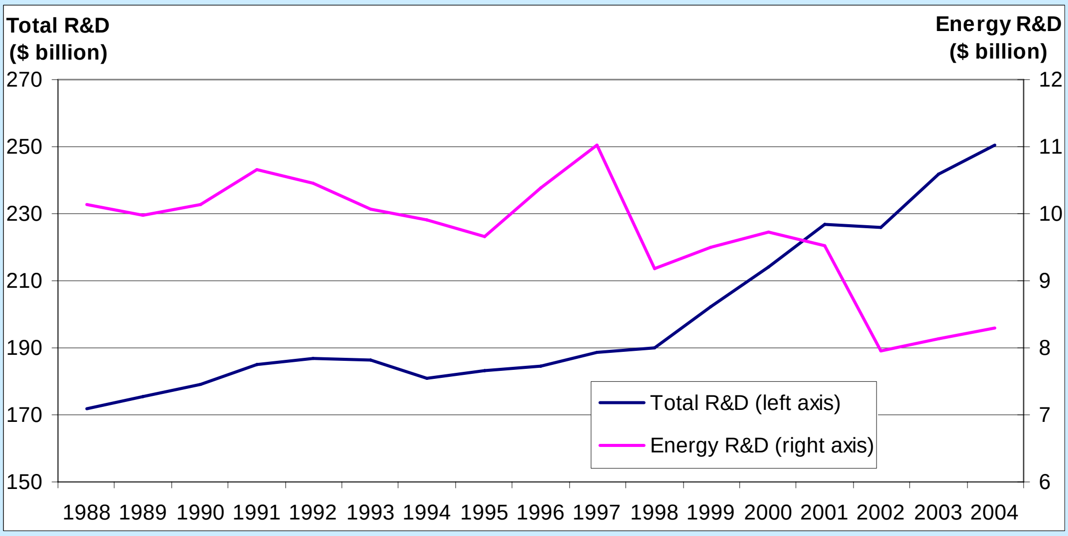


Figure 16.4 Public R&D and public energy R&D investments[19]

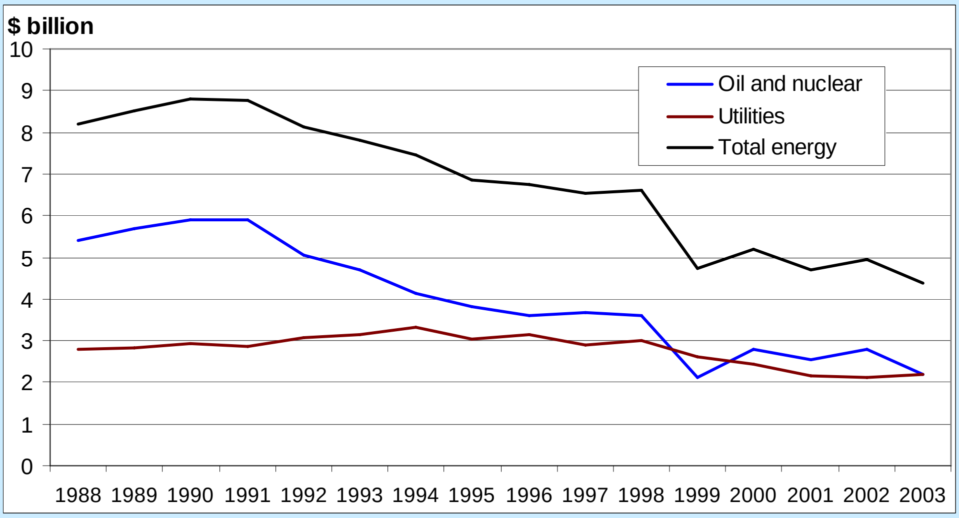


Private energy R&D has followed a similar trend and remains below the level of public R&D. The declines in public and private R&D have been attributed to three factors. *First*, energy R&D budgets had been expanded greatly in the 1970s in response to the oil price shocks in the period , and there was a search for alternatives to imported oil. With the oil price collapse in the 1980s and the generally low energy prices in the 1990s, concerns about energy security diminished, and were mirrored in a relaxation of the R&D effort. Recent rises in oil prices have not, yet, led to a significant increase in energy R&D. *Second*, following the liberalisation of energy markets in the 1990s, competitive forces shifted the focus from long-term investments such as R&D towards the utilisation of existing plant and deploying well-developed technologies and resources - particularly of natural gas for power and heat, themselves the product of R&D and investment over the previous three decades. *Third*, there

[18] Source: IEA R&D database http://www.iea.org/Textbase/stats/rd.asp Categories covered broken down in IEA total Figure 16.8
[19] OECD countries Page 32: OECD (2006*)*

were huge declines in R&D expenditures on nuclear power following the experiences of many countries with cost over-runs, construction delays, and the growth of public concerns about reactor safety, nuclear proliferation and nuclear waste disposal. In 1974, electricity from nuclear fission and fusion accounted for 79% of the public energy R&D budget; it still accounts for 40%. Apart from nuclear technologies, energy R&D budgets decreased across the board (Figure 16.8).

Figure 16.5 Trends in private sector energy R&D[20]



The sector's characteristics explain the low levels of R&D

There are a number of ways to interpret these statistics, but they suggest that private returns to R&D are relatively low in the sector. There are four distinct factors which help explain this.

The first factor is the nature of the learning process. Evidence from historical development of energy-related technologies shows that the learning process is particularly important for new power generation technologies, and that it typically takes several decades before they become commercially viable. Box 9.4 shows historical learning curves for energy technologies.

If early-stage technologies could be sold at a high price, companies could recover this learning cost. In some markets, such as IT, there are a significant number of 'early adopters' willing to pay a high price for a new product. These 'niche markets' allow innovating companies to sell new and higher-cost products at an early profit. Later, when economies of scale and learning bring down the cost, the product can be sold to the mass market. Mobile phones are a classic example. The earliest phones cost significantly more but there were people willing to pay this price.

In the absence of niche markets the innovating firm is forced to pay the learning cost, as a new product can be sold only at a price that is competitive with the incumbent. This may mean that firms would initially have to sell their new product at a loss, in the hope that as they scale up, costs will reduce and they can make a profit. If this loss-making period lasts too long, the firm will not survive.

In the power sector, niche markets are very limited in the absence of government policy, because of the homogeneous nature of the end-product (electricity). Only a very small number of consumers have proved willing to pay extra for carbon-free electricity. As cost reductions typically take several decades this leaves a significant financing gap which capital markets are unable to fill. Compounding this, the power generation sector also operates in a highly regulated environment and tends to be risk averse and wary of taking on technologies that may prove costlier or less reliable. Together, these factors mean that energy generation

[20] Source Page 35 OECD (2006); For US evidence see Kammen and Nemet (2005)

technologies can fall into a 'valley of death', where despite a concept being shown to work and have long-term profit potential they fail to find a market.

For energy technologies, R&D is only the beginning of the story. There is continual feedback between learning from experience in the market, and further R&D activity. There is a dependence on tacit knowledge and a series of incremental innovations in which spillovers play an important role and reduce the potential benefits of intellectual property rights. This is in strong contrast with the pharmaceutical sector. For a new drug, the major expense is R&D. Once a drug has been invented and proven, comparatively little further research is required and limited economies of scale and learning effects can be expected.

The second factor is infrastructure. National grids are usually tailored towards the operation of centralised power plants and thus favour their performance. Technologies that do not easily fit into these networks may struggle to enter the market, even if the technology itself is commercially viable. This applies to distributed generation as most grids are not suited to receive electricity from many small sources. Large-scale renewables may also encounter problems if they are sited in areas far from existing grids. Carbon capture and storage also faces a network issue, though a different one; the transport of large quantities of CO_2, which will require major new pipeline infrastructures, with significant costs.

The third factor is the presence of significant existing market distortions. In a liberalised energy market, investors, operators and consumers should face the full cost of their decisions. But this is not the case in many economies or energy sectors. Many policies distort the market in favour of existing fossil fuel technologies[21], despite the greenhouse gas and other externalities. Direct and indirect subsidies are the most obvious. As discussed in Section 12.5 the estimated subsidy for fossil fuels is between $20-30 billion for OECD countries in 2002 and $150-250 billion per year globally[22]. The IEA estimate that world energy subsidies were $250 billion in 2005 of which subsidies to oil products amounted to $90 billion[23]. Such subsidies compound any failure to internalise the environmental externality of greenhouse gases, and affect the incentive to innovate by reducing the expectations of innovators that their products will be able to compete with existing choices.

Finally, the nature of competition within the market may not be conducive to innovation. A limited number of firms, sometimes only one, generally dominate electricity markets, while electricity distribution is a 'natural' monopoly. Both factors will generally lead to low levels of competition, which, as outlined in Section 16.1, will generally lead to less innovation as there is less pressure to stay ahead of competitors. The market is also usually regulated by the government, which reduces the incentive to invest in innovation if there is a risk that the regulator may prevent firms from reaping the full benefits of successful innovative investments.

These barriers will also affect the deployment of existing technologies

The nature of competition, existing infrastructure and existing distortions affect not only the process of developing new technologies; these sector-specific factors can also reduce the effectiveness of policies to internalise the carbon externality. They inhibit the power of the market to encourage a shift to low-carbon technologies, even when they are already cost-effective and especially if they are not. The generation sector usually favours more traditional (high-carbon) energy systems because of human, technical and institutional capacity. Historically driven by economies of scale, the electricity system becomes easily locked into a technological trajectory that demonstrates momentum and is thereby resistant to the technical change that will be necessary in a shift to a low-carbon economy[24].

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[21] Neuhoff (2005).
[22] Source: REN21 (2005) which cites; UNEP & IEA. (2002). Reforming Energy Subsidies. Paris. www.uneptie.org/energy/publications/pdfs/En-SubsidiesReform.pdf Also Johansson, T. & Turkenburg, W. state in (2004). Policies for renewable energy in the European Union and its member states: an overview. *Energy for Sustainable Development* 8(1): 5-24.that "at present, subsidies to conventional energy are on the order of $250 billion per year" and $244 billion per annum between 1995 and 1998 (34% OECD) in Pershing, J. and Mackenzie (2004) Removing Subsidies.Leveling the Playing Field for Renewable Energy Technologies. Thematic Background Paper. International Conference for Renewable Energies, Bonn (2004)
[23] WEO, (in press)
[24] Amin (2000)

Despite advances in the transport sector, radical change may not be delivered by the markets

Transport currently represents 14% of global emissions, and has been the fastest growing source of emissions because of continued growth of car transport and rapid expansion of air transport. Innovation has been dominated by incremental improvements to existing technologies, which depend on oil. These, however, have been more than offset by the growth in demand and shift towards more powerful and heavier vehicles. The increase in weight is partly due to increased size and partly to additional safety measures. The improvements in the internal combustion engine from a century of learning by doing, the efficiency of fossil fuel as an energy source and the existence of a petrol distribution network lead to some 'lock-in' to existing technologies. Behavioural inertia compounds this 'lock-in' as consumers are also accustomed to existing technologies.

Certain features of road transport suggest further innovative activity could be delivered through market forces. Although there is no explicit carbon price for road fuel, high and stable fuel taxes[25] in most developed countries provide an incentive for the development of more efficient vehicles. Niche markets also exist which help innovative products in transport markets to attract a premium. These factors together help to explain how hybrid vehicles have been developed and are now starting to penetrate markets, with only very limited government support: some consumers are content to pay a premium for what can be a cleaner and more fuel-efficient product. There is also a small number of large global firms in this sector, each of which have the resources to make significant innovation investments and progress. They can also be less concerned about international spillovers as they operate in several markets.

Incremental energy efficiency improvements are expected to continue in the transport sector. These will be stimulated both by fuel savings and, as they have been in the past, by government regulation. Both the hybrid car, and later, the fuel cell vehicle, are capable of doubling the fuel efficiency of road vehicles, whilst behavioural changes - perhaps encouraged, for example, by congestion pricing or intelligent infrastructure[26] - could lead to further improvements.

Markets alone, however, may struggle to deliver more radical changes to transport technologies such as plug-in hybrids or other electrical vehicles. Alternative fuels (such as biofuel blends beyond 5-10%, electricity or hydrogen) may require new networks, the cost of which is unlikely to be met without incentives provided by public policy. The environmental benefit of alternative transport fuels will depend on how they are produced. For example, the benefit of electric and hydrogen cars is limited if the electricity and hydrogen is produced from high emission sources. Obstacles to the commercial deployment of hydrogen cell vehicles, such as the cost of hydrogen vehicles and low-carbon hydrogen production, and the requirement to develop hydrogen storage further, ensure it is unlikely that such vehicles will be widely available commercially for at least another 15 to 20 years.

In Brazil policies to encourage biofuels over the past 30 years through regulation, duty incentives and production subsidies have led to biofuels now accounting for 13% of total road fuel consumption, compared with a 3% worldwide average in 2004. Other countries are now introducing policies to increase the level of biofuels in their fuel mix. Box 16.1 shows how some governments are already acting to create conditions for hydrogen technologies to be used. Making hydrogen fuel cell cars commercial is likely to require further breakthroughs in fundamental science, which may be too large to be delivered by a single company, and are likely to be subject to knowledge spillovers.

The development of alternative technologies in the road transport sector will be important for reducing emissions from other transport sectors such as the aviation, rail and maritime sectors. The local nature of bus usage allows the use of a centralised fuel source and this has led to early demonstration use of hydrogen in buses (see Box 16.1). In other sectors, such as aviation where weight and safety are prominent concerns, early commercial development is unlikely to take place and will be dependent on development in other areas first. The capital stock in the aviation, maritime and rail sectors (ships, planes and trains) lasts several times

[25] There are exceptions in the case of biofuels with many countries offering incentives through tax incentives.
[26] Intelligent infrastructure uses information to encourage efficient use of transport systems. http://www.foresight.gov.uk/Intelligent_Infrastructure_Systems/Index.htm

longer than road vehicles so this may result in a slower rate of take-up of alternative technologies. The emissions associated with rail transport can be reduced through decarbonising the fuel mix through biofuels or low carbon electricity generation. In the aviation sector improved air traffic management and reduced weight, through the use of alternative and advanced materials, can add to continued improvements in the efficiency of existing technologies.

Box 16.1 Hydrogen for transport

Hydrogen could potentially offer complete diversification away from oil and provide very low carbon transport. Hydrogen would be best suited to road vehicles. The main ways of producing hydrogen are by electrolysis of water, or by reforming hydrocarbons. Once produced, hydrogen can be stored as a liquid, a compressed gas, or chemically (bonded within the chemical structure of advanced materials). Hydrogen could release its energy content for use in powering road vehicles by combustion in a hydrogen internal combustion engine or a fuel cell. Fuel cells convert hydrogen and oxygen into water in a process that generates electricity. They are almost silent in operation, highly efficient, and produce only water as a by-product. Hydrogen can produce as little as 5% of the emissions of conventional fuel if produced by low-emission technologies.[27]

There are several hydrogen projects around the world including:

- Norway: plans for a 580km hydrogen corridor between Oslo and Stavanger in a joint project between the private sector, local government and non-government organisations. The first hydrogen station opened in August 2006
- Denmark and Sweden: interested in extending the Norwegian hydrogen corridor
- Iceland: home to the first hydrogen fuelling station in April 2003 and it is proposed that Iceland could be a hydrogen economy by 2030
- EU: trial of hydrogen buses
- China: hydrogen buses to be used at the Beijing Olympics in 2008
- California: plans to introduce hydrogen in 21 interstate highway filling stations

Innovation will also play a role by addressing emissions in other sectors, reducing demand and enabling adaptation to climate change.

Innovation has enabled energy efficiency savings, for example, through compact fluorescent and diode based lights and automated control systems. Furthermore, innovation is likely to continue to increase the potential for energy efficiency savings. Energy efficiency innovation has often been in the form of incremental improvements but there is also a role for more radical progress that may require support. Some markets (such as the cement industry in some developing countries including China and building refurbishment in most countries) are made up of small local firms not large multinationals, which are less likely to undertake research since their resources and potential rewards are smaller. In addition, R&D, for example, in building technologies and urban planning could have a profound impact on the emissions attributed to buildings and increase climate resilience. Chapter 17 discusses energy efficiency in more detail.

[27] E4tech, (2006)

Box 16.2 The scope for innovation to reduce emissions from agriculture

Research into fertilisers and crop varieties associated with lower GHG emissions could help fight climate change[28]. In some instances it may be possible to develop crops that both reduce emissions and have higher yields in a world with more climate change (see Box 26.3).

Another important research area in agriculture will be how to enhance carbon storage in soils, complementing the need to understand emissions from soils (see Section 25.4). The economic potential for enhanced storage is estimated at 1 GtCO2e in 2020, but the technical potential is much greater (see Section 9.6).

Research into sustainable farming practices (such as agroforestry) suitable to local conditions could lead to a reduction in GHG emissions and may also improve crop yields. It could reduce GHG emissions directly by reducing the need to use fertilisers, and indirectly by reducing the emissions from industry and transport sectors to produce the fertiliser[29].

Research into livestock feeds, breeds and feeding practices could also help reduce methane emissions from livestock.

In addition to using biomass energy (see Box 9.5), agriculture, and associated manufacturing industries, have the potential to displace fossil-based inputs for sectors such as chemicals, pharmaceuticals, manufacturing and buildings using a wide range of products made from renewable sources.

Direct emissions from industrial sectors such as cement, chemical and iron and steel can also benefit from further innovation, whether it is in these sectors or in other lower-carbon products that can be substitutes. Innovation in the agricultural sector, discussed in a mitigation context in Box 16.2 above, can also help improve the capacity to adapt to the impacts of climate change. New crop varieties can improve yield resilience to climate change[30]. The Consultative Group on International Agricultural Research (CGIAR) will have a role to play in responding to the climate challenge through innovation in the agricultural sector (see Box 24.4). The development and dissemination of other adaptation technologies is examined in Chapter 19.

16.4 Policy implications for climate change technologies

Policy should be aimed at bringing a portfolio of low-emission technology options to commercial viability

Innovation is, by its nature, unpredictable. Some technologies will succeed and others will fail. The uncertainty and risks inherent in developing low-emission technologies are ideally suited to a portfolio approach. Experience from other areas of investment decisions under uncertainty[31] clearly suggests that the most effective response to the uncertainty of returns is to develop a portfolio. While markets will tend to deliver the least-cost short-term option, it is possible they may ignore technologies that could ultimately deliver huge cost savings in the long term.

As Part III set out, a portfolio of technologies will also be needed to reduce emissions in key sectors, because of the constraints acting on individual technologies. These constraints and energy security issues mean that a portfolio will be required to achieve reductions at the scale required. There is an option value to developing alternatives as it enables greater and potentially less costly abatement in the future. The introduction of new options makes the marginal abatement cost curve (see Section 9.3) more elastic. Early development of economically viable alternatives also avoids the problem of 'locking in' high-carbon capital stock for decades, which would also increase future marginal abatement costs. Policies to encourage low-emission technologies can be seen as a hedge against the risk of high abatement costs.

[28] Norse (2006).
[29] Box 25.4 provides further examples of sustainable farming practices.
[30] IRRI (2006).
[31] Pindyck and Dixit (1994)

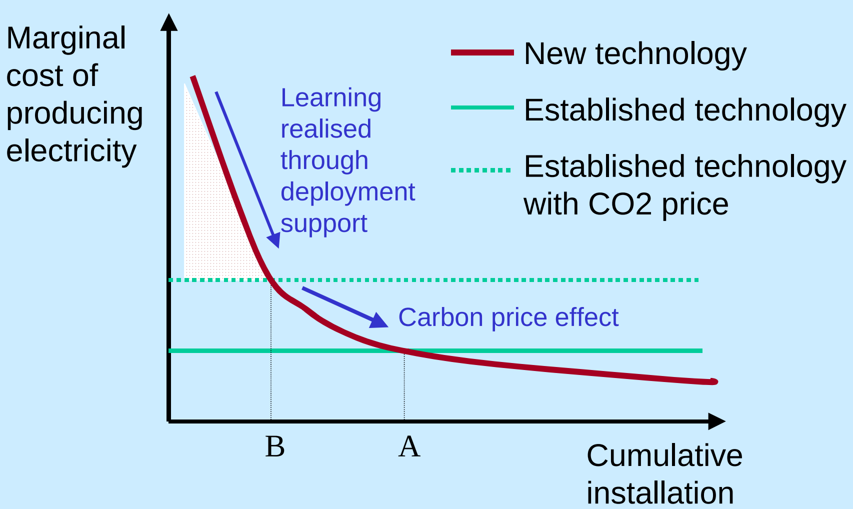
There are costs associated with developing a portfolio. Developing options involves paying the learning cost for more technologies. But policymakers should also bear in mind links to other policy objectives. A greater diversity in sources of energy, for instance, will tend to provide benefits to security of supply, as well as climate change. There is thus a type of externality from creating a new option in terms of risk reduction as well as potential cost reduction. Firms by themselves do not have the same perspective and weight on these criteria as broader society. The next section looks at how the development of a suitable portfolio can be encouraged

Developing a portfolio requires a combination of government interventions including carbon pricing, R&D support and, in some sectors, technology-specific early stage deployment support. These should be complemented by policies to address non-market barriers.

Alongside carbon pricing and the further factors identified in Chapter 17, supporting the development of low-emission technologies can be seen as an important element of climate policy. The further from market the product, given some reasonable probability of success, the greater the prima facie case for policy intervention. In the area of pure research, spillovers can be very significant and direct funding by government support is often warranted. Closer to the market, the required financing flows are larger, and the private returns to individual companies are potentially greater. The government's role here is to provide a credible and clear policy framework to drive private-sector investment.

The area in the innovation process between pure research and technologies ready for commercialisation is more complex. Different sectors may justify different types of intervention. In the electricity market, in particular, deployment policies are likely to be required to bring technologies up to scale. How this support is delivered is important and raises issues about how technology neutral policy should be, which will be discussed later in this chapter in Section 16.6.

Figure 16.6 Interaction between carbon pricing and deployment support[32]



This diagram summarises the links between two of the elements of climate policy. The introduction of the carbon price reduces the learning cost since the new technology, for example a renewable, in this illustrative figure becomes cost effective at point B rather than point A, reducing the size of the learning cost represented by the dotted area. Earlier in the learning curve, deployment support is required to reduce the costs of the technology to the point where the market will adopt the technology. It is the earlier stages of innovation, research, development and demonstration which develop the technology to the point that deployment can begin.

[32] In this figure the policy encourage learning but firms may be prepared to undertake investments in anticipation of technological progress or carbon price incentives.

Across the whole process, non-market barriers need to be identified and, where appropriate, overcome. Without policy incentives when required, support will be unbalanced, and bottlenecks are likely to appear in the innovation process[33]. This would reduce the cost effectiveness at each other stage of support, by increasing the cost of the technology and delaying or preventing its adoption.

Uncertainties, both with respect to climate change and technology development, argue *for* investment in technology development. Uncertainties in irreversible investments argue for postponing policies until the uncertainties are reduced. However, uncertainties, especially with respect to technology development, will not be reduced exogenously with the 'passage of time' but endogenously through investment and the feedback and experience it provides.

Most of the development and deployment of new technologies will be undertaken by the private sector; the role of governments is to provide a stable framework of incentives

Deployment support is generally funded through passing on increased prices to the consumers. But it should still be viewed, alongside public R&D support, as a subsidy and should thus be subject to close scrutiny and, if possible, time limited. The private sector will be the main driver for these new technologies. Deployment support provides a market to encourage firms to invest and relies on market competition to provide the stimulus for cost reductions. Both public R&D and deployment support are expected to have a positive impact on private R&D.

In some sectors the benefits from innovation can be captured by firms without direct support for deployment, other than bringing down institutional barriers and via setting standards. This is particularly so in sectors that rely on incremental innovations to improve efficiency rather than a step change in technology, since the cost gap is unlikely to be so large. In these sectors firms may be comfortable to invest in the learning cost of developing low-emission technologies.

Firms with products that are associated with greenhouse gas emissions are increasingly seeking to diversify in order to ensure their long-run profitability. Oil firms are increasingly investing in low-emission energy sources. General Electric's Ecomagination initiative has seen the sale of energy efficient and environmentally advanced products and services rise to $10.1 billion in 2005, up from $6.2 billion in 2004 - with orders nearly doubling to $17 billion. GE's R&D in cleaner technologies was $700m in 2005 and expected to rise to $1.5 billion per annum by 2010.[34] Indeed in a number of countries the private sector is running ahead of government policy and taking a view on where such policy is likely to go in the future which is in advance of what the current government is doing.

R&D and deployment support have been effective in encouraging the development of generation technologies in the past

Determining the benefits of both R&D and deployment is not easy. Studies have often successfully identified a benefit from R&D but without sufficient accuracy to determine what the appropriate level of R&D should be. Estimating the appropriate level is made more difficult by the broad range of activities that can be classed as R&D. Ultimately the benefits of developing technologies will depend on the amount of abatement that is achieved (and thus the avoided impacts) and the long-term marginal costs of abating across all the other sectors within the economy (linked to the carbon price), both of which are uncertain.

However, some evidence provides indications of the effectiveness of policy in promoting the development of technologies:

- **Estimates of R&D benefits**. Private returns from economy-wide R&D have been estimated at 20-30% whilst the estimated social rate of return was around 50%[35].

[33] Weak demand-side policies risk wasting R&D investments see Norberg-Bohm and Loiter (1999) and Deutch (2005)
[34] Source GE press release May 2006:
http://home.businesswire.com/portal/site/ge/index.jsp?ndmViewId=news_view&newsId=20060517005223&newsLang=en&ndmConfigId=1001109&vnsId=681
[35] Kammen and Margolis (1999)

While it is private-sector not public-sector R&D that has been positively linked with growth, the public-sector R&D can play a vital role in stimulating private spending up to the potential point of crowding out[36]. It also plays an important role in preserving the 'public good' nature of major scientific advances. Examples of valuable breakthroughs stimulated by public R&D must be weighed up alongside examples of wasteful projects.

- **Historical evidence**. Examining the history of existing energy technologies and the prominent role that public R&D and initial deployment have played in their development illustrates the potential effectiveness of technology policy. Extensive and prolonged public support and private markets were both instrumental in the development of all generating technologies. Military R&D, the US space programme and learning from other markets have also been crucial to the process of innovation in the energy sector. This highlights the spillovers that occur between sectors and the need to avoid too narrow an R&D focus. This experience has been mirrored in other sectors such as civil aviation and digital technologies where the source has also been military. Perhaps this is related to the fact that US public defence R&D was eight times greater than that for energy R&D in 2006 (US Federal Budget Authority). Historical R&D and deployment support has delivered the technological choices of the present with many R&D investments that may have seemed wasteful in the 1980s, such as investments in renewable energy and synfuels, now bearing fruit. The technological choices of the coming decades are likely to develop from current R&D.

Box 16.3 Development of existing technology options[37]

Nuclear: From the early stages of the Cold War, the Atomic Energy Commission in the US, created primarily to oversee the development of nuclear weapons, also promoted civilian nuclear power. Alic et al[38] argue that by exploiting the 'peaceful atom' Washington hoped to demonstrate US technological prowess and perhaps regain moral high ground after the atomic devastation of 1945. The focus on weapons left the non-defence R&D disorganised and starved of funds and failed to address the practical issues and uncertainties of commercial reactor design. The government's monopoly of nuclear information, necessary to prevent the spreading of sensitive information, meant state R&D was crucial to development.

Gas: The basic R&D for gas turbine technology was carried out for military jet engines during World War II. Since then developments in material sciences and turbine design have been crucial to the technological innovation that has made gas turbines the most popular technology for electricity generation in recent years. Cooling technology from the drilling industry and space exploration played an important role. In the 1980s improvements came from untapped innovations in jet engine technology from decades of experience in civil aviation. Competitive costs have also been helped by low capital costs, reliability, modularity and lower pollution levels.

Wind: The first electric windmills were developed in 1888 and reliable wind energy has been available since the 1920s. Stand-alone turbines were popular in the Midwestern USA prior to centrally generated power in the 1940s. Little progress was made until the oil shocks led to further investment and deployment, particularly in Denmark (where a 30% capital tax break (1979-1989) mandated electricity prices (85% of retail) and a 10% target in 1981 led to considerable deployment) and California where public support led to extensive deployment in the 1980s. Recent renewable support programmes and technological progress have encouraged an average annual growth rate of over 28 % over the past ten years[39].

Photovoltaics: The first PV cells were designed for the space programme in the late 1950s. They were very expensive and converted less than 2% of the solar energy to electricity. Four decades of steady development, in the early phases stimulated by the space programme, have seen efficiency rise to nearly 25% of the solar energy in laboratories, and costs of commercial cells have fallen by orders of magnitude. The need for storage or ancillary power

[36] When public expenditure limits private expenditure by starving it of potential resources such as scientists OECD (2005)
[37] Alic, Mowery and Rubin (2003)
[38] Alic, Mowery and Rubin (2003)
[39] Global Wind Energy Council http://www.gwec.net/index.php?id=13

sources have held the technology back but there have been some niche markets in remote locations and, opportunities to reduce peak demand in locations where solar peaks and demand peaks coincide.

Public support has been important. A study by Norberg-Bohm[40] found that, of 20 key innovations in the past 30 years, only one of the 14 they could source was funded entirely by the private sector and nine were totally public. Recent deployment support led the PV market to grow by 34% in 2005. Nemet[41] explored in more detail how the innovation process occurred. He found that, of recent cost reductions, 43% were due to economies of scale, 30% to efficiency gains from R&D and learning-by-doing, 12% due to reduced silicon costs (a spillover from the IT industry).

- **Learning curve analysis**. Learning curves, as shown in Box 9.4 and in other studies[42], show that increased deployment is linked with cost reductions suggesting that further deployment will reduce the cost of low-emission technologies. There is a question of causation since cost reductions may lead to greater deployment; so attempts to force the reverse may lead to disappointing learning rates. The data shows technologies starting from different points and achieving very different learning rates. The increasing returns from scale shown in these curves can be used to justify deployment support, but the potential of the technologies must be evaluated and compared with the costs of development.

16.5 Research, development and demonstration policies

Government has an important role in directly funding skills and basic knowledge creation for science and technology

At the pure science end of the spectrum, the knowledge created has less direct commercial application and exhibits the characteristics of a 'public good'. At the applied end of R&D, there is likely to be a greater emphasis on private research, though there still may be a role for some public funding.

Governments also fund the education and training of scientists and engineers. Modelling for this review suggests that the output of low-carbon technologies in the energy sector will need to expand nearly 20-fold over the next 40-50 years to stabilise emissions, requiring new generations of engineers and scientists to work on energy-technology development and use. The prominent role of the challenge of climate change may act as an inspiration to a new generation of scientists and spur a wider interest in science.

R&D funding should avoid volatility to enable the research base to thrive. Funding cycles in some countries have exhibited 'roller-coaster' variations between years, which have made it harder for laboratories to attract, develop, and maintain human capital. Such volatility can also reduce investors' confidence in the likely returns of private R&D. Kammen[43] found levels changed by more than 30% in half the observed years. Similarly it may be difficult to expand research capacity very quickly as the skilled researchers may not be available. Governments should seek to avoid such variability, especially in response to short-term fuel price fluctuations. The allocation of public R&D funds should continue to rely on the valuable peer review process and this should include post-project evaluations and review to maximise the learning from the research. Research with clear objectives but without over-commitment to narrow specifications or performance criteria can eliminate wasteful expenditures[44] and allow researchers more time to apply to their research interests and be creative.

Governments should seek to ensure that, in broad terms, the priorities of publicly funded institutions reflect those of society. The expertise of the researchers creates an information asymmetry with policymakers facing a challenge in selecting suitable projects. Arms-length

[40] Norberg-Bohm (2000)
[41] Source: Nemet, in press
[42] For an example Taylor, Rubin and Nemet (2006)
[43] Kammen (2004)
[44] Newell and Chow (2004)

organisations and expert panels such as research-funding bodies may be best placed to direct funding to individual projects.

Three types of funding are required for university research funding.

- Basic research time and resources for academic staff to pursue research that interests them.
- Research programme funding (such as research councils) that directs funding towards important areas.
- Funding to encourage the transfer of knowledge outside the institution. The dissemination of information encourages progress to be applied and built on by other researchers and industry and ensures that it not be unnecessarily duplicated elsewhere.

Research should cover a broad base and not just focus on what are currently considered key technologies, including basic science and some funding to research the more innovative ideas[45] to address climate change. Historical examples of technological progress when the research was not directed towards specific economic applications (such as developments in nanotechnology, lasers and the transistor) highlight the importance of open-ended problem specification. There must be an appropriate balance between basic science and applied research projects[46]. Increases in energy R&D (as discussed in the final section of this chapter) can be complemented by increased funding for science generally. The potential scale of increase in basic science will vary by country depending on their current level and research capabilities[47].

There may also be a case for demonstration funding to prove viability and reduce risk. An example of this is the UK DTI's 'Wave and Tidal Stream Energy Demonstration Scheme' that will support demonstration projects undertaken by private firms. This has many features to encourage the projects and maximise learning through provision of test site and facilities and systematic comparison of competing alternatives. Governments can help such projects through providing infrastructure. Demonstration projects are best conducted or at least managed by the private sector.[48]

Energy storage is worthy of particular attention

Inherent uncertainty on fruitful areas of research ensures governments should be cautious against picking winners. However, some areas of research suggest significant potential through a combination of probability of success, lead-times and global reward for success. Priorities for scientific progress in the energy sector should include PV (silicon and non-silicon based), biofuel conversion technologies, fusion, and material science.

As markets expand, all the key low carbon primary energy sources will run into constraints. Nuclear power will be confined to base-load electricity generation unless energy storage is available to enable its energy to follow loads and contribute to the markets for transport fuels. Intermittent renewable energy forms with backup generation will face the same problem. Electricity generation from fossil fuels with carbon capture and storage will likewise be unable to enter the transport markets unless improved and lower cost forms of hydrogen storage or new battery technology are developed. Solar energy can in theory meet the world's energy needs many times over, but will, like energy from wind, waves and tides, eventually depend on the storage problem being solved.

The analysis of the costs of climate change mitigation in Chapter 9 provides further confirmation of the need for an expansion of RD&D activities in energy storage technologies. A failure to develop such technologies will inevitably increase the costs of mitigation once low-emission options for electricity generation are exploited. In contrast, success in this area will

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[45] For some examples, see Gibbs (2006)

[46] Newell and Chow (2004)

[47] In 2004 the UK Government published a ten-year Science and Innovation Investment Framework, which set a challenging ambition for public and private investment in R&D to rise from 1.9% to 2.5% of UK GDP, in partnership with business; as well as the policies to underpin this. An additional £1 billion will be invested in science and innovation between 2005-2008, equivalent to real annual growth of 5.8% and to continue to increase investment in the public science base at least in line with economic growth. http://www.dti.gov.uk/science/science-funding/framework/page9306.html

[48] Newell and Chow (2004)

allow low-emission sources to provide energy in other sectors, such as transport. Current R&D and demonstration efforts on hydrogen production and storage along with other promising options for storing energy (such as advanced battery concepts) should be increased. This should include research on devices that convert the stored energy, such as the fuel cell.

In the case of applied energy research, partnership between the public and private sectors is key

It is important that public R&D leverages private R&D and encourages commercialisation. Ultimately the products will be brought into the market by private firms who have a better knowledge of markets, and, so it is important that public R&D maintains the flow of knowledge by ensuring public R&D complements the efforts of the private sector.

The growth and direction of private R&D efforts will be a product of the incentives for low-emission investments provided by the structure of markets and public policies. Public R&D should aim to complement, not compete, with private R&D, generally by concentrating on more fundamental, longer-term possibilities, and by sharing in the risks of some larger-scale projects such as CCS. In many areas the private sector will make research investments without public support, as has been the case recently on advanced biofuels (see Box 16.4).

Box 16.4 Second generation biofuels

Cellulosic ethanol is a not-yet-commercialized fuel derived from woody biomass. In his 2006 State of the Union address, Bush praised the fuel's potential to curb the nation's "addiction to foreign oil". A joint study by the Departments of Agriculture and Energy[49] concludes that U.S. biomass feedstocks could produce enough ethanol to displace 30 percent of the nation's gasoline consumption by 2030.

In May 2006, Goldman Sachs & Co became the first major Wall Street firm to invest in the technology. Goldman Sachs & Co invested more than $26 million in Iogen Corp., an Ottawa-based company that operates the world's first and only demonstration facility that converts straw, corn stalks, switchgrass and other agricultural materials to ethanol. Iogen hopes to begin construction on North America's first commercial cellulosic ethanol plant next year.

In September 2006 Richard Branson announced plans to invest $3 billion in mitigating climate change. Some of this will be invested in Virgin Fuels, which will develop biofuels including cellulosic ethanol.

The OECD[50] found that economic growth was closely linked to general private R&D, not public R&D, but that public R&D plays a vital role in stimulating private spending. There is evidence[51] from the energy sector that patents do track public R&D closely, which suggests that they successfully spur innovation and private sector innovation. R&D collaboration between the public and private-sector is one way of reducing the cost and risks of R&D.

The public sector could fund private sector research through competitive research funding, with private sector companies bidding for public funds as public organisations currently do from research councils. Prizes to reward innovation can be used to encourage breakthroughs. Historically they have proved very successful but defining a suitable prize can be problematic[52]. An alternative approach, as suggested for the pharmaceutical sector, is to commit to purchase new products to reward those that successfully innovate.[53]

[49] US Departments of Agriculture and Energy (2005)
[50] OECD (2005)
[51] Kammen and Nemet (2005)
[52] Newell and Wilson (2005)
[53] Kremer and Glennerster (2004)

Box 16.5 Public-private research models - UK Energy Technologies Institute[54]

In 2006, the UK launched the Energy Technologies Institute (ETI). It will be funded on a 50:50 basis between private companies and the public sector with the government prepared to provide £500 million, creating the potential for a £1 billion institute over a minimum lifetime of ten years.

The institute will aim to accelerate the pace and volume of research directed towards the eventual deployment of the most promising research results. ETI will work to existing UK energy policy goals including a 60% reduction in emissions by 2050.

The ETI will select, commission, fund, manage and, where appropriate, undertake research programmes. Most investment will focus on a small number of key technology areas that have greatest promise for deployment and contributing to low-emission secure energy supplies.

16.6 Deployment policy

A wide range of policies to encourage deployment are already in use.

In addition to direct emissions pricing through taxes and trading and R&D support, there are strong arguments in favour of supporting deployment in some sectors when spillovers, lock-in to existing technologies, or capital market failures prevent the development of potentially low-cost alternatives. Without support the market may never select those technologies that are further from the market but may nevertheless eventually prove cheapest. Policies to support deployment exist throughout the world including many non-OECD countries[55]. China and India have both encouraged large-scale renewable deployment in recent years and now have respectively the largest and fifth largest renewable energy capacity worldwide[56].

There is some deployment support for clean technologies in most developed countries. The mechanism of support takes many forms though the costs are generally passed onto the consumer. The presence of a carbon price reduces the cost and requirement for deployment support. Deployment support is generally a small component of price when spread across all consumption (see Box 16.7) but does add to the impact of carbon pricing on electricity prices. Policymakers should consider the impact of deployment support on energy prices over time. Consumers will be paying for the development of technologies that benefit consumers in the future.

[54] http://www.dti.gov.uk/science/science-funding/eti/page34027.html
[55] Page 20 REN 21 Renewables global status report 2005 - See page 20 REN 21 (2005)
[56] Figures from 2005 - excluding large scale hydropower. Page 6 REN 21 (2006)

Box 16.6 Examples of existing deployment incentives

- **Fiscal incentives**: including reduced taxes on biofuels in the UK and the US; investment tax credits.
- **Capital grants** for demonstrator projects and programmes: clean coal programmes in the US; PV 'rooftop' programmes in the US, Germany and Japan; investments in marine renewables in the UK and Portugal; and numerous other technologies in their demonstration phase.
- **Feed-in tariffs** are a fixed price support mechanism that is usually combined with a regulatory incentive to purchase output: examples include wind and PVs in Germany; biofuels and wind in Austria; wind and solar schemes in Spain, supplemented by 'bonus prices'; wind in Holland.
- **Quota based schemes**: the Renewable Portfolio Standards in twenty three US States; the vehicle fleet efficiency standards in California
- **Tradable quotas**: the Renewables Obligation and Renewable Transport Fuels Obligation in the UK.
- **Tenders for tranches of output** (the former UK Non Fossil Fuel Obligation) with increased output prices subsidised out of the revenues from a general levy on electricity tariffs.
- **Subsidy** of the infrastructure costs of connecting new technologies to networks.
- **Procurement policies of public monopolies:** This was the approach historically of the public monopolies in electricity for purchase of nuclear power throughout the OECD; it is currently the approach in China. It is often combined with regulatory agreements to permit recovery of costs, soft loans by governments, and, in the case of nuclear waste, government assumption of liabilities.
- **Procurement policies of national and local governments**: these include demonstrator projects on public buildings; use of fuel cells and solar technologies by defence and aerospace industries; hydrogen fuel cell buses and taxis in cities; energy efficiency in buildings.

The deployment mechanisms described in Box 16.6 can be characterised as price or quantity support, with some tradable approaches containing elements of both. The costs of these policies are generally passed directly on to consumers though some are financed from general taxation. When quantity deployment instruments are not tradable, the policymaker should consider whether there are sufficient incentives to strive for cost reductions and whether the supplier can profit from passing an excessive cost burden onto the consumer. If the level of a price deployment instrument is too low no deployment will occur, while if it is too high large volumes of deployment will occur with financial rewards for participants which are essentially government created rents. With tradable quantity instruments, the market is left to determine the price, usually with tradable certificates between firms. This does lead to price uncertainty. If the quantity is too high, bottlenecks may lead to a high cost. If the quantity is too low, there may not be sufficient economies of scale to reduce the cost.

Both sets of instruments have proved effective but existing experience favours price-based support mechanisms. Comparisons between deployment support through tradable quotas and feed-in tariff price support suggest that feed-in mechanisms achieve larger deployment at lower costs[57]. Central to this is the assurance of long-term price guarantees. The German scheme, as described in Box 16.7 below, provides legally guaranteed revenue streams for up to twenty years if the technology remains functional. Whilst recognising the importance of planning regimes for both PV and wind, the levels of deployment are much greater in the German scheme and the prices are lower than comparable tradable support mechanisms (though greater deployment increases the total cost in terms of the premium paid by consumers). Contrary to criticisms of the feed-in tariff, analysis suggests that competition is greater than in the UK Renewable Obligation Certificate scheme. These benefits are logical as the technologies are already prone to considerable price uncertainties and the price uncertainty of tradable deployment support mechanisms amplifies this uncertainty. Uncertainty discourages investment and increases the cost of capital as the risks associated with the uncertain rewards require greater rewards.

[57] Butler and Neuhoff (2005); EC (2005); Ragwitz, and Huber (2005); Fouquet et al (2005)

Box 16.7 Deployment support in Germany

Feed-in tariffs have been introduced in Germany to encourage the deployment of onshore and offshore wind, biomass, hydropower, geothermal and solar PV[58]. The aim is to meet Germany's renewable energy goals of 12.5% of gross electricity consumption in 2010 and 20% in 2020. The policy also aims to encourage the development of renewable technologies, reduce external costs and increase the security of supply.

Each generation technology is eligible for a different rate. Within technologies the rate varies depending on the size and type. Solar energy receives between €0.457 to 0.624 per kWh while wind receives €0.055 to 0.091per kWh. Once the technology is built the rate is guaranteed for 20 years. The level of support for deployment in subsequent years declines over time by 1% to 6.5% each year with the rate of decline derived from estimated learning curves[59].

In 2005 10.2% of electricity came from renewables (70% supported with feed-in tariffs) the Federal Environment Ministry (BMU) estimate that the current act will save 52 million tonnes on CO_2 in 2010. The average level of feed-in tariff was €0.0953 per kWh in 2005 (compared to an average cost of displaced energy of €0.047 kWh). The total level of subsidy was €2.4 billion Euro at a cost shared all consumers of €0.0056 per kWh (3% of household electricity costs)[60]. There are an estimated 170,000 people working in the renewable sector with an industry turnover of €8.7 billion.[61]

The 43.7 TWh of electricity covered by the feed in tariffs was split mostly between wind (61%), biomass (19%) and hydropower (18%). It has succeeded in supporting several technologies. Solar accounted for 2% (0.2% of total electricity) with an average growth rate of over 90% over the last four years. Despite photovoltaic's low share Germany has a significant proportion of the global market with 58% of the capacity installed globally in 2005 (39% of the total installed capacity) and 23% of global production.[62]

Regulation can also be used to encourage deployment, for example by reducing uncertainty and accelerating spillover effects, and may be preferable in certain markets (see Chapter 17 for details). Performance standards encourage uptake and innovation in efficient technologies by establishing efficiency requirements for particular goods, in particular encouraging incremental innovation Alternatively, technology specific design standards can be targeted directly at the cleanest technologies by mandating their application or banning alternatives.

There are already considerable sums of money spent on supporting technology deployment. It is estimated that $10 billion[63] was spent in 2004 on renewable deployment, around $16 billion is spent each year supporting existing nuclear energy and around $6.4billion[64] is spent each year supporting biofuels. The total support for these low-carbon energy sources is thus $33 billion each year. Such sums are dwarfed by the existing subsidies for fossil fuels worldwide that are estimated at $150 billion to 250 billion each year. All these costs are generally paid by the consumer.

Technology-neutral incentives should be complemented by focused incentives to bring forward a portfolio of technologies

Policy frameworks can be designed to treat support to all low-carbon technologies in a 'technology-neutral' way. The dangers of public officials 'picking winners' should point to this

[58] Originally introduced in 1991 with the Electricity Feed Act this was replaced in 2000 with the broader Act on Granting Priority to Renewable Energy Sources (Renewable Energy Sources Act) and amended in 2004 http://www.ipf-renewables2004.de/en/dokumente/RES-Act-Germany_2004.pdf
[59] Small hydropower does not decline and is guaranteed for 30 years and large hydropower only 15 years.
[60] BMU (2006a)
[61] BMU (2006b)
[62] http://www.iea-pvps.org/isr/index.htm
[63] Deployment share of figure page 16 REN 21, 2005 grossed up to global figure based on IEA deployment figures. Nuclear figure from same source.
[64] Based on global production of 40 billion litres and on an average support of £0.1 per litre and a PPP exchange rate of $1.6 to £1

as the starting point in most sectors. Markets and profit orientated decisions, where the decision maker is forced to look carefully at cost and risk are better at finding the likely commercial successes. However, the externalities, uncertainties and capital market problems in some sectors combine with the urgency of results and specificity of some of the technological problems that need to be solved when tackling climate change, all point to the necessity to examine the issues around particular technologies and ensure that a portfolio develops.

The policy framework of deployment support could differentiate between technologies, offering greater support to those further from commercialisation, or having particular strategic or national importance. This differentiation can be achieved several ways, including technology-specific quotas, or increased levels of price support for certain technologies. Policies to correct the carbon externality (taxes / trading) are, and should continue to be, technology neutral. Technology neutrality is also desirable for deployment support if the aim is to deliver least cost reductions to meet short-term targets, since the market will deliver the least-cost technology.

However, as has already been discussed, the process of learning means that longer-established technologies will tend to have a price advantage over newer technologies, and untargeted support will favour these more developed technologies and bring them still further down the learning curve. This effect can be seen in markets using technology-neutral instruments: in the USA, onshore wind accounts for 92% of new capacity in green power markets[65].

This concentration on near-to-market technologies will tend to work to the exclusion of other promising technologies, which means that only a very narrow portfolio of technologies will be supported, rather than the broad range which Part III of this report shows are required. This means technology neutrality may be cost efficient in the short term, but not over time.

Most deployment support in the electricity generation sector has been targeted towards renewable and nuclear technologies. However, significant reductions are also expected from other sources. As highlighted in Box 9.2 carbon capture and storage (CCS) is a technology expected to deliver a significant portion of the emission reductions. The forecast growth in emissions from coal, especially in China and India, means CCS technology has particular importance. Failure to develop viable CCS technology, while traditional fossil fuel generation is deployed across the globe, risks locking-in a high emissions trajectory. The demonstration and deployment of CCS is discussed in more detail in Chapter 24. Stabilising emissions below 550ppm CO_2e will require reducing emissions from electricity generation by about 60%[66]. Without CCS that would require a dramatic shift away from existing fossil-fuel technologies.[67]

Policies should have a clear review process and exit strategies, and governments must accept that some technologies will fail.

Uncertainty over the economies of scale and learning-by-doing means that some technological failures are inevitable. Technological failures can still create valuable knowledge, and the closing of technological avenues narrows the investment options and increases confidence in other technologies (as they face less alternatives). The Arrow-Lind theorem[68] states that governments are generally large enough to be risk neutral as they are large enough to spread the risk and thus have a role to play in undertaking riskier investments. It is not a mistake per se to buy insurance or a hedge that later is not needed and that is in many ways a suitable analogy for fostering a wider portfolio of viable technologies than the market would do by itself[69].

Credibility is also important to policy design. Policies benefit from providing clear, bankable, signals to business. There is a role for monitoring and for a clear exit strategy to prevent excessive costs and signal the ultimate goal of these policies: competition on a level playing

65 Bird and Swezey (2005)
66 This is consistent with the IEA ACT scenarios see Box 9.7
67 For more on CCS see Boxes 9.2 and 24.8 and Section 24.3
68 Arrow and Lind (1970)
69 Deutch (2005)

field. A good example has been the Japanese rebates in the 'Solar Roofs' programme, which have declined gradually over time, from 50% of installed cost in 1994 to 12% in 2002 when the scheme ended.

Alternative approaches can also help spur the deployment of new innovations. For example, extension services, the application of scientific research and new knowledge to agricultural practices through farmer education, had a significant impact on the deployment of new crop varieties during the Green Revolution. Also, organisations such as the Carbon Trust in the UK, Sustainable Development Technologies Canada, established by governments but independent of them to allow the application of business acumen, have proved successful in encouraging investment in the development and demonstration of clean technologies. They can play an important role at each stage of the technology process, from R&D to ensuring their widespread deployment once they have become cost effective. They have proved especially successful in acting as a "stamp of approval" that spurs further venture capital investment. Finding niche markets and building these into large-scale commercialisation opportunities is a key challenge for companies with promising low carbon technologies. These organisations are at the forefront of identifying niche markets for commercialisation of new technologies and promoting public-private investment in deployment.

16.7 Other supporting policies

***Other policies have an important impact on the viability of technologies*.**

There are many other policy options available to governments that can affect technology deployment and adoption. Governments set policies such as the planning regime and building standards. How these are set can have an important impact on the adoption of new technologies. They can constrain deployment either directly or indirectly by increasing costs. Regulations can stifle innovation, but if well designed they can drive innovation. Depending how these are set, they can act as a subsidy to low-emission alternative technologies or to traditional fossil fuels. Setting the balance is difficult, since their impacts are hard to value. But they must be considered since they can have an important effect on the outcome.

- The intellectual property regime can act as an incentive to the innovator, but the granting of the property right can also slow the dissemination of technological progress and prohibit others from building on this innovation. Managing this balance is an important challenge for policymakers.

- Planning and licensing regulations have proven a significant factor for nuclear, wind and micro-generation technologies. Planning can significantly increase costs or, in many cases, prevent investments taking place. Local considerations must be set against wider national or global concerns.

- It is important how governments treat risks and liabilities such as waste, safety or decommissioning costs for nuclear power or liabilities for CO_2 leakage from CCS schemes. Governments can bear some of these costs but, unless suppliers and ultimately consumers are charged for this insurance, it will be a subsidy.

- Network issues are particularly important for energy and transport technologies. The existing transport network and infrastructure, especially fuel stations, is tailored to fossil fuel technologies.

- Intermittent technologies such as wind and solar may be charged a premium if they require back-up sources. How this is treated can directly affect economic viability, depending on the extent of the back-up generation required and the premium charged.

- Micro-generation technologies can sell electricity back to the grid and do not incur the same distribution costs and transmission losses as traditional much larger sources. The terms under which such issues are resolved has an important impact on the economics of these technologies. Commercially proven low-carbon technologies require regulatory frameworks that recognise their value, in terms of flexibility and modularity[70], within a distributed energy system. Regulators should innovate in response to the challenge of integrating these technologies to exploit their potential, and unlock the resultant opportunities that arise from shifting the generation mix away from centralised sources.

- Capacity constraints may arise because of a shortage in a required resource. For example, there may be a shortage of skilled labour to install a new technology.
- There are other institutional and even cultural barriers that can be overcome. Public acceptability has proven an issue for both wind and nuclear and this may also be the case for hydrogen vehicles. Consumers may have problems in finding and installing new technologies. Providing information of the risks and justification of particular technologies can help overcome these barriers.

16.8 The scale of action required

Extending and expanding existing deployment incentives will be key

Deployment policies encourage the private sector to develop and deploy low-carbon technologies. The resulting cost reductions will help reduce the cost of mitigation in the future (as explained in Chapter 10). Consumers generally pay the cost of deployment support in the form of higher prices. Deployment support represents only a proportion of the cost of the technology as it leverages private funds that pay for the market price element of the final cost.

It is estimated that existing deployment support for renewables, biofuels and nuclear energy is $33 billion each year (see Section 16.6). The IEA's Energy Technology Perspectives[71] looks at the impact of policies to increase the rate of technological development. It assumes that $720billion of investment in deployment support occurs over the next two to three decades. This estimate is on top of an assumed carbon price (whether through tax, trading or implicitly in regulation) of $25 per tonne of CO_2. If the IEA figure is assumed to be additional to the existing effort, it suggests an increase of deployment incentives of between 73% and 109%, depending on whether this increase is spread over two or three decades.

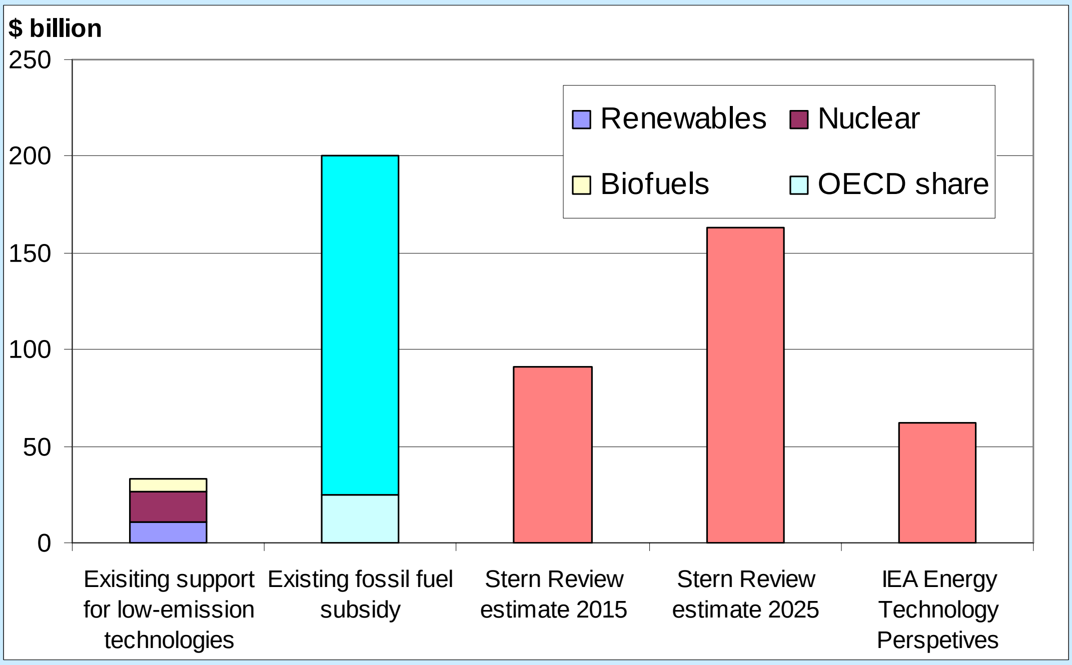
The calculations shown in Section 9.8 include estimates of the level of deployment incentives required to encourage sufficient deployment of new technologies (consistent with a 550ppm CO_2e stabilisation level). The central estimates from this work are that the level of support required will have to increase deployment incentives by 176% in 2015 and 393% in 2025[72]. These estimates are additional to an assumed a carbon price at a level of $25 per tonne of CO_2.

At this price the abatement options are forecast to become cost effective by 2075 so the level of support tails off to zero by this time. If policies lead to a price much higher than this before the technologies are cost effective then less support will be required. Conversely if no carbon price exists the level of support required will have to increase (by a limited amount initially but by much larger amounts in the longer term). While most of this cost is expected to be passed on to consumers, firms may be prepared to incur a proportion of this learning cost in order to gain a competitive advantage.

Such levels of support do represent significant sums but are modest when compared with overall levels of investment in energy supply infrastructure ($20 trillion up to 2030[73]) or even estimates of current levels of fossil-fuel subsidy as shown in the graph below.[74]

[70] Small-scale permits incremental additions in capacity unlike large technologies such as nuclear generation.
[71] Page 58, IEA (2006)
[72] See papers by Dennis Anderson available at www.sternreview.org.uk
[73] IEA (in press)
[74] In this graph mid points in the fossil fuel subsidy range is used in and the IEA increase made over a 20 year period.

Figure 16.7 Estimated scale of current and necessary global deployment support



The level of support required to develop abatement technologies depends on the carbon price and the rate of technological progress, which are both uncertain. It is clear from these numbers that the level of support should increase in the decades to come, especially in the absence of carbon pricing. Based on the numbers above, an increase of 2-5 times current levels over the next 20 years should help encourage the requisite levels of deployment though this level should be evaluated as these uncertainties are resolved.

The scale is, however, not the only issue. It is important that this support is well structured to encourage innovation at low cost. A diverse portfolio of investments is required as it is uncertain which technologies will prove cheapest and constraints on individual technologies will ensure that a mix is necessary. Those technologies that are likely to be the cheapest warrant more investment and these may not be those that are the currently the lowest cost. This requires a reorientation of public support towards technologies that are further from widespread diffusion.

Some countries are already offering significant support for new technologies but globally this support is patchy. Issues on coordinating deployment support internationally to achieve the required diversity and scale are examined in Chapter 24.

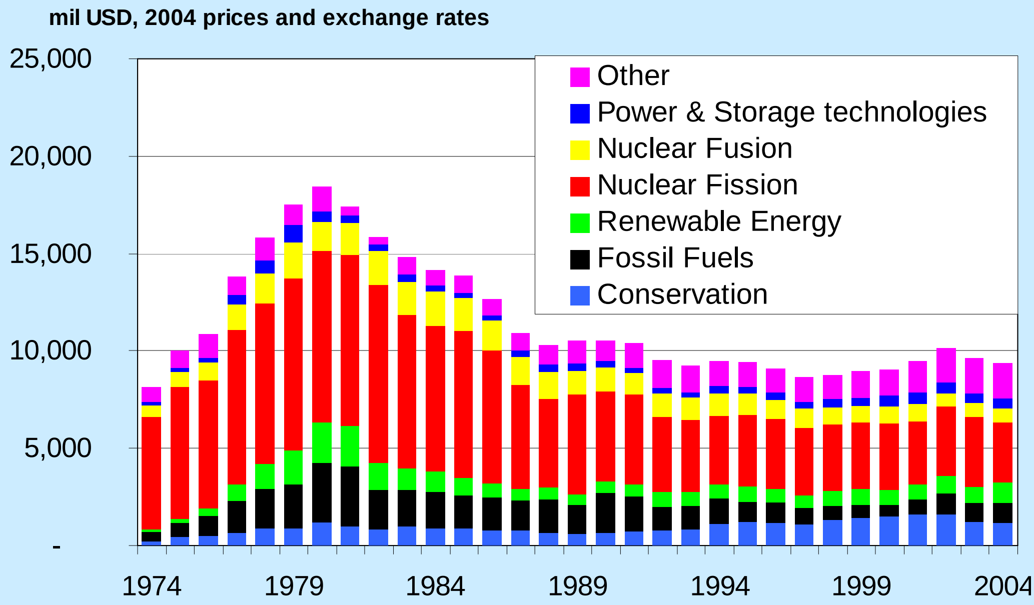
Global energy R&D funding is at a low level and should rise

Though benefits of R&D are difficult to evaluate accurately a diverse range of indicators illustrate the benefits of R&D investments. Global public energy R&D support has declined significantly since the 1980s and this trend should reverse to encourage cost reductions in existing low-carbon technologies and the development of new low-carbon technological options. The IEA R&D database shows a decline of 50% in low-emission R&D[75] between 1980 and 2004. This decline has occurred while overall government R&D has increased significantly[76]. A recent IEA publication on RD&D priorities[77] strongly recommends that governments consider restoring their energy RD&D budgets at least to the levels seen, in the early 1980s. This would involve doubling the budget from the current level of around $10

[75] For countries available includes renewables, conservation and nuclear. The decline is 36% excluding nuclear.
[76] OECD R&D database shows total public R&D increasing by nearly 50% between 1988 and 2004 whilst public energy R&D declined by nearly 20% over the same period.
[77] Page 19 OECD (2006)

billion[78]. This is an appropriate first step that would equate to global levels of public energy R&D around **$20 billion** each year.

Figure 16.8 Public energy R&D in IEA countries[79]



The directions of the effort should also change. A generation ago, the focus was on nuclear power and fossil fuels, including synthetic oil fuels from gas and coal, with comparatively few resources expended on conservation and renewable energy. Now the R&D efforts going into carbon capture and storage, conservation, the full range of renewable energy technologies, hydrogen production and use, fuel cells, and energy storage technologies and systems should all be much larger.

A phased increase in funding, within established frameworks for research priorities, would allow for the expansion in institutional capacity and increased expertise required to use the funding effectively. A proportion of this public money should target be designed to encourage private funds, as is proposed for the UK's Energy Technology Institute (see Box 16.5).

Private R&D should rise in response to market signals. Private energy R&D in OECD countries fell in recent times from around $8.5bn at the end of the 1980s to around $4.5bn in 2003[80]. Significant increases in public energy R&D and deployment support combined with carbon pricing should all help reverse this trend and encourage an upswing in private R&D levels.

This is not just about the total level of support. How this money is spent is crucial. It is important that the funding is spread across a wide range of ideas. It is also important that it is structured to provide stability to researchers while still providing healthy competition. There should be rigorous assessment of these expenditures to ensure that they maintained at an appropriate level. Approaches to encourage international co-operation to achieve these goals are explored in Chapter 24.

16.9 Conclusions

This chapter explores the process of innovation and discovers that externality from the environmental impact of greenhouse gas emissions exacerbates existing market imperfections, limiting the incentive to develop low-carbon technologies. This provides a

[78] 2005 figure Source: IEA R&D database http://www.iea.org/Textbase/stats/rd.asp
[79] Source: IEA Energy R&D Statistics
[80] Page 35, OECD (2006)

strong case for supporting the development of new and existing low-carbon technologies, particularly in a number of key climate change sectors. The power of market forces is the key driver of innovation and technical change but this role should be supplemented with direct public support for R&D and, in some sectors, policies designed to create new markets. Such policies are required to deliver an effective portfolio of low-carbon technologies in the future.

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Executive Summary

The scientific evidence is now overwhelming: climate change presents very serious global risks, and it demands an urgent global response.

This independent Review was commissioned by the Chancellor of the Exchequer, reporting to both the Chancellor and to the Prime Minister, as a contribution to assessing the evidence and building understanding of the economics of climate change.

The Review first examines the evidence on the economic impacts of climate change itself, and explores the economics of stabilising greenhouse gases in the atmosphere. The second half of the Review considers the complex policy challenges involved in managing the transition to a low-carbon economy and in ensuring that societies can adapt to the consequences of climate change that can no longer be avoided.

The Review takes an international perspective. Climate change is global in its causes and consequences, and international collective action will be critical in driving an effective, efficient and equitable response on the scale required. This response will require deeper international co-operation in many areas - most notably in creating price signals and markets for carbon, spurring technology research, development and deployment, and promoting adaptation, particularly for developing countries.

Climate change presents a unique challenge for economics: it is the greatest and widest-ranging market failure ever seen. The economic analysis must therefore be global, deal with long time horizons, have the economics of risk and uncertainty at centre stage, and examine the possibility of major, non-marginal change. To meet these requirements, the Review draws on ideas and techniques from most of the important areas of economics, including many recent advances.

The benefits of strong, early action on climate change outweigh the costs

The effects of our actions now on future changes in the climate have long lead times. What we do now can have only a limited effect on the climate over the next 40 or 50 years. On the other hand what we do in the next 10 or 20 years can have a profound effect on the climate in the second half of this century and in the next.

No-one can predict the consequences of climate change with complete certainty; but we now know enough to understand the risks. Mitigation - taking strong action to reduce emissions - must be viewed as an investment, a cost incurred now and in the coming few decades to avoid the risks of very severe consequences in the future. If these investments are made wisely, the costs will be manageable, and there will be a wide range of opportunities for growth and development along the way. For this to work well, policy must promote sound market signals, overcome market failures and have equity and risk mitigation at its core. That essentially is the conceptual framework of this Review.

The Review considers the economic costs of the impacts of climate change, and the costs and benefits of action to reduce the emissions of greenhouse gases (GHGs) that cause it, in three different ways:

- Using disaggregated techniques, in other words considering the physical impacts of climate change on the economy, on human life and on the environment, and examining the resource costs of different technologies and strategies to reduce greenhouse gas emissions;

- Using economic models, including integrated assessment models that estimate the economic impacts of climate change, and macro-economic models that represent the costs and effects of the transition to low-carbon energy systems for the economy as a whole;

- Using comparisons of the current level and future trajectories of the 'social cost of carbon' (the cost of impacts associated with an additional unit of greenhouse gas emissions) with the marginal abatement cost (the costs associated with incremental reductions in units of emissions).

From all of these perspectives, the evidence gathered by the Review leads to a simple conclusion: the benefits of strong, early action considerably outweigh the costs.

The evidence shows that ignoring climate change will eventually damage economic growth. Our actions over the coming few decades could create risks of major disruption to economic and social activity, later in this century and in the next, on a scale similar to those associated with the great wars and the economic depression of the first half of the 20th century. And it will be difficult or impossible to reverse these changes. Tackling climate change is the pro-growth strategy for the longer term, and it can be done in a way that does not cap the aspirations for growth of rich or poor countries. The earlier effective action is taken, the less costly it will be.

At the same time, given that climate change is happening, measures to help people adapt to it are essential. And the less mitigation we do now, the greater the difficulty of continuing to adapt in future.

***

The first half of the Review considers how the evidence on the economic impacts of climate change, and on the costs and benefits of action to reduce greenhouse gas emissions, relates to the conceptual framework described above.

The scientific evidence points to increasing risks of serious, irreversible impacts from climate change associated with business-as-usual (BAU) paths for emissions.

The scientific evidence on the causes and future paths of climate change is strengthening all the time. In particular, scientists are now able to attach probabilities to the temperature outcomes and impacts on the natural environment associated with different levels of stabilisation of greenhouse gases in the atmosphere. Scientists also now understand much more about the potential for dynamic feedbacks that have, in previous times of climate change, strongly amplified the underlying physical processes.

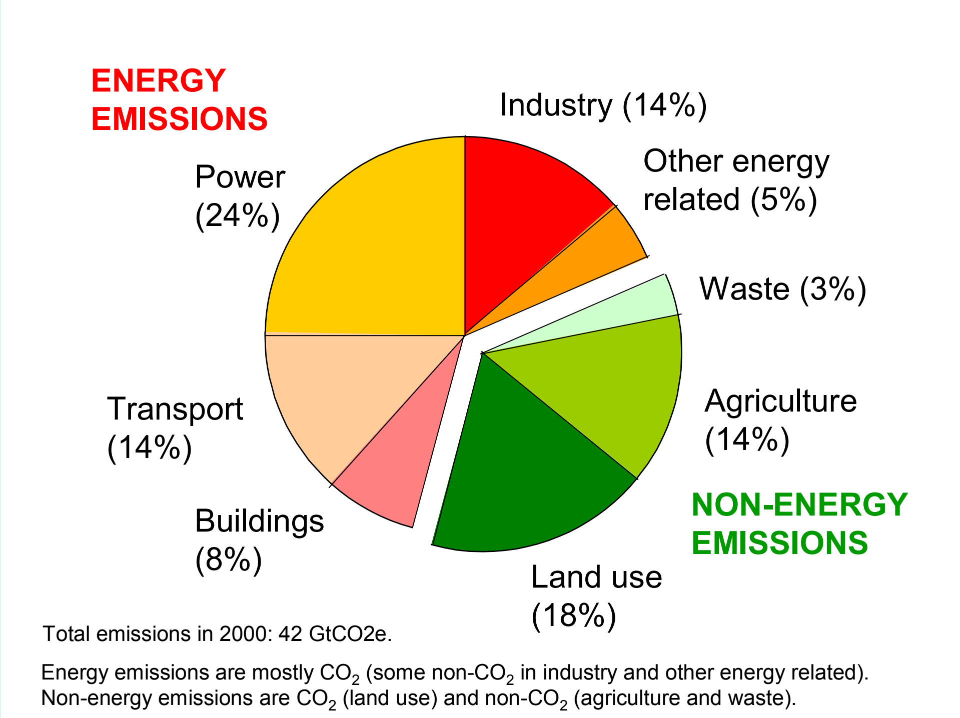
The stocks of greenhouse gases in the atmosphere (including carbon dioxide, methane, nitrous oxides and a number of gases that arise from industrial processes) are rising, as a result of human activity. The sources are summarised in Figure 1 below.

The current level or stock of greenhouse gases in the atmosphere is equivalent to around 430 parts per million (ppm) CO_2 [1], compared with only 280ppm before the Industrial Revolution. These concentrations have already caused the world to warm by more than half a degree Celsius and will lead to at least a further half degree warming over the next few decades, because of the inertia in the climate system.

Even if the annual flow of emissions did not increase beyond today's rate, the stock of greenhouse gases in the atmosphere would reach double pre-industrial levels by 2050 - that is 550ppm CO_2e - and would continue growing thereafter. But the annual flow of emissions is accelerating, as fast-growing economies invest in high-carbon infrastructure and as demand for energy and transport increases around the world. The level of 550ppm CO_2e could be reached as early as 2035. At this level there is at least a 77% chance - and perhaps up to a 99% chance, depending on the climate model used - of a global average temperature rise exceeding 2°C.

[1] Referred to hereafter as CO_2 equivalent, CO_2e

Figure 1 Greenhouse-gas emissions in 2000, by source



Source: Prepared by Stern Review, from data drawn from World Resources Institute Climate Analysis Indicators Tool (CAIT) on-line database version 3.0.

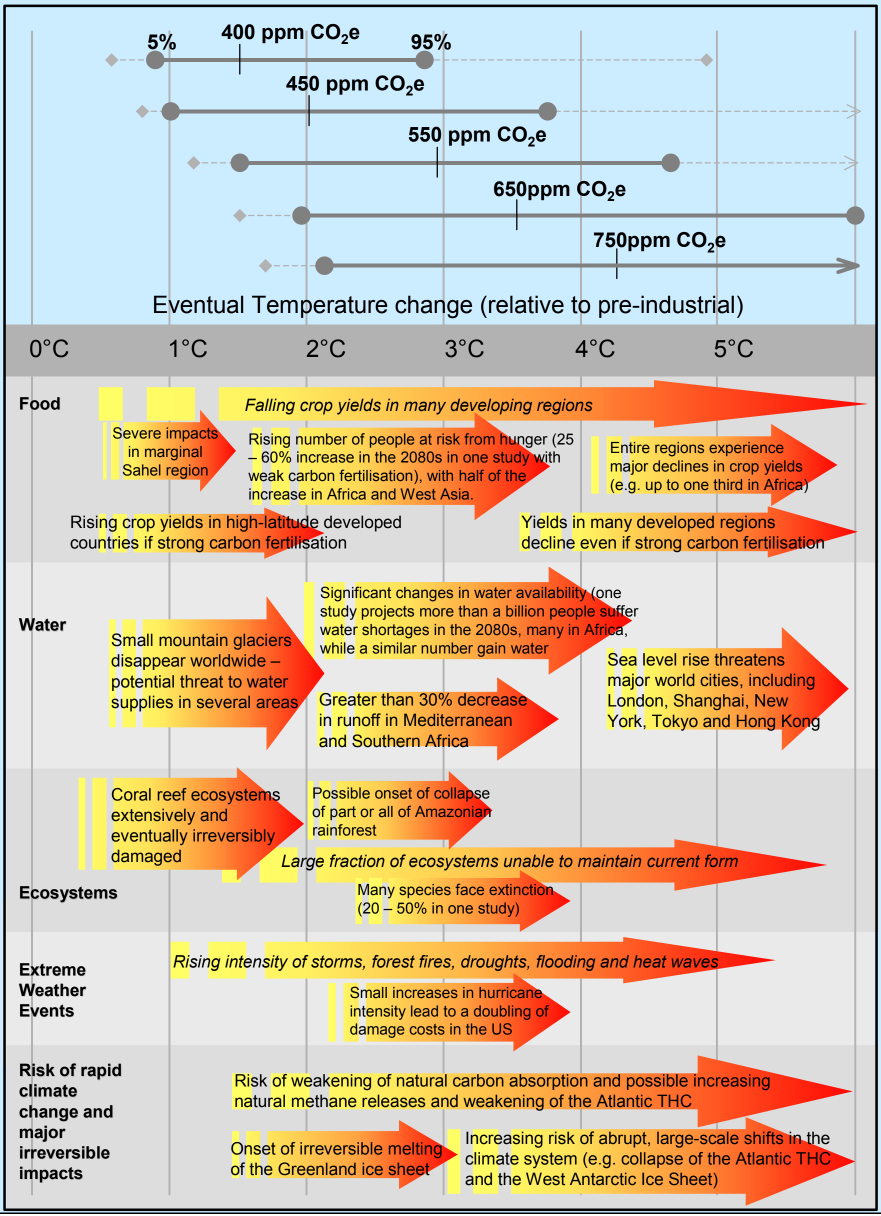
Under a BAU scenario, the stock of greenhouse gases could more than treble by the end of the century, giving at least a 50% risk of exceeding 5°C global average temperature change during the following decades. This would take humans into unknown territory. An illustration of the scale of such an increase is that we are now only around 5°C warmer than in the last ice age.

Such changes would transform the physical geography of the world. A radical change in the physical geography of the world must have powerful implications for the human geography - where people live, and how they live their lives.

Figure 2 summarises the scientific evidence of the links between concentrations of greenhouse gases in the atmosphere, the probability of different levels of global average temperature change, and the physical impacts expected for each level. The risks of serious, irreversible impacts of climate change increase strongly as concentrations of greenhouse gases in the atmosphere rise.

Figure 2 Stabilisation levels and probability ranges for temperature increases

The figure below illustrates the types of impacts that could be experienced as the world comes into equilibrium with more greenhouse gases. The top panel shows the range of temperatures projected at stabilisation levels between 400ppm and 750ppm CO_2e at equilibrium. The solid horizontal lines indicate the 5 - 95% range based on climate sensitivity estimates from the IPCC 2001[2] and a recent Hadley Centre ensemble study[3]. The vertical line indicates the mean of the 50th percentile point. The dashed lines show the 5 - 95% range based on eleven recent studies[4]. The bottom panel illustrates the range of impacts expected at different levels of warming. The relationship between global average temperature changes and regional climate changes is very uncertain, especially with regard to changes in precipitation (see Box 4.2). This figure shows potential changes based on current scientific literature.



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[2] Wigley, T.M.L. and S.C.B. Raper (2001): 'Interpretation of high projections for global-mean warming', Science **293**: 451-454 based on Intergovernmental Panel on Climate Change (2001): 'Climate change 2001: the scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change' [Houghton JT, Ding Y, Griggs DJ, et al. (eds.)], Cambridge: Cambridge University Press.

[3] Murphy, J.M., D.M.H. Sexton D.N. Barnett et al. (2004): 'Quantification of modelling uncertainties in a large ensemble of climate change simulations', Nature **430**: 768 - 772

[4] Meinshausen, M. (2006): 'What does a 2°C target mean for greenhouse gas concentrations? A brief analysis based on multi-gas emission pathways and several climate sensitivity uncertainty estimates', Avoiding dangerous climate change, in H.J. Schellnhuber et al. (eds.), Cambridge: Cambridge University Press, pp.265 - 280.

Climate change threatens the basic elements of life for people around the world - access to water, food production, health, and use of land and the environment.

Estimating the economic costs of climate change is challenging, but there is a range of methods or approaches that enable us to assess the likely magnitude of the risks and compare them with the costs. This Review considers three of these approaches.

This Review has first considered in detail the physical impacts on economic activity, on human life and on the environment.

On current trends, average global temperatures will rise by 2 - 3°C within the next fifty years or so. [5] The Earth will be committed to several degrees more warming if emissions continue to grow.

Warming will have many severe impacts, often mediated through water:

- Melting glaciers will initially increase flood risk and then strongly reduce water supplies, eventually threatening one-sixth of the world's population, predominantly in the Indian sub-continent, parts of China, and the Andes in South America.

- Declining crop yields, especially in Africa, could leave hundreds of millions without the ability to produce or purchase sufficient food. At mid to high latitudes, crop yields may increase for moderate temperature rises (2 - 3°C), but then decline with greater amounts of warming. At 4°C and above, global food production is likely to be seriously affected.

- In higher latitudes, cold-related deaths will decrease. But climate change will increase worldwide deaths from malnutrition and heat stress. Vector-borne diseases such as malaria and dengue fever could become more widespread if effective control measures are not in place.

- Rising sea levels will result in tens to hundreds of millions more people flooded each year with warming of 3 or 4°C. There will be serious risks and increasing pressures for coastal protection in South East Asia (Bangladesh and Vietnam), small islands in the Caribbean and the Pacific, and large coastal cities, such as Tokyo, New York, Cairo and London. According to one estimate, by the middle of the century, 200 million people may become permanently displaced due to rising sea levels, heavier floods, and more intense droughts.

- Ecosystems will be particularly vulnerable to climate change, with around 15 - 40% of species potentially facing extinction after only 2°C of warming. And ocean acidification, a direct result of rising carbon dioxide levels, will have major effects on marine ecosystems, with possible adverse consequences on fish stocks.

[5] All changes in global mean temperature are expressed relative to pre-industrial levels (1750 - 1850).

The damages from climate change will accelerate as the world gets warmer.

Higher temperatures will increase the chance of triggering abrupt and large-scale changes.

- Warming may induce sudden shifts in regional weather patterns such as the monsoon rains in South Asia or the El Niño phenomenon - changes that would have severe consequences for water availability and flooding in tropical regions and threaten the livelihoods of millions of people.

- A number of studies suggest that the Amazon rainforest could be vulnerable to climate change, with models projecting significant drying in this region. One model, for example, finds that the Amazon rainforest could be significantly, and possibly irrevocably, damaged by a warming of 2 - 3°C.

- The melting or collapse of ice sheets would eventually threaten land which today is home to 1 in every 20 people.

While there is much to learn about these risks, the temperatures that may result from unabated climate change will take the world outside the range of human experience. This points to the possibility of very damaging consequences.

The impacts of climate change are not evenly distributed - the poorest countries and people will suffer earliest and most. And if and when the damages appear it will be too late to reverse the process. Thus we are forced to look a long way ahead.

Climate change is a grave threat to the developing world and a major obstacle to continued poverty reduction across its many dimensions. First, developing regions are at a geographic disadvantage: they are already warmer, on average, than developed regions, and they also suffer from high rainfall variability. As a result, further warming will bring poor countries high costs and few benefits. Second, developing countries - in particular the poorest - are heavily dependent on agriculture, the most climate-sensitive of all economic sectors, and suffer from inadequate health provision and low-quality public services. Third, their low incomes and vulnerabilities make adaptation to climate change particularly difficult.

Because of these vulnerabilities, climate change is likely to reduce further already low incomes and increase illness and death rates in developing countries. Falling farm incomes will increase poverty and reduce the ability of households to invest in a better future, forcing them to use up meagre savings just to survive. At a national level, climate change will cut revenues and raise spending needs, worsening public finances.

Many developing countries are already struggling to cope with their current climate. Climatic shocks cause setbacks to economic and social development in developing countries today even with temperature increases of less than 1°C.. The impacts of unabated climate change, - that is, increases of 3 or 4°C and upwards - will be to increase the risks and costs of these events very powerfully.

Impacts on this scale could spill over national borders, exacerbating the damage further. Rising sea levels and other climate-driven changes could drive millions of people to migrate: more than a fifth of Bangladesh could be under water with a 1m rise in sea levels, which is a possibility by the end of the century. Climate-related shocks have sparked violent conflict in the past, and conflict is a serious risk in areas such as West Africa, the Nile Basin and Central Asia.

Climate change may initially have small positive effects for a few developed countries, but is likely to be very damaging for the much higher temperature increases expected by mid- to late-century under BAU scenarios.

In higher latitude regions, such as Canada, Russia and Scandinavia, climate change may lead to net benefits for temperature increases of 2 or 3°C, through higher agricultural yields, lower winter mortality, lower heating requirements, and a possible boost to tourism. But these regions will also experience the most rapid rates of warming, damaging infrastructure, human health, local livelihoods and biodiversity.

Developed countries in lower latitudes will be more vulnerable - for example, water availability and crop yields in southern Europe are expected to decline by 20% with a 2°C increase in global temperatures. Regions where water is already scarce will face serious difficulties and growing costs.

The increased costs of damage from extreme weather (storms, hurricanes, typhoons, floods, droughts, and heat waves) counteract some early benefits of climate change and will increase rapidly at higher temperatures. Based on simple extrapolations, costs of extreme weather alone could reach 0.5 - 1% of world GDP per annum by the middle of the century, and will keep rising if the world continues to warm.

- A 5 or 10% increase in hurricane wind speed, linked to rising sea temperatures, is predicted approximately to double annual damage costs, in the USA.

- In the UK, annual flood losses alone could increase from 0.1% of GDP today to 0.2 - 0.4% of GDP once the increase in global average temperatures reaches 3 or 4°C.

- Heat waves like that experienced in 2003 in Europe, when 35,000 people died and agricultural losses reached $15 billion, will be commonplace by the middle of the century.

At higher temperatures, developed economies face a growing risk of large-scale shocks - for example, the rising costs of extreme weather events could affect global financial markets through higher and more volatile costs of insurance.

Integrated assessment models provide a tool for estimating the total impact on the economy; our estimates suggest that this is likely to be higher than previously suggested.

The second approach to examining the risks and costs of climate change adopted in the Review is to use integrated assessment models to provide aggregate monetary estimates.

Formal modelling of the overall impact of climate change in monetary terms is a formidable challenge, and the limitations to modelling the world over two centuries or more demand great caution in interpreting results. However, as we have explained, the lags from action to effect are very long and the quantitative analysis needed to inform action will depend on such long-range modelling exercises. The monetary impacts of climate change are now expected to be more serious than many earlier studies suggested, not least because those studies tended to exclude some of the most uncertain but potentially most damaging impacts. Thanks to recent advances in the science, it is now possible to examine these risks more directly, using probabilities.

Most formal modelling in the past has used as a starting point a scenario of 2-3°C warming. In this temperature range, the cost of climate change could be equivalent to a permanent loss of around 0-3% in global world output compared with what could have been achieved in a world without climate change. Developing countries will suffer even higher costs.

However, those earlier models were too optimistic about warming: more recent evidence indicates that temperature changes resulting from BAU trends in emissions may exceed 2-3°C by the end of this century. This increases the likelihood of a wider range of impacts than previously considered. Many of these impacts, such as abrupt and large-scale climate change, are more difficult to quantify. With 5-6°C warming - which is a real possibility for the next century - existing models that include the risk of abrupt and large-scale climate change estimate an average 5-10% loss in global GDP, with poor countries suffering costs in excess of 10% of GDP. Further, there is some evidence of small but significant risks of temperature rises even above this range. Such temperature increases would take us into territory unknown to human experience and involve radical changes in the world around us.

With such possibilities on the horizon, it was clear that the modelling framework used by this Review had to be built around the economics of risk. Averaging across possibilities conceals risks. The risks of outcomes much worse than expected are very real and they could be catastrophic. Policy on climate change is in large measure about reducing these risks. They cannot be fully eliminated, but they can be substantially reduced. Such a modelling framework has to take into account ethical judgements on the distribution of income and on how to treat future generations.

The analysis should not focus only on narrow measures of income like GDP. The consequences of climate change for health and for the environment are likely to be severe. Overall comparison of different strategies will include evaluation of these consequences too. Again, difficult conceptual, ethical and measurement issues are involved, and the results have to be treated with due circumspection.

The Review uses the results from one particular model, PAGE2002, to illustrate how the estimates derived from these integrated assessment models change in response to updated scientific evidence on the probabilities attached to degrees of temperature rise. The choice of model was guided by our desire to analyse risks explicitly - this is one of the very few models that would allow that exercise. Further, its underlying assumptions span the range of previous studies. We have used this model with one set of data consistent with the climate predictions of the 2001 report of the Intergovernmental Panel on Climate Change, and with one set that includes a small increase in the amplifying feedbacks in the climate system. This increase illustrates one area of the increased risks of climate change that have appeared in the peer-reviewed scientific literature published since 2001.

We have also considered how the application of appropriate discount rates, assumptions about the equity weighting attached to the valuation of impacts in poor countries, and estimates of the impacts on mortality and the environment would increase the estimated economic costs of climate change.

Using this model, and including those elements of the analysis that can be incorporated at the moment, we estimate the total cost over the next two centuries of climate change associated under BAU emissions involves impacts and risks that are equivalent to an average reduction in global per-capita consumption of at least 5%, now and forever. While this cost estimate is already strikingly high, it also leaves out much that is important.

The cost of BAU would increase still further, were the model systematically to take account of three important factors:

- First, including direct impacts on the environment and human health (sometimes called 'non-market' impacts) increases our estimate of the total cost of climate change on this path from 5% to 11% of global per-capita consumption. There are difficult analytical and ethical issues of measurement here. The methods used in this model are fairly conservative in the value they assign to these impacts.

- Second, some recent scientific evidence indicates that the climate system may be more responsive to greenhouse-gas emissions than previously thought, for example because of the existence of amplifying feedbacks such as the release of methane and weakening of carbon sinks. Our estimates, based on modelling a limited increase in this responsiveness, indicate that the potential scale of the climate response could increase the cost of climate change on the BAU path from 5% to 7% of global consumption, or from 11% to 14% if the non-market impacts described above are included.

- Third, a disproportionate share of the climate-change burden falls on poor regions of the world. If we weight this unequal burden appropriately, the estimated global cost of climate change at 5-6°C warming could be more than one-quarter higher than without such weights.

Putting these additional factors together would increase the total cost of BAU climate change to the equivalent of around a 20% reduction in consumption per head, now and into the future.

In summary, analyses that take into account the full ranges of both impacts and possible outcomes - that is, that employ the basic economics of risk - suggest that BAU climate change will reduce welfare by an amount equivalent to a reduction in consumption per head of between 5 and 20%. Taking account of the increasing scientific evidence of greater risks, of aversion to the possibilities of catastrophe, and of a broader approach to the consequences than implied by narrow output measures, the appropriate estimate is likely to be in the upper part of this range.

Economic forecasting over just a few years is a difficult and imprecise task. The analysis of climate change requires, by its nature, that we look out over 50, 100, 200 years and more. Any such modelling requires caution and humility, and the results are specific to the model and its assumptions. They should not be endowed with a precision and certainty that is simply impossible to achieve. Further, some of the big uncertainties in the science and the economics concern the areas we know least about (for example, the impacts of very high temperatures), and for good reason - this is unknown territory. The main message from these models is that when we try to take due account of the upside risks and uncertainties, the probability-weighted costs look very large. Much (but not all) of the risk can be reduced through a strong mitigation policy, and we argue that this can be achieved at a far lower cost than those calculated for the impacts. In this sense, mitigation is a highly productive investment.

Emissions have been, and continue to be, driven by economic growth; yet stabilisation of greenhouse-gas concentrations in the atmosphere is feasible and consistent with continued growth.

CO_2 emissions per head have been strongly correlated with GDP per head. As a result, since 1850, North America and Europe have produced around 70% of all the CO_2 emissions due to energy production, while developing countries have accounted for less than one quarter. Most future emissions growth will come from today's developing countries, because of their more rapid population and GDP growth and their increasing share of energy-intensive industries.

Yet despite the historical pattern and the BAU projections, the world does not need to choose between averting climate change and promoting growth and development. Changes in energy technologies and the structure of economies have reduced the responsiveness of emissions to income growth, particularly in some of the richest countries. With strong, deliberate policy choices, it is possible to 'decarbonise' both developed and developing economies on the scale required for climate stabilisation, while maintaining economic growth in both.

Stabilisation - at whatever level - requires that annual emissions be brought down to the level that balances the Earth's natural capacity to remove greenhouse gases from the atmosphere. The longer emissions remain above this level, the higher the final stabilisation level. In the long term, annual global emissions will need to be reduced to below 5 $GtCO_2e$, the level that the earth can absorb without adding to the concentration of GHGs in the atmosphere. This is more than 80% below the absolute level of current annual emissions.

This Review has focused on the feasibility and costs of stabilisation of greenhouse gas concentrations in the atmosphere in the range of 450-550ppm CO_2e.

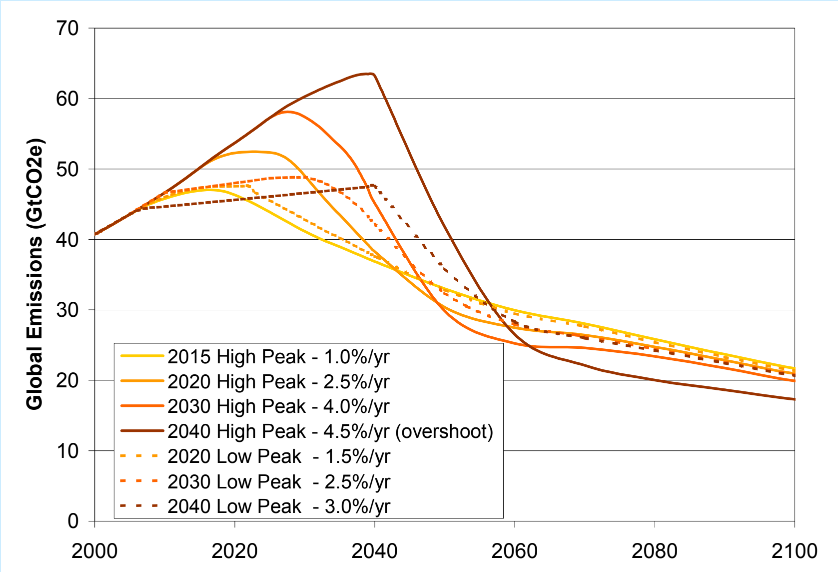
Stabilising at or below 550ppm CO_2e would require global emissions to peak in the next 10 - 20 years, and then fall at a rate of at least 1 - 3% per year. The range of paths is illustrated in Figure 3. By 2050, global emissions would need to be around 25% below current levels. These cuts will have to be made in the context of a world economy in 2050 that may be 3 - 4 times larger than today - so emissions per unit of GDP would need to be just one quarter of current levels by 2050.

To stabilise at 450ppm CO_2e, without overshooting, global emissions would need to peak in the next 10 years and then fall at more than 5% per year, reaching 70% below current levels by 2050.

Theoretically it might be possible to "overshoot" by allowing the atmospheric GHG concentration to peak above the stabilisation level and then fall, but this would be both practically very difficult and very unwise. Overshooting paths involve greater risks, as temperatures will also rise rapidly and peak at a higher level for many decades before falling back down. Also, overshooting requires that emissions subsequently be reduced to extremely low levels, below the level of natural carbon absorption, which may not be feasible. Furthermore, if the high temperatures were to weaken the capacity of the Earth to absorb carbon - as becomes more likely with overshooting - future emissions would need to be cut even more rapidly to hit any given stabilisation target for atmospheric concentration.

Figure 3 Illustrative emissions paths to stabilise at 550ppm CO_2e.

The figure below shows six illustrative paths to stabilisation at 550ppm CO_2e. The rates of emissions cuts given in the legend are the *maximum* 10-year average rate of decline of global emissions. The figure shows that delaying emissions cuts (shifting the peak to the right) means that emissions must be reduced more rapidly to achieve the same stabilisation goal. The rate of emissions cuts is also very sensitive to the height of the peak. For example, if emissions peak at 48 $GtCO_2$ rather than 52 $GtCO_2$ in 2020, the rate of cuts is reduced from 2.5%/yr to 1.5%/yr.



Source: Reproduced by the Stern Review based on Meinshausen, M. (2006): 'What does a 2°C target mean for greenhouse gas concentrations? A brief analysis based on multi-gas emission pathways and several climate sensitivity uncertainty estimates', Avoiding dangerous climate change, in H.J. Schellnhuber et al. (eds.), Cambridge: Cambridge University Press, pp.265 - 280.

Achieving these deep cuts in emissions will have a cost. The Review estimates the annual costs of stabilisation at 500-550ppm CO_2e to be around 1% of GDP by 2050 - a level that is significant but manageable.

Reversing the historical trend in emissions growth, and achieving cuts of 25% or more against today's levels is a major challenge. Costs will be incurred as the world shifts from a high-carbon to a low-carbon trajectory. But there will also be business opportunities as the markets for low-carbon, high-efficiency goods and services expand.

Greenhouse-gas emissions can be cut in four ways. Costs will differ considerably depending on which combination of these methods is used, and in which sector:

- Reducing demand for emissions-intensive goods and services
- Increased efficiency, which can save both money and emissions
- Action on non-energy emissions, such as avoiding deforestation
- Switching to lower-carbon technologies for power, heat and transport

Estimating the costs of these changes can be done in two ways. One is to look at the resource costs of measures, including the introduction of low-carbon technologies and changes in land use, compared with the costs of the BAU alternative. This provides an upper bound on costs, as it does not take account of opportunities to respond involving reductions in demand for high-carbon goods and services.

The second is to use macroeconomic models to explore the system-wide effects of the transition to a low-carbon energy economy. These can be useful in tracking the dynamic interactions of different factors over time, including the response of economies to changes in prices. But they can be complex, with their results affected by a whole range of assumptions.

On the basis of these two methods, central estimate is that stabilisation of greenhouse gases at levels of 500-550ppm CO_2e will cost, on average, around 1% of annual global GDP by 2050. This is significant, but is fully consistent with continued growth and development, in contrast with unabated climate change, which will eventually pose significant threats to growth.

Resource cost estimates suggest that an upper bound for the expected annual cost of emissions reductions consistent with a trajectory leading to stabilisation at 550ppm CO_2e is likely to be around 1% of GDP by 2050.

This Review has considered in detail the potential for, and costs of, technologies and measures to cut emissions across different sectors. As with the impacts of climate change, this is subject to important uncertainties. These include the difficulties of estimating the costs of technologies several decades into the future, as well as the way in which fossil-fuel prices evolve in the future. It is also hard to know how people will respond to price changes.

The precise evolution of the mitigation effort, and the composition across sectors of emissions reductions, will therefore depend on all these factors. But it is possible to make a central projection of costs across a portfolio of likely options, subject to a range.

The technical potential for efficiency improvements to reduce emissions and costs is substantial. Over the past century, efficiency in energy supply improved ten-fold or more in developed countries, and the possibilities for further gains are far from being exhausted. Studies by the International Energy Agency show that, by 2050, energy efficiency has the potential to be the biggest single source of emissions savings in the energy sector. This would have both environmental and economic benefits: energy-efficiency measures cut waste and often save money.

Non-energy emissions make up one-third of total greenhouse-gas emissions; action here will make an important contribution. A substantial body of evidence suggests that action to prevent further deforestation would be relatively cheap compared with other types of mitigation, if the right policies and institutional structures are put in place.

Large-scale uptake of a range of clean power, heat, and transport technologies is required for radical emission cuts in the medium to long term. The power sector around the world will have to be least 60%, and perhaps as much as 75%, decarbonised by 2050 to stabilise at or below 550ppm CO_2e. Deep cuts in the transport sector are likely to be more difficult in the shorter term, but will ultimately be needed. While many of the technologies to achieve this already exist, the priority is to bring down their costs so that they are competitive with fossil-fuel alternatives under a carbon-pricing policy regime.

A portfolio of technologies will be required to stabilise emissions. It is highly unlikely that any single technology will deliver all the necessary emission savings, because all technologies are subject to constraints of some kind, and because of the wide range of activities and sectors that generate greenhouse-gas emissions. It is also uncertain which technologies will turn out to be cheapest. Hence a portfolio will be required for low-cost abatement.

The shift to a low-carbon global economy will take place against the background of an abundant supply of fossil fuels. That is to say, the stocks of hydrocarbons that are profitable to extract (under current policies) are more than enough to take the world to levels of greenhouse-gas concentrations well beyond 750ppm CO_2e, with very dangerous consequences. Indeed, under BAU, energy users are likely to switch towards more carbon-intensive coal and oil shales, increasing rates of emissions growth.

Even with very strong expansion of the use of renewable energy and other low-carbon energy sources, hydrocarbons may still make over half of global energy supply in 2050. Extensive carbon capture and storage would allow this continued use of fossil fuels without damage to the atmosphere, and also guard against the danger of strong climate-change policy being undermined at some stage by falls in fossil-fuel prices.

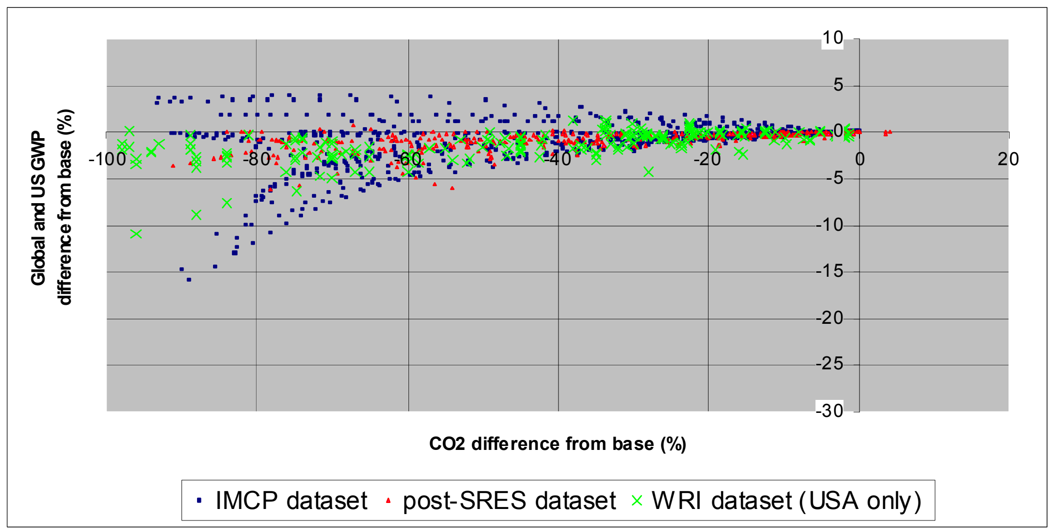
Estimates based on the likely costs of these methods of emissions reduction show that the annual costs of stabilising at around 550ppm CO_2e are likely to be around 1% of global GDP by 2050, with a range from –1% (net gains) to +3.5% of GDP.

Looking at broader macroeconomic models confirms these estimates.

The second approach adopted by the Review was based comparisons of a broad range of macro-economic model estimates (such as that presented in Figure 4 below). This comparison found that the costs for stabilisation at 500-550ppm CO_2e were centred on 1% of GDP by 2050, with a range of -2% to +5% of GDP. The range reflects a number of factors, including the pace of technological innovation and the efficiency with which policy is applied across the globe: the faster the innovation and the greater the efficiency, the lower the cost. These factors can be influenced by policy.

The average expected cost is likely to remain around 1% of GDP from mid-century, but the range of estimates around the 1% diverges strongly thereafter, with some falling and others rising sharply by 2100, reflecting the greater uncertainty about the costs of seeking out ever more innovative methods of mitigation.

Figure 4 Model cost projections scatter plot
Costs of CO_2 reductions as a fraction of world GDP against level of reduction



Source: Barker, T., M.S. Qureshi and J. Köhler (2006): 'The costs of greenhouse-gas mitigation with induced technological change: A Meta-Analysis of estimates in the literature', 4CMR, Cambridge Centre for Climate Change Mitigation Research, Cambridge: University of Cambridge.

A broad range of modelling studies, which include exercises undertaken by the IMCP, EMF and USCCSP as well at work commissioned by the IPCC, show that costs for 2050 consistent with an emissions trajectory leading to stabilisation at around 500-550ppm CO2e are clustered in the range of –2% to 5% of GDP, with an average around 1% of GDP. The range reflects uncertainties over the scale of mitigation required, the pace of technological innovation and the degree of policy flexibility.

The figure above uses Barker's combined three-model dataset to show the reduction in annual CO_2 emissions from the baseline and the associated changes in world GDP. The wide range of model results reflects the design of the models and the choice of assumptions included within them, which itself reflects uncertainties and differing approaches inherent in projecting the future. This shows that the full range of estimates drawn from a variety of stabilisation paths and years extends from –4% of GDP (that is, net gains) to +15% of GDP costs, but this mainly reflects outlying studies; most estimates are still centred around 1% of GDP. In particular, the models arriving at higher cost estimates make assumptions about technological progress that are very pessimistic by historical standards.

Stabilisation at 450ppm CO_2e is already almost out of reach, given that we are likely to reach this level within ten years and that there are real difficulties of making the sharp reductions required with current and foreseeable technologies. Costs rise significantly as mitigation efforts become more ambitious or sudden. Efforts to reduce emissions rapidly are likely to be very costly.

An important corollary is that there is a high price to delay. Delay in taking action on climate change would make it necessary to accept both more climate change and, eventually, higher mitigation costs. Weak action in the next 10-20 years would put stabilisation even at 550ppm CO_2e beyond reach – and this level is already associated with significant risks.

The transition to a low-carbon economy will bring challenges for competitiveness but also opportunities for growth.

Costs of mitigation of around 1% of GDP are small relative to the costs and risks of climate change that will be avoided. However, for some countries and some sectors, the costs will be higher. There may be some impacts on the competitiveness of a small number of internationally traded products and processes. These should not be overestimated, and can be reduced or eliminated if countries or sectors act together; nevertheless, there will be a transition to be managed. For the economy as a whole, there will be benefits from innovation that will offset some of these costs. All economies undergo continuous structural change; the most successful economies are those that have the flexibility and dynamism to embrace the change.

There are also significant new opportunities across a wide range of industries and services. Markets for low-carbon energy products are likely to be worth at least $500bn per year by 2050, and perhaps much more. Individual companies and countries should position themselves to take advantage of these opportunities.

Climate-change policy can help to root out existing inefficiencies. At the company level, implementing climate policies may draw attention to money-saving opportunities. At the economy-wide level, climate-change policy may be a lever for reforming inefficient energy systems and removing distorting energy subsidies, on which governments around the world currently spend around $250bn a year.

Policies on climate change can also help to achieve other objectives**.** These co-benefits can significantly reduce the overall cost to the economy of reducing greenhouse-gas emissions. If climate policy is designed well, it can, for example, contribute to reducing ill-health and mortality from air pollution, and to preserving forests that contain a significant proportion of the world's biodiversity.

National objectives for energy security can also be pursued alongside climate change objectives. Energy efficiency and diversification of energy sources and supplies support energy security, as do clear long-term policy frameworks for investors in power generation. Carbon capture and storage is essential to maintain the role of coal in providing secure and reliable energy for many economies.

Reducing the expected adverse impacts of climate change is therefore both highly desirable and feasible.

This conclusion follows from a comparison of the above estimates of the costs of mitigation with the high costs of inaction described from our first two methods (the aggregated and the disaggregated) of assessing the risks and costs of climate change impacts.

The third approach to analysing the costs and benefits of action on climate change adopted by this Review compares the marginal costs of abatement with the social cost of carbon. This approach compares estimates of the changes in the expected benefits and costs over time from a little extra reduction in emissions, and avoids large-scale formal economic models.

Preliminary calculations adopting the approach to valuation taken in this Review suggest that the social cost of carbon today, if we remain on a BAU trajectory, is of the order of $85 per tonne of CO_2 - higher than typical numbers in the literature, largely because we treat risk explicitly and incorporate recent evidence on the risks, but nevertheless well within the range of published estimates. This number is well above marginal abatement costs in many sectors. Comparing the social costs of carbon on a BAU trajectory and on a path towards stabilisation at 550ppm CO2e, we estimate the excess of benefits over costs, in net present value terms, from implementing strong mitigation policies this year, shifting the world onto the better path: the net benefits would be of the order of $2.5 trillion. This figure will increase over time. This is not an estimate of net benefits occurring in this year, but a measure of the benefits that could flow from actions taken this year; many of the costs and benefits would be in the medium to long term.

Even if we have sensible policies in place, the social cost of carbon will also rise steadily over time, making more and more technological options for mitigation cost-effective. This does not mean that consumers will always face rising prices for the goods and services that they currently enjoy, as innovation driven by strong policy will ultimately reduce the carbon intensity of our economies, and consumers will then see reductions in the prices that they pay as low-carbon technologies mature.

The three approaches to the analysis of the costs of climate change used in the Review all point to the desirability of strong action, given estimates of the costs of action on mitigation. But how much action? The Review goes on to examine the economics of this question.

The current evidence suggests aiming for stabilisation somewhere within the range 450 - 550ppm CO_2e. Anything higher would substantially increase the risks of very harmful impacts while reducing the expected costs of mitigation by comparatively little. Aiming for the lower end of this range would mean that the costs of mitigation would be likely to rise rapidly. Anything lower would certainly impose very high adjustment costs in the near term for small gains and might not even be feasible, not least because of past delays in taking strong action.

Uncertainty is an argument for a more, not less, demanding goal, because of the size of the adverse climate-change impacts in the worst-case scenarios.

The ultimate concentration of greenhouse gases determines the trajectory for estimates of the social cost of carbon; these also reflect the particular ethical judgements and approach to the treatment of uncertainty embodied in the modelling. Preliminary work for this Review suggests that, if the target were between 450-550ppm CO_2e, then the social cost of carbon would start in the region of $25-30 per tonne of CO_2 – around one third of the level if the world stays with BAU.

The social cost of carbon is likely to increase steadily over time because marginal damages increase with the stock of GHGs in the atmosphere, and that stock rises over time. Policy should therefore ensure that abatement efforts at the margin also intensify over time. But it should also foster the development of technology that can drive down the average costs of abatement; although pricing carbon, by itself, will not be sufficient to bring forth all the necessary innovation, particularly in the early years.

The first half of the Review therefore demonstrates that strong action on climate change, including both mitigation and adaptation, is worthwhile, and suggests appropriate goals for climate-change policy.

The second half of the Review examines the appropriate form of such policy, and how it can be placed within a framework of international collective action.

Policy to reduce emissions should be based on three essential elements: carbon pricing, technology policy, and removal of barriers to behavioural change.

There are complex challenges in reducing greenhouse-gas emissions. Policy frameworks must deal with long time horizons and with interactions with a range of other market imperfections and dynamics.

A shared understanding of the long-term goals for stabilisation is a crucial guide to policy-making on climate change: it narrows down strongly the range of acceptable emissions paths. But from year to year, flexibility in what, where and when reductions are made will reduce the costs of meeting these stabilisation goals.

Policies should adapt to changing circumstances as the costs and benefits of responding to climate change become clearer over time. They should also build on diverse national conditions and approaches to policy-making. But the strong links between current actions and the long-term goal should be at the forefront of policy.

Three elements of policy for mitigation are essential: a carbon price, technology policy, and the removal of barriers to behavioural change. Leaving out any one of these elements will significantly increase the costs of action.

Establishing a carbon price, through tax, trading or regulation, is an essential foundation for climate-change policy.

The first element of policy is carbon pricing. Greenhouse gases are, in economic terms, an externality: those who produce greenhouse-gas emissions are bringing about climate change, thereby imposing costs on the world and on future generations, but they do not face the full consequences of their actions themselves.

Putting an appropriate price on carbon – explicitly through tax or trading, or implicitly through regulation – means that people are faced with the full social cost of their actions. This will lead individuals and businesses to switch away from high-carbon goods and services, and to invest in low-carbon alternatives. Economic efficiency points to the advantages of a common global carbon price: emissions reductions will then take place wherever they are cheapest.

The choice of policy tool will depend on countries' national circumstances, on the characteristics of particular sectors, and on the interaction between climate-change policy and other policies. Policies also have important differences in their consequences for the distribution of costs across individuals, and their impact on the public finances. Taxation has the advantage of delivering a steady flow of revenue, while, in the case of trading, increasing the use of auctioning is likely to have strong benefits for efficiency, for distribution and for the public finances. Some administrations may choose to focus on trading initiatives, others on taxation or regulation, and others on a mix of policies. And their choices may vary across sectors.

Trading schemes can be an effective way to equalise carbon prices across countries and sectors, and the EU Emissions Trading Scheme is now the centrepiece of European efforts to cut emissions. To reap the benefits of emissions trading, schemes must provide incentives for a flexible and efficient response. Broadening the scope of trading schemes will tend to lower costs and reduce volatility. Clarity and predictability about the future rules and shape of schemes will help to build confidence in a future carbon price.

In order to influence behaviour and investment decisions, investors and consumers must believe that the carbon price will be maintained into the future. This is particularly important for investments in long-lived capital stock. Investments such as power stations, buildings, industrial plants and aircraft last for many decades. If there is a lack of confidence that climate change policies will persist, then businesses may not factor a carbon price into their decision-making. The result may be overinvestment in long-lived, high-carbon infrastructure – which will make emissions cuts later on much more expensive and difficult.

But establishing credibility takes time. The next 10 to 20 years will be a period of transition, from a world where carbon-pricing schemes are in their infancy, to one where carbon pricing is universal and is automatically factored into decision making. In this transitional period, while the credibility of policy is still being established and the international framework is taking shape, it is critical that governments consider how to avoid the risks of locking into a high-carbon infrastructure, including considering whether any additional measures may be justified to reduce the risks.

Policies are required to support the development of a range of low-carbon and high-efficiency technologies on an urgent timescale.

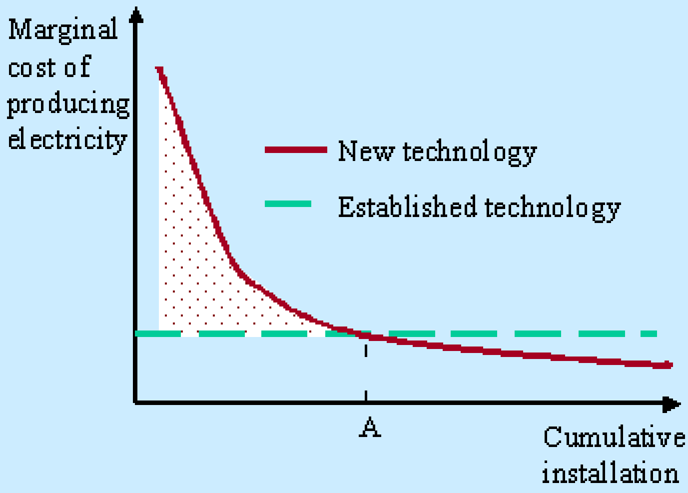
The second element of climate-change policy is technology policy, covering the full spectrum from research and development, to demonstration and early stage deployment. The development and deployment of a wide range of low-carbon technologies is essential in achieving the deep cuts in emissions that are needed. The private sector plays the major role in R&D and technology diffusion, but closer collaboration between government and industry will further stimulate the development of a broad portfolio of low carbon technologies and reduce costs.

Many low-carbon technologies are currently more expensive than the fossil-fuel alternatives. But experience shows that the costs of technologies fall with scale and experience, as shown in Figure 5 below.

Carbon pricing gives an incentive to invest in new technologies to reduce carbon; indeed, without it, there is little reason to make such investments. But investing in new lower-carbon technologies carries risks. Companies may worry that they will not have a market for their new product if carbon-pricing policy is not maintained into the future. And the knowledge gained from research and development is a public good; companies may under-invest in projects with a big social payoff if they fear they will be unable to capture the full benefits. Thus there are good economic reasons to promote new technology directly.

Public spending on research, development and demonstration has fallen significantly in the last two decades and is now low relative to other industries. There are likely to be high returns to a doubling of investments in this area to around $20 billion per annum globally, to support the development of a diverse portfolio of technologies.

Figure 5: The costs of technologies are likely to fall over time



Historical experience of both fossil-fuel and low-carbon technologies shows that as scale increases, costs tend to fall. Economists have fitted 'learning curves' to costs data to estimate the size of this effect. An illustrative curve is shown above for a new electricity-generation technology; the technology is initially much more expensive than the established alternative, but as its scale increases, the costs fall, and beyond Point A it becomes cheaper. Work by the International Energy Agency and others shows that such relationships hold for a range of different energy technologies.

A number of factors explain this, including the effects of learning and economies of scale. But the relationship is more complex than the figure suggests. Step-change improvements in a technology might accelerate progress, while constraints such as the availability of land or materials could result in increasing marginal costs.

In some sectors - particularly electricity generation, where new technologies can struggle to gain a foothold - policies to support the market for early-stage technologies will be critical. The Review argues that the scale of existing deployment incentives worldwide should increase by two to five times, from the current level of around $34 billion per annum. Such measures will be a powerful motivation for innovation across the private sector to bring forward the range of technologies needed.

The removal of barriers to behavioural change is a third essential element, one that is particularly important in encouraging the take-up of opportunities for energy efficiency.

The third element is the removal of barriers to behavioural change. Even where measures to reduce emissions are cost-effective, there may be barriers preventing action. These include a lack of reliable information, transaction costs, and behavioural and organisational inertia. The impact of these barriers can be most clearly seen in the frequent failure to realise the potential for cost-effective energy efficiency measures.

Regulatory measures can play a powerful role in cutting through these complexities, and providing clarity and certainty. Minimum standards for buildings and appliances have proved a cost-effective way to improve performance, where price signals alone may be too muted to have a significant impact.

Information policies, including labelling and the sharing of best practice, can help consumers and businesses make sound decisions, and stimulate competitive markets for low-carbon and high-efficiency goods and services. Financing measures can also help, through overcoming possible constraints to paying the upfront cost of efficiency improvements.

Fostering a shared understanding of the nature of climate change, and its consequences, is critical in shaping behaviour, as well as in underpinning national and international action. Governments can be a catalyst for dialogue through evidence, education, persuasion and discussion. Educating those currently at school about climate change will help to shape and sustain future policy-making, and a broad public and international debate will support today's policy-makers in taking strong action now.

Adaptation policy is crucial for dealing with the unavoidable impacts of climate change, but it has been under-emphasised in many countries.

Adaptation is the only response available for the impacts that will occur over the next several decades before mitigation measures can have an effect.

Unlike mitigation, adaptation will in most cases provide local benefits, realised without long lead times. Therefore some adaptation will occur autonomously, as individuals respond to market or environmental changes. Some aspects of adaptation, such as major infrastructure decisions, will require greater foresight and planning. There are also some aspects of adaptation that require public goods delivering global benefits, including improved information about the climate system and more climate-resilient crops and technologies.

Quantitative information on the costs and benefits of economy-wide adaptation is currently limited. Studies in climate-sensitive sectors point to many adaptation options that will provide benefits in excess of cost. But at higher temperatures, the costs of adaptation will rise sharply and the residual damages remain large. The additional costs of making new infrastructure and buildings resilient to climate change in OECD countries could be $15 – 150 billion each year (0.05 – 0.5% of GDP).

The challenge of adaptation will be particularly acute in developing countries, where greater vulnerability and poverty will limit the capacity to act. As in developed countries, the costs are hard to estimate, but are likely to run into tens of billions of dollars.

Markets that respond to climate information will stimulate adaptation among individuals and firms. Risk-based insurance schemes, for example, provide strong signals about the size of climate risks and therefore encourage good risk management.

Governments have a role in providing a policy framework to guide effective adaptation by individuals and firms in the medium and longer term. There are four key areas:

- High-quality climate information and tools for risk management will help to drive efficient markets. Improved regional climate predictions will be critical, particularly for rainfall and storm patterns.

- Land-use planning and performance standards should encourage both private and public investment in buildings and other long-lived infrastructure to take account of climate change.

- Governments can contribute through long-term polices for climate-sensitive public goods, including natural resources protection, coastal protection, and emergency preparedness.

- A financial safety net may be required for the poorest in society, who are likely to be the most vulnerable to the impacts and least able to afford protection (including insurance).

Sustainable development itself brings the diversification, flexibility and human capital which are crucial components of adaptation. Indeed, much adaptation will simply be an extension of good development practice – for example, promoting overall development, better disaster management and emergency response. Adaptation action should be integrated into development policy and planning at every level.

An effective response to climate change will depend on creating the conditions for international collective action.

This Review has identified many actions that communities and countries can take on their own to tackle climate change.

Indeed, many countries, states and companies are already beginning to act. However, the emissions of most individual countries are small relative to the global total, and very large reductions are required to stabilise greenhouse gas concentrations in the atmosphere. Climate change mitigation raises the classic problem of the provision of a global public good. It shares key characteristics with other environmental challenges that require the international management of common resources to avoid free riding.

The UN Framework Convention on Climate Change (UNFCCC), Kyoto Protocol and a range of other informal partnerships and dialogues provide a framework that supports co-operation, and a foundation from which to build further collective action.

A shared global perspective on the urgency of the problem and on the long-term goals for climate change policy, and an international approach based on multilateral frameworks and co-ordinated action, are essential to respond to the scale of the challenge. International frameworks for action on climate change should encourage and respond to the leadership shown by different countries in different ways, and should facilitate and motivate the involvement of all states. They should build on the principles of effectiveness, efficiency and equity that have already provided the foundations of the existing multilateral framework.

The need for action is urgent: demand for energy and transportation is growing rapidly in many developing countries, and many developed countries are also due to renew a significant proportion of capital stock. The investments made in the next 10-20 years could lock in very high emissions for the next half-century, or present an opportunity to move the world onto a more sustainable path.

International co-operation must cover all aspects of policy to reduce emissions – pricing, technology and the removal of behavioural barriers, as well as action on emissions from land use. And it must promote and support adaptation. There are significant opportunities for action now, including in areas with immediate economic benefits (such as energy efficiency and reduced gas flaring) and in areas where large-scale pilot programmes would generate important experience to guide future negotiations.

Agreement on a broad set of mutual responsibilities across each of the relevant dimensions of action would contribute to the overall goal of reducing the risks of climate change. These responsibilities should take account of costs and the ability to bear them, as well as starting points, prospects for growth and past histories.

Securing broad-based and sustained co-operation requires an equitable distribution of effort across both developed and developing countries. There is no single formula that captures all dimensions of equity, but calculations based on income, historic responsibility and per capita emissions all point to rich countries taking responsibility for emissions reductions of 60-80% from 1990 levels by 2050.

Co-operation can be encouraged and sustained by greater transparency and comparability of national action.

Creating a broadly similar carbon price signal around the world, and using carbon finance to accelerate action in developing countries, are urgent priorities for international co-operation.

A broadly similar price of carbon is necessary to keep down the overall costs of making these reductions, and can be created through tax, trading or regulation. The transfer of technologies to developing countries by the private sector can be accelerated through national action and international co-operation.

The Kyoto Protocol has established valuable institutions to underpin international emissions trading. There are strong reasons to build on and learn from this approach. There are opportunities to use the UNFCCC dialogue and the review of the effectiveness of the Kyoto Protocol, as well as a wide range of informal dialogues, to explore ways to move forward.

Private sector trading schemes are now at the heart of international flows of carbon finance. Linking and expanding regional and sectoral emissions trading schemes, including sub-national and voluntary schemes, requires greater international co-operation and the development of appropriate new institutional arrangements.

Decisions made now on the third phase of the EU ETS provide an opportunity for the scheme to influence, and become the nucleus of, future global carbon markets.

The EU ETS is the world's largest carbon market. The structure of the third phase of the scheme, beyond 2012, is currently under debate. This is an opportunity to set out a clear, long-term vision to place the scheme at the heart of future global carbon markets.

There are a number of elements which will contribute to a credible vision for the EU ETS. The overall EU limit on emissions should be set at a level that ensures scarcity in the market for emissions allowances, with stringent criteria for allocation volumes across all relevant sectors. Clear and frequent information on emissions during the trading period would improve transparency in the market, reducing the risks of unnecessary price spikes or of unexpected collapses.

Clear revision rules covering the basis for allocations in future trading periods would create greater predictability for investors. The possibility of banking (and perhaps borrowing) emissions allowances between periods could help smooth prices over time.

Broadening participation to other major industrial sectors, and to sectors such as aviation, would help deepen the market, and increased use of auctioning would promote efficiency.

Enabling the EU ETS to link with other emerging trading schemes (including in the USA and Japan), and maintaining and developing mechanisms to allow the use of carbon reductions made in developing countries, could improve liquidity while also establishing the nucleus of a global carbon market.

Scaling up flows of carbon finance to developing countries to support effective policies and programmes for reducing emissions would accelerate the transition to a low-carbon economy.

Developing countries are already taking significant action to decouple their economic growth from the growth in greenhouse gas emissions. For example, China has adopted very ambitious domestic goals to reduce energy used for each unit of GDP by 20% from 2006-2010 and to promote the use of renewable energy. India has created an Integrated Energy Policy for the same period that includes measures to expand access to cleaner energy for poor people and to increase energy efficiency.

The Clean Development Mechanism, created by the Kyoto Protocol, is currently the main formal channel for supporting low-carbon investment in developing countries. It allows both governments and the private sector to invest in projects that reduce emissions in fast-growing emerging economies, and provides one way to support links between different regional emissions trading schemes.

In future, a transformation in the scale of, and institutions for, international carbon finance flows will be required to support cost-effective emissions reductions. The incremental costs of low-carbon investments in developing countries are likely to be at least $20-30 billion per year. Providing assistance with these costs will require a major increase in the level of ambition of trading schemes such as the EU ETS. This will also require mechanisms that link private-sector carbon finance to policies and programmes rather than to individual projects. And it should work within a context of national, regional or sectoral objectives for emissions reductions. These flows will be crucial in accelerating private investment and national government action in developing countries.

There are opportunities now to build trust and to pilot new approaches to creating large-scale flows for investment in low-carbon development paths. Early signals from existing emissions trading schemes, including the EU ETS, about the extent to which they will accept carbon credits from developing countries, would help to maintain continuity during this important stage of building markets and demonstrating what is possible.

The International Financial Institutions have an important role to play in accelerating this process: the establishment of a Clean Energy Investment Framework by the World Bank and other multilateral development banks offers significant potential for catalysing and scaling up investment flows.

Greater international co-operation to accelerate technological innovation and diffusion will reduce the costs of mitigation.

The private sector is the major driver of innovation and the diffusion of technologies around the world. But governments can help to promote international collaboration to overcome barriers in this area, including through formal arrangements and through arrangements that promote public-private co-operation such as the Asia Pacific Partnership. Technology co-operation enables the sharing of risks, rewards and progress of technology development and enables co-ordination of priorities.

A global portfolio that emerges from individual national R&D priorities and deployment support may not be sufficiently diverse, and is likely to place too little weight on some technologies that are particularly important for developing countries, such as biomass.

International R&D co-operation can take many forms. Coherent, urgent and broadly based action requires international understanding and co-operation. These may be embodied in formal multilateral agreements that allow countries to pool the risks and rewards for major investments in R&D, including demonstration projects and dedicated international programmes to accelerate key technologies. But formal agreements are only one part of the story - informal arrangements for greater co-ordination and enhanced linkages between national programmes can also play a very prominent role.

Both informal and formal co-ordination of national policies for deployment support can accelerate cost reductions by increasing the scale of new markets across borders. Many countries and US states now have specific national objectives and policy frameworks to support the deployment of renewable energy technologies. Transparency and information-sharing have already helped to boost interest in these markets. Exploring the scope for making deployment instruments tradable across borders could increase the effectiveness of support, including mobilising the resources that will be required to accelerate the widespread deployment of carbon capture and storage and the use of technologies that are particularly appropriate for developing countries.

International co-ordination of regulations and product standards can be a powerful way to encourage greater energy efficiency. It can raise their cost effectiveness, strengthen the incentives to innovate, improve transparency, and promote international trade.

The reduction of tariff and non-tariff barriers for low-carbon goods and services, including within the Doha Development Round of international trade negotiations, could provide further opportunities to accelerate the diffusion of key technologies.

Curbing deforestation is a highly cost-effective way of reducing greenhouse gas emissions.

Emissions from deforestation are very significant – they are estimated to represent more than 18% of global emissions, a share greater than is produced by the global transport sector.

Action to preserve the remaining areas of natural forest is needed urgently. Large-scale pilot schemes are required to explore effective approaches to combining national action and international support.

Policies on deforestation should be shaped and led by the nation where the particular forest stands. But those countries should receive strong help from the international community, which benefits from their actions to reduce deforestation. At a national level, defining property rights to forestland, and determining the rights and responsibilities of landowners, communities and loggers, is key to effective forest management. This should involve local communities, respect informal rights and social structures, work with development goals and reinforce the process of protecting the forests.

Research carried out for this report indicates that the opportunity cost of forest protection in 8 countries responsible for 70 per cent of emissions from land use could be around $5 billion per annum initially, although over time marginal costs would rise.

Compensation from the international community should take account of the opportunity costs of alternative uses of the land, the costs of administering and enforcing protection, and the challenges of managing the political transition as established interests are displaced.

Carbon markets could play an important role in providing such incentives in the longer term. But there are short-term risks of destabilising the crucial process of strengthening existing strong carbon markets if deforestation is integrated without agreements that strongly increase demand for emissions reductions. These agreements must be based on an understanding of the scale of transfers likely to be involved.

Adaptation efforts in developing countries must be accelerated and supported, including through international development assistance.

The poorest developing countries will be hit earliest and hardest by climate change, even though they have contributed little to causing the problem. Their low incomes make it difficult to finance adaptation. The international community has an obligation to support them in adapting to climate change. Without such support there is a serious risk that development progress will be undermined.

It is for the developing countries themselves to determine their approach to adaptation in the context of their own circumstances and aspirations. Rapid growth and development will enhance countries' ability to adapt. The additional costs to developing countries of adapting to climate change could run into tens of billions of dollars.

The scale of the challenge makes it more urgent than ever for developed countries to honour their existing commitments – made in Monterrey in 2002, and strengthened at EU Councils in June 2005 and at the July 2005 G8 Gleneagles Summit – to double aid flows by 2010.

Donors and multilateral development institutions should mainstream and support adaptation across their assistance to developing countries. The international community should also support adaptation through investment in global public goods, including improved monitoring and prediction of climate change, better modelling of regional impacts, and the development and deployment of drought- and flood-resistant crops.

In addition, efforts should be increased to build public-private partnerships for climate-related insurance; and to strengthen mechanisms for improving risk management and preparedness, disaster response and refugee resettlement.

Strong and early mitigation has a key role to play in limiting the long- run costs of adaptation. Without this, the costs of adaptation will rise dramatically.

Building and sustaining collective action is now an urgent challenge.

The key building blocks for any collective action include developing a shared understanding of the long-term goals for climate policy, building effective institutions for co-operation, and demonstrating leadership and working to build trust with others.

Without a clear perspective on the long-term goals for stabilisation of greenhouse gas concentrations in the atmosphere, it is unlikely that action will be sufficient to meet the objective.

Action must include mitigation, innovation and adaptation. There are many opportunities to start now, including where there are immediate benefits and where large-scale pilot programmes will generate valuable experience. And we have already begun to create the institutions to underpin co-operation.

The challenge is to broaden and deepen participation across all the relevant dimensions of action – including co-operation to create carbon prices and markets, to accelerate innovation and deployment of low-carbon technologies, to reverse emissions from land-use change and to help poor countries adapt to the worst impacts of climate change.

There is still time to avoid the worst impacts of climate change if strong collective action starts now.

This Review has focused on the economics of risk and uncertainty, using a wide range of economic tools to tackle the challenges of a global problem which has profound long-term implications. Much more work is required, by scientists and economists, to tackle the analytical challenges and resolve some of the uncertainties across a broad front. But it is already very clear that the economic risks of inaction in the face of climate change are very severe.

There are ways to reduce the risks of climate change. With the right incentives, the private sector will respond and can deliver solutions. The stabilisation of greenhouse gas concentrations in the atmosphere is feasible, at significant but manageable costs.

The policy tools exist to create the incentives required to change investment patterns and move the global economy onto a low-carbon path. This must go hand-in-hand with increased action to adapt to the impacts of the climate change that can no longer be avoided.

Above all, reducing the risks of climate change requires collective action. It requires co-operation between countries, through international frameworks that support the achievement of shared goals. It requires a partnership between the public and private sector, working with civil society and with individuals. It is still possible to avoid the worst impacts of climate change; but it requires strong and urgent collective action. Delay would be costly and dangerous.

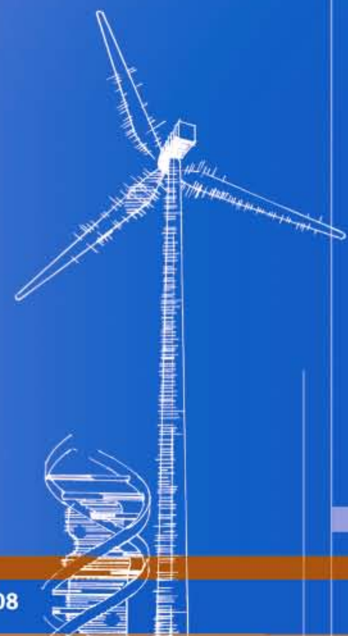
A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

National Renewable Energy Laboratory
Innovation for Our Energy Future

Feed-in Tariff Policy: Design, Implementation, and RPS Policy Interactions

Karlynn Cory, Toby Couture, and Claire Kreycik

Technical Report
NREL/TP-6A2-45549
March 2009



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National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, Colorado 80401-3393
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Introduction

Feed-in tariff (FIT) policies are implemented in more than 40 countries around the world and are cited as the primary reason for the success of the German and Spanish renewable energy markets (Grace 2008, Stern 2006). As a result of that success, FIT policy proposals are starting to gain traction in several U.S. states and municipalities. A number of states have considered FIT legislation or regulation, including Florida, Hawaii, Illinois, Indiana, Maine, Massachusetts, Michigan, Minnesota, New Jersey, New York, Oregon, Rhode Island, Virginia, Washington and Wisconsin; and a federal FIT proposal has also been developed (Gipe 2009, Rickerson et. al. 2008b). Three other municipal utilities have also proposed FIT policies, including Los Angeles, California (Los Angeles 2008); Palm Desert, California; and Santa Monica, California (Ferguson 2009).

Experience from Europe is also beginning to demonstrate that properly designed FITs may be more cost-effective than renewable portfolio standards (RPS), which make use of competitive solicitations. This article explores the design and operation of feed-in tariff policies, including a FIT policy definition, payment-structure options, and payment differentiation. The article also touches on the potential interactions between FIT policies and RPS policies at the state level.

FIT Policy Definition

A feed-in tariff (FIT) is an energy-supply policy focused on supporting the development of new renewable power generation. In the United States, FIT policies may require utilities to purchase either electricity, or both electricity and the renewable energy (RE) attributes from eligible renewable energy generators.[1] The FIT contract provides a guarantee of payments in dollars per kilowatt hour ($/kWh) for the full output of the system[2] for a guaranteed period of time (typically 15-20 years). A separate meter is required to track the actual total system output.[3] This payment guarantee is often coupled with the assurance of access to the grid (Rickerson et. al. 2008b), and the actual payment amount is usually differentiated based on technology type, project size, quality of the resource and/or other project-specific variables (Klein et. al. 2008). Feed-in tariffs are also generally structured according to a standard power purchase contract.

There are two main methodologies for setting the overall return that RE developers receive through FIT policies. The first is to base the FIT payments **on the levelized cost of RE generation**; the second is to base the FIT payments **on the value of that generation to the utility and/or society**.[4] In the first approach, the payment level is based on the levelized cost of RE generation, plus a stipulated return (set by the policy makers, regulators, or program administrators). The advantage of this approach is that the FIT payments can be specifically designed to ensure that project investors obtain a reasonable rate of return, while creating conditions more conducive to market growth.

The second method of setting FIT payments is by estimating the value of the renewable energy (Grace 2008). This value can be defined in a number of ways, either according to the utility's avoided costs, or by attempting to internalize the "externality" costs of conventional generation. Externality costs can include things such as the value of climate mitigation, health and air quality impacts, and/or effects on the energy security (Klein et. al. 2008). This can be considered the "value-based" approach, which contrasts with the first, "RE project cost-based" approach. Value-based FIT payments require quantification of these numerous benefits (either to the utility, society, and/or the environment) to establish the total compensation, potentially leading to a high degree of administrative complexity. The challenge is that value-based approaches may not match the actual RE generation costs, and may provide insufficient payments to stimulate rapid market growth. Alternatively, they may provide payments that are higher than generation costs, leading to cost-inefficiency.

Most successful European FIT policies, which resulted in quick and substantial RE capacity expansion (often at both distributed and utility-scale levels), have FIT payments structured to

---

[1] In Europe, FIT policies may or may not include the attributes. It is presumed that under current U.S. law, payment for the power would be made under Federal Energy Regulatory Commission (FERC) wholesale power rules, and payment for the RECs could be made under state law. However, this is an assumption, and these issues will need to be clarified using a proper legal review in due course.

[2] The payment guarantee is usually designed to cover the all-in cost of project development, which includes a specified target return on equity investment (determined by the policy makers). However, the payment guarantee may be at a fixed or variable price.

[3] FIT policies pay for the entire output of the system and are different from net metering, because net- metered generation only receives credit for the excess generation sent to the grid.

[4] The Chabot Profitability Index is not explored here, but is a third, less frequently used option.

cover the RE project cost, plus an estimated profit (Klein et. al. 2008). Many U.S. states currently use value-based cost methodologies to support renewable projects. However, value-based FIT policies, whether tied to avoided costs or to external social and environmental costs, have so far been unsuccessful at driving rapid growth in renewable energy (Grace 2008, Jacobsson and Lauber 2005).

FIT Payment Structure

Given that they have proved to be the most effective, only FIT policy designs that are based on the levelized cost of RE generation are included here. Accordingly, this section provides an overview of the two most common FIT payment designs: the fixed-price and the premium-price FIT options. One variation of the premium-price FIT design is the "spot-market gap" model, currently implemented in the Netherlands (van Erck 2008). A spot market is one where energy can be sold for cash and delivered immediately. It may be of particular interest to policy makers in the United States, because it represents a novel FIT design that may be found to be more compatible with the current U.S. regulatory policy environment.

Fundamental FIT Payment Options

One primary FIT payment-structure choice is whether the project owner's compensation is tied to fluctuations in the actual market price of electricity. These two different policy options are often characterized as either fixed-price or premium-price policies (the premium being a FIT payment above spot-market prices) (Held et al. 2007, Klein et. al. 2008). These two models dominate FIT policy design;[5] however, most countries with FIT policies choose the fixed-price approach (Klein et al. 2008, Mendonca 2007).

Figure 1 illustrates a fixed-price FIT policy. In this policy design, the total FIT payment to the project remains independent from the market price, and is a predetermined payment for a guaranteed period of time. Because fixed-price FIT policies offer market-independent payments, they create stable conditions for investors. This risk reduction can lead to lower project-financing costs (de Jager and Rathmann 2008).

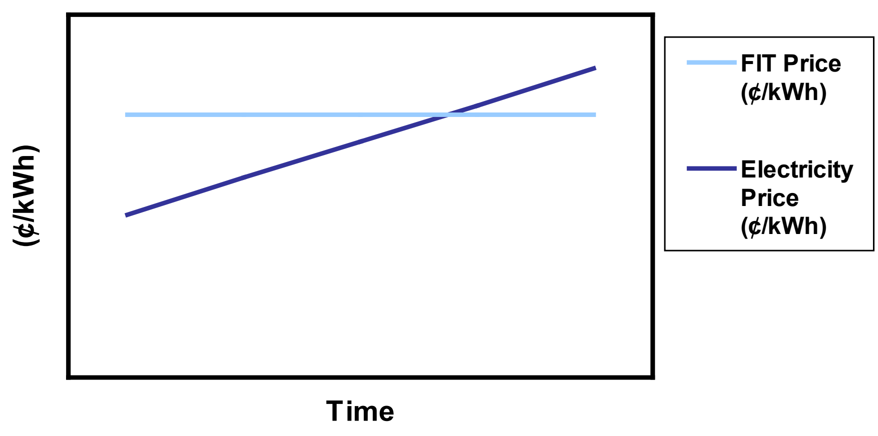

Figure 1. Fixed-price FIT model

[5] Another design is the percentage of retail price methodology, where the FIT payment is based on a percentage of the retail rate (which could be lower or higher than 100%). This structure was abandoned by Germany and Denmark in 2000 (Jacobsson and Lauber 2005, Nielsen 2005) and by Spain in 2006 (Held et al. 2007); today, both Spain and Germany use the renewable energy cost-based methodology.

FIT payments can also be offered as a premium on top of the spot-market electricity price. One variation is shown in Figure 2. Under a premium-level FIT policy, the project owner receives payment for the total electricity generated (at market prices), as well as a FIT payment.

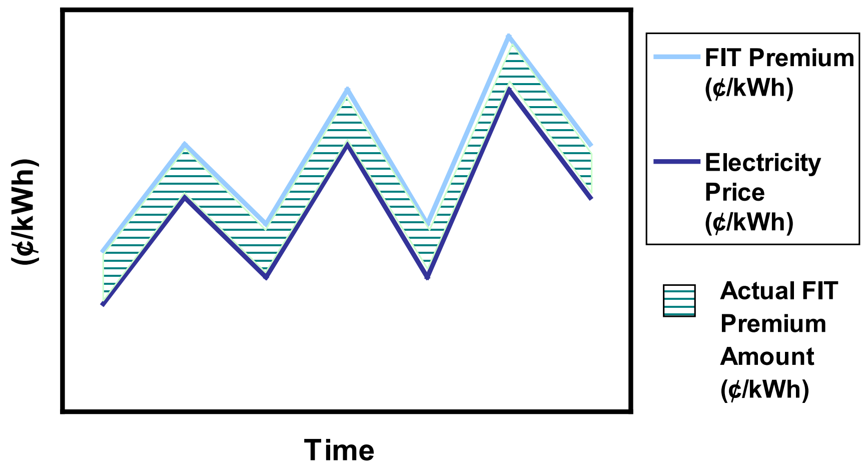

Figure 2. Non-variable premium-price FIT model

The premium FIT payments can be either non-variable (as a fixed, predetermined adder), or variable (where the premium varies as a function of the spot-market electricity price). Although a non-variable premium is a simpler design (shown in Figure 2), it risks resulting in windfall profits for developers if spot-market prices for electricity increase significantly. Similarly, if electricity prices fall, the investor return would be at risk, which would tend to put upward pressure on project-financing costs. This risk premium method would require proportionally higher payments to obtain the same amount of renewable energy development (Mendonca 2007, Klein et. al. 2008).

Two premium-price FIT designs attempt to address the challenges of over- or under-compensation by more closely targeting compensation based on renewable energy project costs. Spain introduced a variable premium-price FIT design with both a price cap and a price floor as part of its Royal Decree 661/2007 (Held et al. 2007). On an hourly basis, it ensures that the FIT premium payment declines as electricity prices increase, and vice versa (Klein et. al. 2008). This strategy provides more stable revenues for developers by introducing a minimum compensation level, and limits the exposure of the ratepayers by reducing the FIT payment level if electricity prices increase.

The other variable-premium FIT payment structure based on RE project costs is the "spot-market gap" model currently implemented in the Netherlands (Figure 3). It represents a hybrid approach between the fixed-price and the premium-price models. In this approach, the government guarantees that projects will receive a predetermined, minimum total payment. From a developer's standpoint, this makes it virtually indistinguishable from a fixed-price FIT. However, instead of paying projects the total amount through a FIT payment (as the fixed-price FIT policy in Figure 1), the project receives this payment through two separate revenue streams. The first is the prevailing spot-market price of electricity. The second is a variable FIT payment that covers the real-time difference between a minimum total payment guarantee and the spot-market price (van Erck 2008). Because the FIT payment covers the difference between the spot-market price and the required FIT price, the actual FIT payment fluctuates over time, covering the "gap" between the two. And because the actual FIT payment only includes the fluctuating premium, the FIT program costs could be more easily calculated. The incremental burden of the FIT policy on utilities may also be minimized.

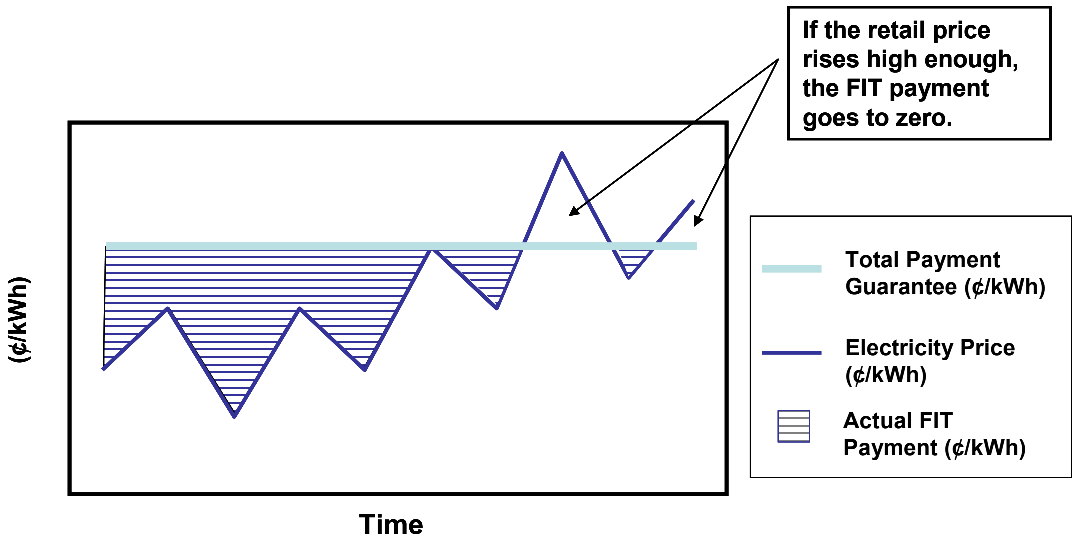

Figure 3. The Netherlands' premium-price FIT (Spot-Market Gap Model)

For both the Spanish and the Dutch premium-FIT models, if the market price rises above the guaranteed payment, then the FIT premium drops to zero (Held et al. 2007, Klein et. al. 2008). By providing limits on premium-price FIT payments, Spain and the Netherlands have provided developers the necessary revenues to secure investment while limiting the total costs of their FIT programs.

There are a few reasons why the spot-market gap model may be suitable to the U.S. political and regulatory context. First, the incremental cost of the policy can be transparently derived from the sum of the "spot-market gap" payments. Second, if electricity prices increase over time, the FIT payment eventually converges to zero, as the spot price rises above the required FIT price. This also provides a concrete means of quantifying the hedge benefit of fixed-price FIT payments. Finally, the spot-market gap could be designed to represent the fluctuating REC value, which could be contracted in conjunction with wholesale electricity purchases.[6] However, there would remain two main challenges to using this model in the United States: The first is that the spot-market price of electricity is not transparent everywhere in the United States, although it could be represented using the utility's avoided cost of generation or another similar cost estimation. Second, this model is much more complex to administer than a fixed-price model, which could add to the overall policy cost.

[6] This may be important if there are legal questions surrounding a state's ability to regulate power costs above wholesale rates, (which are under the jurisdiction of the Federal Energy Regulatory Commission).

FIT Payment Differentiation

Another important distinction in feed-in tariff design is how the payment levels will be differentiated, based on project-specific factors. These factors can include the **technology type** (whether solar, wind, geothermal, etc.; or the fuel type, in the case of biomass and biogas), the **size of the project** (to account for economies of scale), the **quality of the resource** at that particular site (to encourage broad deployment of wind and solar power, and limit windfall profits at high-quality sites), and/or the **specific location** of the project (e.g., building integrated, offshore wind) (Grace 2008, Klein et. al. 2008).

Because each renewable energy generation project is unique, differentiation of FIT payments to account for these differences can ensure that a variety of technologies and project sizes come online. Many European FITs provide an equal opportunity for both small (residential) and large (industrial) customers to own renewable energy generation. In most cases, the utility with whom the generator interconnects provides the FIT payment and is then allowed to pass on any incremental costs to its customers (Klein et. al. 2008). Also, in most jurisdictions, utilities are eligible to participate and are provided the same payment-level guarantee (Jacobsson and Lauber 2005, Held et al. 2007, Klein et al. 2008) (i.e., in the United States, this would mean that regulatory "prudency" issues are addressed in the program design[7]). The fact that FITs impose very few limits, if any, on who can participate in selling renewable power to the grid has made them a powerful vehicle for leveraging both local and global capital toward RE development.

[7] Regulators may question whether a utility investment was prudent or not; the utility is not allowed to recover any cost from their customers that is disallowed as "not prudent."

FIT–RPS Policy Interactions

The renewable portfolio standard[8] (RPS) is the most common state-level policy in the United States today. As such, one of the first questions when a FIT policy is considered in the United States is whether it would replace or conflict with existing RPS policies. While the design details of each policy will determine the answer, it is clear that the two policies can be structured to work together – and can even do so synergistically (Rickerson and Grace 2007, Grace 2008).

RPS Overview

RPS policies require electric utilities to provide renewable electricity to their customers, typically as a percentage of total energy use. Twenty-eight states and the District of Columbia have mandatory RPS policies, five states have voluntary RPS goals (DSIRE 2009c), and more states (as well as the federal government) are considering implementing similar policies.

RPS policies appear to have successfully motivated new renewable development in certain regions of the United States. From 1998-2007, an estimated 8,900 MW of new non-hydro renewable capacity (more than half of that constructed) was built in states with RPS policies (although it is difficult to demonstrate that RPS policies were the only factor driving RE development in these states).[9] In addition, most states have achieved compliance in the early years of their RPS requirements (Wiser and Barbose 2008). However, some RPS policies appear to have a number of challenges encouraging new and rapid RE development in the United States. These include uncertainties associated with project financing (Wiser and Barbose 2008), relatively high contract failure rates in states such as California (Wiser and Barbose 2008), a high level of market concentration due to the limited number of investors (Chadbourne and Parke 2008), and little local and community-scale involvement in renewable energy development (Bolinger 2004). The combination of these challenges has increased the interest in alternative approaches for RE procurement such as feed-in tariffs in the United States.

FIT and RPS Policy Distinctions

It is important to note the main differences between FIT and RPS policies to understand their potential relationship to each other. RPS mandates prescribe *how much customer demand* must be met with renewables, while properly structured FIT policies attempt to support *new supply development* by providing investor certainty. As mentioned earlier, FIT policies are typically designed to provide a renewable project with revenue streams sufficient to cover development costs, plus a reasonable return. They are focused on setting the right *price* to drive RE deployment. In contrast, most RPS policies are focused on the *quantity*, leaving the price up to competitive bidding.

Under an RPS, the load-serving entities or central procurement agency must determine how they will comply with the mandate. Typically, a competitive solicitation is used to secure supply to meet RPS policies in the United States. Utilities issue a request for proposals and select the projects that offer the most promising package of siting, operational expertise, and cost. However, due to the high costs of developing a bid, the high risk of failing to obtain a contract,

[8] In Europe, RPS policies are called quota-based mechanisms, quota obligations, or renewables obligations.
[9] Other factors include the voluntary green power market (which covers about half of new renewable projects) and favorable wind project economics compared to current electricity prices.

and the nature of the investors financing projects at this scale, the return on investment requirements in competitive solicitations are generally much higher than in jurisdictions employing feed-in tariffs (de Jager and Rathmann 2008, Ragwitz et. al. 2007, EREF 2007, Ernst & Young 2008, Fouquet and Johansson 2008). While the transaction costs may be only a small percentage of the total project cost, they increase the return on investment requirement, which ultimately increases the required payment price. These high transaction costs also make it difficult for smaller investors to participate. Also, the overall market structure that results from a competitive bidding framework limits the investor pool and can lead to a less-dynamic RE market (Dinica 2006, Grace 2008).

Experience in Europe is beginning to demonstrate that due to the stable investment environment created under well-designed FIT policies, renewable energy development and financing can happen more quickly and often more cost-effectively than under competitive solicitations (de Jager and Rathmann 2008, Ernst & Young 2008, Stern 2006, EREF 2007, Fouquet and Johansson 2008). In addition, the guaranteed contract terms enable project developers to finance a larger proportion of the project with debt financing, as opposed to equity, which puts further downward pressure on the cost of capital (de Jager and Rathmann 2008, Kahn 1996).

One of the most important elements of FIT design is the guarantee of reliable revenue streams (Klein et. al. 2008). This has helped catalyze renewable energy development in countries such as Germany, where both small and large developers can invest for a profit in renewable energy technology. And the fact that FIT policies are generally designed to cover the cost of the renewable energy project, plus a reasonable return, helps ensure that the costs to society of RE development are minimized.

FIT Application in the U.S.

As of early 2009, only a few U.S. jurisdictions have enacted FIT policies. The most notable example is the solar photovoltaic (PV) FIT passed by the municipal utility in Gainesville, Florida in February 2009 (RE World 2009). It is the first and only U.S. FIT policy structured the same way as many successful European FIT policies: It is based on the cost to develop the renewable generation project, plus a stipulated 5%-6% return. California has also created a statewide FIT program, but the payments are based on the utility's avoided cost and not on the actual cost of the RE project (DSIRE 2009a, Rickerson et al. 2008a). Several U.S. utilities have enacted fixed-price production-based incentive policies that can be considered FITs, including Green Mountain Power (Vermont) (GMP 2008), Eugene Water & Electric Board in Oregon (DSIRE 2009b), WE Energies in Wisconsin (WE Energies 2009), and Madison Gas and Electric in Wisconsin (MG&E 2009). Finally, Washington State passed voluntary FIT legislation, and all but one public utility district now has a FIT policy (Nelson 2008). These FIT programs are structured rather simply, were implemented in the past two or three years, and have enjoyed limited success.

How FITs Can Complement RPS Policies

Several challenges to new renewable project financing (not always addressed using RPS policies) may be addressed using FIT policies. In fact, FIT policies can be used to help meet RPS policy targets, as described below. It is important to note that considerable research is still required concerning these interactions, and that few actual designs have been tested.[10]

1. **Project-financing support.** Not all states have RPS design elements that support new project financing, such as a requirement for long-term contracts or centralized state procurement (Wiser and Barbose 2008). Without long-term support to secure investment, renewable projects will likely have difficulty securing financing (Cory et. al. 2004), which could result in a shortage of supply to meet RPS demand. FIT policies provide the revenues that project investors require and can ensure that enough supply will come online.

2. **Cost-effective procurement mechanism.** Due to the guaranteed contract terms and the stable investment environment created by FITs, these policies appear to be a cost-effective procurement mechanism for renewable energy development. They could be used alongside competitive solicitations; or, provided the FIT payments are differentiated to account for economies of scale, they could be used to replace competitive solicitations to meet government-established renewable goals, similar to what is done in countries such as Germany and Spain.

3. **Hedge against project delays and cancellations.** Among other things, project siting and access to transmission can challenge even the best and most economical renewable projects (Wiser et. al. 2005). If a utility's renewable procurement process does not consider the likelihood that a project will be developed (and just looks at lowest cost, for instance), then it is likely that not all of the projects under contract will be built – the utility, therefore, is less likely to meet its RPS. Rather than having the utility determine which projects go forward (i.e., with whom it will sign contracts), the government or utility can establish eligibility criteria as well as a payment level under a FIT – anyone who qualifies and is interested in investing in RE technology can do so and obtain a standardized utility supply contract (without the transaction costs or any potential gaming). This can help ensure that the best portfolio of projects moves forward.

4. **Focus on "reasonable-cost" renewables.** Similar to other power production, utilities must justify their costs for RPS compliance, whether through power purchase agreements or utility-owned projects. While the focus on "least-cost" principles attempts to minimize ratepayer costs, they may pressure utilities to negotiate contract prices for renewable projects that are inadequate to secure financing (and fail to adequately address investor risks). Instead of focusing on least cost, FIT policies focus on estimates of the actual costs required to build renewable projects based on technology and other project-specific considerations. If designed well, the FIT can ensure that a variety of projects receive just enough to cover their costs and a reasonable return.

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[10] In an attempt to arrive at a European Union-wide RE policy, the European Commission conducted several comparisons of country-specific renewable energy policies. As a direct result, most European literature has focused on the benefits of FIT policies and RPS policies as alternatives to one another, rather than as complements to each other. Only recently (2008) did the commission decide that using a single policy across all of Europe may not be appropriate. In the United States, information comparing FITs and RPS policies can be found in regulatory dockets in both California and New Jersey.

5. **Assured support for emerging technologies.** New or emerging technologies[11] may not be able to secure financing, even with long-term utility contracts. The projected revenues need to be high enough to support the additional investment risk faced by investors. This higher risk requires higher-equity returns than commercially available renewable energy projects. Appropriately structured FIT policies will include this risk premium for emerging technologies (paid for by the ratepayers) and provide the long-term assurance that investors require.

6. **Provide ratepayer backing.** Regulated utility generation is sometimes subject to "prudence" reviews of investments and contracts after projects are built. If costs are deemed to not be prudent, the utility will have to cover the costs itself instead of relying on ratepayers, sometimes retroactively. Ultimately, this means that utilities may be uncertain as to whether they will be able to recover the costs from a contract or the ownership of new renewable projects. Overall, the FIT structure can provide more certainty, because the FIT payments are backed by the ratepayers and typically are not subject to retroactive regulatory prudency review. This certainty can help utilities become interested in FIT policies, particularly if the utilities are eligible to participate as project owners.

Overall, decision makers have several options to consider when considering FIT policies. They can be used in parallel and wholly separate from RPS policies, they can replace a part of the current mechanism (perhaps to support a solar carve-out, or distributed generation), or they can be used to entirely replace RPS mechanisms. Of course, they can also be used by states with voluntary renewable energy goals to advance renewable energy development.

FIT Policy Challenges

As with most policies, the FIT policy has some notable challenges. The first is the up-front administrative requirement: Detailed analysis is required to properly set the payment level at the outset. The payment level must ensure revenues will be adequate to cover project costs. If the FIT payments are set too low, then little new RE development will result. And if set too high, the FIT may provide unwarranted profits to developers. To achieve the right balance across a wide range of technologies and project sizes, many levels of differentiation are used. However, if the FIT policy is too complex with too many bonuses, exemptions, and qualifications, it may hinder program implementation. And as costs change and markets shift due to technological innovation and increasing market maturity, the FIT policy needs periodic revision to reflect evolving costs and market conditions.

Second, in contrast to other financial incentives for renewables, FITs do not decrease a developer's up-front costs. Policy makers enact investment tax credits, grants, and rebates to reduce the high, up-front capital costs of RE installations. As seen in the U.S. context, grants and rebates can be integral in increasing the market penetration of small, customer-sited projects.

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[11] Based on a series of conversations with the insurance industry (for another project), the insurance industry believes that any new product from any company (e.g., a specific PV module from company X) is still a prototype until it has reached 3,000–8,000 hours of operation (lower end for PV or other products without moving parts, and higher end for natural gas turbines and wind turbines).

Unlike production incentives or FITs, grants and rebates do not require a long-term policy and financial commitment to a specific project, allowing for flexible support based on changes in the market (Wiser and Pickle 1997). However, these mechanisms may not be effective at spurring broad market adoption, and they have often failed to provide stable conditions for market growth (Lantz and Doris 2009).

Another concern is the total cost of the program if it is designed to include tariffs for costlier emerging technologies. While FITs can be efficient at promoting these technologies, a decision must be made regarding the total acceptable cost burden, and how that impact is weighed related to the job creation and economic benefits that result. For instance, locking in large amounts of solar PV in long-term contracts could be considered cost-inefficient, and could put unwarranted upward pressure on rates in the near term. However, a capacity cap (either program-wise or annually) can limit this exposure.

Finally, frequent updates to the FIT program *structure* can lead to policy uncertainty. The more uncertain the policy structure – even a few years out – the riskier the RE investment is to the project financier. The result may be that either an additional risk premium is added to investor returns, or the investor may leave the RE market and choose to invest in something else with less exposure to policy risk (Chadbourne & Parke 2009).

Conclusions

Feed-in tariffs are intended to increase the adoption of renewable energy technologies, encourage the development of the RE industry, and provide significant economic development benefits. Experience from Europe suggests that a well-designed feed-in tariff can generate rapid growth for targeted RE technologies by creating conditions that attract capital to those particular sectors. By using a variety of design variables to incentivize production in different areas as well as projects of different sizes, FIT policies can help encourage a variety of RE technology types and different-sized RE projects.

Feed-in tariffs differ from one jurisdiction to another, reflecting a wide spectrum in the sophistication and refinement of the policy design. Supporters of FIT policies consider this ability to adapt to particular contexts, and to be finely tuned according to particular policy goals, a crucial element in their success and overall cost-efficiency. Further, the price guarantee and long-term policy certainty offered by FITs have propelled some countries to the forefront of the global RE industry, creating hundreds of thousands of jobs and countless economic opportunities in new and emerging sectors. Their success at driving rapid RE growth will continue to fuel interest in FIT policies as the demand for renewable energy technologies continues to grow both in the United States and around the world.

Overall, a FIT policy can be developed to work in concert with an RPS policy, which sets a goal or mandate of *how much* customer demand should be provided by renewables. A properly structured FIT policy attempts to provide investor certainty to help support new supply development. FIT policies generally provide preapproved guarantees of payments to the developer and investors, whereas RPS policies leave the compliance and investment up to the market. For states that want to provide assurance to investors, drive more capital to the market, and get more projects built, a FIT can be a useful, complementary policy to an RPS.

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14. ABSTRACT *(Maximum 200 Words)*
Feed-in tariff (FIT) policies are implemented in more than 40 countries around the world and are cited as the primary reason for the success of the German and Spanish renewable energy markets. As a result of that success, FIT policy proposals are starting to gain traction in several U.S. states and municipalities. Experience from Europe is also beginning to demonstrate that properly designed FITs may be more cost-effective than renewable portfolio standards (RPS), which make use of competitive solicitations. This article explores the design and operation of feed-in tariff policies, including a FIT policy definition, payment-structure options, and payment differentiation. The article also touches on the potential interactions between FIT policies and RPS policies at the state level.

15. SUBJECT TERMS
NREL; feed-in tariff; FIT; renewable portfolio standard; RPS; renewable energy certificate; REC; electricity; Europe; renewable energy markets; levelized cost; FIT policy; Toby Couture; Karlynn Cory; Claire Kreycik

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E R E F

European Renewable Energies Federation

Prices for Renewable Energies in Europe: Feed in tariffs versus Quota Systems – a comparison

Report 2006/2007

Editor: Dr. Doerte Fouquet

Content

I. Introduction

This is the fourth EREF report on Renewable Electricity Prices in the European Union and it is the first report ever prepared in this field which covers EU-27, Croatia, Turkey and the Former Yugoslav Republic of Macedonia. Since Romania and Bulgaria were not members of the European Union in 2006 they may sometimes still be tabled as adhesion countries in this report.
The following chapter will show the present total price levels for electricity from renewable energy sources received by the renewable electricity (RES) producers.

1. A crucial time for energy in Europe calls for challenging sectoral targets for Renewables

This report comes out at a crucial time for energy supply and for renewable energies in Europe. The European Commission recently published in January 2007 its important new energy package.

In line with our experience as independent power producers and related industry operating in several countries we share the evaluation of the Commission, that Europe will unfortunately not be able to fulfil its 2010 Renewable Energy targets and promises.

The new Roadmap for Renewable Energy published by the Commission within the Energy Package has the following main views:

- underlines that Europe will fall short in reaching its 2010 target of a 12 % share of share of renewable energy in gross inland consumption. 10 % is the realistic projection for now until 2010.
- sees the Road Map as an integral part of the Strategic European Energy Review, sets out a “long-term vision” for renewable energy sources in the EU
- proposes that the EU establishes a mandatory (legally binding) global target of 20% for renewable energy's share of energy consumption in the EU by 2020, not subdivided into different sectors such as electricity, heating/cooling,
- proposes a new legislative framework for the promotion and the use of renewable energy in the European Union
- appeals and underlines the necessity that **all** EU Member States must get their act together and in all sectors (electricity, transport, heating/cooling)
- underlines the uneven growth path in the EU with substantial inadequacies in many Member States
- huge amount of barriers (grid access, planning obstacles)
- support mechanisms that are too vulnerable to political change
- criticises the absence of legally binding targets for renewable energies at EU level,
- acknowledges the relatively weak EU regulatory framework for the use of renewables in the transport sector, and the
- complete absence of a legal framework in the heating and cooling sector

EREF demands that Europe continue to encourage Member States to do much more in all sectors: transport, heating/cooling and electricity. Together with the other industry associations, NGOs and academia, we will certainly continue the dialogue with the Commission, the Parliament and the Council, especially under the German Presidency.

Sectoral targets will ensure that Member States cannot easily move for “cheap” renewable energies or for efforts in just one sector. And it will help to maintain growth for independent power producers which are, together with the supplying industry, the main driving forces for sustainable job creation, regional and local economic and social added value. By continued growth in the overall variety of RES technologies and application the learning curve benefits and price reduction will rapidly continue to have beneficial effects on the market.

The big utilities with power in the production and the grid have created a politically dangerous, under-controlled market situation in Europe. This drove prices for electricity and gas far beyond any expectations of politicians for liberalisation of the energy markets, even excluding direct link to the rise in oil and gas prices which just added to the burden. It narrowed democratic and political control and the current response by the European Commission to stop this cartelisation by those oligopolies is a very important step towards some normality on a highly disturbed so-called energy market.

Member States should be careful not to opt just for big, cost-intensive RES installations as offshore wind farms alone, especially if those farms would predominately be under the control of the big utilities due to their financial resources.

Offshore is a great step forward for mass RES production and certainly needed, but current bitter experience of severe distortions in the energy market caused by the incumbent industry must lead to awareness by politicians to strive for a support approach which gives a clear signal of openness for independent power production. The same caution should be exercised concerning concentration on just co-firing of palm-tree residues in waste incinerators. No unsustainable biomass use should be permitted in the future. Clear ecological standards, European-wide and internationally, must be introduced and respected.

And there is still a lot of room for sustainable development of new onshore wind energy and small hydro in most Member States.

2. Feed-in is the hit

As also underlined by the European Commission within its new Energy Package the overall distortion of the energy market, the non-internalisation of externalities of fossil and nuclear power production still requires renewable energy support mechanisms in the Member States that ensure investor confidence and guarantee fair and stable access to the overall energy market.

In Europe, two major different compensation systems are used in order to promote the generation of electricity from renewable energy sources: quota systems and minimum price systems.

Feed-in Tariffs

- (Priority) Access of RES to the grid at guaranteed tariff for a specific and defined time period
- Some Feed-in systems (Spain) have a special extra premium tariff paid in addition to the market price

Quota Obligation with green certificates

- Government defines quota target
- RES is traded at market electricity price
- Additional income from certificate trading
- Prices for certificates are based on quota target and depend market variation

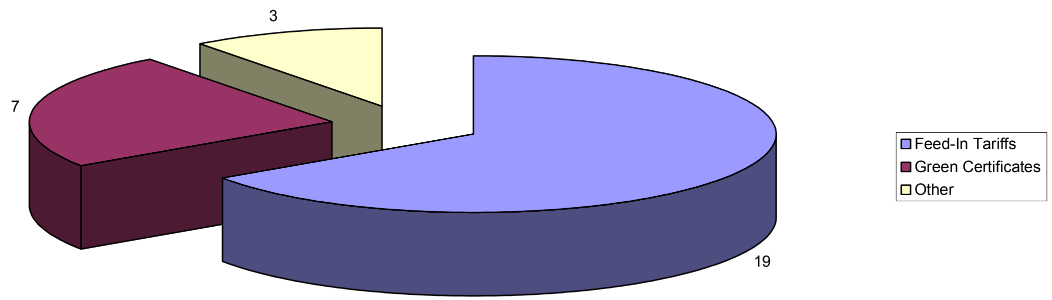
In feed-in-systems fixed tariffs for the feed-in of green electricity into the grid are guaranteed. Moreover it sets a legal obligation for utilities and grid operators to buy electricity from producers who use renewable energy sources.
The main advantages of feed-in systems are in EREF's experience:

- Rapid growth of renewable energies within good and sustainable planning procedures without any cap or artificial restrictions by quota
- Investment security and efficient financing schemes with much lower risk assessment than in certificate systems
- Incentive to create RES based independent power production with
- Enormous benefit in economic value for SMEs and for formerly deprived rural or peripheral areas in Europe
- Strong growth in new, qualified jobs (e.g. 175.000 in Germany in 2006)
- Rapid decrease in costs for RES technology

On the other hand, in a quota system the quantity of energy produced from renewable sources is specified as a percentage of the total annual electricity consumption. Compensation can be applied by emitting certificates to the supplier of renewable electricity. The outcome for an investor depends on the electricity and certificate market prices in the years to come.

The vast majority of all EU Member States uses feed-in mechanisms.

<u>Graphic 1</u> **RES support schemes in EU Member States**



- *Feed-in tariffs: Austria, Cyprus, Czech Republic, Denmark, Estonia, France, Germany, Greece, Hungary, Ireland, Italy (only PV plants not eligible for Green Certificates), Lithuania, Luxembourg, Malta (PV only), Netherlands, Portugal, Slovak republic, Slovenia, Spain.*
- *Green Certificates: Belgium, Bulgaria, Great Britain, Italy, Poland, Romania, Sweden*
- *Other: Finland (tax subsidies), Latvia (solely quota obligation), Malta (tax-subsidies)*

When stable feed-in systems are in place together with well-organised legislation and frameworks for allowances and grid connection, development of capacity for electricity from renewable energy sources is very fast. At the same time the cost for such a system often is considerably lower than for other systems in force.

3. The instability of quota/ certificate mechanisms threatens investor’s confidence

EREF supports since many years well-designed feed-in system with priority access to the grid and in a functioning administrative and political environment with clear objectives.

But especially the incumbent centralised industry in its oligopoly structure always calls for quota and certificate systems for supporting RES. They claim these systems are closer to the market. Calls for harmonisation towards a unified support scheme from this industry continuously ask for a shift to quota/certificate.

Reality is different though. Ireland had in the past relied on a quota/tendering system and did not manage to increase its RES share substantially. Since 2006 they switched to feed-in systems in order to finally accelerate the market penetration of RES.

Quota systems face a high volatility and uncertainty concerning the value of the certificate in the future. This makes investment structure difficult.

As an example, the following variation of prices occurred in Sweden only in 2006:

For wind power:	Between	(28+20+6)	=	**54** to	(70+20+6)	=	**96** EUR/MWh
For other RES-E:	Between	(28+20)	=	**48** to	(70+20)	=	**90** EUR/MWh

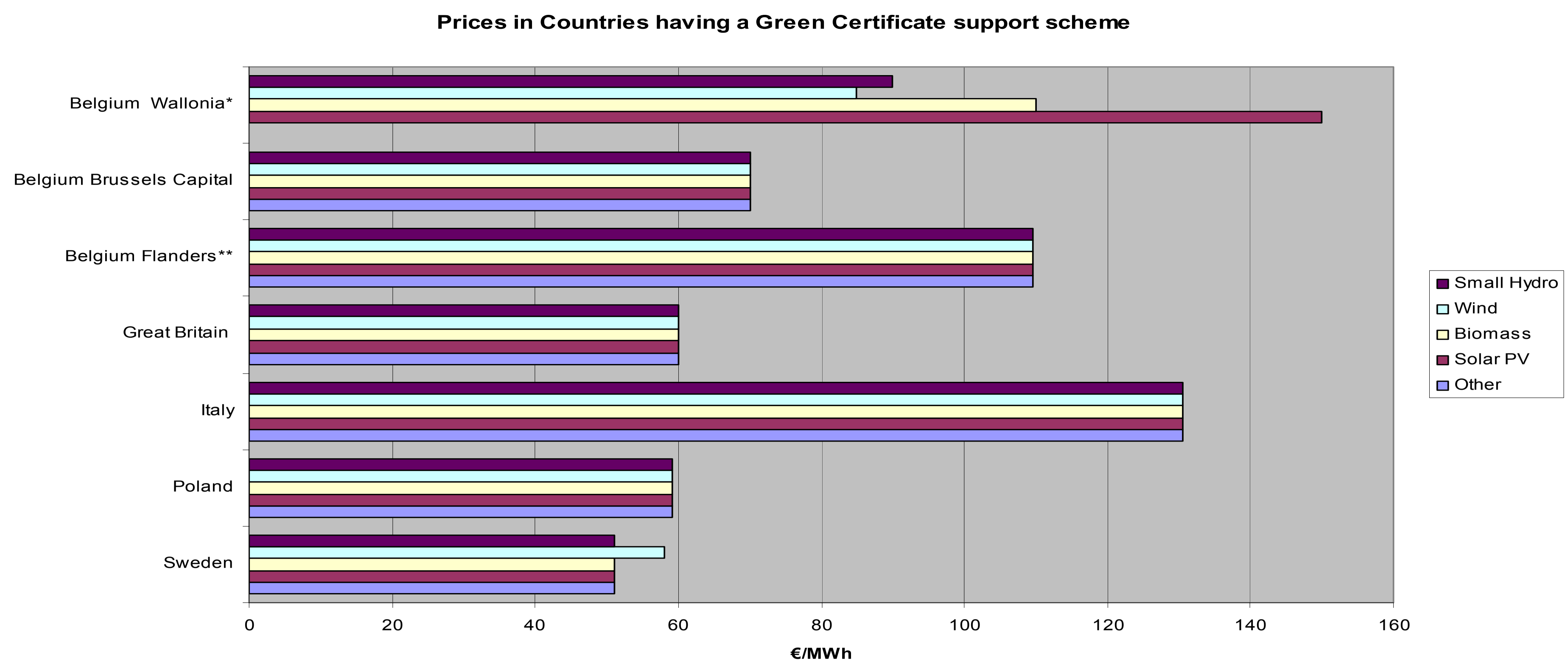
The calculation is based on Market Price + Certificate Price + Bonus (only for wind).

This price report 2006/2007 again underlines that the assumption of better competitiveness of quota schemes is far from true. The biggest price reduction of technologies and learning curve effects were generated only in stable well-organised feed-in markets such as in Germany and in Spain. Other countries do profit from the acquisition of RES technologies which are now much cheaper than a decade ago across all technologies including PV and Solar thermal thanks to pioneer work of those successful feed-in systems such as the Danish, German or Spanish systems.

We tried to draw tables, overviews concerning the different price systems, technologies and support mechanisms. They are shown below. It has to be underlined that especially the real price paid under quota and certificate systems to the producers often depends from various factors such as the current overall electricity price or the .

We also would like to stress, that Belgium with it three different types of systems in the different regions makes it difficult to come to an average price per country Belgium. We have tried to define this average and use it but one should not go with this average price and seek Belgian reality. It is an indicative price as result of evaluating the indicative prices in the three regions, which adds to complication. Moreover this, depending the region, the RES source (hydro, wind, biomass, solar etc.) and the individual agreement one finds strong variations. For example in Wallonia in 2006 the average price (price for electricity + price for quota) for hydro was about 90 EUR /MWh, for wind 85 EUR/MWh and for biomass 110 EUR/MWh. In some cases especially in biomass the price for the certificate is fairly low (20 EUR/MWh), but the biomass electricity producer receive the highest price for the electricity. The Belgian situation as such is on average as following in the different regions in comparison to the other non feed-in countries:

Graphic2



* market price + market Green Certificate
** price of Green Certificate with guarantee of origin

4. The overall electricity market price situation in Europe and the RES prices

The different price levels for RES have also to be seen in comparison with overall electricity prices for wholesale in the different countries respectively electricity trade regions. This has to be kept in mind when looking at the following graphs and country reports.

Electricity prices on the spot market and for the different consumer groups are constantly increasing in the whole European Union.

According to statistics of the European Commission the “forward prices” for 2007 and 2008 on the Nordic Market have “continued at historically high levels and lately exceeded EUR 50/MWh for the calendar year 2007” (*DG Energy and Transport, Q*uarterly Review of European Electricity and Gas Prices, issue 8, September 2006).

For the Western market sphere (*BE, NL, FR,DE, AT, SI*) by the end of 2005 the forward price for a 2006 calendar year base load contract on the French and German wholesale markets had increased to EUR 53/MWh. Prices for the calendar year 2007 are even higher at around EUR 57/MWh. Day ahead prices during the winter period 2005/2006 have been in the range EUR 65-75/MWh. [In *comparison: The average household price (small customer range) in Germany climbed in 2006 to just under EUR 120/MWh before tax-* (*DG Energy and Transport, Q*uarterly Review of European Electricity and Gas Prices, issue 7, April 2006.)].

In the United Kingdom forward prices are expected with prices for Q1 2007 between EUR 80-90/MWh (DG Energy and Transport, issue 8).

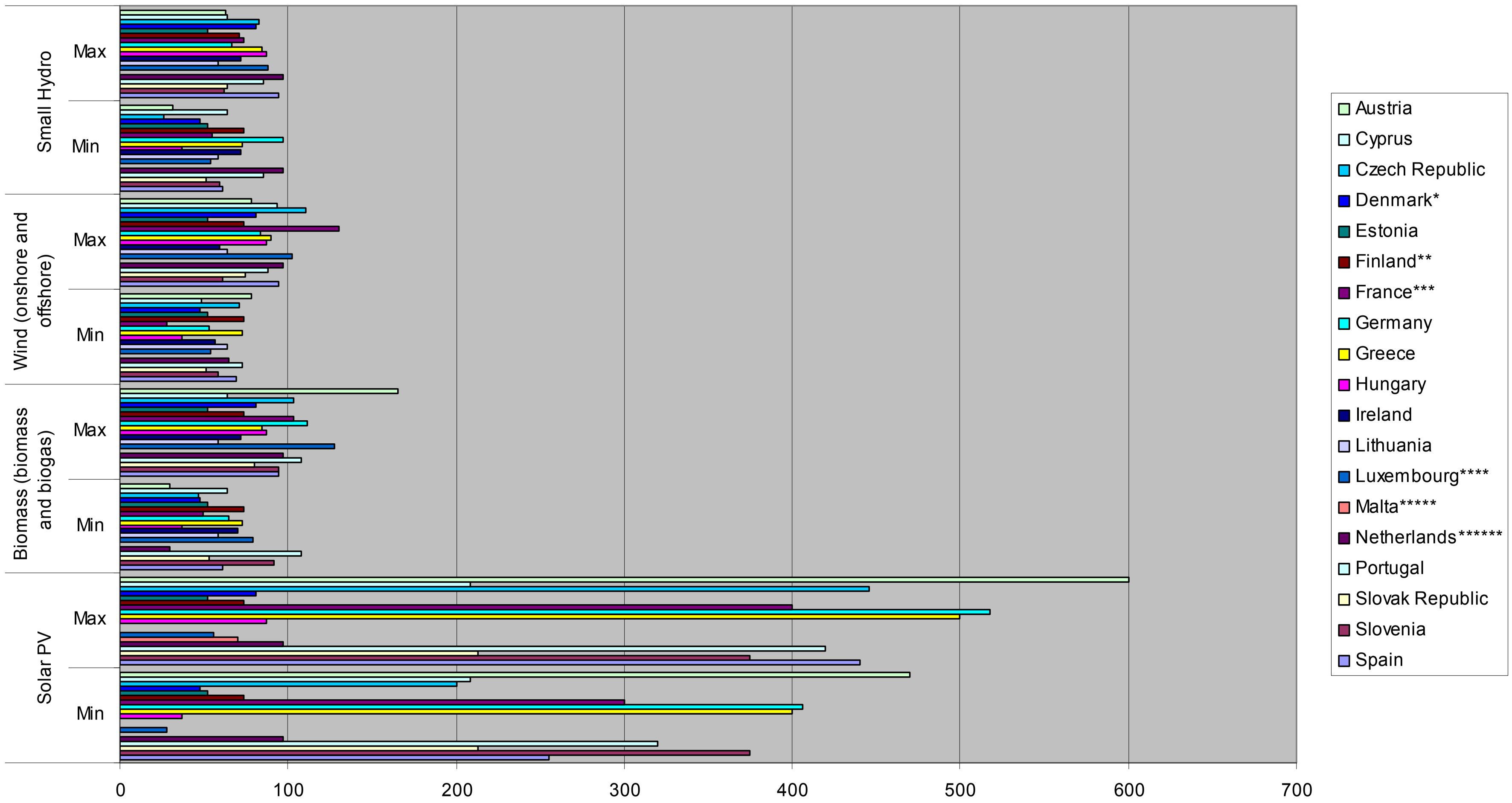
For Spain wholesale prices for 2006 and the expected forward price for 2007 are around EUR 50/MWh (DG Energy and Transport, issue 8).

Italy price level average for wholesale lays at around EUR 80/MWh. *[In Italy household prices were at EUR 140/MWh in January 2006 and remain the highest in Europe], (* DG Energy and Transport, issue 8).

In the EU Member States in Central Europe *(PL, CZ, SL, HU)* wholesale prices increased. The average wholesale price in Czech Republic and in Poland is now at about EUR 40/MWh with a peak of €43/MWh seen in January 2006. Further upwards convergence with the German market is expected. (DG Energy and Transport, issue7). *["Household and small commercial prices have also been increasing rapidly and are now almost at €100/MWh, very similar to other parts of the European Union",* (DG Energy and Transport, issue 7)].

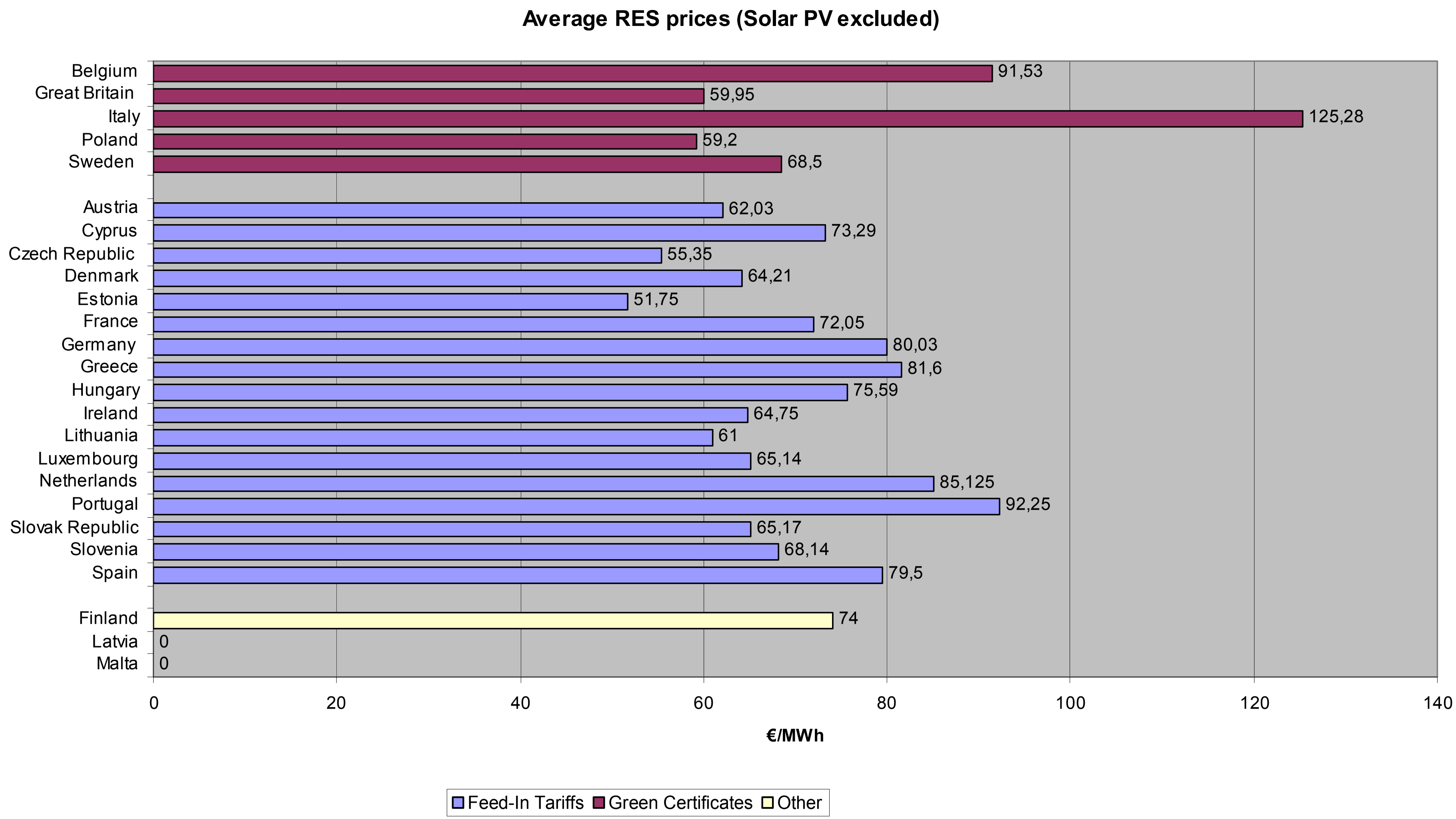
The following tables now mirror the information EREF collected on prices for RES in the European Union, with all reservations for some instabilities in the quota markets to be kept in mind.

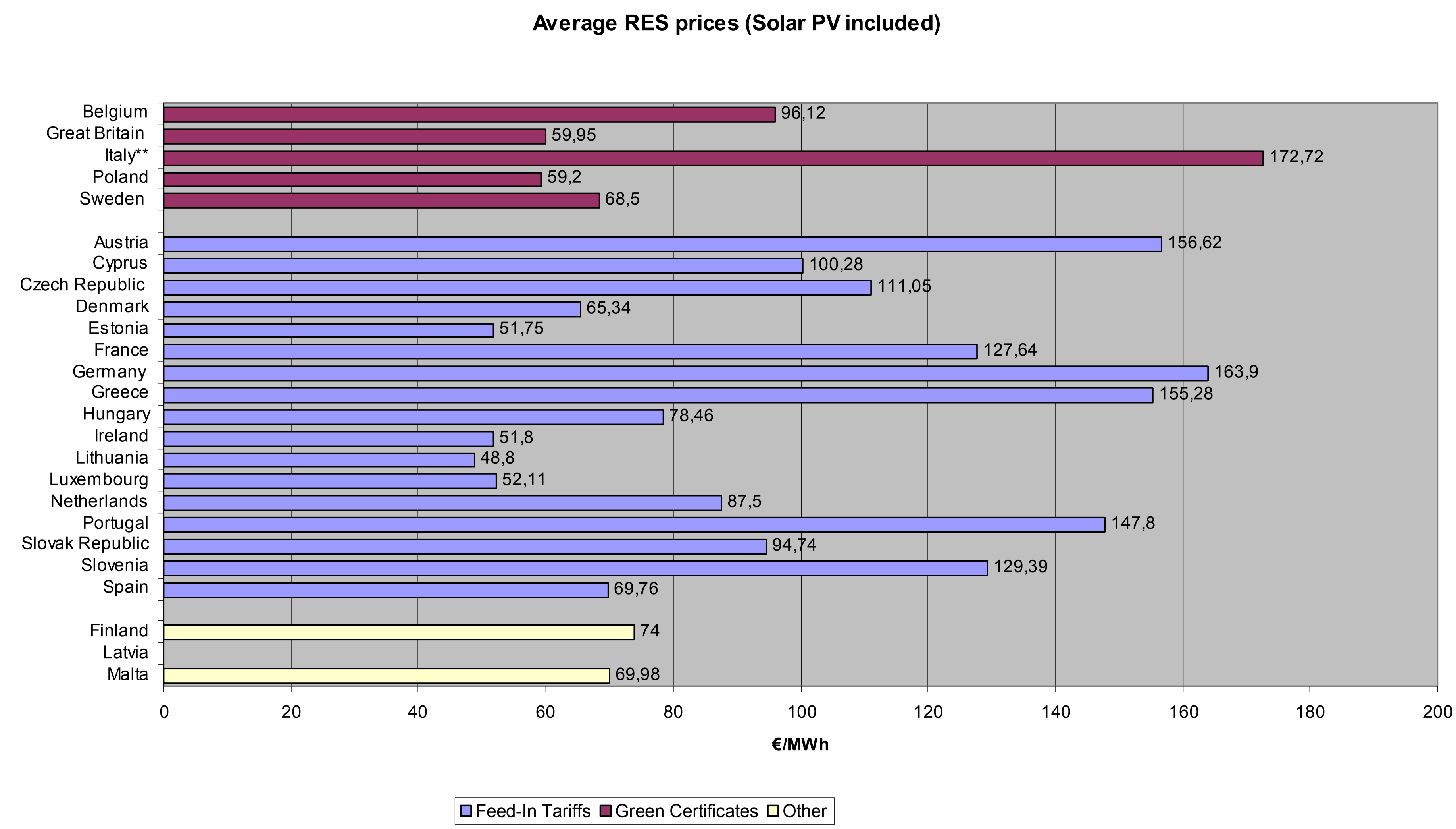
Graphic 3
Average price per technology in Feed-In countries and in Finland



* considered prices are only indicative since the actual total tariff (premium + market price) depends on variable market prices
** it must be noticed that tax subsidies are the only support scheme in force in Finland
*** in certain cases an extra premium could be provided
**** including provided premiums
***** in Malta feed-in tariffs are in force only for solar PV. Other RES are subject to tax incentives. In August 2006 a possible change to feed-in tariffs for all RES was announced.
****** for the minimum price of biomass landfill gas is not considered

<u>Graphics 4a and 4b</u> Average RES prices in Countries with different support schemes.





*** In Italy, electricity generated from Solar PV is traded normally in the Green Certificates market. In case a Solar PV plant is not eligible for Green Certificates, it is possible to apply for a feed-in tariff. In the present graphic the average value of the feed-in tariff has been included.*

With reference to Countries with a Quota Obligation / Green Certificates scheme: the indicated price includes the spot electricity market price

5. The myth of a (niche-) market for Renewable Energies

EREF strongly opposes current trends to promote the creation of an artificial Renewable Energy Market. All energy produced and offered has to compete on one energy market with its subdivisions on transport, heating/cooling and electricity. Current distortion of this market makes support mechanisms necessary. Recent calls for the promotion of a separated market for renewable electricity and of harmonisation of support mechanisms for such a market are counter productive. They try to suggest that Renewables compete only with Renewables. This is wrong; renewable energy aims overall increase of market share on the energy market. EREF welcomes the initiative by the German and Spanish government to establish a feed-in community in order to exchange experience, help other countries to introduce good and reliable systems and to harmonise key parameters for the sake of easy adaptation.

EREF underlines the great success story of so-called expensive RES technologies especially solar technology. Here again, PV alone underwent a drastic cost reduction thanks to feed-in environment. And it is due to the German PV success story and fair promotion of PV technology that other European countries will profit from this experience. The key data for Germany are:

- 2005- PV installation: 1.500 MW
- Cost reduction since 1995: 50%
- Investment in 2005 in PV: 3.75 bio €
- Employment: 42.500 (PV and Solar Thermal)

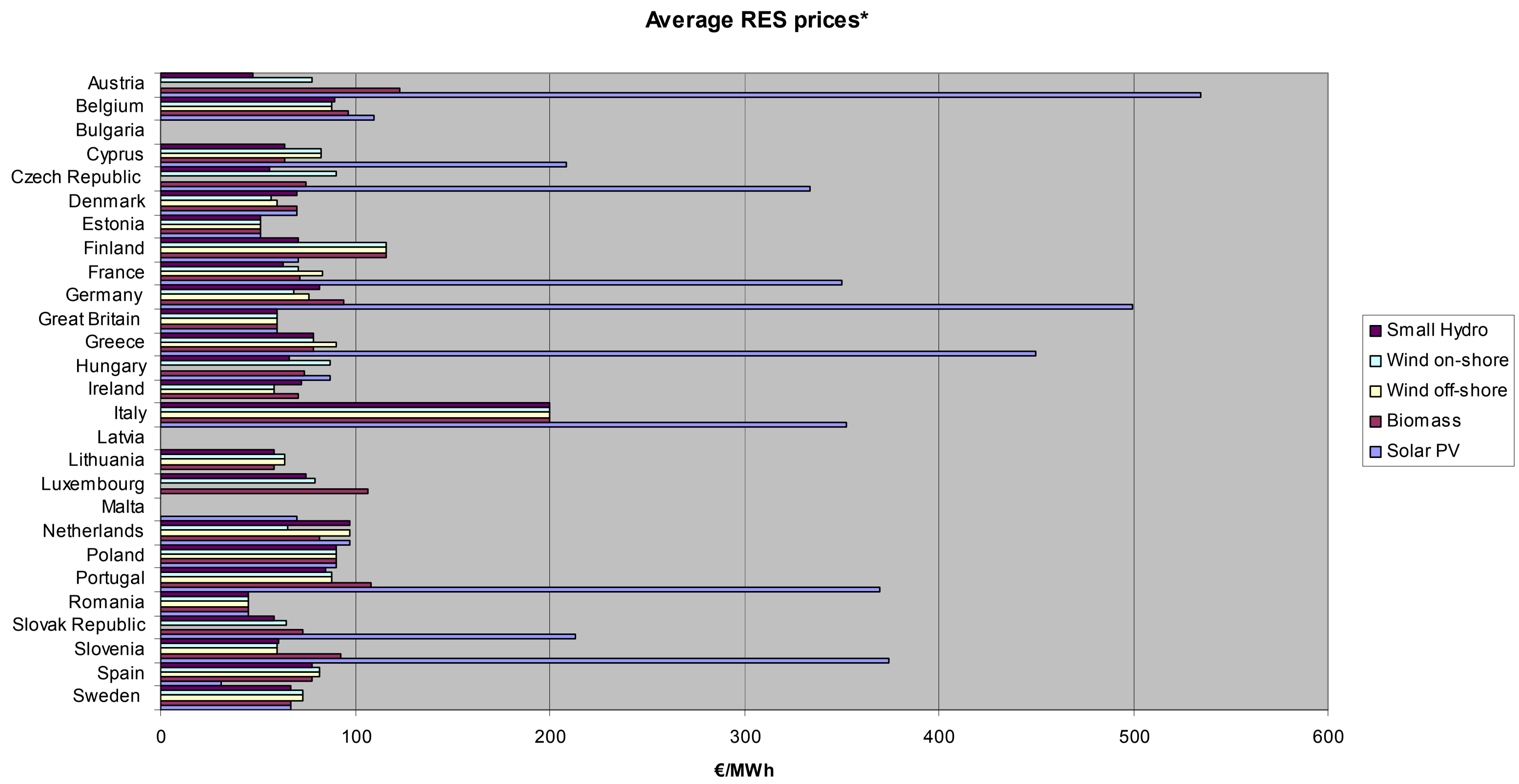
More than 85 % of all PV installed in the EU 27 is installed in Germany.

The share of renewable energies in Germany in terms of electricity consumption reached record levels in 2006 and climbed up to 11,6 percent. This corresponds to a production level of 71,5 bio kWh (in 2005 64,35 bio kWh RES were produced in Germany). Main RES drivers are wind, biogas and PV. This increase in 2006 alone is more than the annual electricity output of the German nuclear power plant Brunsbüttel. (Source: http://www.bee-ev.de)

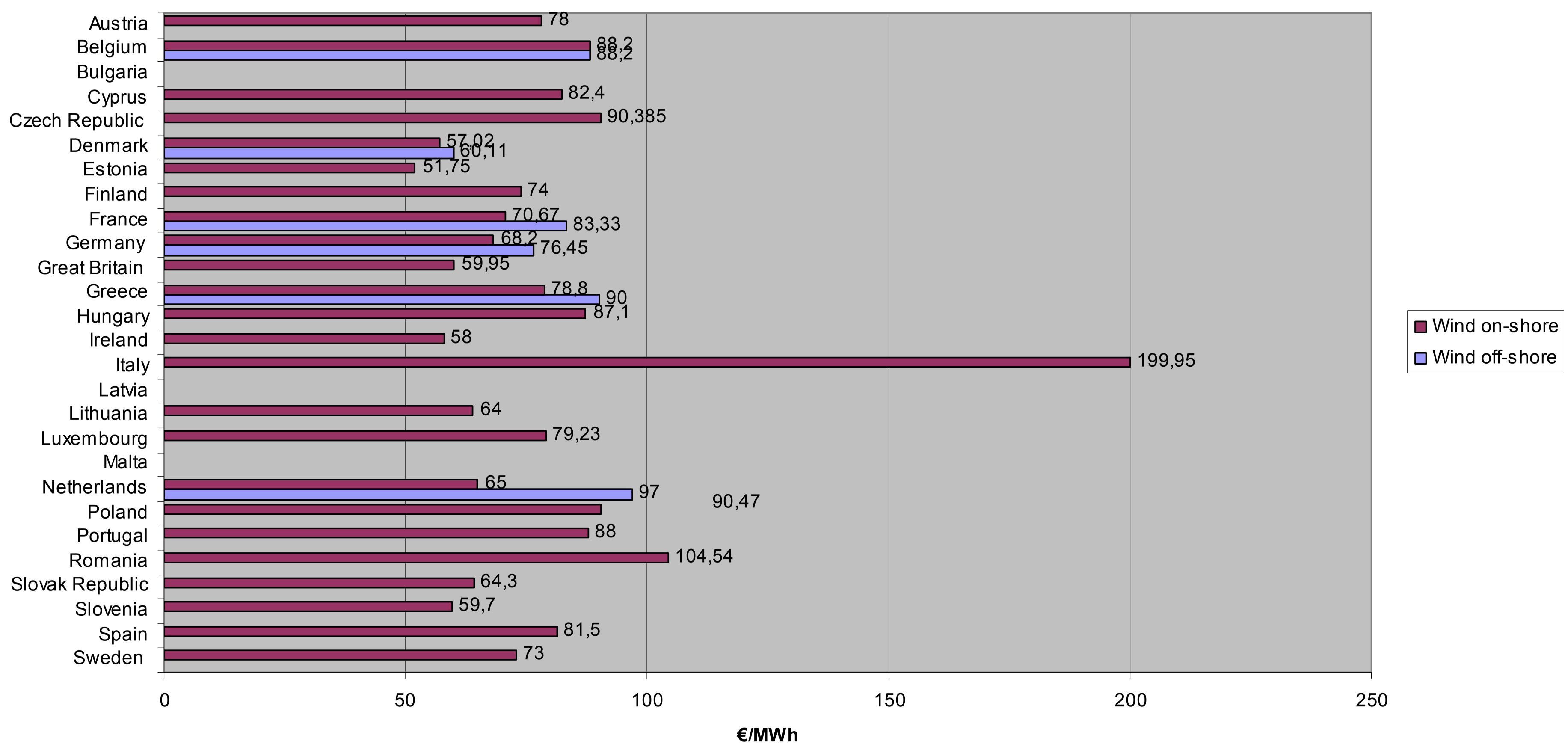
6. RES development needs adequate prices

There is a clear rule of experience that countries with unrealistically low prices paid to the producers of renewable energies do not have increase of RES capacity or very few. In this respect our tables with the different prices have to be seen in comparison with real uptake of those different technologies in the respective countries.
Our report comes to the following tables on average RES prices in the different Member States and we also can provide with average data per renewable energy source.

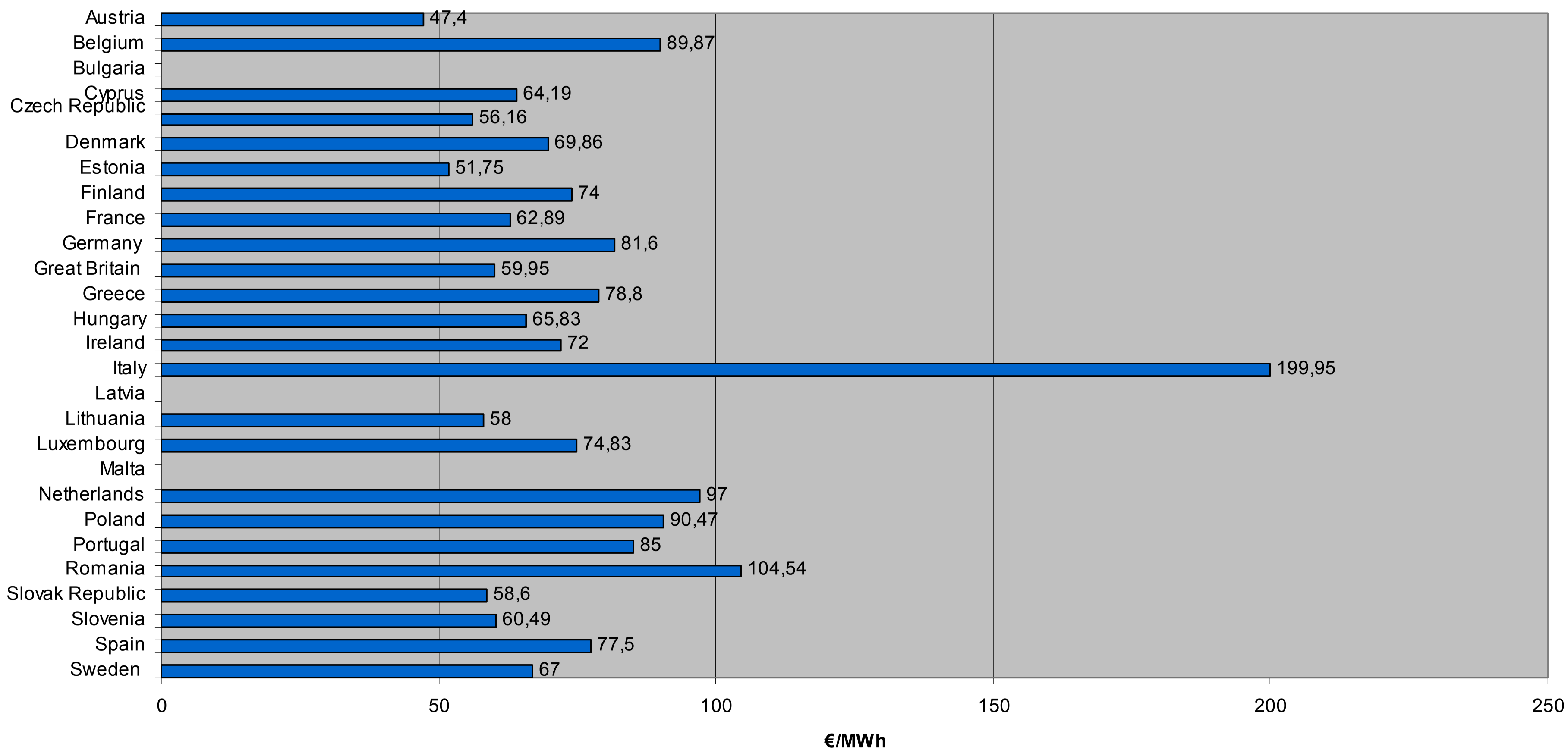
<u>Graphics 5a to 5e</u>: Comparison of RES prices in the EU Member States



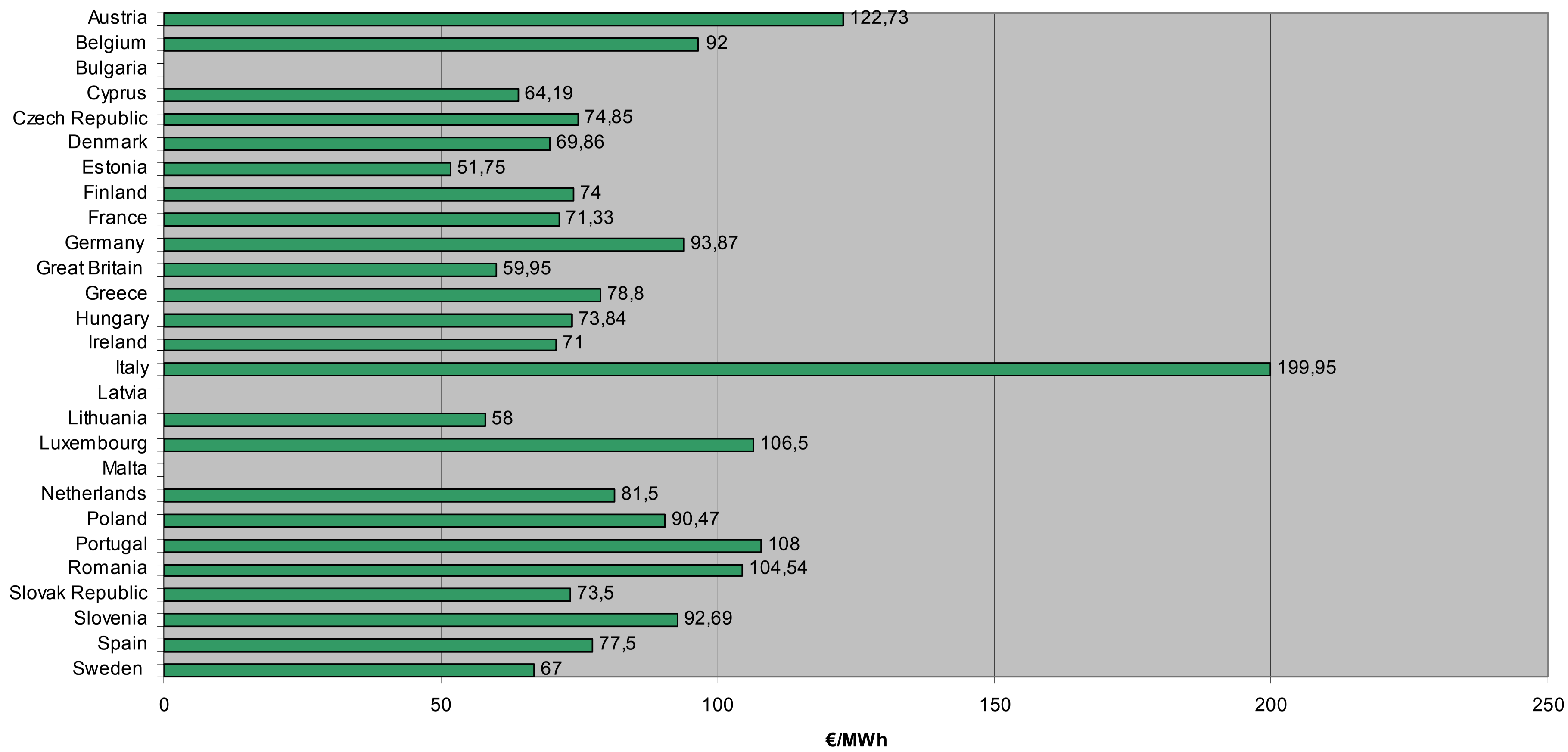
Average prices for Wind Power*

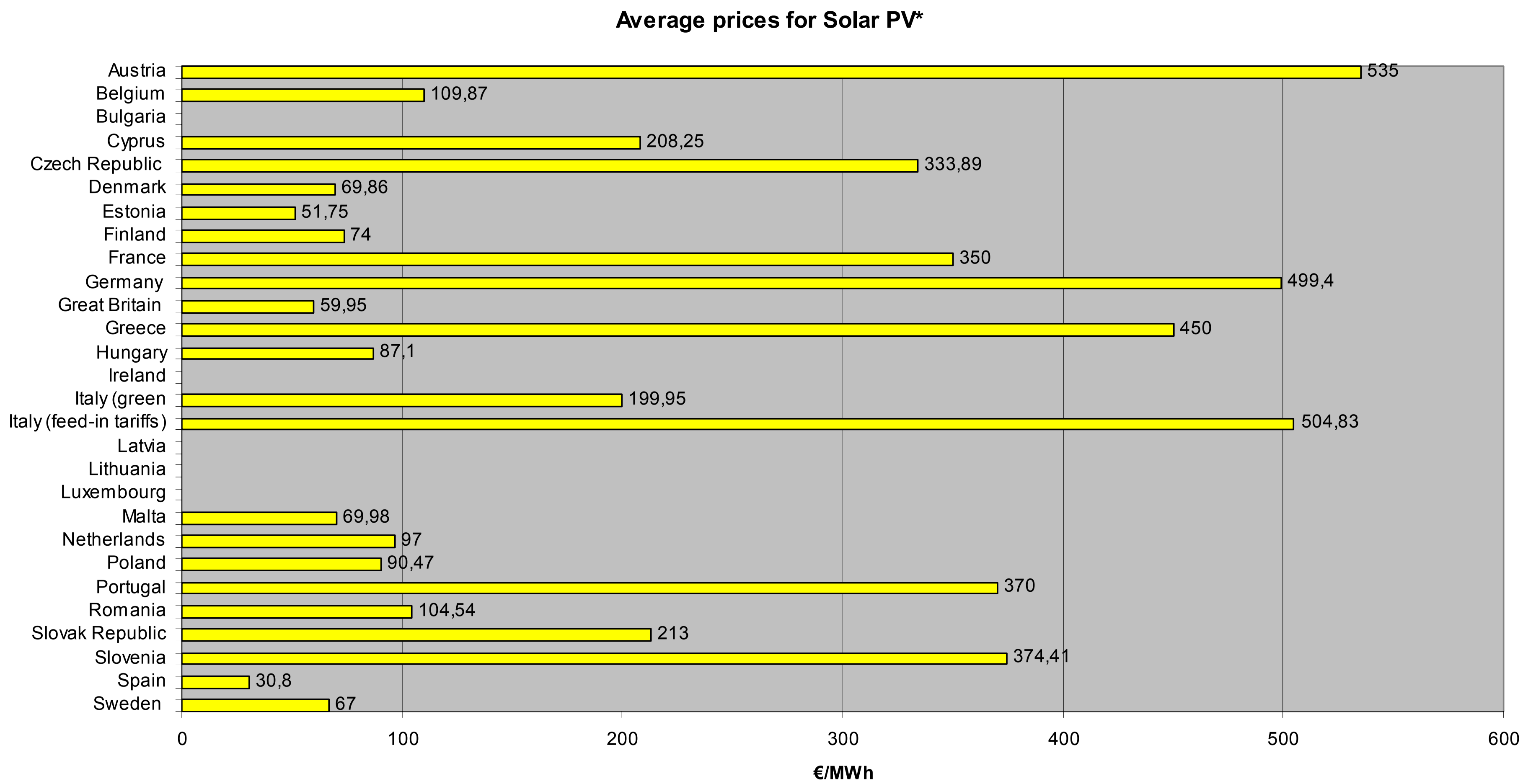


Average prices for Small Hydro*



Average prices for Biomass*




Average prices for Solar PV*
Austria
Belgium
Bulgaria
Cyprus
Czech Republic
Denmark
Estonia
Finland
France
Germany
Great Britain
Greece
Hungary
Ireland
Italy (green
Italy (feed-in tariffs)
Latvia
Lithuania
Luxembourg
Malta
Netherlands
Poland
Portugal
Romania
Slovak Republic
Slovenia
Spain
Sweden
535
109,87
208,25
333,89
69,86
51,75
74
350
499,4
59,95
450
87,1
199,95
504,83
69,98
97
90,47
370
104,54
213
374,41
30,8
67
0
100
200
300
400
500
600
€/MWh

**** Remarks***

Austria. *Biomass: average price calculated from prices for solid biomass, liquid biomass and biogas*

Belgium. *Prices differ in Wallonia, Flanders and Brussels-Capital. The price of Green Certificates in Brussels-Capital has a particular impact on the overall average price for Belgium since it is considerably lower then the prices in Flanders and Wallonia. Regarding Flanders, the price is calculated on the basis of Green Certificates with Guarantee of Origin.*

Cyprus*. Wind: prices for small scale turbines (<30 kW) are excluded. The graphic shows the average price calculated from the price for the first 5 years (93.7 €) and the arithmetic mean of the prices for the following ten years (48.58 € - 93.71 €)*

Czech Republic*. Average price out of purchase price and green premiums. VAT excluded.*

Denmark. *Wind: The average price is calculated from the average market price of 45.9 €/MWh in the first half of 2006 for turbines not older than 20 years and the maximum tariff allowed.*

Biomass: average price from general biomass and biogas (biogas used in CHP and connected to grid between 22 April 2004 and 31 December 2008).

Solar PV: solar cell systems of less than 6 kW have not been considered since they are not eligible for subsidy.

France. *Prices excluding plants in overseas departments and territories.*

Hydro: the price refers to old plants and new plants.

Biomass: average price calculated from biogas and general biomass, excluding energy efficiency based premiums.

Solar PV: extra premium excluded from average price calculation

Germany. *Hydro: only prices for new installed plants are included in the calculation*

Wind: average price calculated from initial tariff and basic tariff.

Biomass: average price from generic biomass, excluding landfill and sewage gas.

Solar PV: price for new roof-top installations; average price for open-space installations is 406 €/MWh.

Italy*. VAT excluded (125.28+ 20% VAT)*

Luxembourg*. All prices include premiums*

The Netherlands*. Biomass: average price from pure biomass excluding landfill gas, sewage/wastewater, biogas and animal fat.*

Portugal*. Wind: only tariffs for projects starting before February 2007 are considered*

Biomass: average price from purpose-grown biomass and biogas

Spain*. Average price calculated from free market price and regulated price*

With reference to Countries with a Quota Obligation / Green Certificates scheme: the indicated price includes the spot electricity market price

7. Time for change – Europe needs the paradigm of absolute priority for energy efficiency and for Renewables

The way forward towards a sustainable energy system in Europe and its Member States is still not focussed enough in EREF's view. Notwithstanding support to many of the positive elements of the current energy package of the European Commission we criticise the lack of a coherent sustainable overall energy policy.

A European sustainable energy policy has to go back to the individual per capita energy needs and its lowest possible amount. The point of departure is for the individual household to clearly focus on a shift in paradigm and to postulate a supply priority where each household has to be made responsible and has to be assisted to produce its own energy supply to respond to the lowest energy amount needed. All surplus energy which cannot be produced locally should be available primarily from renewable energy sources. All fossil and nuclear energies as severe unsustainable energies have to be phased out systematically and in a planned and reliable way.

In 1985 José Goldemberg, Thomas B. Johansson, Amulya K.N. Reddy and Robert H. Williams wrote in a scientific article for the Royal Swedish Academy of Science, entitled "Basic Needs and Much More With One Kilowatt Per Capita": "Conventional thinking holds that increased energy consumption is a perquisite for economic and social development". The authors showed that this is disbelief and that realistic scenarios with energy efficiency, modern energy technologies and services can lead to a situation where all activities (residential, commercial, transportation, manufacturing, agriculture, mining and construction) would only need an average energy use per capita of slightly above 1 Kilowatt per capita.

It would be great if the article could be written again in 2007, this time focussing on the developed world and especially on Europe and including the success story of renewable technologies which were not foreseen to this extent in those scenarios in 1985.

EREF cannot understand and will continue discussions on this point that the European Commission promotes unsustainable energies. As EREF President Peter Danielsson recently commented on the new Energy package of the Commission: "We constantly try to convince the European Commission to come to terms with a changed world in energy in Europe and to realise that no more money has to be spent in costly and extremely risky fossil and nuclear technologies but all has to be submitted under the priority of a fast growing renewable energy society in Europe with strict energy efficiency rules." This dialogue will certainly continue.

A last remark: For this EREF price report 2006/2007 we intensively examined and cross-checked as much information available as possible in order to present a harmonised picture for all countries. We hope we did not miss out too much but we certainly cannot guarantee for all exactness and latest update especially since many Member States still do not publish their statistical information adequately and in English or another of the official European working languages.

I certainly have to thank my colleague Andrea Jelitte from my law firm and especially our interns Karola Falasca and Julius Hasse for their valuable input. I also thank the member associations of EREF for constant checking and double checking of data and for their input.

Despite all our efforts for accuracy EREF cannot guarantee correctness of all data collected and used.

Doerte Fouquet
Brussels, January 2007

II. Overview on RES Prices and Support Mechanisms in EU 27 and Neighbouring Countries

A. EU Member States

Austria

	Small Hydro	Wind
Price (€/MWh)	1st GWh : 56,80* / 59,60** / 62,50*** next 4 GWh : 43,60* / 45,80** / 50,10 *** next 10 GWh : 36,30* / 38,10** / 41,70 *** next 10 GWh : 32,80* / 34,40** / 39,40 *** > 25 GWh : 31,50* / 33,10** / 37,80*** *Existing plants (licensed before 1 January 2003) **Plant after investment with at least 15% yield increase (between 1 January 2003 and 1 January 2007) ***New plant or plant after investment with at least 50% yield increase (between 1 January 2003 and 1 January 2007)	78
Support scheme type	Feed- in tariffs	
Current applicable law	Green Electricity Act of 23 August 2002; Green Electricity Decree in the version of 12 August 2005	
Additional information	From 1 January 2003 on the feed in tariffs have been standardised on national level. The previous tariffs regulated on Bundesland level continue to apply only to plants that were authorised before 1 January 2003. The above listed tariffs apply to new plants for a period of 13 years starting from the commissioning date. New plants are defined as plants that obtain license between 1 January 2003 to 31 December 2004 and start operating at the latest on 30 June 2006 (for solar PV, wind, geothermal and sewage gas) respectively on 31 December 2004 (for biomass, biogas, highly biogenous waste)	

	Biomass	Solar PV	Others
Price (€/MWh)	Solid biomass: < 2 MW: 160 > 2 MW to ≤ 5 MW : 150 > 5 MW to ≤ 10 MW : 130 > 10 MW : 102 all hybrid and mixed combustion plants: 650 Highly biogenous waste: same tariffs as for solid biomass with a reduction of 20 % respectively 35% depending on the type of combustibles Liquid biomass: ≤ 200 kW: 130 > 200 kW: 100 Sewage gas: ≤ 1MW: 60 >1 MW: 30 Biogas: ≤ 100 kW : 165 / 123,75* > 100 kW to 500kW: 145 / 108,75* ≤ 500 kW to 1MW : 125 / 93,75* > 1 MW : 103 / 77,25* *co-fermentation	≤20 kW (peak): 600 >20 kW (peak): 470	Geothermal: 70
Support scheme type	Feed- in tariffs		
Current applicable law	Green Electricity Act of 23 August 2002; Green Electricity Decree in the version of 12 August 2005		
Additional information	From 1 January 2003 on the feed in tariffs have been standardised on national level. The previous tariffs regulated on Bundesland level continue to apply only to plants that were authorised before 1 January 2003. The above listed tariffs apply to new plants for a period of 13 years starting from the commissioning date. New plants are defined as plants that obtain license between 1 January 2003 to 31 December 2004 and start operating at the latest on 30 June 2006 (for solar PV, wind, geothermal and sewage gas) respectively on 31 December 2004 (for biomass, biogas, highly biogenous waste)		

Belgium[1]

I. Wallonia

		Small Hydro *	Wind *	Biomass *	Solar PV *	Others *
Price (€/MWh)*	(1)	Min. price GC : 50 Penalty price : 100	Min. price GC : 50 Penalty price : 100	Min. price GC : 20 Penalty price : 100	Min. price GC : 150 Penalty price : 100	Min. price GC : / Penalty price : 100
	(2)	30 – 40	27	37	150 **	
Support scheme type		Quota Obligation + Green certificates***				
Current applicable law		• Royal Decree of 5th October 2005 modifying the Royal Decree of 16th July 2002 • Royal Decree of 16th July 2002 regarding the establishment of mechanisms supporting the production of electricity from renewable energy sources (as amended) Regional Decrees: • Decree of Walloon Government adopted on 12th April 2001, as amended. Establishes a legal scheme to give propulsion to the green electricity market. This decree has been amended in 2002, 2003 and 2005 • Decree of Walloon Government adopted on 4th July 2002, regarding the promotion of green electricity (as amended)				
Additional information		(1) Reference price of Green Certificates on the Walloon market for the period 2005/2006. From January 2005 to September 2006 the price of Green Certificates has been nearly constant, varying from a minimum price of 91,29 to a maximum price of 92,29 (2) Average market price for electricity (average price in 2006 for main producers in each sector) * 1 GC = 456 kg CO_2 avoided. For Wind, Hydro and Solar PV = 1 MWh. For biomass CHP can be more than 1 GC / MWh – for fossil CHP is less than 1 GC / MWh **This price is the same as the households pay at present for their electricity. In fact producers subtract their production from their consumption. If they produce 250 kWh with PV and the household consumption is 1000 kWh, the owner will pay only a 750 kWh bill. Therefore, the PV market price for electricity mentioned in this report is based on the average household consumption price (150 €/MWh). If the production exceed the consumption, the additional produced electricity is paid at market price before taxes. ***In Wallonia the green certificate system started on 1st October 2002. It obliges all suppliers (retailers) to purchase a certain percentage of their total electricity sales from renewable sources or quality cogeneration. The percentage for the first period was 3% in 2003 and raise to 7% in 2007. For the second period the percentage will annually increase by 1% starting at 8% in 2008				

[1] In Belgium the regulation of renewable energy falls under the responsibility of its three Regions Wallonia, Flanders and Brussels -Capital. All regions have implemented a quota system with tradable green certificates. However, the market in Brussels-Capital plays only a marginal role due to the limited number of RES electricity projects.

	and reach 12% in 2012. Each green certificate is valid five years. Those suppliers who fail to reach the target are charged with 100 € fine per missing green certificate. The money deriving from the fines are financing a public Fund promoting Renewable Energy Sources. Green electricity producers may sell their certificates to the Energy Authority at minimum price of 65 € per certificate.

II. Flanders

		Small Hydro	Wind	Biomass	Solar PV	Others
Price (€/MWh)*	(1)	• 109,60 (market price Green Certificates with Guarantee of Origin) • 110,04 (market price Green Certificates without Guarantee of Origin**)			450	109,60 (GoO) 110,04
	(2)	163,47 = 109,60 + 53,87	163,47 = 109,60 + 53,87	163,47 = 109,60 + 53,87	503,87 = 450 + 53,87	163,47 = 109,60 + 53,87
Support scheme type		Quota obligation + Green Certificates***				
Current applicable law		• Royal Decree of 5th October 2005 modifying the Royal Decree of 16th July 2002 • Royal Decree of 16th July 2002 on the establishment of mechanisms supporting the production of electricity from renewable energy sources (as amended) Regional Decrees • Decree of the Flemish Government of 5th March 2004 regarding the promotion of production of electricity from RES, as amended (replacing the Decree of the Flemish Government of 28th September 2001) • Decree of the Flemish Government of 17th July 2000 on the Green Certificates system, as amended Decree of the Flemish Government of 7th May 2004, which exempts supplies to major customers from the certificate obligation for a consumption between 20 and 100 GWh up to 25% and for a consumption exceeding100 GWh up to 50 %.				
Additional information		(1) Average price of Green Certificates in July 2006. (2) Total price = market price Green Certificate with Guarantee of Origin + market price for electricity (average price for the day 28th November 2006) * For Wind, Hydro and Solar PV: 1 Green Certificate = 1 MWh. With reference to biomass more than 1 Green Certificate can be issued for 1 MWh has to be considered a minimum price. ** Guarantee of origin: the guarantee of origin was introduced by the amendment of Decree of 5th March 2004 in July 2005. The guarantees are divided in two categories: "none used" or "used". It is classified as "none used" when creating the green certificate. The status is "used" when the electricity covered by the guarantee is either consumed on the spot, exported or delivered to a final customer. In case of the latter the supplier has to declare his guarantees of origin as "used" up to the amount of electricity delivered thereby indicating the number of the respective customer. This system enables the customer to verify if the electricity he received from his supplier has been produced by RE sources. The statuses of the guarantees are published in a central data base for each guarantee.				

III. Brussels-Capital

		Small Hydro	Wind	Biomass	Solar PV	Others
Price (€/MWh)	(1)	70				
	(2)	123,87 = 70 + 53,87				
Support scheme type		Quota obligation* + Green Certificates				
Current applicable law		• Royal Decree of 5th October 2005 modifying the Royal Decree of 16th July 2002 • Royal Decree of 16th July 2002 on the establishment of mechanisms supporting the production of electricity from renewable energy sources (as amended) Regional Decree • Decree of the Government of the Region of Brussels-Capital adopted on the 6th May 2004 • Order of 19th July 2001				
Additional information		(1) Average price of Green Certificates for the first trimester 2006 (2) Total price = market price Green Certificate + market price for electricity (average price for the day 28th November 2006) * Quota obligations containing quality co-generation (the territory of this Region does not provide enough space for RES electricity plants)				

Bulgaria

	Small Hydro	Wind	Biomass	Solar PV	Others
Price (€/MWh)*	n.a.	n.a.	n.a.	n.a.	n.a.
Support scheme type	Quota obligation + Green certificates				
Current applicable law	• Energy Law Act (2003) • Energy Efficiency Act (2004) • Ordinance on Setting and Applying prices and Rates of Electric Energy • Regulation for certification of the origin of electric power generated by renewable and/or combined generation sources, issuance of green certificates and their trading				
Additional information	* Figures are not yet available Green Certificates scheme has been recently introduced (July 2006)				

Cyprus

	Small Hydro	Wind	Biomass	Solar PV (<5 kW)	Others
Price (€/MWh) *	64,19**	Large scale first 5 years: 93,7 following 10 years: 48,58 to 93,71 according to wind resource Small scale (< 30 kW) 64,19**	64,19**	208,25 (64,19 from EAC + 144,06 subsidy) for 15 years Only for households: 388 for 15 years	
Support scheme type	Feed- in tariffs				
Current applicable law	Law N33(I)/2003, of 18.4.2003, on promotion of the use of RES and Energy Conservation investments				
Additional information	* Grant scheme updated in January 2006 ** No subsidy; only fixed prices paid by the Electricity Authority of Cyprus (EAC). The EAC is obliged to buy RES-e at a fixed feed-in purchase price of 64 €/MWh (3.7 CYP cents/KWh)				

Czech Republic

		Small Hydro		Wind	
	Plants commissioned	**Purchase prices****	**Green premiums****	**Purchase prices****	**Green premiums****
Price (€/MWh)*	after 1st January 2006	82,8	50,6	86,78	71,26
	1st January–31st December 2005	75,37	43,05	95,26	79,74
	1st January–31st December 2004	-	-	99,80	84,29
	before 1st January 2005	58,67	26,46	-	-
	before 1st January 2004	-	-	110,74	95,21
Support scheme type	Feed-in tariffs				
Current applicable law	• Act No. 526/1990 on Prices (as amended)** • Act. 265/1991 on the Competencies of the Czech Republic's Authorities in the Area of Prices • Act No. 458/2000 on the Conditions for Business and State Administration in the Energy Industries and on Amendments to Certain Laws • Act No. 180/2005 on Support for Electricity Generation from Renewable Energy Sources and on Changes to Certain Laws, Energy Regulatory Office (ERO) • Price Decision No. 10/2005 of 30 November 2005 Laying down support for electricity generation from renewable energy sources, combined heat & power, and secondary sources				

Additional information	* Prices excluding VAT. Exchange rate of September 2006

	** Pursuant to Act 526/1990, as amended, two different schemes have been set up: purchase prices and green premiums. Purchase prices apply to electricity supplied and metered at the delivery point between the generating plant and the respective distribution system operator's network, or the transmission system operator's network, which [the delivery point] appears in the clearing of imbalances to the entity subject to clearing ['cleared entity'] responsible for losses in the regional distribution system, or to the cleared entity responsible for losses in the transmission system. Green premiums apply to electricity supplied and metered at the delivery point between the generating plant and the regional distribution system operator's network, or the transmission system operator's network, and supplied by the generator to an electricity trader or eligible customer, and also to the 'other house load' under a separate legal regulation. Within one generating plant, the method of purchase prices and the method of green premiums may not be combined

	Biomass				Solar PV		Geothermal	
	Plants Commissioned	**Purchase Price****	**Green Premiums****	**Plants commissioned**	**Purchase Price ****	**Green Premiums****	**Purchase Price****	**Green Premiums****
Price (€/MWh)*	After 1st January 2006 O1 category O2 category O3 category Before 1st January 2006 O1 category O2 category O3 category	 103,36 91,75 80,76 103,36 91,75 80,76	 69,16 57,48 46,58 69,16 57,48 46,58	After 1st January 2006 Before 1st January 2006	467,12 222,24	445,54 200,65	158,71 128,81	128,81 98,37
Support	Feed-in tariffs							

scheme type	
Current applicable law	• Act No. 526/1990 on Prices (as amended) • Act. 265/1991 on the Competencies of the Czech Republic's Authorities in the Area of Prices • Act No. 458/2000 on the Conditions for Business and State Administration in the Energy Industries and on Amendments to Certain Laws • Act No. 180/2005 on Support for Electricity Generation from Renewable Energy Sources and on Changes to Certain Laws, Energy Regulatory Office (ERO) • Price Decision No. 10/2005 of 30 November 2005 Laying down support for electricity generation from renewable energy sources, combined heat & power, and secondary sources
Additional information	* Prices excluding VAT. Exchange rate of September 2006 ** Pursuant to Act 526/1990, as amended, two different schemes have been set: purchase prices and green premiums. Purchase prices shall apply to electricity supplied and metered at the delivery point between the generating plant and the respective distribution system operator's network, or the transmission system operator's network, which [the delivery point] appears in the clearing of imbalances to the entity subject to clearing ['cleared entity'] responsible for losses in the regional distribution system, or to the cleared entity responsible for losses in the transmission system Green premiums shall apply to electricity supplied and metered at the delivery point between the generating plant and the regional distribution system operator's network, or the transmission system operator's network, and supplied by the generator to an electricity trader or eligible customer, and also to the 'other house load' under a separate legal regulation Within one generating plant, the method of purchase prices and the method of green premiums may not be combined

Denmark

	Small Hydro	Wind
Price (€/MWh)*	Plants connected to the grid Before 21st April 2004 total tariff: 80,43 (for 20 years from date of grid connection) 1st January 2004 - 21st April 2004 total tariff: 80,43 (for at least 15 years) After 21st April 2004 market price + 13.40 (for 20 years)	Turbines connected to the grid from January 2005 13,40: premium for 20 years 3, 08: allowance for offset costs etc. Turbines connected to the grid in the period 2003-2004 up to 13,40: premium for 20 years 3, 08: allowance for offset costs etc. Total tariff (market price + premium) may not exceed 48,06 Turbines connected to the grid in the period 2000-2002 57,64: total tariff (market price + premium) for 22,000 full load hours [onshore] 13,40: premium after full load hours are used up, for turbines younger than 20 years 57,64: total tariff (market price + premium) for 10 years [off-shore] 3, 08: Allowance for offset costs Total tariff (premium + market price) may not exceed 48, 06 Turbines acquired before end 1999 for full load hours**: 80,43: total tariff (market price + premium) after full load hours are used up: 57,64 €/MWh: total tariff for turbines younger than 10 years. 13,40 €/MWh: premium of for turbines younger than 20 years 3,08 €/MWh: allowance of for offset costs Total tariff (premium + market price) may not exceed 48, 06 Turbines financed by electricity utilities (as a result of an order or special agreement) Onshore, connected to the grid as of 1 January 2000 57,64: total tariff (subsidy + market price). Subsidy for turbines not older than 10 years.

		up to 13,40: premium for turbines older than 10 years and younger than 20 years. Total tariff (subsidy + market price) may not exceed 48,06. Offshore, connected to the grid after 1 January 2000 57,64: total tariff (subsidy + market price) for turbines not older than 10 years for 42,000 full load hours Up to 0.93: compensation if production is subject to a grid tariff up to 13,40: premium for turbine not older than 20 years after all full load hours are used up Total tariff may not exceed 48,06 €/MWh Wind turbines with removing certificates: extra premium Household turbines (25 kW or less): total tariff 80,43
Support scheme type	Feed-in tariffs	Feed-in tariffs
Current applicable law	Danish Electricity Supply Act (Elforsyningsloven) as amended	• Danish Electricity Supply Act (Elforsyningsloven)as amended • Executive Order no.1365 of 15 December 2004 (Wind turbine executive order)
Additional information		** Full load hours: turbines of 200 kW or less: 25,000 hours turbines of 201 kW-599 kW: 15,000 hours turbines of 600 kW and over: 12,000 hours
	*Tariff = price market + subsidy/premium. Exchange rate DKK to EUR of September 2006	

	Biomass		Solar PV	Others
	Biogas**	**Biomass*****		
Price (€/MWh)*	80,43 for 10 years 53,62 for following 10 years To be entitled to subsidies, the total use of biogas may not exceed 8 PJ/year	Plants connected to the grid Before 21st April 2004 total tariff: 80,43 (for 20 years from date of grid connection) 1st January 2004 - 21st April 2004 total tariff: 80,43 (for at least 15 years) After 21st April 2004 market price + 13.40 (for 20 years)	Plants connected to the grid Before 21st April 2004 total tariff: 80,43 (for 20 years from grid connection and for at least 15 years if connected as of 1 January 2004) After 21st April 2004 market price + premium of 13,40 €/MWh for 20 years small solar cell systems less than 6kW not eligible for subsidy	Special RE plants of major importance to future exploitation of RE electricity (including wave power, solar energy etc), connected to the grid after 21st April 2004: 80,43 €/MWh: tariff for 10 years 53,62 €/MWh: tariff for the following 10 years
Support scheme type	Feed-in tariffs (fixed-premium mechanism)	Feed-in tariffs (fixed-premium mechanism) Obligation for central power stations to use biomass	Feed-in tariffs (fixed-premium mechanism)	Feed-in tariffs (fixed-premium mechanism)
Current applicable law	Danish Electricity Supply Act (Elforsyningsloven)	Danish Electricity Supply Act (Elforsyningsloven) Biomass Agreement of 1993	Danish Electricity Supply Act (Elforsyningsloven)	Danish Electricity Supply Act (Elforsyningsloven)
Additional information	* Tariff = price market + subsidy/premium. Exchange rate DKK to EUR of September 2006 ** Grid Connection between 22 April 2004 and 31 December 2008; prices for biogas used in combined heat and power plants (CHP) *** For biomass incinerators built by electricity utilities as result of an order or special agreement,the following special tariffs apply: 53,62 for the first 10 years (premium of up to 13,40 €/ton biomass up to a maximum of 4.021.529 €/year) and premium of 13,40 for the following 10 years			

Estonia

	Small Hydro	Wind	Biomass	Solar PV	Others
Price (€/MWh)*	51,75**				
Support scheme type	Feed-in tariffs				
Current applicable law	Electricity Market Act as amended				
Additional information	* Exchange rate EEK to € of September 2006 ** EEK 810/MWh				

Finland

	Small Hydro	Wind	Biomass	Solar PV	Others
Price (€/MWh)	74(= 50 € market price + 7 € tax deduction + 17 € investment support*)				
Support scheme type **	Tax subsidies				
Current applicable law	Electricity Market Act				
Additional information	* The investment support is only granted for new technologies upon application ** According to Finnish law all tax subsidies are in force until further notice. The European Commission has authorised the tax subsidies for power production in Finland until the end of 2006. The authorisation for the refund scheme of energy-intensive consumers will expire by the end of 2011.				

France

	Small Hydro	Wind	
Price (€/MWh)	**Existing plants**: 55.04 €/MWh (average) **New plants**: <500 kW: 74 €/MWh > 500kW: 67.5 €/MWh	**Onshore** For the first 10 years: 82 €/MWh in the mainland For the next 5 years ≤2400 h/y: 82 €/MWh 2800 h/y: 68 €/MWh ≥3600 h/y: 28 €/MWh with linear interpolation in the mainland Annual degression 2% Overseas: 110 €/MWh for 15 years independent from productivity *	**Offshore** For the first 10 years: 130 €/MWh For the next 10 years ≤2800 h/y, 130 €/MWh 3200 h/y 90 €/MWh ≥3900 h/y 30 €/MWh with linear interpolation Annual degression 3%
Support scheme type	Feed-in tariff	feed-in tariff based on annual productivity	
Current applicable law	Decree of 25 June 2001 A new decree is envisaged for October 2006: it shall increase tariffs by a small margin for smaller plants; plants exceeding 3 MW will have no change in tariff.	Decree of 10 July 2006 and articles 10 and 10-1 of the 2000-108 Law of 10 February 2000	
Additional information	The buy out obligation is limited to power plants under 12 MW. Contract duration: 15 or 20 years.	The buy out obligation is limited to wind farms established in wind development areas (ZDE) and plants with a capacity below 12 MW until 13 July 2007. Bigger wind farms follow a tender procedure. The contract duration is 15 years for onshore and 20 years for offshore installations. *The productivity is defined as producing time equivalent to the amount of generated	

		electricity at maximum output power
	Tariffs are indexed on labour price and industry production and services to enterprises prices. Other applicable laws changed 5 times in the past 5 years. EDF is the only firm which can benefit from a compensation fund furnished by end users, therefore EDF is the only firm able to buy green electricity; there is no French market for green electricity. Green electricity with certified origin is subject to import tax.	

	Biomass		**Solar PV**	**Others**
Price (€/MWh)	**Biogas**	**Combustion of animal or vegetable biomass material**	300 €/MWh in the mainland; 400 €/MWh overseas and in Corsica Building frame integration premium: 250 €/MWh in the mainland, 150 €/MWh overseas and in Corsica no annual degression Tariff delivered until a ceiling is reached, defined as the product of the installation crest power and a 1500 h duration in the continental mainland (1800 h for other cases). Then electricity is bought out at a 50 €/MWh price.	geothermal: 120 €/MWh in the mainland, 100 €/MWh overseas energy efficiency-based premium between 0 (energy yield ≤ 30 %) and 30 €/MWh (≥ 50 %) with linear interpolation between
	≤ 150 kW: 90 €/MWh in the mainland, 103 €/MWh overseas, ≤ 2 MW: 75 €/MWh in the mainland, 86 €/MWh overseas, with linear interpolation between energy efficiency-based premium between 0 (energy yield < 40 %) and 30 €/MWh (> 75 %) with linear interpolation between 20 €/MWh methanisation premium for all biogas installations excepted for those based upon non hazardous waste storage facilities no annual degression	49 €/MWh in the mainland, 55 €/MWh overseas, these reference tariffs are modulated according to the averaged power delivered in comparison with the power guaranteed by the producer energy efficiency-based premium between 0 (energy yield ≤ 40 %) and 12 €/MWh (≥ 70 %), with linear interpolation between stages (5 €/MWh at 50 % and 10 €/MWh at 60 %)		
Support scheme type	feed-in + premium	feed-in + premium	feed-in + premium	feed-in + premium
Current applicable law	Decree of 10.07.2006	Decree of 16.04.2002	Decree of 10.07.2006	Decree of 10.07.2006
Additional information	Contract for 15 years	Contract for 15 years.	Contract for 20 years.	Contract for 15 years.

	Tariffs are indexed on labour price and industry production and services to enterprises prices. They are reviewed annually. Other applicable laws changed 5 times in the past 5 years. EDF for 95% of France and pre-existing local utilities in the remaining5% are the only firms which can benefit from a compensation fund furnished by end users, therefore they are the only ones able to buy green electricity; there is no French market for green electricity. Green electricity with certified origin is subject to import tax.

Germany

	Small Hydro	Wind
Price (€/MWh) *	**For new installed plants:** 96,7 (≤ 500 kW), 66,5 (500 kW to 5MW) **Modernisation of older plants:** 75,1 (≤ 500 kW added), 6,51 (500 kW to 10 MW added) Degression rate**: 1,0%	**For new installed plants:** **Onshore** 52,8: basic tariff for new installations in 2006: 83,6: initial tariff in 2006 (at least for 5 years; move down to basic tariff according to quality of site (actual yield of first five years / reference yield) **Onshore - Repowering of old turbines** Longer duration of initial tariff for repowering of turbines installed before end of December 1995; same tariffs as onshore in 2006, in addition prolongation of 2 months for each 0.6 % of the reference yield which their yield stays below 150 % of the reference yield. **Offshore** In 2006: for new installations 91 initial tariff, 61.9 basic tariff; initial tariff for 12 years. Prolongation of higher tariff according to distance from coast and water depth. **Average tariff** paid in Germany (for all wind turbines, new and existing ones): 90,0 in 2005, presumably 89,4 in 2006; calculation is based on the fact that older turbines still get a higher tariff according to the one that was valid in the year when they went into operation.
Support scheme type	Feed-in Tariff	
Current applicable law	Erneuerbare-Energien-Gesetz (EEG) / Renewable Energies Act ***	
Additional information	* These fixed prices are applied to plants commissioned in 2006 for a runtime of 20 years, except for hydropower whose runtime is 30 years for new plants and 15 years for modernised older plants. ** Degression rate: the nominal remuneration rates for new plants decrease annually. There is no compensation for inflation, thus degression in real terms is higher – also for plants already in operation. ***Next report on the EEG in 2007; next amendment-process will presumably start in 2008	

	Biomass	Solar PV	Geothermal Energy
Price (€/MWh) *	**For new installed plants (general biomass):** 111,6 (≤ 150 kW) 96,0 (≤ 500 kW) 86,4 (≤ 5 MW) 81,5 (≤ 20 MW) **Landfill & sewage gas:** 74,4 (≤ 500 kW) 64,5 (≤ 5 MW) Annual degression rate: 1,5% Energy Crop Bonus: ≤ 500 kW: 0,06 € 500-5 MW: 0,04 € > 5 MW: no Bonus Cogeneration Bonus: 20 Innovation Bonus: 20	**For new installations (rooftop):** 518 (≤ 30 kW) 492,8 (between 30 and 100 kWh) 487,4 (> 100 kW) **Facade bonus:** 50,00 degression rate**: 5,0% **Open-space installations:** 406,0 Annual degression rate: 6,5%	**For new installed plants:** 150,0 (≤ 5 MW) 140,0 (≤ 10 MW) 89,5 (≤ 20 MW) 71,6 (> 20 MW) degression rate(22): 1,0% (starting 2010)
Support scheme type	Feed-in Tariff		
Current applicable law	Erneuerbare-Energien-Gesetz (EEG) / Renewable Energies Act **		
Additional information	* These fixed prices apply for plants commissioned in 2006 for a runtime of 20 years, except for hydropower whose runtime is 30 years for new plants and 15 years for modernised older plants. **Next report on EEG in 2007; next amendment-process will presumably start in 2008		

Great Britain

		Small Hydro	Wind	Biomass	Solar PV	Others
Price (€/MWh)	(1)	59,95				
	(2)	115,26 = 59,95 + 55,31				
Support scheme type		Quota Obligation + Green Certificates (Renewable Obligation Certificates, ROCs)**				
Current applicable law		• Energy Act of 22 July 2004 • Sustainable Energy Act of 30 October 2003 • Renewables Obligation Order and following revisions				
Additional information		(1) Average ROC price in July 2006 (2) Total price = market price Green Certificate + market price for electricity (average price for the day 28th November 2006) ** Renewable energy is primarily supported by the Renewables Obligation and, to a lesser extent, through an exemption from the Climate Change Levy Additional capital grants for offshore wind and energy crops				

Greece

	Small Hydro (≤ 15 MW)	Wind		Biomass	Solar PV		Geothermal
Price (€/MWh)		On-shore	Off-shore		≤ 100 kW_{peak}	> 100 kW_{peak}	
Interconnected system (mainland)	73	73	90	73	450	400	73
Non-interconnected islands	84,6	84,6		84,6	500	450	84,6
Support scheme type	Feed-in						
Current applicable law	Greek Law 3468/06 on the Production of electricity from renewable energy sources and cogeneration						
Additional information	VAT (9%) is not included						

Hungary

	Small Hydro	Wind	Biomass	Solar PV	Others (geothermal)
Price (€/MWh)*	< 5 MW: 87,10 > 5 MW: 73,60 (peak) 36,80 (off-peak and lowest off-peak)	87,10	98,90 (peak) 87,10 (off-peak) 35,53 (lowest off-peak)	87,10	98,90 (peak) 87,10 (off-peak) 35,53 (lowest off-peak)
Support scheme type	Feed in tariffs (peak and off-peak)				
Current applicable law	• Ministerial Decree 55/1996 on the Establishment of the Purchase Price of Electricity by Public Power Stations • MoET Decree No. 56/2002 (XII. 29.) of the Minister for Economy and Transport concerning the rules governing the acceptance and the setting of prices for electricity covered by feed in obligation				
Additional information	* VAT included. Conversion rate from HUF to EUR of 21 September 2006.				

Ireland

	Small Hydro	Wind	Biomass	Solar PV	Others
Price (€/MWh)	72	Large scale: 57 Small scale: 59	Biomass landfill gas: 70 Other biomass: 72	-	
Support scheme type	Feed-in Tariffs			No tariff	
Current applicable law	Renewable Energy Feed In Tariff (REFIT) Programme, published by the Minister for Communications, Marine and Natural Resources on 1st May 2006				
Additional information					

Italy

		Small Hydro	Wind	Biomass	Solar PV	Others
Price (€/MWh)	(1)	125,28			125,28	125,28
	(2)	199,95 = 74,67 + 125,28			199,95 = 74,67 + 125,28	199,95 = 74,67 + 125,28
Support scheme type		Quota obligation + Green Certificates			Quota obligation + Green Certificates -- Feed-in Tariffs possible upon application at the GSE* a) "exchange of electricity on the spot" system ** (for plants > 1 kW and < 20 kW): 445 or 589 (in case of architectural integration) b) Plants connected to the grid: → for plants < 50 kW: 460 or 506 (in case of architectural integration) → for plants > 50 kW and < 1000 kW: feed- in tariff is what asked by the applicant with a maximum ceiling of 490 or 539 (in case of architectural integration)	Quota obligation + Green Certificates
Current applicable law		Legislative Decree 79/1999 (Bersani Decree) as amended by Legislative Decree 387/2003 and by Law 239/04 (Marzano Law) Ministerial Decree of 24 October 2005			Legislative Decree 79/1999 (Bersani Decree) as amended by Legislative Decree 387/2003 and by Law 239/04 (Marzano Law) Ministerial Decree of 24 October 2005 Ministerial Decree 28/07/2005 (Official Gazette 181 of 5/08/2005) as amended by Ministerial Decree 6/02/2006	Legislative Decree 79/1999 (Bersani Decree) as amended by Legislative Decree 387/2003 and by Law 239/04 (Marzano Law) Ministerial Decree of 24 October 2005

Additional information		* only for Solar PV plants not eligible for Green Certificates. Incentives are given only to selected applicants. Tariffs given for 20 years ** “Scambio sul posto” system is a grid metering mechanism according to which a balance between energy supplied to the grid (by PV plants) and energy taken from the grid (by PV plants) is yearly calculated.	
	(1) Reference price for Green Certificates for the year 2006 given by GSE, VAT excluded. Price in €/MWh (1 Green Certificate = 50 MWh) (2) Total price = market price Green Certificate + market price for electricity (average price for the period January-October 2006)		

Latvia

	Small Hydro	Wind	Biomass	Solar PV	Others
Price (€/MWh)	n.a.	n. a.	n. a.	n.a.	n.a.
Support scheme type	Quota obligation*				
Current applicable law	• Energy Law of September 1998 and following amendments (3 August 2000, 10 May 2001, 17 March 2005, 26 May 2005) • Electricity Market Law of 2005 • Regulations of the Cabinet of Ministers 2006, implementing provisions of Electricity Market Law				
Additional information		The regions in Latvia with the highest estimated wind utilization potential are partly protected nature reservation territories and thus economic activities are restricted			
	*Until 2005 a support scheme of fixed tariffs applied. The Electricity Market Law of 2005 provides for the mandatory purchase of electricity generated by RES. Now fixed tariffs are not applied any loner, although some RES-E producers still receive the price of the previous fixed tariffs if their contracts were concluded before the aforementioned law entered into force. The provisions of the Electricity Market Law were to be implemented by Regulations of the Cabinet of Ministers in first half of 2006. Art 29(2) of the Electricity Market Law provides that "A definite part of the total electricity consumption of the end users in Latvia shall be mandatory covered by the electricity, which is produced by using renewable energy resources. The Cabinet shall determine such part for each type of the renewable energy resources for a time period of five years, beginning with 1 January 2006, so that by 31 December 2010 the percentage proportion of such part in relation to the total electricity consumption reaches not less than 49.3 per cent." The share of renewable energy resources in electricity generation in Latvia is very significant. In 2004 it amounted up to 46.5 %, but mainly due to the big hydropower plants belonging to Latvenergo, the state owned energy supply group.				

Lithuania

	Small Hydro	Wind	Biomass	Solar PV	Others
Price (€/MWh) *	~ 58	~ 64	~ 58	-	
Support scheme type	Feed-in tariffs				
Current applicable law	• Law on Energy No. IX-884of 16 May 2002 • Law on electricity No. VIII –1881 of 20 July 2000 (amended by Law No. IX-408 of 26 June 2001)				
Additional information	* Exchange rate LTL to € of September 2006				

Luxemburg

	Small Hydro	Wind	Biomass*	Solar PV	Others (Cogeneration)
Price (€/MWh)**	≥1 kW and ≤500 kW 77.6 (+ 5) >0.5 MW and ≤3 MW decreasing from 77.6 to 62.8 (+ 25) >3 MW and ≤10 MW decreasing from 62.8 to 54.1	≥1 kW and ≤500 kW 77.6 €/MWh (+ 25) >0.5 MW and ≤5 MW decreasing from 77.6 to 56.0 (+ 25) >5 MW and ≤10 MW: decreasing from 56.0 to 54.1	≥1 kW and ≤500 kW 102.6 (+ 25) >0.5 MW and ≤3 MW decreasing from 102.6 to 87.8 (+ 25) >3 MW and ≤10 MW decreasing from 87.8 to 79.1	private installations*** < 30kW crest and put into service before 31 December 2007: 56 Communal installations put into service before 31 December 2007: 28 other PV installations: gross electricity market price	≥1 kW and ≤150 kW 73.1 ≥151 kW and ≤1500 kW 111.55 €/kW of installed capacity + 57 on day hours and 29.7 on night hours
Support scheme type	Feed-in + premium****			Feed-in/market	Feed-in/subsidy
Current applicable law	• Regulation of the Grand-Duchy (Règlement Grand-Ducal) adopted on 14 October 2005 on the supply of electricity from renewable energies modifying the Regulation of the Grand-Duchy of 30 May 1994 on the production of electricity from renewable energies or from co-generation and the Regulation of the Grand-Duchy of 22 May 2001 on the introduction of a compensation fund within the framework of the electricity market				
	• Regulation of the Grand-Duchy of 3 August 2005 on the promotion of electricity from wind power, hydropower, biomass and biogas.				New regulation in progress
Additional information	* Biomass, biogas, sewage and landfills gas ** Plants starting operation as of 1 January 2005 *** Natural persons who received investment subsidies according to the Regulation of the Grand-Duchy of 3 August 2005 **** Premium for a maximum of 10 years for installations starting operation between 1 January 2005 and 31 December 2007; has to be renewed on a yearly basis				

Malta

	Small Hydro	Wind	Biomass	Solar PV	Others
Price (€/MWh)	-	-	-	69,98	
Support scheme type	Tax incentives; a possible future change to feed-in tariffs was announced in August 2006			Feed-in tariff	
Current applicable law		Development Planning Act 1992, as amended (Regarding offshore wind farms).			
	L. N.186 of 2004 on the Promotion of Electricity produced from Renewable Energy Sources Regulations				
Additional information		The Government often expressed its concerns about wind power impacts on Maltese landscape.		Fixed purchase price to be paid to the distribution system operator (Enemalta Corporation)	
	The Malta Resources Authority is the competent authority for the regulation of RES-Energies. It is competent to issue "guarantees of origin" of electricity produced from renewable energy sources. Other entities involved in RES issues are the Malta Environment and Planning Authority and the Minister for Resources and Infrastructure.				

Netherlands

	Small Hydro	Wind	Biomass			Solar PV	Others
Price (€/MWh) as for 01.07.2006 until 31.12.2007	97 €/MWh	offshore: 97 €/MWh	≤50 MW:	>50 MW:	Landfill gas	97 €/MWh	Wave energy: 97 €/MWh
			Pure biomass, excluding landfill gas, sewage and wastewater biogas: 97 €/MWh	pure biomass, excluding landfill gas, sewage, wastewater biogas and animal fat: 66 €/MWh	13 €/MWh		waste incineration: 29 €/MWh until 1 July 2006; currently no data available for the next period
		onshore: 65 €/MWh	mixed biomass: 36 €/MWh	mixed biomass, excluding animal fat: 36 €/MWh			
				animal fat: 30 €/MWh			
Support Scheme type	Feed-in tariffs						
Current applicable law	Environmental Quality of Electricity Production of 20 December 2004 / Regeling subsidiebedragen milieukwaliteit elektriciteitsproductie (MEP)						
Additional information	Under the MEP scheme Dutch RES electricity producers feeding into the public grid receive a fixed fee per kWh for a guaranteed period of ten years It must be noticed that the indicated tariffs are valid only for those having applied for MEP grant scheme before 18 August 2006. These tariffs - indicated in the current Ministerial MEP Grant Scheme Regulation - are currently due to change. The new government installed in November 2006 still has to take a decision with reference to new tariffs.						

Poland

		Small Hydro	Wind	Biomass	Solar PV	Others
Price (€/MWh)*	(1)	Continuous quotation system* (average price): 59.2 Fixed price quotation system*: 59,25 OTC** (average price): 48,78				
	(2)	90.47 = 59.2 + 31,27				
Support scheme type		Quota obligation + Green Certificates***				
Current applicable law		• Energy Law of 10 April 1997 and following amendments • Act of the 4 March 2005 on the amendment of the Energy Law and the Environment Protection Law				
Additional information		(1) Results of the trading session of the Green Certificate Market of 20/09/2006. Conversion from PLN to EUR of September 2006 (2) Total price = market price Green Certificate + market price for electricity (average price for the month of October 2006) * Green Certificates are quoted using the single-price auction system and continuous trading system, exclusively using the IT system of the Exchange. ** The off-session OTC transaction orders are entered exclusively using the Exchange IT system, a day prior to the trading day. An *over-the-counter* contract is a bi-lateral contract in which the two parties agree. ***In April 2005 tradable Green Certificates have been introduced thanks to amendments to the Energy Law. These are issued by the Energy Regulatory Office (URE) from October 2005.				

Portugal

	Small Hydro	Wind	Biomass	Solar PV	Others
Price (€/MWh) *	85* ^ 85 for the first 42.5 MWh for each MW licensed ** ^^	88* ^ 73 for the first 33 MWh for each MW licensed** ^^	108	Power < = 5 kW 420** Power > 5 kW 320**	
Support scheme type	Feed-in tariffs				
Current applicable law	• Decree Law 339 C/2001 • Decree Law 33 A/2005		Decree Law 33 A/2005		
Additional information	* For all period of the license ** with a maximum of 15 years ^ Tariff indicated in DL 339C/01 and applied to projects starting before February 2007. Values are updated on a monthly basis. ^^ Tariff indicated in DL 33 A/05 and applied to projects starting after February 2007. Values are constant until the starting of the power plant and only afterwards updated monthly				

Romania

		Small Hydro	Wind	Biomass	Solar PV	Others
Price (€/MWh)*	(1)	45,29				
	(2)	104,54 = 45,29 + 59,25				
Support scheme type		Quota obligation + Green certificates**				
Current applicable law		• Electricity Law no. 318/2003 • Government Decision no. 1535/2003 (on the approval of the Strategy for the use of renewable energy sources) • Government Decision no. 443/2003 (on the promotion of electricity produced from RES) • Government Decision no. 1429/2004 on the approval of the Regulation on the guarantee of origin for electricity produced from renewable energy sources • Government Decision no. 1892/2004 on the system for promotion of electricity produced from renewable energy sources Secondary legislation by the Romanian Energy Regulatory Authority • ANRE Order no. 15/2005 (organisation of the green certificates market) • ANRE Order no. 19/2005 (minimum and maximum prices of green certificates) • ANRE Order no. 20/2005 (minimum and maximum prices of green certificates)				
Additional information		(1) Average price of green certificates in November 2006 (2) Total price = market price Green Certificate + market price for electricity (average price in November 2006) * Exchange rate RON to EUR of December 2006 ** Green certificates trade: either bilateral contracts concluded between producers and suppliers or centralized auction within the Centralized Market of Green Certificates (organized and administrated by OPCOM)				

Slovak Republic

	Small Hydro (up to 5 MW)	Wind
Price (€/MWh)*	plants starting operation before 1 January 2005: 51 plants starting operation after 1 January 2005: 61 reconstructed plant with capacity increase after 1 January 2005: 64	plants starting operation before 1 January 2005: 67 plants starting operation after 1 January 2005: 75 plants older then 3 years starting operation after 1 January 2005: 51
Support scheme type	Feed-in tariffs	
Current applicable law	• Act No. 275/2001 Coll. • Decree No. 2/2005 of 30 June 2005 issued by the Regulatory Office for Network Industries; effective since 1st January 2006	
Additional information	* Rounded prices due to currency conversion. These prices are fixed prices which are calculated in order to allow a return of investment within 12 years. For 2007 they will be adapted to inflation according to inflation index published by the Statistical Office of the Slovak Republic. In case the purchase of a RES or co-generation plant was supported by state aid or an EU fund, the prices will be reduced by 15%.	

	Biomass	Solar PV	Others (geothermal energy)
Price (€/MWh)*	• electricity produced from combustion purpose-grown biomass: 80 • waste biomass for facilities starting operation before 1 January 2005: 53 • waste biomass for facilities starting operation after 1 January 2005: 72 • co-firing of biomass or waste with fossil fuels for plants starting operation before 1 January 2005: 53 • co-firing of biomass or waste with fossil fuels for facilities starting operation after 1 January 2005: 59 • combustion of biogas 67	213	93
Support scheme type	Feed-in tariffs		
Current applicable law	• Act No. 275/2001 Coll. • Decree No. 2/2005 of 30 June 2005 issued by the Regulatory Office for Network Industries, effective since 1st January 2006		
Additional information	* Rounded prices due to currency conversion. These prices are fixed prices which are calculated in order to allow a return of investment within 12 years. For 2007 they will be adapted to inflation according to inflation index published by the Statistical Office of the Slovak Republic. In case the purchase of a RES or co-generation plant was supported by state aid or an EU fund the prices will be reduced by 15%.		

Slovenia

	Small Hydro	Wind	Biomass	Solar PV	Geothermal
Price (€/MWh)	Uniform annual price 61,58 (≤ 1MW) 59,41 (> 1MW ≤ 10MW) Uniform annual premium 24 (≤ 1MW) 21,83 (> 1MW ≤ 10MW)	Uniform annual price 60,75 (≤ 1MW) 58,66 (> 1MW) Uniform annual premium 22,96 (≤ 1MW) 21,08 (> 1MW)	Uniform annual price 94,15 (≤ 1MW) 91,23 (> 1MW) Uniform annual premium 56,57(≤ 1MW) 53,65 (> 1MW)	Uniform annual price 374,41 (≤ 36 kW) 374,41 (> 36 kW) Uniform annual premium 336,83 (≤ 36 kW) 336,83 (> 36 kW)	Uniform annual price 58,66 Uniform annual premium 21,08
Support scheme type	Feed-in Tariffs				
Current applicable law	The Energy Act (OJ RS, No. 26/05, official consolidated text – EZ-UPB1)				
Additional information	The uniform annual price is the feed-in price. The uniform annual premium is the difference between the feed-in price and the average annual market price of electricity. Uniform annual prices and uniform annual premiums for electricity from qualified producers are fixed at least once a year by the Government. The figures of 2004 have not been changed, except for • biomass: a 35% increase for annual biomass prices and a 56% increase for annual premiums • solar: a more than 5-fold increase for prices and premiums for installations > 36kW				

Spain

	Small Hydro	Wind	Biomass	Solar PV	Solar Thermoelectric
Price (€/MWh)	FM <=25MW: 94 FM <=50MW: 86 RM <=25MW:69 RM <=50MW:61	FM <=50MW: 94 RM <=50MW: 69	- crops, agric. wastes, forests, biofuels, biogas: 94 (FM), 69 (RM) - agro-forest industries: 86 (FM), 61 (RM)	FM >100kW: 255 RM <=100kW: 440 RM >100kW: 229	FM: 255 RM: 229
Support scheme type	Feed-in tariffs				
Current applicable law	• Ley 54/1997 as amended • Real Decreto 436/1994 • Real Decreto 1556/2005 • Real Decreto-Ley 7/2006				
Additional information	There are two possibilities to sell renewable electricity: at the free market price (FM) or at regulated price (RM), both with premium. The prices listed above are assuming: a market price of 5.573 €c/kWh and a mean reference tariff of 7,658801 €c/kWh (there are other considerations to be considered regarding reactive power, etc.) Due to the high market prices during 2005, the government decided in July 2006 to put a cap on the selling prices. A new decree has been announced by a strong opposition of the industry sector (ASIF, AEE, ASIT).				

Sweden

		Small Hydro	Wind	Biomass	Solar PV	Others
Price (€/MWh)	(1)	67	73	67	67	67
Support scheme type		Quota obligation + Green Certificates				
Current applicable law		Lag (2003:113) om elcertifikat				
Additional information		(1) Green Certificates Total price = market price Green Certificate + market price for electricity (average price for the period January-October 2006) During the last year the electricity market price has varied between 3,5 and 7 eurocent/kWh and certificate price between 1,5 and 2,2 eurocent/kWh				

B. Neighbouring countries

Croatia

	Small Hydro	Wind	Biomass	Solar PV	Others
Price (€/MWh)*	n.a.	n.a.	n.a.	n.a.	n.a.
Support scheme type	Feed-in tariffs				
Current applicable law	• Energy Law (2001 and amended in 2004) • Law on Electricity Market (2001; 2004 new) • Law on Regulation of Energy Activities (2001; 2004 new)				
Additional information	* No further data available				

Turkey

	Small Hydro	Wind	Biomass	Solar PV	Others
Price (€/MWh)	average wholesale price 45,02				
Support scheme type	Feed-in tariffs (and tax incentives)				
Current applicable law	• Law No. 5346 of 18 May 2005 (Law concerning the use of Renewable Energy Sources for the generation of electricity) • Electricity Market Law No. 4628 of March 2001, authorizing Energy Market Regulatory Authority to take the necessary measures to promote the utilization of renewable energy resources • Electricity Market Licensing Regulation [Article 12(4) exemption from the annual license fee payment requirement for a period of 8 years]				
Additional information					

Former Yugoslav Republic of Macedonia

	Small Hydro	Wind	Biomass	Solar PV	Others
Price (€/MWh)	not yet available.*	not yet available.**			
Support scheme type	Feed-in tariffs				
Current applicable law	New Law on Energy 63/2006 adopted on 11 May 2006 (articles 133-142)				
Additional information	* Energy Regulatory Commission is expected to issue feed-in tariffs by the end of 2006 **The Energy Regulatory Commission is expected to establish preferential tariffs for RES-E producers Pursuant to article 133 of the Law 63/2006 a "Strategy for the exploitation of Renewable Energy Sources" shall be adopted, which will define transitional measures supporting RES-E, including preferential tariffs for preferential producers of electricity and other support mechanisms. Pursuant to article 140 of the Law 63/2006, preferential producers of electricity are those entitled with a *guarantee of origin* for electricity produced from RES issued by the Energy Agency of the Republic of Macedonia. Pursuant to article 141 of the Law 63/2006, the Market Operator is obliged to purchase all electricity produced from RES.				

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How about supporting EREF?

EREF asbl is the European Renewable Energies Federation. Since 1999 it is the voice of independent RES-producers and supporting industry.

The European Renewable Energy Industry has reached a stage where it is ready to assume the responsibility to provide the necessary new capacities to supply a growing European economy. Renewable energy can provide clean energy and at the same time reduce greenhouse gas emission. Renewables are the indispensable basis of a sustainable energy system.
However, as the industry is growing, institutional barriers are being built up. Not only are the existing barriers of centralized power systems to be removed, but the increasing competitiveness of RES Industry is provoking the introduction of new obstacles and barriers.

The European Renewable Energy Federation, EREF, has taken on the task to support the renewable energy industry by legal action in the European institutions as well as in Member States.

In a nutshell:

- EREF is the renewable energy value chain voice;
- EREF is the watchdog of the energy sector;
- EREF is providing information for public and media.

EREF is a non-for profit organisation. EREF always aims to remain a critical, independent partner to European Institutions, national governments and parliaments. EREF does not want to rely on public funding of those institutions we are cooperating with. EREF is defending the interest of independent power producers and related industry.

Our bank information:

Bank Account

Centea, Agence Parc du 50°naire, 1040 Brussels, Belgium
Account: 850-814 1365-56
IBAN: BE20 850 814 1365 56
Swift-Code (BIC): BE20 850 814 1365 56

Many thanks for your support!

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EREF asbl
European Renewable Energy Federation
Director: Dr. Doerte Fouquet
Avenue de la Fauconnerie 73
1170 Brussels
Belgium
+3226724367
+3226727016 facsimile
www.eref-europe.org