Analysis of a Severn Barrage

A REPORT PREPARED FOR THE NGO STEERING GROUP

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Part 1: What is the role of Government?

Part 2: How does a barrage compare?

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Executive summary

On 22nd January 2008, the Secretary of State for Business, Enterprise and Regulatory Reform (BERR) published the terms of reference for a feasibility study into the use of tidal power to generate electricity in the Severn estuary. This development brings into focus two important debates.

The first is over the uses of the Severn estuary. It is currently a valuable natural habitat. Over the years various schemes have been suggested, of which generating electricity through tidal power is one.

The second debate is about climate change and Government's commitment to reducing greenhouse gas emissions. This has resulted in specific targets for both emissions reduction and renewable electricity production. The Severn estuary provides one potential source for helping to meet these commitments.

With these debates in mind, this study was commissioned by a group of nongovernmental organisations to consider two closely related issues:

1. the framework used by Government to decide on how best to intervene in support of its commitments for emissions reduction; and
2. application of the standard Government framework to understand the costs and benefits of a barrage in the Severn estuary.

Only with clarity about the framework and the role of Government is it possible to coherently undertake an analysis of alternative renewable options. Consequently, this study (and the main report that follows) is divided into two parts.

The analysis was undertaken to a relatively short timescale. It is intended to raise issues for consideration and provide indicative results based on initial analysis. These are intended to raise questions that a full study would have to address. Throughout the report we note where a full study would have to examine issues in more detail to reach definitive conclusions.

Part 1: What is the role of Government?

Government has established a rigorous framework for deciding how to intervene effectively and efficiently in the economy to ensure best use of taxpayer money. The overarching approach has been developed by HM Treasury. It is based on:

- establishing a clear rationale for Government involvement;
- developing objectives that address the rationale; and
- assessing the costs and benefits of alternative means of intervention in light of those objectives.

A rigorous application of the framework suggests that there are compelling reasons for Government intervention to promote the development of renewable electricity. The analysis in the report identifies two main rationales for intervention:

- **First,** the need to ensure a price of carbon is felt by investors in a way that properly reflects the impact of greenhouse gases on climate change and ensures enough behaviour change to reduce emissions. The UK Government has, in particular through the EU Emissions Trading Scheme, successfully intervened to develop a price for carbon. However, the youth and volatility of the carbon market may provide further justification for Government action to generate greater certainty over future carbon prices. This could facilitate the financing of projects over long time horizons for which developers require greater certainty over the price of carbon into the future.
- **Second,** the spillover benefits from early research and development into new technologies means there may be inefficiently low levels of investment in the absence of some Government support. This may justify some support during the early stages of research and development.

Clearly Government intervention is needed to ensure that greenhouse gas reductions occur. But neither of these rationales (nor others examined in the main report), provides a justification for specific, targeted support for a Severn barrage. The full analysis indicates that this conclusion holds even when the wider moral hazard and related issues are considered.

Part 2: How does a barrage compare?

The second part of the project follows on from the conclusions in Part 1 to compare the costs of options for a Severn barrage to alternative means of generating renewable electricity. For the purposes of this report we entirely ignore any impact of the barrage on the local environment. For this, and other reasons discussed in the main report, the estimates are likely to be a conservative representation of the cost of a barrage (i.e. the true cost is likely to be higher than estimated in this report).

We build a bottom-up model of the costs of alternative renewable options. This involves:

- adding together capital, operating and other relevant costs over the lifetime of different forms of generation (e.g. wind, hydro, combined heat and power, solar, tidal); and
- incorporating relevant load factors; in order to
- calculate a total lifetime cost per unit of generation for the alternative technologies.

The results of this analysis suggest that:

- under a range of plausible scenarios, a large barrage on the Severn is expensive compared to alternative ways of generating renewable electricity; and
- there appears to be sufficient capacity to use other technologies to meet Government targets for renewable generation.

These conclusions are subject to the detailed issues discussed in the main report (e.g. importance of minimising overall system cost). However, the extent of the analysis, the in-built conservatism in the estimates used and range of sensitivity analysis undertaken suggests that considerable new evidence would be needed to make a large barrage in the Severn estuary an attractive option for meeting Government's overall objectives.

1 Introduction

1.1 BACKGROUND

On 22nd January 2008, the Secretary of State for Business, Enterprise and Regulatory Reform (BERR) published the terms of reference for a feasibility study into the use of tidal power to generate electricity in the Severn estuary. This followed an earlier report by the Sustainable Development Commission (SDC) about tidal power in the UK. The SDC report had a specific focus on potential projects on the Severn, and in particular on the possibility of a Severn barrage.[1]

These developments are bringing into focus a longstanding debate over the potential for the Severn estuary to be used as a source of electricity generation. In theory, the estuary contains natural conditions that could allow the generation of significant amounts of electricity (potentially up to about 4.5% of UK demand). Realising this, or smaller, levels of generation comes with some costs (e.g. in terms of construction, of the site specific environmental impacts) and some benefits (e.g. in terms of electricity generation that emits relatively little greenhouse gas). The extent to which the benefits outweigh the costs is subject to ongoing analysis.

Frontier Economics was commissioned by a group of nongovernmental organisations to examine two specific aspects of the existing discussion around a Severn barrage.[2] Frontier was asked to examine:

1. The framework within which Government should analyse the costs and benefits of a barrage on the Severn. What does this imply for its role in such a project?
2. How do current proposals for a Severn barrage compare with alternative means of electricity generation?

These two issues are equally important and inter-related. It is not possible to coherently compare the costs and benefits of a barrage (question 2) to alternatives without properly setting out the framework within which to calculate those costs and benefits (question 1). Crucial issues, such as the appropriate discount rate, the relevant counterfactual and the appropriate costs and benefits to include, depend on the response to the first question. This report discusses the findings in both of these areas.

The analysis was undertaken to a relatively short timescale. It is intended to raise issues for consideration and provide indicative results based on initial analysis.

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[1] The SDC report is entitled "Turing the tide, tidal power in the UK" and is available at: http://www.sd-commission.org.uk/publications.php?id=607

[2] The members of the commissioning group are: Anglers' Conservation Association, Royal Society for the Protection of Birds, Salmon and Trout Association, The National Trust, The Wildfowl and Wetlands Trust, The Wildlife Trusts, United Usk Fisherman's Association, WWF-UK, Wye and Usk Foundation, Wye Salmon Fishery Owners Group.

These are intended to raise questions that a full study would have to address. Throughout the report we note where a full study would have to examine issues in more detail to reach definitive conclusion.

1.2 OVERVIEW

The rest of the report is divided into two parts:

- Part 1 focuses on the framework and the first question posed above:
  - it discusses our approach – in Section 2; and
  - analysis and conclusions related to the framework and the role of Government – in Section 3.
- Part 2 takes this analysis and discusses:
  - our approach to the specific comparison of the costs and benefits of a barrage with alternatives – in Section 4; and
  - analysis and conclusions from this comparison – in Section 5.
- A final Section 6 provides a conclusion.

There are also two detailed annexes. The first provides a more technical description of the modelling and data used in Part 2. The second provides further sensitivity analysis to illustrate the impact of different assumptions on the conclusions reached in the report.

PART 1: What is the role of Government?

2 Approach

There exists a well established framework used by Government to decide whether and how it should support specific projects or initiatives with tax payer money. The high-level guidance, developed by HM Treasury for use by all Departments, is known as "The Green Book".[3] To quote from its Preface and Introduction sections:

"*The Government is committed to continuing improvement in the delivery of public services. A major part of this is ensuring that public funds are spent on activities that provide the greatest benefits to society, and that they are spent in the most efficient way.*" (p. v) … "*All new policies, programmes and projects, whether revenue, capital or regulatory, should be subject to comprehensive but proportionate assessment, wherever practicable, so as to promote the public interest*" (p. 1).

The Green Book goes on to describe, at a high level, the framework within which this objective can be met.

The framework is known by the acronym ROAMEF which describes the steps that must be taken in order to decide whether a proposed policy, programme or project is a suitable candidate for Government support. The key steps are:

- **Rationale:** Government intervention is costly, therefore it must be justified. The description of the rationale answers the question: why should the Government intervene? Broadly speaking, Government intervenes in two types of circumstances. The first is when it has concerns about distributional issues. The second is when the market is unable to efficiently deliver a particular product or service. There are well-known market failures (discussed in more detail in Section 3.1) which justify some Government intervention.
- **Objectives:** if intervention can be justified, what precisely are its objectives? These objectives should be linked to the rationale because meeting the objective should imply solving the problem identified by the rationale. The objectives provide the foundation for then assessing how much and what type of intervention is appropriate.
- **Assessment:** what are the costs and benefits of potential ways of intervening to meet the objectives? A comparison of alternative approaches that meet the objectives allows the most efficient one to be chosen.
- **Measurement, Evaluation and Feedback:** the final three stages in the ROAMEF framework are concerned with measuring the impact of the

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[3] It is available at : http://www.hmtreasury.gov.uk/economic_data_and_tools/greenbook/data_greenbook_index.cfm

intervention after it has occurred, evaluating its success in meeting the stated objectives and feeding that back into the decision-making process (e.g. about whether to continue, adapt or cancel the measure in question).

The precise application of each of these steps varies depending on the particular circumstances. Departments have issued more specific guidance setting out how factors specific to their areas (e.g. to education, to healthcare, to culture, to the environment) should be taken into account within this framework. Nevertheless, this remains the central framework.

In deciding on whether and what type of Government support should be made available for a barrage in the Severn estuary, it is this framework that must be applied. We discuss the consequences of its application in Section 3.

3 The role of Government

The framework set out in Section 2 provides the basis for deciding on the appropriate role for Government in support of particular initiatives. In this section we examine the first two elements of this framework as it relates to a potential barrage in the Severn.

3.1 RATIONALE

Four types of rationales are accepted as reasons for market failure, and potential justification for Government intervention.[4] The four reasons are the existence of public goods, externalities, imperfect information or market power. They are discussed in detail in the Green Book, we focus here on the one of most relevance to a potential barrage.

The clearest reasons for Government involvement in electricity generation generally stem from two types of externalities: those created by carbon emissions and those created by spillovers from learning during the development of new technology.[5] This is distinct from Government involvement in other areas of the electricity industry (e.g. in transmission and distribution). In these areas, the existence of (natural) monopolies provides a further justification for the very extensive regulatory regime that exists.

The externality created by greenhouse gas (mainly carbon dioxide) emissions from generating stations is linked to the harm that it causes. There is now considerable evidence that those emissions create damage in the form of global warming.[6] Until recently, neither the producers of the emissions (i.e. the generators) nor the consumers of the product (i.e. the households and businesses) incorporated these costs in their decisions about how much to produce or consume. As a consequence, an inefficiently high level of production and consumption may have existed.

The emissions externality provides a potential justification for Government intervention. Standard economic theory suggests that the most efficient response to such an externality is to ensure that its cost is properly incorporated into these

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[4] Government actions can also fail. Consequently, a failure in a market is not automatically a justification for Government action. A full discussion of this issue is beyond the scope of this report. The purpose of the rest of the ROAMEF framework is to evaluate whether Government action is warranted if a rationale for intervention exists.

[5] In this respect, a barrage is different from, for example, the recently announced CrossRail project. In the case of CrossRail, there are large positive economic externalities. Their existence means that the private sector will not be able to internalise, through fares, the full economic benefit of the project so government support is needed if this economically worthwhile project is to happen. In the case of a barrage, the benefits are priced directly, primarily through the electricity market and through the carbon market.

[6] This report does not discuss the links between greenhouse gases, global warming and damage. For a recent overview see the Stern Review on the economics of Climate Change: http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm

decisions. That requires putting a price on emissions, which is what Government has done.[7]

Government has implemented, in some cases in cooperation with the European Union, a range of measures that have resulted in a market for carbon. The most prominent of these is the EU Emissions Trading Scheme (EU ETS). Sectors of the economy covered by the EU ETS must limit their emissions to the amount of allowances they own. They can buy additional allowances, and sell surplus allowances, to other companies. This establishes a price of carbon. EU ETS covers electricity generation and, as such, the cost of emissions is incorporated into the decision about how much to generate.

In particular, pricing carbon means the conventional generation (e.g. coal and gas fired generators) become relatively more expensive and renewable generation relatively less expensive. This is the intended effect and begins to make renewable generation competitive in the market for electricity generation. In effect, pricing carbon removes the market failure.

Given that Government has taken this action (albeit with ongoing refinements and reforms still to come), the question remains about whether there is any need for further Government involvement. There are two main potential rationales that still exist for additional Government intervention:[8]

1. **Immaturity of the carbon market:** the market that has developed over the past few years for carbon is still new. While it has increased rapidly in size, its youth and dependence on Government policy for price determination (i.e. through the issuance of permits) mean that a relatively stable, predictable price has yet to emerge.

   The European Emissions Trading Scheme (EU ETS) was formed in 2005 as a key instrument to set carbon price and thus to tackle emission problems. One outcome of trading in Phase I (2005-2007) was a large volatility in price: trading started with prices higher than predicted (above €30 per ton in April 2006) and then sank to nearly zero in September 2007 (partly because banking of permits for Phase II was not allowed).[9] A number of amendments were made in preparation for trading in Phase II (2008-2012) to attempt to address some of the issues, but there is still considerable uncertainty over how prices will evolve.

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[7] There is a much wider discussion about the appropriate level of the price and how it should be incorporated into decisions (e.g. through carbon trading or carbon taxes). We do not explore that in this report.

[8] Other rationales include the need to coordinate planning issues which requires Government involvement (but not necessarily participation in the project itself) and Government involvement to resolve the fact that two barrages cannot both be built and so a decision is needed on which (if any) to advance.

[9] See report by Carbon trust "EU ETS Phase II allocation: implications and lessons".

In more liquid, well-established markets it is possible to hedge against future price movements. This is not currently possible to any great extent in the carbon market. The ability to hedge allows companies to finance big, risky capital projects because (at a cost) it allows them much greater certainty over future revenue streams. The inability to do that at the current stage of development in the carbon market may mean that it is very difficult to finance significant capital projects whose returns depend to an important extent on the future price of carbon.

2. **Spillovers from research and development:** A number of the renewable technologies currently being developed are new. Technologies such as various ways of tapping tidal power, offshore wind, solar photovoltaics and others are at the early stages of their development.

   It has been established that these early stages of development may be characterised by externalities.[10] In essence, it is not possible for companies investing in this new knowledge to fully capture the returns from that knowledge (e.g. because staff leave to other companies, other companies reverse engineer products, it is difficult to fully patent new ideas etc). This inability to fully benefit from investments at this early stage in the process means there may be inefficiently low levels of such investment. There is specific evidence in the case of renewable generation that costs for some technologies do fall considerably over time. For this reason, in many areas, Government steps in to offer specific support for the research and development of new ideas, technologies and products.

   This is distinct from "picking winners" (i.e. selected a specific company or project to support, see also Section 3.1.1). It should not involve supporting a particular company or a particular technology. Instead, it recognises a particular objective (e.g. increasing renewable generation) whose accomplishment requires overcoming certain market failures (e.g. pricing carbon, overcoming learning spillovers) and targets those market failures, not one particular "winner".

These two externalities provide some reasons for continued Government involvement in the sector beyond developing a market in which carbon can be priced. In the second area – support for early-stage R&D – there are already a number of initiatives in place. The most widespread is support provided through the renewables obligation. It is described in the box below.

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[10] See, for example, Helpman and Coe (1995) "International R&D spillovers", European Economic Review, 39(5): 859; and Griliches (1992) "The search for R&D spillovers", National Bureau of Economic Research Working Paper 3768. For Government's research in this area see: http://www.berr.gov.uk/files/file44504.pdf

Renewables obligation

The Renewables Obligation (RO) scheme was introduce in 2002 in order to provide incentives for the construction of more renewable generation.

Under the scheme, all licensed retail suppliers of the electricity are obliged to present Renewables Obligation Certificates (ROCs) equivalent to a specified proportion of their retail sales or pay a large penalty. The proceeds of the penalty fund are paid back to suppliers in proportion to how many ROCs they presented for the year.

Originally, one ROC was issued for each MWh of renewable electricity produced, independent of the renewable technology used for generation. The renewable generator could then sell this to suppliers. As a result, renewable electricity producers generate additional revenue alongside the value of the electricity produced.

The RO for 2007/08 is 7.9% of total electricity supplied, and it will gradually rise to 15.4% in 2015/16. Initially, Government intended to place the renewables obligation on suppliers until 2027. This statement of long term intent was required to encourage the long lived sunk investments required in renewable generation.

More recently, some concerns have been expressed regarding the efficiency of RO scheme. In particular, the fact that it is technology blind (i.e. 1 ROC is issued for every unit of renewable generation independent of whether it comes from wind, tidal, solar or other sources) was thought to provide windfall gains to some generators (those using relatively cheap renewable options) and fail to provide incentives to other types of generation. This resulted in proposals to band the RO. In essence, to issue a different number of ROCs depending on whether the technology was well-established or whether it was at the early stage in its development.[11]

Figure 1 provides an overview of the arguments set out in this section. It builds up the rationale for Government involvement based on a clear identification of market failures. These lead to specific areas of potential involvement for Government. In general, these can be characterised as:

- developing a price for carbon that properly reflects its impact; and
- supporting early stage R&D where there is evidence of strong spillover or learning effects.

The next stage in the process is to move from these rationales to specific objectives for Government in the sector.

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[11] See the BERR consultation on Renewable Energy – Reform Of The Renewables Obligation.

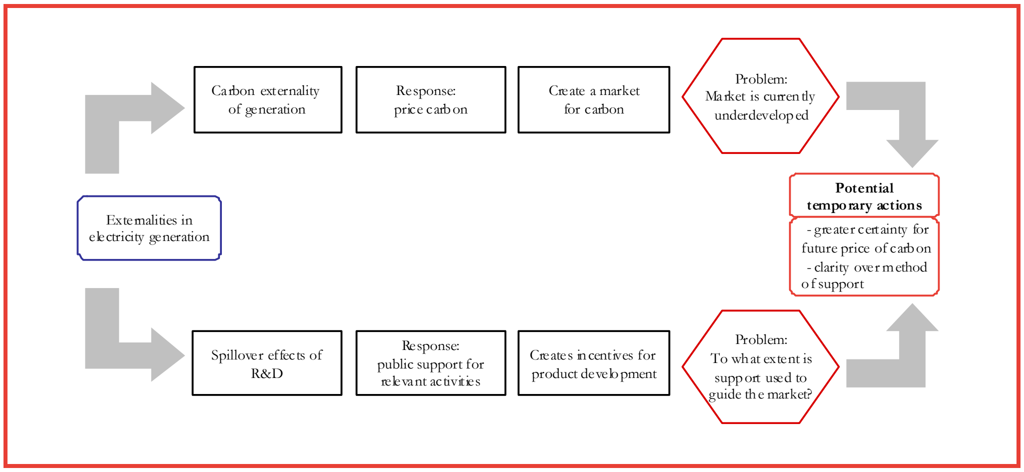

Figure 1: Rationale for government intervention in electricity generation market

3.1.1 Scale and moral hazard

Three further rationales are sometimes put forward for government ownership of projects like a Severn barrage.

- The **first** is simply one of scale: at £15 billion this is a large project and, perhaps, only the government could take on such a commitment.
- The **second** is associated with possible issues of "moral hazard": with large, nationally important, projects of this type, it is argued, the government will have to rescue any private sector operator which goes bust but if things go well the private operator will keep the benefits. So, the argument goes, the public sector has all the downside and the private sector all the upside.
- The **third** focuses on a different spin on the moral hazard issue. Suppose the barrage gets built by the private sector. There will then be a large and valuable asset which produces electricity at very low marginal cost. There is a risk that Government acts to (wholly or partially) expropriate the asset by, for example, changing the regulatory regime such that they do not receive a price which covers the full economic cost. The fear of such an outcome may result in the private sector being unwilling to undertake the project.

These quasi-rationales are not related to market failures *per se* but issues of political economy. As such, they can always be debated but in the case of a barrage do not seem likely to justify specific government intervention:

- **Scale:** the issue of scale seems largely irrelevant. The private sector is more than able to finance projects of this scale. The opening of new oil and gas reserves for instance, often in very risky environments, routinely costs many billions of pounds. Assets of similar sizes are owned and financed in the private sector.
- **Government will have to bail out private provider:** The first type of moral hazard – that the government will always bail out the private sector – is much less relevant in this particular case. Unlike other occasions, there is no

fixed deadline by which it absolutely must be completed and the large sunk costs mean that government would be able to find another operator – who would take revenue with little additional cost – to take over in case of the failure of the original operator.

- **After-the-fact expropriation** The second form of moral hazard, that government will expropriate the owners, is one which, in theory at least, always exists. The risk of government action is something that private providers will want to build into their considerations. However, the UK is a mature liberal democracy with an established free market in which these risks are, and are perceived to be, relatively small and manageable.

Perhaps most importantly the barrage is not qualitatively different from other investments in the utilities. It is hard to think of reasons for the public sector to build or operate a barrage which would not be equally applicable to many other projects and assets that sit in the private sector. There is neither the available public finance, nor the economic arguments, to change so significantly the way in which the economy is managed.

In summary, a Severn Barrage is not an exceptional project. It is neither so large, nor so risky, nor so subject to issues of moral hazard and government action, that we should overthrow the usual rationales for considering the appropriate role of government. Therefore, we return to the rationales discussed above: the potential market failures arising from carbon and learning externalities that exist. The solutions to these are not specific to a barrage but common to a very wide range of renewable technologies.

3.2 OBJECTIVES

The objectives for Government should flow from these rationales. Government has already stated several specific objectives for the sector. The Energy White Paper sets out four main objectives:

1. To be on a path to cut emissions by 60% by 2050 with real progress by 2020.[12]
2. Maintain the reliability of energy supplies.
3. Promote competitive markets in the UK and beyond.
4. Ensure every home is adequately and affordably heated.

Additionally, the White Paper adds the basis for achieving these objectives continues to be a competitive energy markets:

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[12] The Climate Change Bill, currently being developed, seeks to make this objective more concrete by setting specific ranges for emissions reductions by 2020 and 2050, setting up mechanisms to monitor emissions reductions and related actions (see: http://www.defra.gov.uk/environment/climatechange/uk/legislation/index.htm). In practice, the Committee on Climate Change, which is set up under the Bill, will advise Government on the precise 2020 and 2050 targets. For 2050 it could recommend a target above 60%.

"*Our strategy continues to be based on the principle that independently regulated, competitive energy markets, are the most cost-effective and efficient way of delivering our objectives*" (White Paper on Energy, 2007, page 8)

This is effectively a re-assertion of the market failure framework set out in the previous section: Government intervention in markets is only justified on the basis of clearly defined market failures.

In order to help to meet the first (and, to some extent, second) objective in particular, Government has also announced some specific initiatives. The most important are:

- a domestic commitment to achieve at least 20% of electricity generation from renewable sources by 2020; and
- an agreement with a pan-European target to achieve 20% of total energy consumption from renewable sources by 2020.

The EU commitment will result in specific national commitments. These are being finalised at the time of writing but would appear to require the UK to achieve about 15% of total energy consumption from renewable sources by 2020. Total energy consumption includes electricity generation but also energy used in transport and for the generation of heat. In practice, substituting renewable energy sources in sectors outside of electricity generation is difficult and expensive. Consequently, meeting the energy target will likely require greater than 20% of electricity generation to come from renewable sources.[13] How much greater than 20% depends on the savings achieved in the other sectors. It could be up to 40% renewable generation if the other sectors perform poorly.[14]

The means by which Government seeks to reach these objectives should be governed by the ROAMEF framework and the discussion of rationale in the preceding section. Clearly an important part of this is the use of renewable electricity generation. Exactly what is the best mix of renewable generation depends on the relative costs and benefits of the alternatives. That requires their measurement.

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[13] In other words, if transport and heat achieve only a smaller than 15% proportion of renewable energy, it would require electricity generation to include a much greater proportion of renewables in order to achieve the overall target.

[14] See, for example, http://www.greenpeace.org.uk/media/press-releases/renewable-energy-target-entirely-achievable-20080122 .

PART 2: How does a barrage compare?

4 Approach

This section provides an overview of the results from the analysis of alternative renewable generation options. Further detailed data and discussion can be found in Annexe 1.

4.1 GENERAL BACKGROUND

The third stage of the framework set out above involves measuring the costs and benefits of alternative means of achieving the stated objectives. This report also provides some preliminary analysis to inform this stage of the process. It compares different versions of a Severn Barrage to alternative ways of generating renewable electricity (i.e. of meeting one of Government's objectives in this area).

The approach is based on understanding the costs of generation using different types of technologies. The box below provides a brief overview of aspects of the electricity industry and the generation of electricity in particular. We report the costs in a standard format of £ per MWh: the cost of generating on mega-watt every hour. The approach adopted provides a first step towards the development of a cost that is comparable across the different generation technologies. It allows initial conclusions to be drawn and important questions to be raised on the basis of the cost comparison, subject to the limitations we discuss.[15]

The focus on generation costs abstracts from a number of issues (e.g. connection to the grid, total system costs). The consequences of these simplifications are discussed in detail following the reporting of the main results.

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[15] These relate to the need to properly incorporate the timing of generation into the analysis (i.e. the impact on overall system costs of incorporating into the analysis the fact that generation needs to meet demand every minute of every day).

Electricity generation

Electricity can be generated from a very wide range of technologies. So-called conventional technologies use coal, gas and oil to generate heat to raise steam (or other hot gases in some technologies) to turn turbines which generates electricity. Electricity generated using coal, gas or oil also produces greenhouse gas emissions as a by-product.

Other forms of generation include using the wind, water in various forms (e.g. damming rivers, waves, tides), the sun and waste products. These are generally termed renewable because they do not produce greenhouse gases as a by-product (although some processes that use waste may do so). Generation by nuclear sometimes falls in-between the two categories: it does not produce greenhouse gases during production but is largescale and has wider environmental consequences.

Generating stations have a rated capacity (i.e. the amount they can theoretically produce) and an actual production (i.e. the amount they do produce). Capacity is reported in mega-watts (MW). A station with a capacity of, say, 500 MW could produce 500 MW of electricity every hour. In other words, its production of electricity in an hour would be said to be 500 MWh.

In practice, no station produces every hour of the day, every day of the year for both technical and financial reasons. Technically, stations must be turned off for repair and maintenance and some forms of generation (e.g. those that use wind, water, sun) can only generate when there is a sufficient amount of the required input (e.g. sufficient wind, water, sun). For these technical reasons, a generation station with a 500 MW capacity will not generate 500 MW every hour of the day for every day of the year. The load factor describes the relationship between actual generation and a theoretical maximum equal to the generating capacity running for all hours in the year. For example, a typical coal station might generate 85% of the time (i.e. have a load factor of 85%). Over the course of a year such a station would produce 500 MW x (0.85 x 8760) = 3,723,000 MWh per year, where 8760 is the number of hours in a year.

Stations may also choose not to produce for financial reasons. If the price for the electricity they could produce is too low they may choose not to produce despite being technically able to do so. In practice, this means that at some times of day (e.g. when demand is low and so prices for generation fall) some stations may choose not to produce.

Finally, in order to get the generated electricity to consumers it is transported in the electricity network. The network consists of high voltage transmission lines and lower voltage distribution lines. Depending on the type of generation they will connect into different parts of the network to deliver the electricity. The costs of connecting and transporting electricity are only discussed briefly in this report at relevant points. It should be noted that network constraints (i.e. the inability of part of the network to carry any more electricity) are a third reason why generation stations may not be able to generate even when technically available.

4.2 OVERVIEW OF APPROACH TO MODELLING

The model consists of a bottom-up calculation of the costs of generation. It takes data from the International Energy Agency (IEA)[16] about the actual construction and operating costs of plant being built around Europe today. To those costs are added:[17]

- fuel costs: future fuel costs are calculated based on current relationships between the price of the relevant fuel (e.g. gas, coal) and that of oil, for plant requiring those fuels; and
- carbon costs: a price of carbon is calculated based on the Government's recommended carbon price for use in such evaluations, and added to the production costs for plant that emit carbon dioxide.[18]

The model incorporates the likely load factor for the different generation technologies. This recognises the fact that, for example, a coal-fired generating station can generate electricity almost all the time (other than outages for repair and maintenance) while a wind turbine only generates when the wind is blowing. A simple comparison of costs per unit of capacity ignores the fact that a unit of capacity results in different levels of electricity generation depending on the type of capacity in question.[19] The load factor is important for the accurate calculation of the costs per unit of electricity generated of different technologies (see box in Section 4.1).

The bottom-up approach to the calculation of the costs ensures that like-for-like comparisons are made across the range of technologies considered.

The central output of the model is a cost, in real 2010£ per MWh of electricity generated, of a large range of generation technologies. In addition to the generation options for the Severn estuary, the technologies considered are:[20]

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[16] The main IEA report used is entitled "Projected Costs of Generating Electricity, 2005 update" and is available at: http://www.iea.org/textbase/npsum/ElecCostSUM.pdf. It is the sixth report prepared by IEA that estimates the construction costs across a wide variety of power plants to be commissioned in Europe and elsewhere in the world between 2010 and 2015. It is a recognised authoritative source for such information. Its numbers were also cross-checked using data from other public sources – see footnote 40 and discussion around it in Annexe 1.

[17] Sensitivity analysis is conducted around all of these values in recognition of their uncertainty.

[18] See: http://www.defra.gov.uk/environment/climatechange/research/carboncost/step1.htm

[19] The type of capacity includes both the technology (e.g. whether wind, tidal, coal etc) and also its location (e.g. a wind turbine will generate different amounts depending on its location). The model takes an average load factor to represent all projects. It deliberately chooses a low load factor to approximate the fact that it is the cost of the marginal, rather than average, plant that is of interest (i.e. we need to consider what plant would be displaced by a new technology). This is discussed in more detail in Section 5.2.2.

[20] We also consider combined heat and power as a small scale technology that is an efficient way to produce energy under some conditions, and fuel cell technology as a potential future technology.

- conventional power sources: largescale coal, gas and nuclear plant and medium-sized hydro; and
- renewable power sources: onshore and offshore wind, small scale hydro, solar, landfill gas.

The focus of the model is on the latter, renewable, technologies. It investigates the balance between the amount of renewable electricity generation that could be produced by a Severn barrage and the cost of producing equivalent amounts of renewable electricity from alternative sources. The model stops short of estimating the generation mix that would minimise total system costs. That raises issues that are beyond the scope of this project. However, the analysis is designed to indicate what the key questions would be for a much more detailed study along those lines.

An overview of the model is provided in Figure 2 and the box that follows provides an example calculation. Full details of the model and the data are provided in Annexe 1.

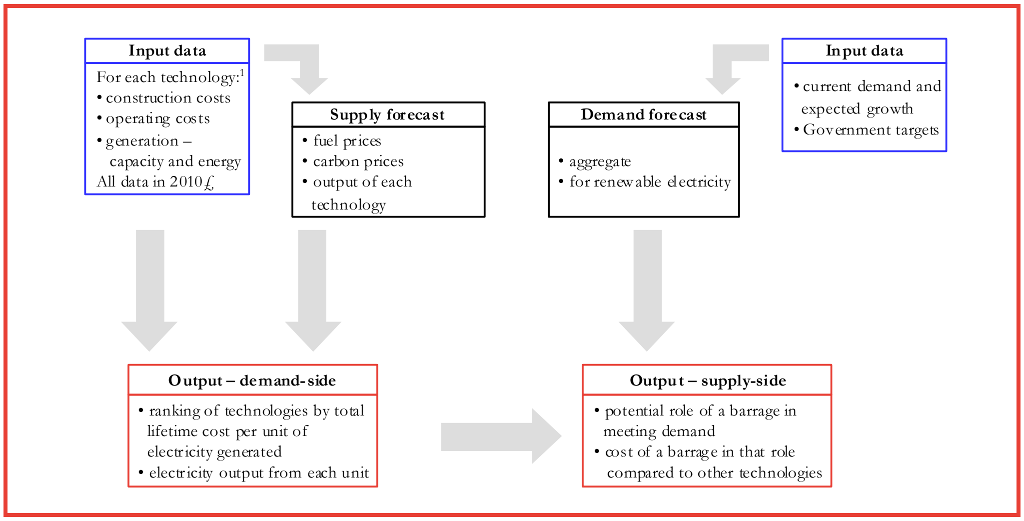

Figure 2: Overview of model

1: a specific decommissioning cost is also added for nuclear.

Example calculation

Total generation cost is calculated in five steps (this example uses a discount rate of 7%, we discuss discount rates in detail in Section 4.2 below):

1. **Initial capital costs during construction:** taking into account the time it takes to build the project and the distribution of costs across that time period. For example, the database includes an offshore wind project with an overnight construction cost of about £203 million. In practice, it would be built over two years with spending spread across that timetable and so actual construction costs (under base case assumptions – see below) is about £224 million.
2. **Lifetime fuel costs:** present value of the total cost of fuel required to produce the anticipated level of generation. Using the above example, fuel costs for wind are zero. However, for technologies with fuel costs they are calculated annually based on the formula below with total lifetime cost then being the discounted value of the annual costs:

   [(fuel price £/MWh in year i)/(thermal efficiency)]x(output in year i)
3. **Lifetime operation and maintenance costs:** present value of the total cost of repairs and maintenance required to maintain the plant operating at anticipated levels. They are based on reported annual O&M costs under the assumption that they remain the same (in real terms) every year. In this example, they are about £52/kW, equivalent to £8.3 million per year given a 160 MW plant (i.e. 52x160/1000). The present value of this stream of expenditure out to 2050 is then about £95 million.
4. **Carbon costs:** present value of the total lifetime cost of carbon emissions from the plant given anticipated levels of production. For the wind turbine considered in this example it is zero. For technologies that do produce carbon, we know emissions from the plant in tonnes per MWh from the IEA report, these are multiplied by total output and the relevant cost of carbon to generate an annual cost of carbon:

   (cost of carbon, £/t)x(carbon output, t/MWh)x(plant output, MWh)
5. Add together all the costs and divide by the (present value of lifetime) total expected output to generate a total cost per MWh. In this case, (£224m + £95m)/(6,514,068 MWh) = £49/MWh

This same process is repeated for every plant in the sample (see Annexe 1 for a description of the sample). The results are then reported for the average cost across all plants using the same technology (e.g. average for offshore wind) with a range around that average provided by the most and least cost plant.

4.2.1 Generation in the Severn estuary

A number of options have been considered to generate electricity in the Severn estuary. A detailed description can be found in the SDC report referenced in footnote 1. This report focuses in particular on a barrage, although there is also a discussion of tidal stream options for the estuary.

The SDC report undertakes one of the most detailed analyses to-date of two options for a barrage in the Severn estuary. The two options are known as the Cardiff-Weston and the Shoots.

The Cardiff-Weston is a very large project to place a dam across the mouth of the river. It would connect the two sides of the river just downstream from Cardiff and Weston Super Mare with a dam about 16 km long. The Shoots barrage is a significant but smaller scheme that would involve a dam about 4 km long connecting the two banks upstream from Bristol.

The two dams would work on the same principle: trapping water behind the dam at high tide to release it through turbines when water levels in the river are lower thereby generating electricity. The capacity of the larger barrage would be about 8.6 GW compared to about 1 GW for the smaller one. In practice, both barrages would only be able to generate for a limited number of hours per day. Consequently, this large capacity is not directly comparable to similarly large capacities for conventional generation (see box in Section 4.1). It translates into relatively less electricity generation. Table 1 provides an overview of the two schemes.

	Cardiff-Weston barrage	Shoots barrage
Length of embankments, km	16.1	4.1
Installed capacity, GW	8.6	1.1
Load factor, %	22.5	29.9
Annual output, TWh	17.0	2.75
Engineering cost of construction, bn	15.0	1.5

Table 1: Main characteristics of options for tidal barrage in the Severn

Notes: there are other variations on these themes discussed in the SDC report, these two options represent the main categories (i.e. large downstream barrage or smaller upstream barrage)

Source: "Turning the Tide", Sustainable Development Commission

As is fully recognised in the SDC report, the data (including estimates of cost and generation potential) should be treated as indicative. They are the best currently available but are based on preliminary studies undertaken in 1988 and 1990. In recognition of this, our modelling includes sensitivity analysis to examine the impact of changes to these estimates. In particular, we examine the impact of higher or lower construction costs.

The SDC report does also consider other technologies that could be used to generation electricity from the Severn's tidal range. In particular, it discusses the possibility of tidal stream technology. Tidal stream is similar to an underwater windmill – it generates electricity using a free standing turbine that is turned directly by the passage of water (rather than trapping water behind a dam before releasing it).

The SDC report contains a much more qualitative discussion of this option. It does not examine the costs of installing tidal stream generation or its potential to generate electricity. Since its publication, more investigation has been undertaken into tidal stream technologies. In particular, the Carbon Trust and a number of industry bodies have published some details about their potential costs.[21] We refer to these costs to provide further context to the analysis of a barrage presented in the next section.

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[21] For the Carbon Trust work see: http://www.carbontrust.co.uk/Publications/publicationdetail.htm?productid=CTC601&metaNoCache=1

5 Analysis and discussion

The overall objective of this stage in a ROAMEF analysis is to compare the costs of different ways to meet the stated objectives. In this case, alternative forms of renewable generation.[22]

The base case uses a standard set of assumptions for the values of the unknown parameters. An important unknown parameter is the discount rate. This should, in theory, be set at the cost of capital relevant to the project under consideration (i.e. a Severn barrage). It is not at all clear at this stage what the appropriate cost of capital should be.

At the lowest end, HM Treasury's Green Book suggests 3.5% for public projects.[23] This is the rate typically used for projects wholly within the public domain (e.g. schools, hospitals, museums). As discussed in Section 3.1.1, it is not clear that a barrage should (or could) fall within this category.[24]

At the highest end of the range is the cost of capital that a private sector company would require to undertake the entire project from start to finish. There is no agreement on what such a rate would be. The very safe network elements of electricity tend to have (pre-tax) cost of capital of between about 5.5% and 7.5%. Generation is more risky and may have a pre-tax rate upwards of 9 – 10%. [25]

In the base case we use 7%, about half-way between the completely publicly owned and operated model and the higher risk private sector rate. However, in recognition of the uncertainty over the relevant discount rate we undertake

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[22] The objective of a full study of the approach to meeting Government's objectives for renewables should investigate how to minimise total system costs (see Section 5.2.1 for details). This would take into consideration the pattern of demand across the day, week and year in order to understand the mix of generation that minimises the cost of meeting demand given renewable targets. This study limits itself to a comparison of generation costs. We discuss the implications of the findings of this work for the wider analysis in the concluding section.

[23] It also suggests the rate declines slightly over time for very long lived public projects (from 3.5% to 3% after 30 years and down to 2.5% after 75 years).

[24] There is a large, and sometimes confused, debate over using discount rates below 3.5% for projects designed to mitigate climate change. It stems, in part, from a misinterpretation of the Stern Review (see footnote 6). The Stern Review does use a different approach to discounting which effectively results in discount rates significantly below 3.5%. However, it does so specifically to determine whether any action on climate change itself is appropriate: it is comparing two very different states of the world, not two or more particular projects within the current state of the world. This is an appropriate way to discount to estimate, for example, a price of carbon. The price of carbon reflects the trade-off between current and future generations. Once an appropriate price of carbon has been determined, individual projects (which include that price of carbon for their emissions) should then be judged using appropriate discount rates (i.e. 3.5% for publicly funded projects, higher rates for privately funded ones). This is laid out clearly in DEFRA's guidance on the social cost of carbon and how to discount when considering climate change related policies (see: http://www.defra.gov.uk/environment/climatechange/research/carboncost/step1.htm).

[25] An overview of the theory for utilities is provided in Wright, Mason and Miles (2003) in a report for all UK economic regulators and the OFT, available at: http://www.ofgem.gov.uk/Networks/Policy/Documents1/2198-jointregscoc.pdf .

sensitivity analysis across the full range of values from the low to the high end. This analysis is discussed following the presentation of the base case results.

Where relevant the modelling also incorporates a:

- price of carbon set as per Defra guidance;[26] and
- fuel price based on the forward price of oil and its impact on current gas and coal prices.

However, most of the renewable technologies under consideration do not produce carbon or use conventional fuels. As such, their relative costs are not affected by the choice of carbon and fuel costs. Annexe 1 discusses these issues in more detail.

The overarching results are illustrated in Figure 3. It indicates that, under the base case assumptions, CHP and wind power are towards the lower end of the cost spectrum and solar, fuel cells and a large barrage towards the upper end of the cost spectrum. For example, production from a large Severn barrage costs about £127 per MWh, compared to about £55 for wind.[27] The boxes in Sections 4.1 and 4.2, as well as Annexe 1, provide detail about the calculations.

Tidal stream technology (see Section 4.2.1) is another alternative renewable source of generation. It is early in the development process, although a number of pilot projects are underway.[28] It is currently more expensive than the non-barrage technologies examined in detail as part of this study.

A study by the Carbon Trust indicates current costs ranging between about £60 and £100 per MWh. The Carbon Trust uses slightly different assumptions to those used in this study and so the figures are not directly comparable. It is a technology where early evidence indicates the presence of strong economies of scale and learning effects. Evidence indicates that tidal stream may be competitive with the barrage at current costs, although it has yet to be exploited on a scale comparable to the barrage. There does also appear to be greater potential for tidal stream technology to become less expensive (per MW installed) over time than may be the case with the barrage. This arises because of the

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[26] This amounts to £26 per tonne of CO2 in 2007 and increasing at 2% real thereafter – see http://www.defra.gov.uk/environment/climatechange/research/carboncost/step1.htm (our analysis is done in 2010£ and so the real price of carbon has been adjusted to 2010£).

[27] Within this modelling framework on-shore and off-shore wind have comparable levels of cost. This reflects the fact that off-shore wind while more expensive to install tends to have a higher load factor which means that per MWh it becomes comparable to on-shore wind based on current data. This does not include grid connection and transportation costs which may result in offshore wind being more or less expensive than on-shore depending on the location of specific projects. See Annexe 1 for a discussion of wind costs and current developments.

[28] The most recent, at the time of writing, announced by BERR on 7th April 2008, see: http://nds.coi.gov.uk/environment/fullDetail.asp?ReleaseID=364658&NewsAreaID=2&NavigatedFromDepartment=True

economies of scale and learning effects as more tidal stream technology is installed.[29]

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[29] See: http://www.carbontrust.co.uk/NR/rdonlyres/19E09EBC-5A44-4032-80BB-C6AFDAD4DC73/0/TidalStreamResourceandTechnologySummaryReport.pdf

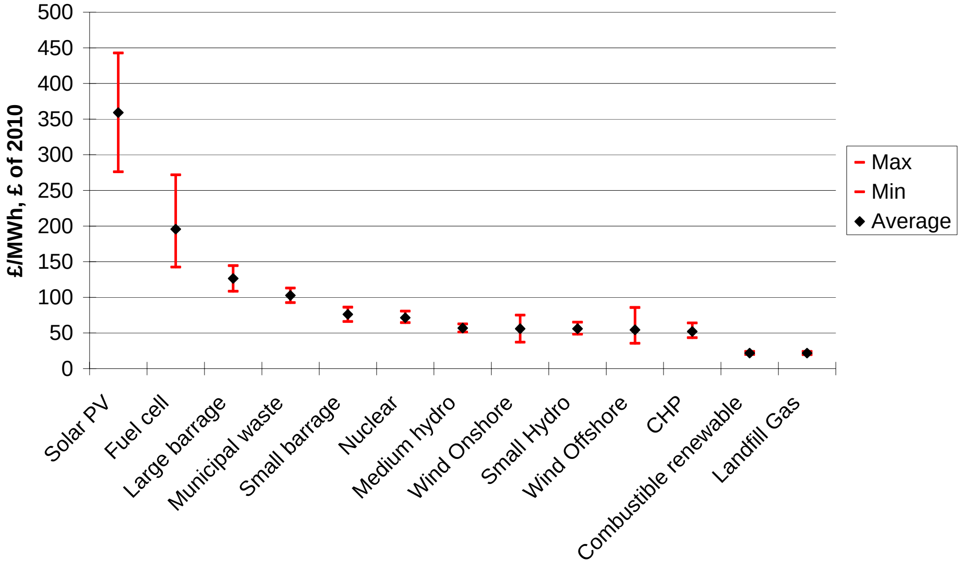

Figure below is the same as above but with the highest cost technologies removed to allow the reader to see the cost differences more easily

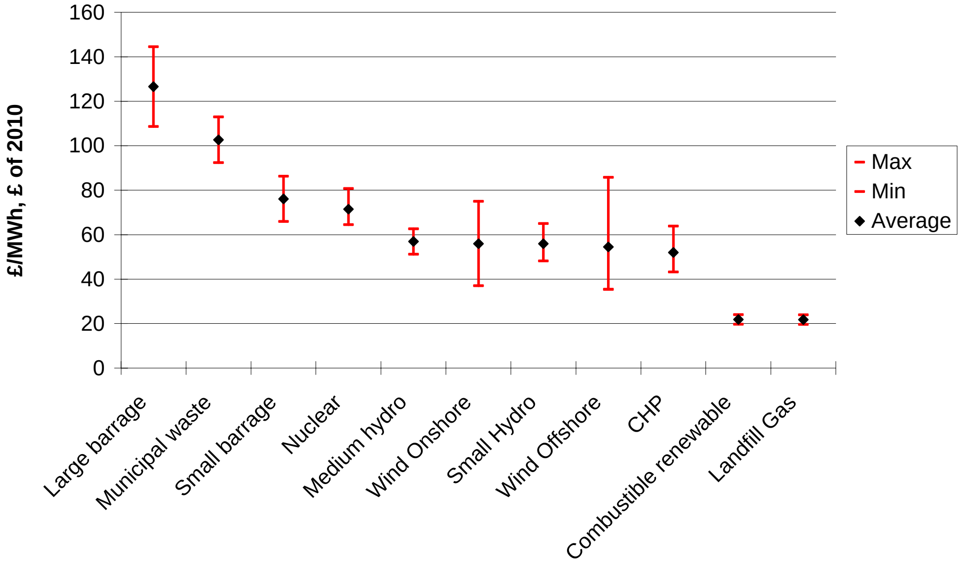

Figure 3: Comparison of alternative generation costs

Source: Frontier analysis based on IEA statistics and SDC report, details in Annexe 1

Note: the variance shown by the red bars in the graphs reflects the variance in project costs for projects in the database (see Annex 1 for a description of the database). It is not intended to measure a statistically significant range of project costs, nor to imply that projects cannot cost amounts outside the range.

5.1 SENSITIVITY ANALYSIS

A range of sensitivity analysis has been performed to understand whether the conclusions set out immediately above change under different assumptions. Overall, the ordering of the technologies, from least to most costly, does not change substantively with changes in the main assumed parameters. This includes changing the:

- discount rate: we have examined discount rates ranging from 3.5% (the Government's recommended rate in the Green Book for public projects) to 10%;[30]
- carbon price assumptions: investigating carbon pricing rising up to £40 per tonne; and
- fuel price assumptions: examining different future scenarios for fuel prices under which they grow more or less rapidly than envisioned in the base case forecast.

Clearly the latter two have no impact on the relative competitiveness of alternative renewable technologies. Since that is the focus of the analysis, Table 2 presents the impact on renewable costs of the alternative discount rates.

The numbers in Table 2 represent the average cost of generating a unit of output using the different technologies (a unit of output is known as a MWh – see box in Section 4.1). The cost is calculated over the entire expected lifetime of the project. Therefore, the choice of discount rate affects the level of the cost. Each column in the table reports the results from precisely the same calculation (i.e. the unit cost of generation over the lifetime of the project) using different discount rates. The first column uses the base case rate of 7%, the middle column uses the rate of 3.5% and the righthand column a rate of 10%. Further details on all the sensitivity analysis can be found in Annexe 2, and discussion of discount rates in the preceding section.

Analysis of the discount rate indicates that the large version of the barrage is the most costly option, among the main renewable categories, under all scenarios.[31] The level of the cost for a large barrage falls for lower discount rates, but so do the levels of all the other technologies and a large barrage remains relatively expensive. A barrage project benefits from a lower discount rate (i.e. its apparent cost falls quite a lot) because of its long lifetime: high upfront costs followed by over a hundred years of generation. However, even using the lowest conceivable

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[30] The Green Book suggests a decreasing discount rate for projects that last a very long time (more than 50 years). This was investigated and does not change the relative order of the technologies presented here. It reduces the per MWh cost of a large barrage by about 10% which is not sufficient to bring it into line with other technologies, notwithstanding the discussion in Section 3.1.1 about whether a public discount rate is appropriate.

[31] Solar PV and Fuel cell technologies are not shown here for ease of presentation but remain higher cost (see Figure 3).

discount rate it is still the most expensive option (after solar and fuel cells, see footnote 31). As discussed above, there is little justification for such a low discount rate.

Finally, it is worth emphasising the degree of optimism built into these barrage estimates. In particular, it is based on the best currently available reported construction costs. However, these:

- are quite old, despite being included in the recent SDC report they appear to originate from studies undertaken in the 1980s and the SDC notes that they likely underestimate its costs; and
- exclude all other site specific costs, including costs of land acquisition and, potentially crucially, site specific environmental costs from the destruction of habitat that would result in costs associated with compensatory habitat requirements which may be legally obliged under the EU Nature Directives.

Consequently, the costs presented for the barrage in this study probably represent the most optimistic view of final cost. Even with these optimistic assumptions the large version of the barrage appears to be an expensive option in all the scenarios.

Technology	Base case	Discount rate of 3.5%	Discount rate of 10%
Wind Onshore	55.93	44.45	67.20
Wind Offshore	52.04	41.32	62.60
Solar PV	359.14	260.40	454.82
Small Hydro	54.47	34.95	73.48
Medium hydro	56.92	37.87	75.81
Combustible renewable	21.85	15.71	28.27
CHP	55.92	56.54	56.49
Small barrage	64.51	38.75	88.17
Large barrage	107.86	60.65	154.30

Table 2: Sensitivity analysis – cost of technologies under alternative discount rates (£/MWh, real 2010)

Source: Frontier analysis based on IEA statistics and SDC report, details in Annexe 1

NOTES:

1 – this table presents averages. In practice there is a range of uncertainty around these average values. Particular projects will vary in cost due to local conditions. The figures provided elsewhere in this report provide an illustration of the variations that exist in costs for current projects.

2 – the generation costs calculated in the model exclude project-specific costs. As such they exclude (amongst other things) the costs of connecting to the grid. This may affect, amongst others, the relative cost of onshore versus offshore wind (e.g. also see footnote 27). However, the relationship is not straightforward because annual transmission charges are also a function of geographic location relative to demand. Depending on the precise location of projects relative to both the grid and demand, specific projects might cost more or less than quoted here.

5.2 IMPLICATIONS FOR RENEWABLES IN THE UK

The analysis presented in this section suggests that there is a relatively clear ordering of technologies from least cost to highest cost, with other technologies (e.g. tidal stream) also appearing to be strong candidates to be considered alongside more proven systems.

This simple analysis does leave out a number of factors. Perhaps most importantly are the following:

1. System costs: as mentioned above, the real concern is to minimise total system costs. Our comparison of one generation option against another does not capture this more general objective.

2. Opportunity cost: the real relevant comparison is not necessarily between the technologies but rather between a particular technology and what it would displace if it were built.
3. Government targets: Government is committed to a significant level of renewable generation. Even if some renewable technologies are less expensive than others, if there is insufficient capacity available in the lower cost technologies then other more expensive options will have to be considered.

We very briefly discuss the first and second issue which, while important, are beyond the scope of this study. They should be studied in detail as part of a full feasibility analysis. We then focus more attention on the third issue.

5.2.1 System costs

The objective of the electricity sector is to meet demand at least cost, subject to existing constraints (which may include specific renewables targets, carbon pricing etc). Minimising the cost of meeting demand is considerably more complicated than simply choosing the least cost technology. Instead, it requires recognising that the characteristics of demand vary, as do the characteristics of generation technologies.

At the simplest level, demand varies across different times of day, days of the week and weeks of the year. Meeting this varying demand at least cost requires a mixture of different types of generation – in order to take advantage of the different properties of generation. For example, different generation options have a different balance of:

- fixed versus variable costs;
- costs and speeds of start-up and shut down; and
- locations.

All of these (and other) factors need to be taken into account, alongside the simple costs calculated in this report, to understand the mix that minimises the cost of meeting demand. A full investigate of this multi-dimensional problem is beyond the scope of this report. The analysis in this report provides the first step. To the extent that the barrage appears expensive at this simple level, very detailed evidence would be needed of considerable systemic benefits (compared to alternatives) if this is to be the basis on which it is approved.

5.2.2 Opportunity cost

In practice, any new, more efficient, technology replaces the most expensive of the existing technologies. Consequently, new technologies are never competing against the best or even the average but against the worst. For example, justifying the cost of a barrage does not require that it be cheaper than the most efficient wind project, or even than the average wind project. Instead, it would have to be cheaper than the most expensive wind project required to meet demand. The cost of future wind projects will decrease a little due to economies of scale in production and some more learning but may also increase as the best sites (i.e. those with the best wind conditions) are taken up and new projects get sited in worse locations (and so cost more). The question that arises is whether the barrage is actually cheaper than the highest cost renewable projects that would be necessary in the barrage's absence in order to meet demand.

The analysis undertaken for this project suggests that the barrage is still expensive even when compared on this basis. In particular, the results presented in the previous section do not assume either particularly low construction costs for the alternative technologies, nor particularly favourable sites. For example, the numbers presented above assume a load factor for onshore wind of 23% (see Annex 1 for information about load factors). This is far lower than the best sites, and comparable to the worst sites; similarly for offshore wind. Further sensitivity analysis reveals that even under very poor conditions, the large barrage continues to appear more expensive than the most expensive versions of alternative technologies against which it would be competing.

One potential advantage of the barrage over wind is that its generation is predictable. Tidal movements can be forecast with great accuracy far into the future, unlike wind speeds. However, the SDC report indicates that forecasting barrage output indicates a large barrage would not produce much of its energy at peak times.

5.2.3 Government targets

It is possible to consider these technologies in light of Government's objectives for renewable generation by 2020, keeping the above issues in mind. Section 3.2 described the central objectives. They indicate that at least 20%, and likely considerably more, generation would have to come from renewable sources by 2020. It is beyond the scope of this report to fully determine the most efficient technology mix to meet that target (see Section 5.2.1 above). However, some analysis based on the earlier modelling is illustrative.

In particular, the analysis above allows a comparison of the costs of generating different levels of output. Data available on the largest version of a Severn barrage indicates that it could generate around 17,000 GWh of electricity per year. Depending on the level of supply in 2020, 17,000 GWh is probably between 3.6% and 4.5% of total annual electricity demand.[32] The cost calculations set out above indicate that the production of this electricity would cost about £2 billion per year. This is the cost that would have to be paid out each year to ensure the full lifetime costs of the barrage (as calculated above) were paid off over its 120 year lifetime. [33]

With the 2020 target for renewables in mind, it is reasonable to ask how much it would cost to produce the same amount as a barrage. The answer is provided in Figure 4. Each bar represents the total cost of generating output equivalent to

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[32] This is a large amount of generation in one station but not unprecedented. Drax, a large coal generator, provides about 6 to 7% of total electricity demand.

[33] This calculation uses the basecase assumptions and excludes the issues discussed at the beginning of Section 5.2 (i.e. the optimism built into the estimate of the barrage cost).

that of a large version of the barrage. For example, using solely offshore wind power the same level of output (i.e. 17,000 GWh) may be produced for about£900 million, about half the cost of the large barrage. Other technologies also appear to cost less than the barrage (the opportunity cost issues discussed in Section 5.2.2 are certainly relevant in this context). In addition, the information currently available about tidal stream technology (see footnote 29 and text around it) suggests that were it to be proven at such a large scale, the economies of scale and learning would mean that its costs would rapidly fall to levels at least similar to wind. Consequently, there appear to be a range of technologies that could generate output equivalent to the barrage at lower cost.

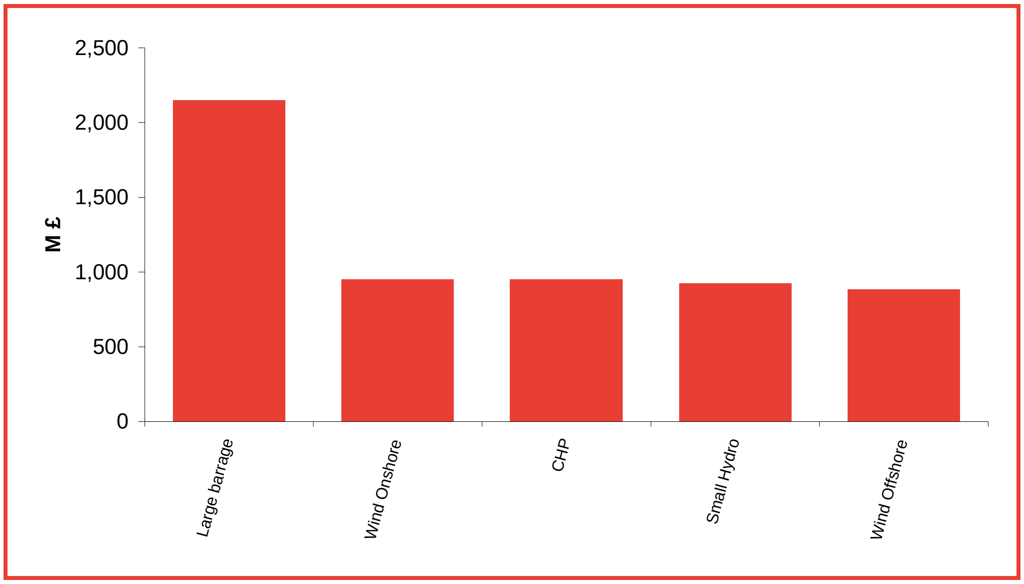

Figure 4: Annual cost of generating output equivalent to that of a large barrage

Source: Frontier analysis based on IAE data, details in Annexe 1

While it may be cheaper to generate the barrage's output using alternative technologies, there must also be sufficient resource available (i.e. sufficient wind, water or other means of actually generating the electricity). Initial estimates indicate that is likely to be the case.

Government studies indicate that there is, conservatively, about 50,000 GWh of on-shore wind capacity and about 100,000 GWh of off-shore wind capacity available to be exploited in the UK.[34]

This level of wind resource alone is clearly sufficient potential to meet Government's target of 20% renewables electricity generation by 2020. Such a target implies around 93,000 GWh from renewable electricity, well below the

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[34] See BERR (2001) "Wind Energy Fact Sheet # 8" for on-shore wind and BERR (2001) "Wind Energy Fact Sheet # 1" for off-shore wind. Both of the values for available resource are conservative. For example, the offshore wind data indicates about three times the amount quoted (i.e. up to 300 TWh) is theoretically possible but probably only about 100 TWh realisable.

combined 150,000 GWh forecast for wind, before taking into account other forms of renewable generation.[35]

A target of 40% renewable electricity generation, potentially implied by some of Government's other commitments (e.g. its EU commitment to 15% renewables in total energy consumption, see Section 3.2), is more difficult to achieve. It would imply renewable generation of about 187,000 GWh, in excess of what is available solely from wind but likely within what is available from all renewable sources.[36]

A final issue to be considered relates to the network implications of increased levels of small scale generation. This increase in small scale generation is necessary to meet Government targets with or without a barrage, but more is clearly needed in its absence. There is a considerable body of literature, and extensive discussion, of the implications for the design of transmission and distribution networks of such large increases in smaller scale generation. The network has historically been designed to facilitate the use of large, centrally dispatched conventional power sources. In some respects, a large barrage is more similar to these than wind, tidal stream, small hydro and other renewable technologies. A question arises about whether extensive, and expensive, changes would be required to the network in order to accommodate these other technologies.

Accommodating large quantities of these renewable technologies may increase some network costs. Their unpredictable intermittency (i.e. only generating when wind is blowing or non-tidal water flowing at sufficient speeds) creates some voltage and power flow issues, alongside other potential network costs. It is important to note that the current network has been designed to cope with many of these issues (after-all, the network has to be robust to large, conventional power stations unexpectedly failing to generate when needed). Consequently, at low levels of penetration of renewables most current studies agree that there are very limited network costs. At higher levels, there may be some costs but the best current estimates indicate that these would be much lower than the additional cost of the barrage. The most recent government study estimates that about £2.5 billion (in 2005£) would be needed to mitigate voltage, reverse power flow and other issues associated with a large increase in microgeneration.[37]

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[35] Clearly the precise target depends on the speed of total electricity demand growth between now and 2020. These figures assume a 1% per annum increase in electricity demand from 2006 onwards. This is a level consistent with recent historical experience but future growth may be lower (e.g. if costs continue to rise and environment programmes to limit demand have greater success) or higher (e.g. if costs fall, household growth continues).

[36] At the time of writing a number of developments were taking place that may or may not affect these overall estimates. In particular, planning permission for a wind farm on the Isle of Lewis was turned down and one private sector supporter decided to pull out of an offshore wind farm in the Thames estuary. It is not clear whether these changes significantly impact the available wind resource.

[37] "Potential for microgeneration", November 2005; available at: http://www.berr.gov.uk/files/file27559.pdf . An earlier Carbon Trust study estimated costs (at the high end) of £4 billion in network upgrades to meet Government's 2020 target for renewables. A more detailed study for the former DTI in 2006 entitled "Accommodating Distributed Generation" (http://www.berr.gov.uk/files/file31648.pdf) investigates the costs and benefits of network changes

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required for distributed energy in the UK. It does not derive a single cost figure but indicates that costs are likely to be minimal (perhaps £10 million) until about 3.5 GW has been installed and higher thereafter. However, it suggests that wind power is financially viable even with higher connection costs to support network reconfiguration. It does also note that there are compensating benefits (e.g. carbon savings, improved energy security and reduced electricity losses in transmission) that also arise from this expenditure.

6 Part 1 and 2: conclusions

This study has considered two closely related issues:

- the framework used by Government to decide on how best to spend taxpayer money; and
- its application to the potential construction of a barrage in the Severn estuary.

The application of the framework provides some rationales for Government's objectives and actions in the electricity generation sector (e.g. for developing a price for carbon, providing specific support through the Renewables Obligation). It also indicates where further support might be considered (e.g. generating more certainty over future carbon prices, considering spillovers during the early stages of technological development). However, it would be difficult to justify support specifically for a Severn barrage within this framework. This is true even when the wider moral hazard and related issues are considered.

The justification for a barrage should flow from it being the least cost option amongst the range of options available to meet Government's objectives. This study examines one particular aspect of that least cost decision: a comparison of the individual costs of generating from different sources. The analysis is based on a bottom-up calculation of generation costs that takes the specific characteristics of the different technologies into account. In addition, it uses cost data from actual projects currently being commissioned.

This analysis suggests that:

- under a range of plausible scenarios, a large barrage on the Severn is expensive compared to alternative ways of generating renewable electricity; and
- there appears to be sufficient capacity to use other technologies to meet the barrage's output and Government's targets.

These conclusions are subject to the issues raised elsewhere in the report (e.g. importance of minimising overall system cost). Within the limitations of the timescale and budget, the report provides preliminary findings that raise questions that would have to be thoroughly addressed as part of a full study. It is not intended to be the definitive last word. However, the extent of the analysis, the in-built conservatism in the estimates used and range of sensitivity analysis undertaken suggests that considerable new evidence would be needed to make a large barrage in the Severn estuary an attractive option for meeting Government's overall objectives.

Annexe 1: Technical details of the modelling

The annex describes the assumptions and methods used to estimate the costs for a number of generation technologies.

The main goal of this modelling exercise was to compare costs of a Severn barrage relative to alternative means of meeting electricity demand, given current policy constraints. Those policy constraints relate particularly to Government's commitment to increase the amount of renewable electricity generation. As such, the main report focuses on comparing the cost of renewables. The model and database developed as part of this project does also include conventional gas and coal-fired generation. These are also discussed in the annexe.

In order to provide quantitative estimates we first calculate levelised costs of different generation technologies and then use them to calculate the costs of supplying the volume equivalent to production from a barrage.

LEVELISED COST OF GENERATION

Calculation of the costs requires assumptions about capital costs, operation and fuel costs, other relevant costs (e.g. costs of CO_2 emissions, decommissioning costs) and the lifetime of the assets. Macroeconomic assumptions about inflation and exchange rate dynamics are also required to adjust original data.

Levelised costs reflect the costs of generating electricity per MWh discounted to a particular date over the operational lifetime of the asset. It shows the costs that need to be covered in order to produce electricity using certain technology.

We calculated levelised costs of generation in 2010, all estimates are represented in 2010£.

General assumptions

Inflation

In order to calculate the costs in 2010£, we inflated the construction costs using the forecast of CPI from 2008 onwards. This may, in fact, underestimate total construction costs because inflation tends to be above CPI in the construction industry. We assumed that UK inflation will be stable at the level of 2.3% per year; inflation in European Union is assumed to be at 2.1%.

Severn barrage

The SDC report (see footnote 1) provides the source for all the data relating to barrage options in the Severn. It discusses many potential designs but ultimately focuses on two main alternatives: Cardiff-Weston scheme with about 8.6 GW of installed capacity and the Shoots scheme with about 1 GW.

We consider both options for the barrage in our model and compare the unit costs of both potential installations with alternative options. In the sensitivity analysis we consider the impact of scaling the costs upwards and downwards to reflect potential cost over-runs or savings. Table 3 sets out the main characteristics of the two options.

	Cardiff-Weston barrage	**Shoots barrage**
Length of embankments, km	16.1	4.1
Installed capacity, GW	8.6	1.0
Load factor, %	22.5	29.9
Annual output, TWh	17.0	2.75
Engineering cost of construction, bn	15.0	1.5

Table 3: Main characteristics of both barrages

Source: "Turning the Tide", SDC report

Capital costs of the Severn barrage are based on those in the SDC report. We use the proposed engineering estimates taking into account the note made by SDC that a 10-15% margin of error should be applied to their numbers. We assume that the operation costs of the barrage are similar to the operating costs of hydro power plants.

Key cost drivers

Capital and operation costs

The model uses data on capital and operating costs collected by the International Energy Agency (IEA) in its report "*Projected Costs of Generating Electricity*", update of 2005. The report is based on data collected in 2003/04. It provides cost data on more than 130 plants across all technologies, in 21 (18 OECD and 3 non-OECD) countries. The plants included are under construction or planned for commissioning between 2010 and 2015, and for which cost estimates have been developed through studies or specific bids.[38]

The IEA dataset does have some disadvantages (e.g. excludes UK-based plant). Consequently, detailed verification has been conducted and is discussed below. The important advantages of the IEA dataset, and why it was used, are:

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[38] Some of our initial data about capital costs and other costs was available in US dollars and euros. We used relevant forward exchange rates in order to convert data from the different currencies into pounds. The exchange rate data is provided by the Bank of England.

- it is an internationally recognised, authoritative dataset produced by an independent source; and
- it provides a detailed breakdown of the different elements of the costs of generation and so allows us to build generation costs from the bottom up. This has the advantage that we do not need to take a "black-box" estimate of total cost from another source and also that we can conduct detailed sensitivity and other analysis on any sub-component of total cost.

For the purposes of our study a subsample of 39 plants was selected. The subsample is all the plant in the IEA study (see footnote 16) for the relevant technologies built in countries broadly comparable to the UK (i.e. it excludes plant built in the USA, African and Asian countries).[39] This subsample includes 5 coal, 3 gas and 3 nuclear plants; 6 wind, 3 solar and 3 hydro plants; 9 CHP plants and 6 plants of combustible renewables and embedded technologies. Table 4 provides an overview of the plants in the sample. The averages presented in the analysis in the main report represent averages across the set of plants in Table 4. The IEA report is recognised as an authoritative source of electricity generation costs. It reports actual construction costs for recently commissioned plant. The data was also verified against other published benchmarks to ensure values were a reasonable representation of industry averages.[40]

At the time of writing there has been an increase in the cost of wind turbines, particularly for offshore wind, that is not reflected in the database. The very recent cost increases appear to have been driven by the significant increase in demand relative to manufacturing capacity and the increase in some raw material and component costs. This appears to be part of a natural cycle with many new technologies: initial high costs of development give way to lower costs which boost demand beyond available manufacturing capacity. That drives up prices in the short run which results in new investment, new capacity and prices that return to former trends. If that is the case then our estimates continue to be a reasonable view of the longer term trends. It is too early to say whether that is what is happening in this case and, at least in the short run, there is some evidence that the increased cost of wind may affect either its price or the number of turbines delivered, or both.

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[39] The IEA report does not include any data for plant built in the UK.

[40] See also, for example, (former) DTI (2005) "*The costs of supplying renewable energy*"; Royal Academy of Engineering (2004) "*The Cost of Generating Electricity*".

Plant type	**Number of plants in a sample**	**Generation technology**	**Country of origin**	**Capacity (MW)** ***Capital cost (£ millions)***[1]	**Overnight construction costs (£/kW)**[2]	**Annual operation and maintenance costs (£/kW)** [2]
Coal plants	5	Pulverised fuel, IGCC, Fluidised bed	Germany, France	400-1000 *£478 – 1,069m*	*£725-1077*	*£ 38.3-71.2*
CCGT plants	3	CCGT	Germany, France, Netherlands	500-1000 *£389 – 417m*	*£389-796*	*£26.5-30.0*
Nuclear plants	3	Nuclear	Germany, France, Netherlands	1500 *£5,740 – 7,972m*	*£1200-1700*	*£35.7-52.2*
Wind farms	3	Wind onshore	Germany, Denmark	1.5-15 *£1.2 – 13.3m*	*£750-884*	*£12.5-29.9*
Wind farms	3	Wind offshore	Germany, Denmark	150-300 *£203 – 438m*	*£1270-1460*	*£33.4-52.4*
Solar panels	3	Solar PV	Germany, Denmark	0.002-0.5 *£0.007 – 2m*	*£3540-4100*	*£0.0-35.4*
Hydro plants	4	Run of the river, Small Hydro	Austria, Czech republic, Germany	0.7-14 *£1.9 – 46m*	*£1240-3300*	*£17.0-52.0*

Annexe 1: Technical details of the modelling

Landfill gas	1	Biogas	USA	30 *£34m*	*£1140*	*£67.1*
Municipal waste	1	Firing	Netherlands	60 *£317m*	*£5400*	*£103.3*
Combustible renewable	1	Co-firing	USA	100 *£132m*	*£1300*	*£49.2*
Fuel cell	3	Gas fuel	USA	1-10 *£0.7 – 16.8m*	*£620-1700*	*£30.4-81.4*
CHP plant	9	Gas, coal, co-firing	Austria, Germany	1-500 *£2 – 510m*	*£470-2800*	*£24.1-144.2*

Table 4: Sub sample of plants selected for cost estimations

Source: "Projected Costs of Generating Electricity", IEA

1: the capital costs are overnight construction costs, see main report (Section 4.1) for the detail of how these are use to calculate actual capital costs and feed into total cost.

2 the overnight construction costs per unit and O&M costs are reported in constant 2010£

Annexe 1: Technical details of the modelling

As mentioned above, the IEA dataset does not include power plants to be constructed in the UK. However, the estimations that exist for UK power plants indicate that costs derived from the IEA database do also reflect the costs of similar plant in the UK. Two published studies for the (former) DTI provide an indication of levelised costs for renewables in the UK. The first is authored by Enviros Consulting, [41] the second by Ernst and Young. [42] The different methodologies used mean that direct comparisons are not appropriate. However, our analysis of the IEA dataset, the Enviros report and the Ernst and Young report all produce costs of the different renewable technologies within similar ranges. For example, Enviros estimate capital costs for onshore wind farm are estimated to be around £0.9 – 1.2m for a single turbine plant and £1.5 to 2m for a medium size hydro plant; both of which fall into the range estimated by IEA. Similar ranges are found by Ernst and Young.

We now continue to describe our methodology. The original overnight capital costs are used to calculate the effective investment costs given data about the construction time required. The IEA report provides the data on the construction period for most of the plants; however for some plants this information is not available, and SDC report does not provide the construction profile for the barrage. For these cases we used the industry reviews as the basis of the construction time. The resulting construction times are presented in Table 5.

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[41] "The Costs of Supplying Renewable Energy", a report by Enviros Consulting, 1 September 2005

[42] "Impact of banding the Renewables Obligation – Costs of Electricity production", April 2007

Technology	Average construction time	Load factor
Coal plants	3-4 years	85%
CCGT plants	2-3 years	85%
Nuclear plants	5-6 years	85%
Wind farms	2 years	25% (offshore) 23% (onshore)
Solar panels	1 year	10%
Waste, combustible renewables, embedded generation	4 years	85%
Fuel cell	3 years	60%
CHP plants	2 years	85%
Small barrage	3 years	30%
Large barrage	7 years	22%

Table 5: Assumed construction times and load factors

Source: Frontier analysis

Finally, we assume that the operation and maintenance costs (also taken from the IEA) stay constant (in real terms) over the operation of the plant. In practice, this may slightly over-estimate them at the beginning of the plants life and under-estimate them towards the end.

The capital costs for nuclear plants include decommissioning costs, but do not include refurbishment costs. There is considerable uncertainty and much research into the actual cost of decommissioning the next generation of nuclear power plants. Fully incorporating this into the analysis in this report is beyond its scope. The report is not intended to focus on the relative cost of nuclear. The model allows sensitivity analysis to be performed to investigate the impact of changes in decommissioning cost. Under the base case results reported in the main report, decommissioning costs are assumed to double the initial construction costs of the plant (i.e. a lump sum equivalent to the initial construction cost of the plant must be set-aside a the time of construction to accrue interest in order to ultimately pay for the decommissioning of the plant).

Fuel costs

We forecast coal and gas prices using the relationship that exist between them and the oil price. We undertook a simple regression analysis to derive relevant correlation coefficients. These are then applied to forward oil prices to estimate coal and gas price. For prices beyond 2030, we apply the same constant growth rates to coal and gas prices.

The starting point for forecast is 6.7£/MWh for coal and 17.4 £/MWh for gas.

As for the nuclear fuel, we adjust the estimates provided in IEA report and extrapolate them forwards using a constant growth rate. The starting point for nuclear fuel is 4.6 £/MWh in 2010.

We have included sensitivity that allows modelling various growth rates of the fuel prices over the long run. The sensitivities allow a comparison of the costs of renewable and conventional generation technologies under different fuel prices. The sensitivity scenarios are summarised in Table 6 and the resulting forecasts in Figure 5, Figure 6 and Figure 7.

	Coal price	**Gas price**	**Nuclear fuel price**
Low case	1%	1%	1%
Base case	2%	2%	2%
High case	3%	4%	2.5%

Table 6: Fuel price growth rates from 2030

Source: Frontier analysis

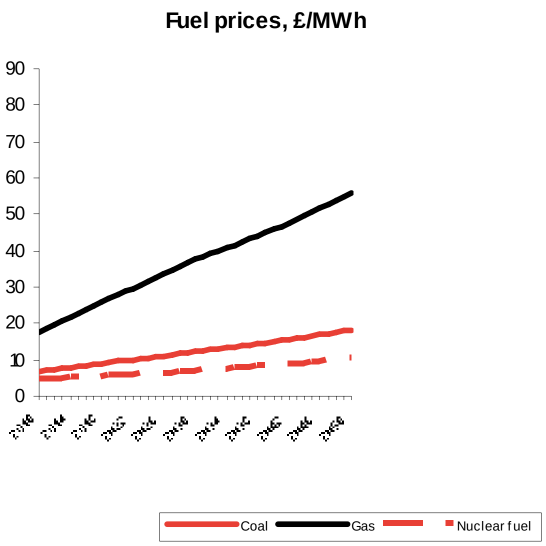

Figure 5: Forecast of the fuel prices till 2050, **Base case**

Source: Frontier estimates

Figure 6: Forecast of the fuel prices till 2050, **Low case**

Source: Frontier estimates

Figure 7: Forecast of the fuel prices till 2050, **High case**

Source: Frontier estimates

Carbon prices

In order to compare barrage and other renewable technologies to thermal generation we have to take into account the cost of carbon emissions. In our evaluation we increase the costs of CO_2 emitting technologies for the cost of their emission over the lifetime of the plants.

We used the official estimates for the social cost of carbon provided by Defra and recommended for use in policy appraisal. Defra assumes an increase in carbon price of approximately 2% (real) annually from initial value of 25.50 £/tCO_2 in 2007.

We also examine various scenarios around Defra's values. These include a scenario in which the growth rate of carbon price will fall to 0% per annum, and a high case situation when price of the certificates will grow at the rate of 5% per year. These are summarised in Figure 8, Figure 9 and Figure 10.

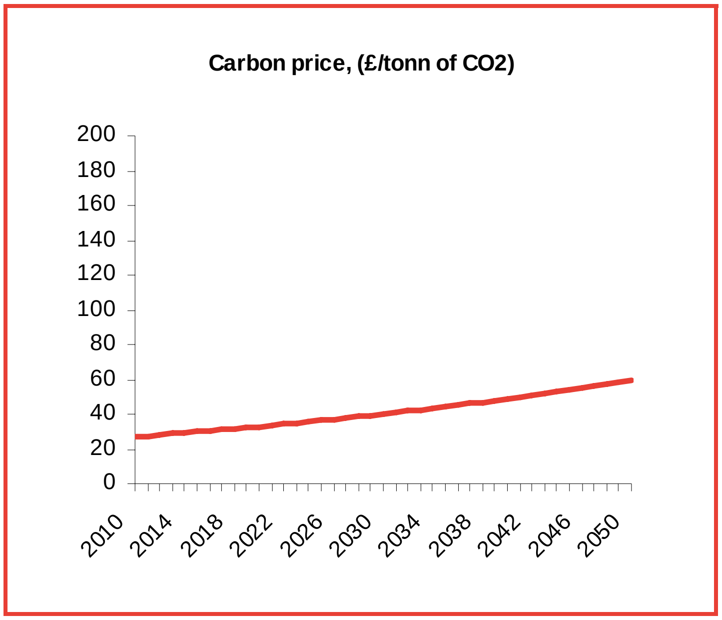

Figure 8: Dynamics of the carbon price: Defra assumption (real, 2010£)

Source: Defra, Frontier Economics

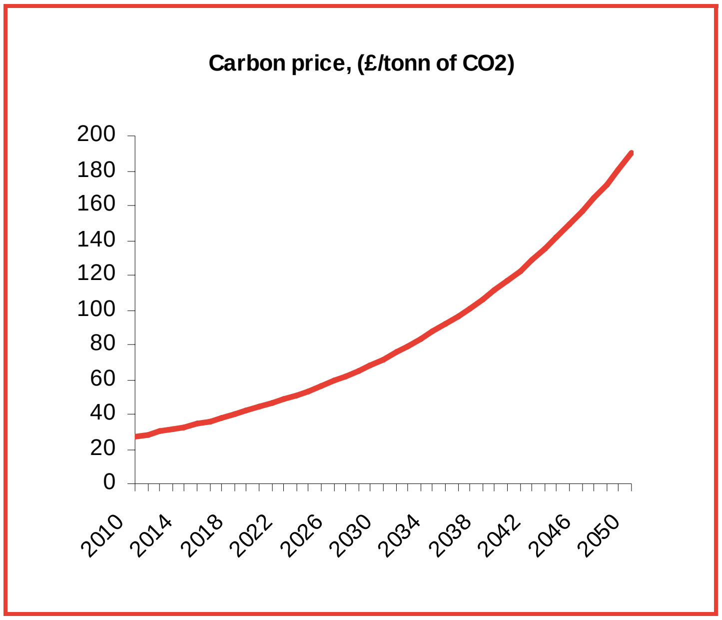

Figure 9: Dynamics of the carbon price: High case assumption (real, 2010£)

Source: Defra, Frontier Economics

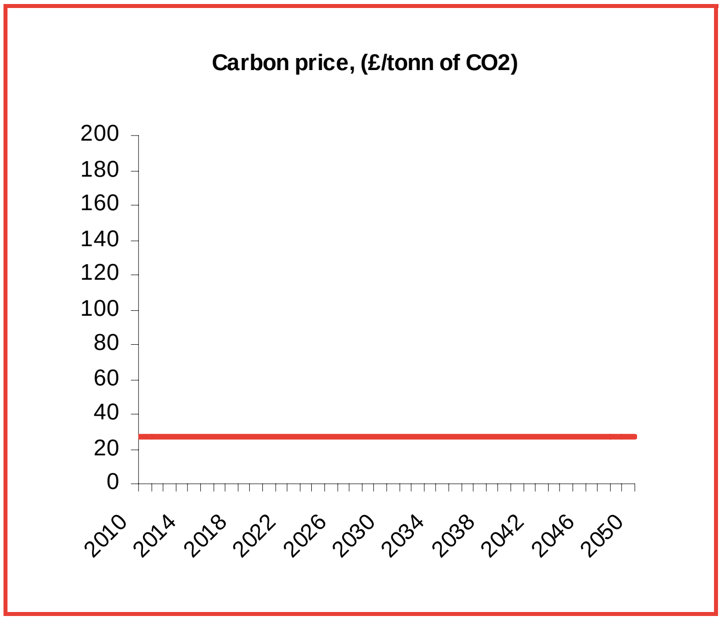

Figure 10: Dynamics of the carbon price: ETS fail assumption (real, 2010£)

Source: Defra, Frontier Economics

Annexe 1: Technical details of the modelling

Electricity output

The calculation of electricity output for each particular technology relies on capacity and assumptions about load factors (i.e. proportion of hours when the capacity is being used to generate electricity). These data is taken from the IEA report for all the technologies except the barrage. The SDC report provides specific forecasts of the amount of electricity that would be generated by the large and small barrages (from which a load factor can be derived).

ANALYSIS OF A SEVERN BARRAGE AND ALTERNATIVE OPTIONS GIVEN GOVERNMENT TARGETS FOR RENEWABLE GENERATION

The second part of Section 0 extends the analysis to consider the least cost approach to meeting the Government's renewables targets. This is based on an estimate of the cost of producing an amount of output equivalent to that of a large barrage through other means.

To compare a large barrage to alternative generation technologies we estimated the levelised costs (i.e. present value of costs divided by present value of output) of supplying the same amount of electricity using other technologies.

The estimation for the output of the barrage is 17 TWh for a large scheme and 2.75 TWh for a small one. In order to estimate the levelised costs of producing this volume with alternative technologies we multiplied levelised unit costs of generation by the volume of the barrage. The results indicate how much it may costs to deliver the electricity output equivalent to a barrage on annual basis.

Technology	Large barrage
CHP	951
Wind Onshore	951
Wind Offshore	885
Solar PV	6,105
Small Hydro	926
Medium hydro	968
Landfill Gas	370
Municipal waste	1745
Combustible renewable	372
CHP - cofiring	1,273
Fuel cell	3,323

Table 7: Cost of producing the output equivalent of a large barrage, (2010£million)

Source: Frontier analysis, based on data for plant from IEA and SDC

Note: this is not intended to imply that sufficient potential capacity exists to implement this level of generation in any of the above resources. This is discussed in Section 5.2.3 of the main report.

Annexe 2: Sensitivity analysis

This annexe provides further sensitivity analysis around the central results reported in the main report.

BASE CASE SCENARIO: DISCOUNT RATE SENSITIVITIES

Base case scenario has the following characteristics:

- Discount rate equals 7%;
- Fuel prices are set according to base rates (see Annexe 1);
- Carbon price are set as per Defra recommendation (£27/tonne CO2 in 2010, see Annexe 1);
- decommissioning costs for nuclear station doubles actual construction costs.

Figure 11 provides the base case results.

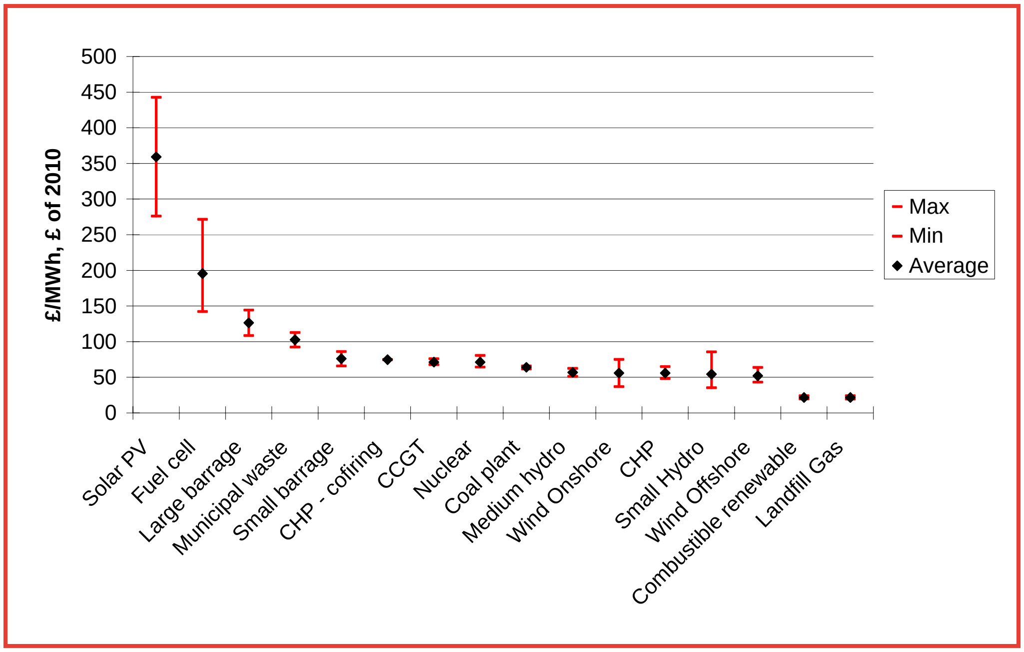

Figure 11: Comparison of alternative generation costs, base case scenario, **discount rate = 7%**

Source: Frontier analysis based on IEA statistics

Discount rate sensitivities

Figure 12 and Figure 13 provide the results with alternative discount rates.

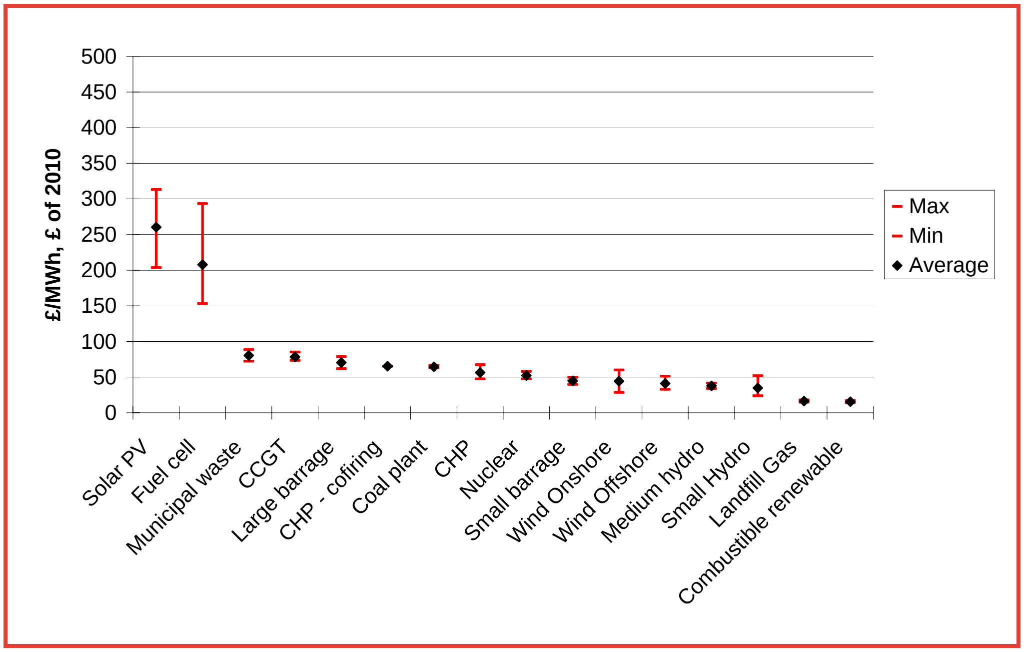

Figure 12: Comparison of alternative generation costs, base case scenario, **discount rate = 3.5%**

Source: Frontier analysis based on IEA statistics

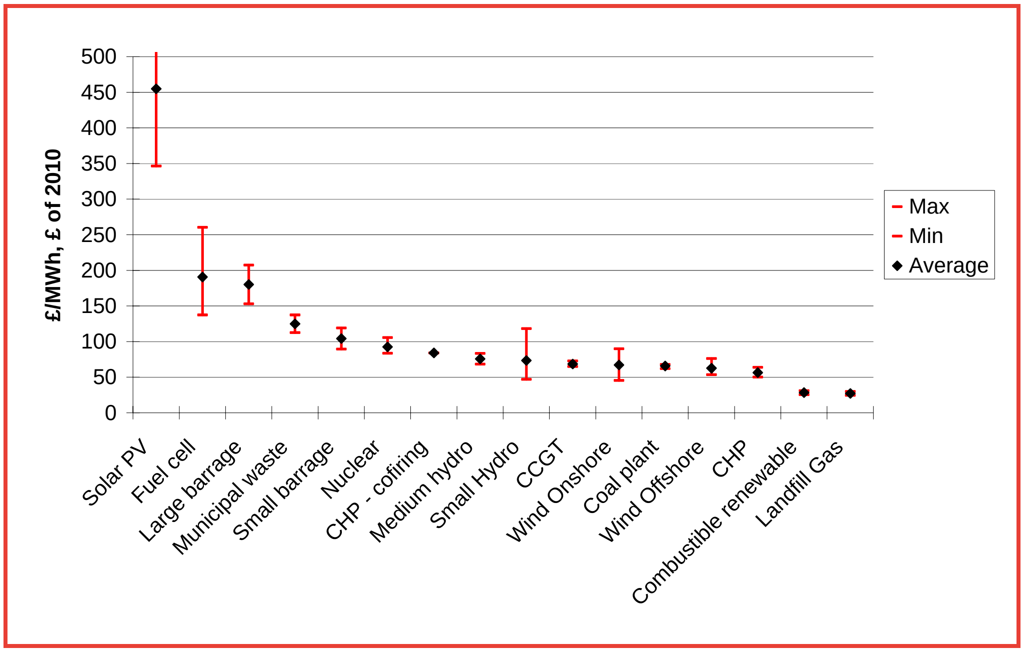

Figure 13: Comparison of alternative generation costs, base case scenario, **discount rate = 10%**

Source: Frontier analysis based on IEA statistics

BASE CASE SCENARIO: FUEL AND CARBON PRICE SENSITIVITIES

Returning to the base case assumption on the discount rate (of 7%), Figure 14 and Figure 15 consider the impact of alternative fuel price scenarios (see Annexe 1 for a description of the derivation of the fuel price scenarios).

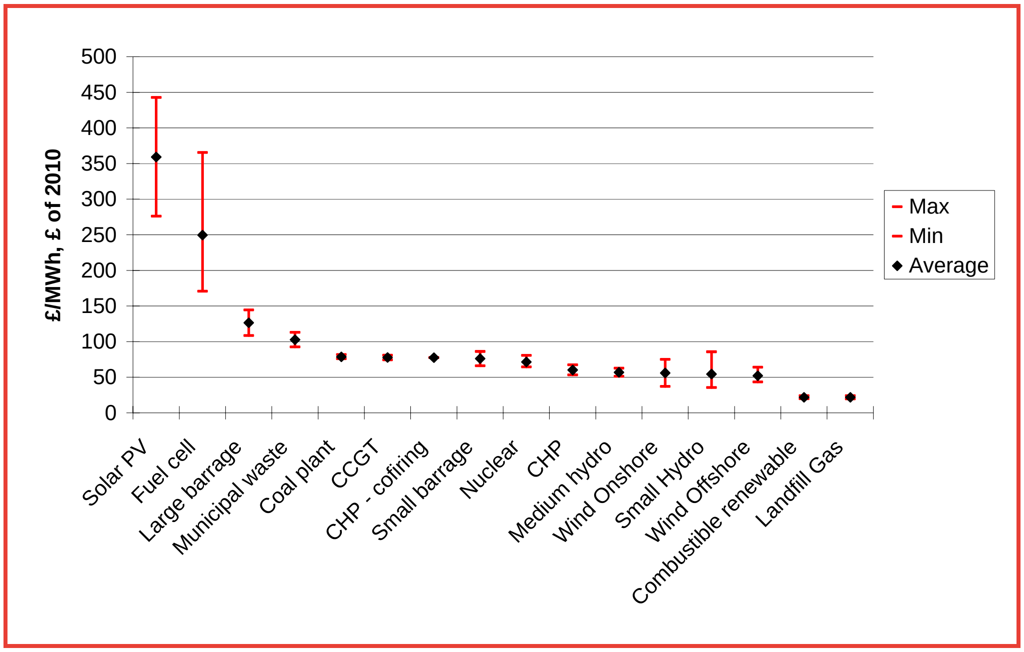

Figure 14: Comparison of alternative generation costs, base case scenario, **discount rate = 7%, high carbon prices**

Source: Frontier analysis based on IEA statistics

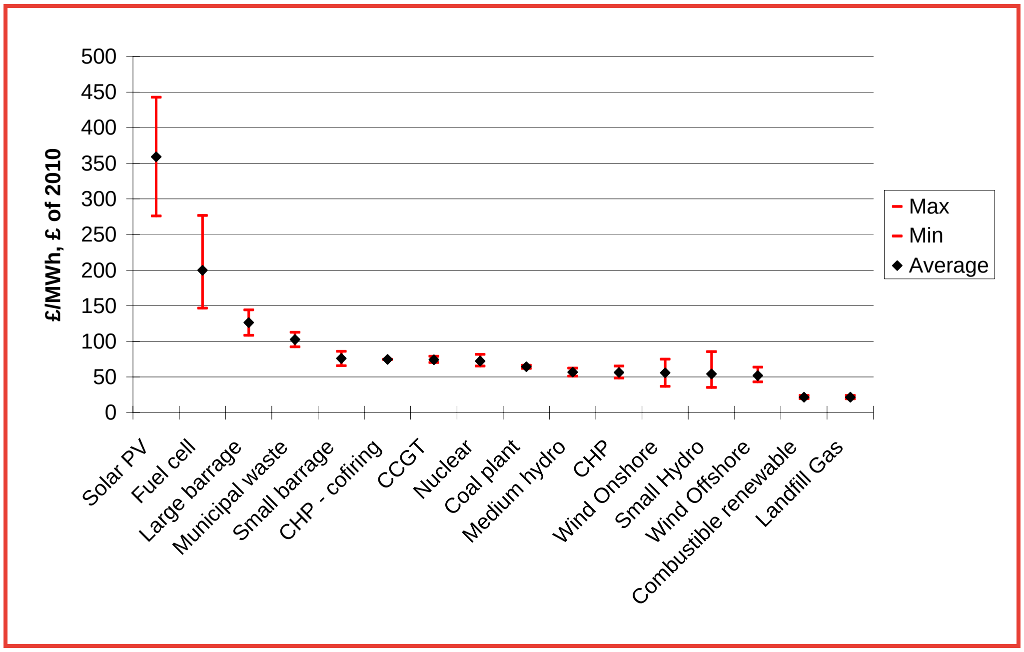

Figure 15: Comparison of alternative generation costs, base case scenario, **discount rate = 7%, high fuel prices**

Source: Frontier analysis based on IEA statistics

Nuclear power stations sensitivities

The competitiveness of nuclear technology is to a large extent is determined by assumptions about decommissioning and refurbishment costs. Figure 16 provides results for a lower decommissioning cost than assumed under the base case.

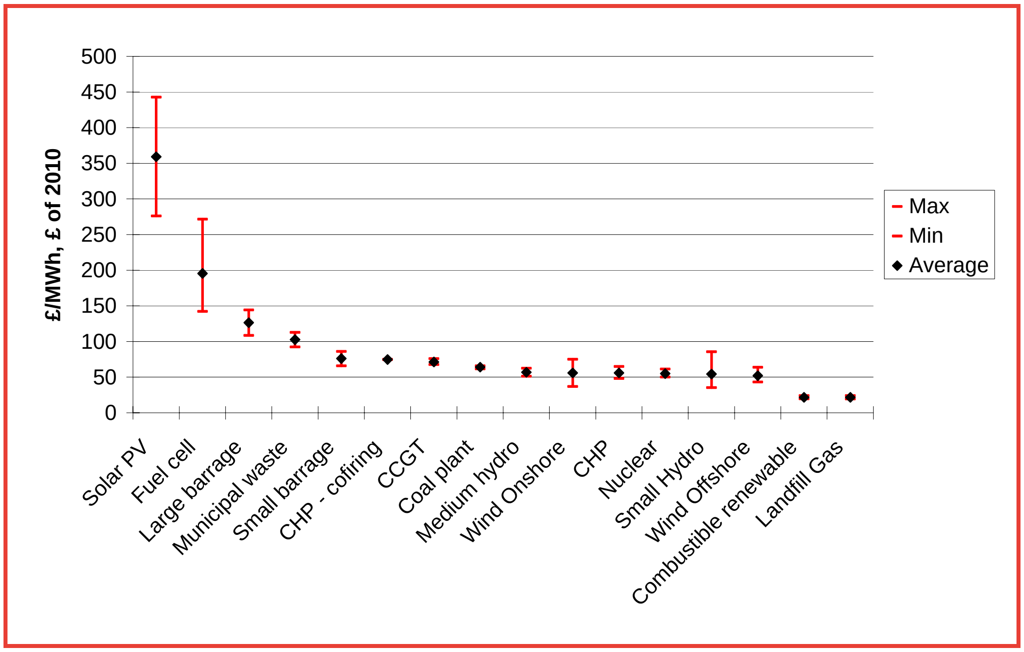

Figure 16: Comparison of alternative generation costs, base case scenario, **discount rate = 7%, low decommissioning costs**

Source: Frontier analysis based on IEA statistics

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