Final report

CABINET OFFICE, PERFORMANCE AND INNOVATION UNIT

RENEWABLE OBLIGATION CERTIFICATE PRICE SCENARIOS AND LEARNING BENEFITS FROM SUPPORTED PROJECTS

JULY 11TH 2001

OXERA Environmental

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Contents

1. Introduction

The first part of this paper describes the results of a model of the entry of renewable electricity generation between 2002 and 2020 in response to the Renewables Obligation, and the effect of a number of potential influences on the volume and mix of entry. The paper presents estimates of the prices of Renewable Obligation Certificates (ROCs) associated with these entry scenarios.

The second part of the paper (section 5) describes an application of the learning curves analysis conducted by the Performance and Innovation Unit to inform both the likely entry of renewables to 2020, and the policy analysis that will precede the targeting of direct financial support for renewable generation. The paper describes a spreadsheet that can be used to calculate learning benefits, and discusses the questions that have to be answered by the policy-maker in order to determine learning benefits. It also remarks briefly on the placement of learning benefits within the wider evaluation of direct financial support.

2. Assumptions

2.1 Entry costs

OXERA Environmental used the entry cost assumptions in Table 2.3 as inputs to the model. All monetary values in the model are in real terms in 2001 money. The derivation of the entry costs for selected technologies are explained in the paragraphs below.

2.1.1 Wind

The entry cost assumptions for onshore wind, are taken from a number of reports including the US Energy Information Administration (1997) report 'Advanced Horizontal Axis Wind Turbines in Windfarms', which gave capital costs of $750/kW in 1996 $; European Commission reports; and brokers' market reports. For the medium-cost estimate, OXERA assumed a capital cost of £600/kW, operating life of 20 years, maintenance costs of £14/kW/year, and a cost of capital of 10%. The cost falls to 2.8p/kWh for a cost of capital of 8% or lower capital and maintenance cost assumptions. For offshore wind mid estimate, the capital cost was assumed to be £1,000/kW; maintenance £26/kW/year; and cost of capital 10%. The offshore wind central cost assumptions are consistent with the BWEA report, 'Prospects for Offshore Wind Energy'. Table 2.1 summarises the components of the entry cost assumptions.[1]

Table 2.1: Wind cost model

	Onshore			Offshore		
	Low	**Med**	**High**	**Low**	**Med**	**High**
capital cost, £/kW	500	600	700	800	1,000	1230
maintenance cost, £/kW/yr	10	14	17	20	26	26
operating life	20	20	20	20	20	20
interest rate	10%	10%	10%	10%	10%	10%
load factor	35%	31%	30%	40%	40%	40%
capital cost, £/kW/yr	75	90	105	120	150	185
total cost, £/kW/yr	85	104	122	140	176	211
generation kWh/yr	3,066	2,716	2,628	3,504	3,504	3,504
cost, £/MWh	28	38	46	40	50	60

2.1.2 Energy crops

The energy-crop cost estimates are consistent with DEFRA's expectations, and are assumed to be consistent with a repeat of the build of the ARBRE plant, excluding the

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[1] *Post script*: Since July 2001, OXERA Environmental has undertaken a more comprehensive analysis of costs, the results of which are consistent with the figures in table 2.1.

capital grant and agricultural subsidies from which it benefited. In other words, it is assumed that future plant would be cheaper to the value of those subsidies.

2.1.3 Energy from waste

The figures for energy from waste are in line with ETSU (1999)[2] published figures, and consistent with cost models used for calculating the gate fee of conventional waste incineration plant such that the gate fees are in the range £30–60/tonnes for plant processing 100–600 ktonnes per annum. It is assumed that waste policy instruments, such as the landfill tax and planning policy for landfill sites, would maintain this level of gate fees. The DTI has assumed a lower, but overlapping range of gate fees, £25–45 in its recent analysis, which places the energy from waste entry cost estimates in Table 2.2 at the higher end of the range quoted. The costs are uncertain, but uncertainties within this range will have little impact on the model results for energy from waste because the entry costs are still low in comparison with the value of generation output under nearly all of the scenarios examined.

Table 2.2: Input cost assumptions

Technology	Cost estimate (p/kWh)			Technology cost trend: reduction per annum (%)
	Low	Medium	High	
Onshore wind	2.8	3.8	4.6	0.5
Energy crops	8.0	8.5	9.0	5
Energy from waste	2.3	2.6	2.9	1
Landfill	2.4	2.6	2.9	0.5
Offshore wind	4.0	5.0	6.0	5

Source: OXERA Environmental assumptions, after discussion with Cabinet Office.

2.2 Accessible resources

2.2.1 Wind

The accessible resource assumption for onshore wind is taken from ETSU (1999).[3] The offshore wind figure has been published by the BWEA in a study of sites which have sufficient wind speed, are not protected from development, and offer connection to the electricity grid at reasonable cost. These figures are shown in Table 2.5.

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[2] ETSU (1999), 'New and Renewable Energy: Prospects for the 21st Century'.

[3] ETSU (1999), ibid.

2.2.2 Energy crops

The figure for energy crops assumes that 1.5m ha is taken out of food production, and that crops could yield 10–15 tonnes per hectare per annum, with a conversion efficiency of about 42%. The calculation is shown in Table 2.3.

Table 2.3: Calculation of the technically available resource of energy crops[4]

Element	Low value	Med value	Units
Area	1.5	1.5	M ha
Yield	10	15	oven dry t/ha/yr
Tonnes harvested	15	22.5	M oven dry t/yr
Calorific value[1]	19	19	GJ/t
Calorific value	5,278	5,278	KWh/t
Efficiency	42%	50%	
Output	33.3	59.4	TWh/yr
Load factor	0.8	0.8	
Capacity	4,745	8,472	MW

Note: [1] from ETSU (1999), ibid., p.68.

2.2.3 Energy from waste

The derivation of the accessible resource for energy from waste is given in Appendix 2.[5]

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[4] *Post script*: alternative estimates have become available since this tables was prepared, and OXERA has revised its energy crops assumptions.

[5] *Post script*: this appendix was added in October 2001.

Table 2.5: Input resource assumptions[6]

Technology	Technically accessible resource			Maximum build rate
	MW	Load factor	TWh/year	MW/year
Onshore wind	20,000	0.3	53	500
Energy crops	8,500	0.8	60	500
Energy from waste	2,000	0.8	14	200
Landfill	800	0.9	6.3	100
Offshore wind	30,000	0.4	92	500

2.3 Maximum build rates

The maximum build rates assumed for each technology are embedded in the model and shown in Table 2.5 in the right-hand column. They are much higher than any build rates experienced before in the UK renewables sector—for example, about ten times higher the average rate of build of wind turbines over the last five years, but still no greater than recent build rates in Germany or Spain. While they should be technically achievable, the capacity of the industry to deliver new build would have to be raised very rapidly.

Future build rates might be determined by infrastructure factors (availability of connection points) and regulatory factors (planning consents) to a greater extent than manufacturing and installation capacity in most cases. There may be specific manufacturing bottlenecks for some technologies, such as specialist installation equipment for offshore wind turbines or crop-harvesting vehicles, but otherwise UK demand for plant is a small part of global demand.

The build rates for wind turbines and incineration of waste have been limited in recent years by the slow planning consenting processes and the rejection of planning applications. There are also concerns held by renewable energy developers that there may be restricted access to electricity networks through pricing structures and capacity constraints. There are ongoing reviews of planning policy (DTLR) and of network access pricing policy (OFGEM).

For the novel energy from waste technologies and offshore wind, developers may wish to increase build rates slowly in order to gain experience from prototypes and small-scale projects before launching large programmes. For these technologies, the build rates may

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[6] *Post script*: the resource figures were adjusted in later work.

be restricted by the rate of learning about technology performance and risks. This paper does not explore any of the constraints mentioned above in the modelling, except the sensitivity of ROC prices to the rate of new build.[7]

The maximum rates of build have been chosen to enable the 10% target in 2010 to be met, and a 20% target in 2020 to be met from a fairly equally balanced mixture of resources. The rate of build for landfill gas is consistent with the expectation that the remaining resource will be exploited within two or three years, and the figures for waste are for the purpose of illustration.

2.4 Other assumptions

2.4.1 Introduction

The assumption in the baseline scenarios is that the renewables target increases to 20% in 2020, with a constant buy-out price of 3p/kWh in real terms. DTI estimates of 'total electricity available' are used for the years 2001–10. Thereafter, electricity consumption is assumed to grow at 0.8% per annum.[8] The obligated supply (GWh) is endogenous to the model, and is calculated by subtracting the amount of ineligible renewables from the national target. OXERA assumes a 10% real discount rate in calculating the present value of future revenue streams for generation projects. Other assumptions are a wholesale electricity price of 2p/kWh, a Climate Change Levy (CCL) exemption benefit of 0.43p/kWh, and an embedded generation benefit of 0.2p/kWh.[9]

2.4.2 Wholesale price of electricity

The 2p/kWh wholesale electricity price is based on the premise that the wholesale price is set by the new entry cost for combined-cycle gas turbines (CCGT), which OXERA calculates to be in the range 1.6–2.3p/kWh. Table 2.6 shows the central case assumptions for the CCGT entry cost model.

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[7] *Post script*: They are discussed in detail in a forthcoming report by OXERA Environmental and Arup Economics & Planning, expected to be published by the DTI in January 2002.

[8] *UK Digest of Energy Statistics 1999*; Energy Paper 68.

[9] *Post script*: Following the publication of the statutory consultation on the Renewables Obligation in August 2001, the modelling was modified to reflect changes in the design of the Obligation.

Table 2.6: Assumptions for entry cost of CCGT plant

Cost assumptions	Central estimate
Average load factor (%)	0.8
Construction cost (£/kW)	380
Plant life (years)	25
NGC transmission charge	1.0
NGC entry charge	2.5
Employees	0.1
Operating costs	10.0
Average pre-tax return on assets	0.12
Gas price (p/therm)	16
Thermal efficiency	0.58
New entry cost (p/kWh)	**1.9**

2.4.3 Benefits of embedded generation

The embedded generation benefit is derived from avoided transmission (National Grid) charges. These comprise avoided transmission losses, use of system charges and balancing services use of system charges. The total transmission charges avoided vary from region to region, between about 0.1 and 0.3p/kWh. Where the power from renewable generation plant is used on site, there will be an additional saving of distribution charges. Together, transmission and distribution charges total 50% of the retail price of electricity. However, it is assumed that most of the plant to be built will sell power through licensed suppliers.

2.4.4 Imbalance costs for wind

The imbalance costs faced by wind generators through the New Electricity Trading Arrangements (NETA) balancing mechanism have been assumed to be 0.6p/kWh as a central estimate, and 1.2p/kWh as a high estimate. This range is based on a calculation of optimal contracting (ie, contracting some output and spilling some output to optimise exposure to the balancing mechanism), a range of 10–20% error in forecasting volume of output 3.5 hours ahead, and a 2p/kWh spread between system sell and system buy prices. Whereas the spread was greater than 3p/kWh in the first six weeks of the operation of NETA, it has fallen over time, and may continue to fall. The error in forecasting volume of output is based on historic variations in wind farm output between rolling periods four hours apart. If the data had been available, a more appropriate measure would have been the difference between actual output and the output forecast four hours ahead from wind-speed forecasts. Wind turbine output is very sensitive to errors in forecasting wind speed, because turbine output is a function of the fourth power of the wind speed. An assumption of 0.2p/kWh NETA average imbalance charge was tested as a low estimate.[10]

2.4.5 Appropriation of value by generators

The proportion of the CCL exemption and ROC certificate value passed through to generators is assumed to be in the range 0.5–0.9. There is little evidence yet as to the value of this factor. It is thought that small, independent generators with little trading experience will have the most difficulty appropriating the full value because of the transaction costs of trading. It is also thought that generators who are dependent on debt-funded, project-specific finance may be forced by their financiers to sign back-to-back long-term contracts with suppliers, and that suppliers, being uncertain of their future supply obligations, would discount the price they are prepared to offer for a certificate. Hence certificates may take a range of values, partly determined by the length of the power purchase agreement. A further element is the liquidity of the certificates. Some certificates may be traded within vertically integrated generation–supply businesses; others may be traded between independent generators and suppliers. It is not known whether the traded certificate market will exhibit different ROC prices to vertically-integrated trades, but it would do so only if there is imperfect arbitrage between the independently traded and vertically integrated markets.

2.4.6 Imports

The contribution of ROC-eligible renewables imported into the UK is assumed to be either 0 or 4 GW. Where it is assumed to be 4 GW, the capacity is limited to 2 GW until 2004, reflecting the capacity of the existing England–France interconnector, with the additional 2 GW capacity reflecting a possible second Channel interconnector, which was announced earlier this year by NGC.[11]

A further interconnector has been discussed in the public arena—NORDICE—a link between the UK and Norway, but it is at an early stage of evaluation. In the past, a connector to Iceland has also been mooted.

The model assumes that imported renewable electricity that meets the eligibility criteria would attract ROCs, but this assumption may not hold. First, it may not be possible to demonstrate eligibility for imported electricity either because the contracts between the source plant and the customer cannot be verified, or because the plant also receives subsidies form other sources, making it ineligible. It may also be possible, although as yet untested in law, to exclude imports from eligibility *en masse* despite the Directives on the liberalisation of European energy markets.[12]

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[10] *Post script*: In later modelling, imbalance costs were assumed to be 0.2–0.6 p/kWh. These figures may have to be changed if the rules of NETA are revised.

[11] *Post script*: NGC has issued press releases with more details of the proposed interconnectors.

[12] *Post script*: The draft Renewables Obligation Order excludes imported renewables. It is consistent with the Utilities Act 2000. At the beginning of December 2001, the European Commission had not yet adjudicated on State aid approval.

There is a possibility that at some time, trading in greenhouse gas emissions or Europe-wide trading in ROCs might be introduced and invalidate the model forecasts. A recent court ruling regarding Germany's renewables support mechanisms suggests that long-term contracts with renewables generators will not be undermined by these developments, but it remains to be seen whether trading schemes would provide the same protection as individual contracts.[13]

2.4.7 Other technologies

In the charts which follow in Section 3, further renewable technologies are included, namely photovoltaics (PV), biomass and small hydro, and large hydro. The model assumes exogenous levels of generation by these technologies for the following reasons:

- there is no expectation of any new build of large hydro in the UK;
- the opportunities for small hydro appear to be low in volume;
- PV entry costs are so high that PV will not enter with the support of ROCs unless it also receives specific capital grants. The prospective grants available for the next few years were announced by the Prime Minister in April 2001 and would only support a few MW of capacity;
- the volumes available from biomass outside energy from waste or energy crops is small.

Biomass makes a small contribution, consisting of existing forestry waste, straw and chicken litter schemes. PV is assumed to start at 1 MW, the current UK installed capacity, and to rise to 6 MW in 2011, consistent with the installation of 1 kW peak units on 50,000 properties. It is assumed that large-scale hydro-electric output remains constant at 3,500 GWh/year, and that small-scale hydro capacity and biomass plants together rise to 310 MW, or 1,629 GWh/year, in 2007, and remain constant thereafter.

The cost of thermal technologies has been based on the cost of dedicated renewable electricity generation plant. However, there is an alternative, which is to co-burn combustible material from renewable sources with fossil fuels in existing fossil fuel plant. A large capacity would be immediately available, although the fossil fuel electricity generators may not wish to operate their plant in this way, the electricity may not be eligible for ROCs, and the plant may not be able to comply with emissions or other operating consents. None of these possible restrictions have been explored for this paper.[14]

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[13] *Post script*: A European Community directive has since been adopted, setting out a timetable for review of Member State schemes.

[14] *Post script*: These rules were clarified by the DTI in its August 2001 consultation paper.

3. Scenario Modelling

3.1 The scenarios

This section presents the results of the following scenarios:

1. the ‘achieve target’ scenario, with the renewables target increasing to 20% in 2010;
2. a central scenario with maximum build rates halved. This scenario might be consistent with institutional constraints, such as difficulties obtaining planning permission;
3. 2 GW of interconnector capacity to supply eligible renewables until 2004, with interconnector capacity rising to 4 GW thereafter. This is consistent with a successful legal challenge to the exclusion of imported renewables from the renewables obligation;
4. the obligation frozen at 10% of electricity supplied after 2010. This might result from a change in political priorities in the future;
5. generators receive only 50% of the value of a ROC and 50% of the value of CCL exemption, and wind generators face an imbalance charge of 1.2p/kWh (compared to the central assumption of 0.6p/kWh). The limited pass-though of ROC and CCL exemption in this scenario could be caused by suppliers having market power in relation to renewable electricity generators. The harsh imbalance penalty might come about if prices in the NETA Balancing Mechanism are very peaky.

These scenarios were developed by OXERA after discussion with the Cabinet Office.[15]

3.2 Scenario results

The predicted level of renewable generation capacity is shown from now until 2025. The arrows on these graphs show the profile of the renewable target (dark arrows) and the renewables obligation (light arrows) over time.

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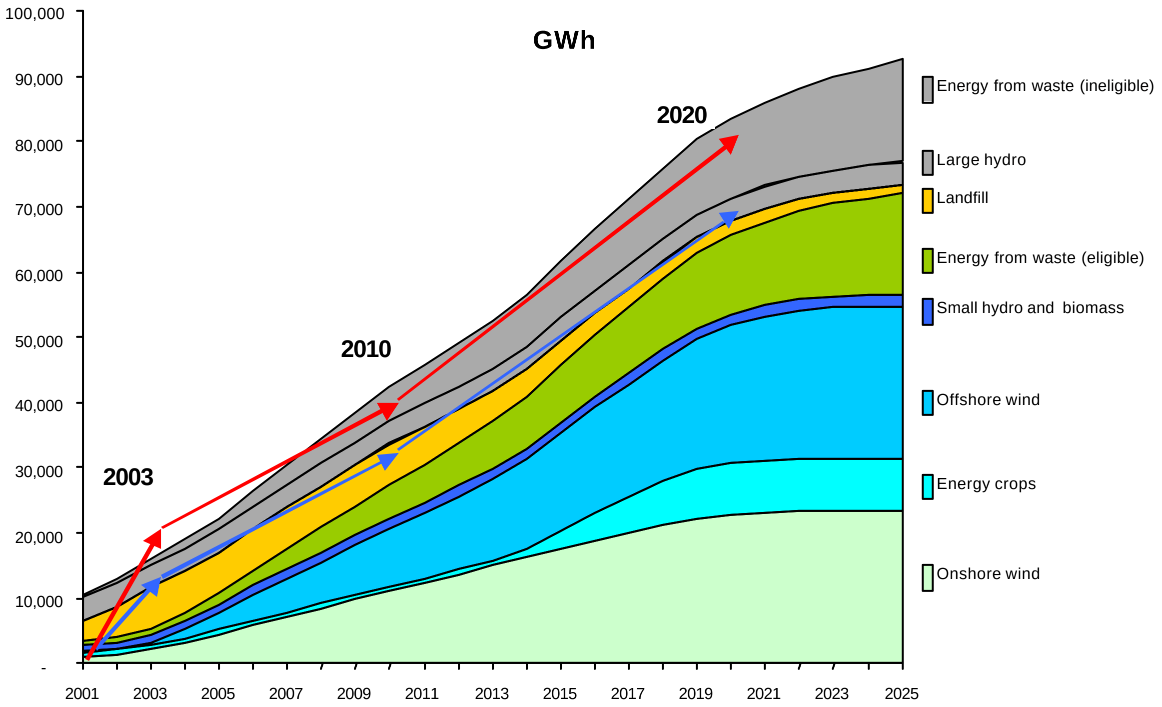
[15] *Post script*: Several other scenarios were also examined.

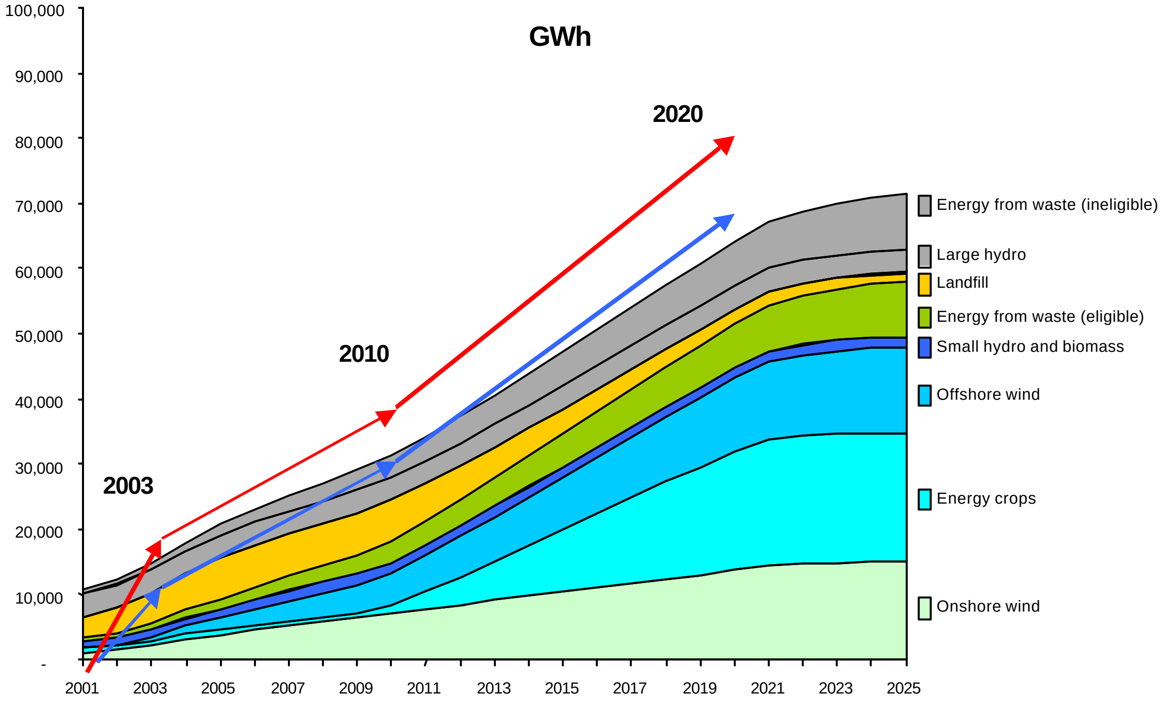
Figure 3.1: Scenario 1, 'achieve target' scenario



Note: the model assumes 50% of energy from waste is derived from biomass material and is therefore counted as eligible renewables, and the other 50% is counted as ineligible.

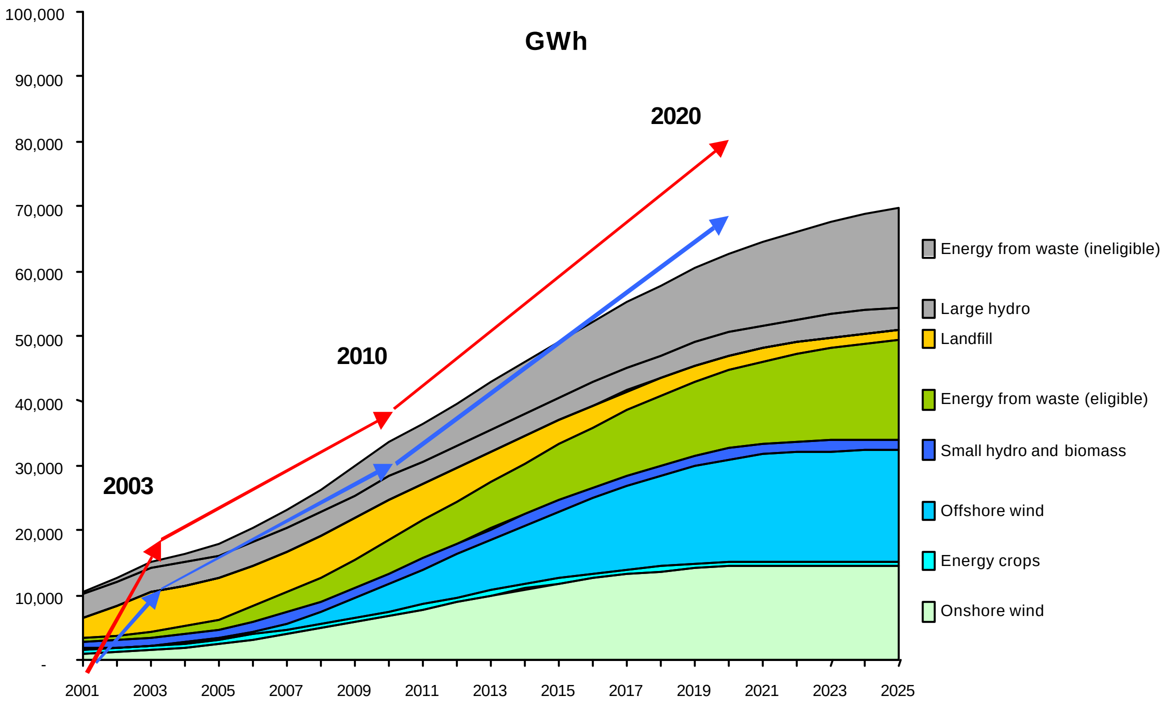
The achieve target scenario has been set up so that the target for eligible renewables in 2010 is met. Onshore and offshore wind both enter at the maximum rate from the start of the period. Energy from waste begins to make a contribution from 2005, restricted by planning and construction timetables, and energy crops make no significant contribution until about 2015.

Figure 3.2: Scenario 2, a central scenario with reduced build rates



The build rates assumed in Figure 3.1 are much higher than historic rates in the UK, and there is uncertainty whether the industry, the planning system, and electricity network operators will be able to deliver such a large increase in build. Since the build rate that can be achieved is uncertain, the model has been run under an assumption of a halved rate of build. Shown in Figure 3.2, this assumption results in under-achievement of targets in both 2010 and 2020. The date of entry of energy crops is advanced by three or four years.

Figure 3.3: Scenario 3, significant interconnector imports of renewables



This scenario shows the effect of the sale of ROCs from imported eligible sources.[16] The rate of entry of wind is reduced, and the entry of offshore wind in significant volume postponed from 2003 to 2007. There is no entry of energy crops under this scenario.[17]

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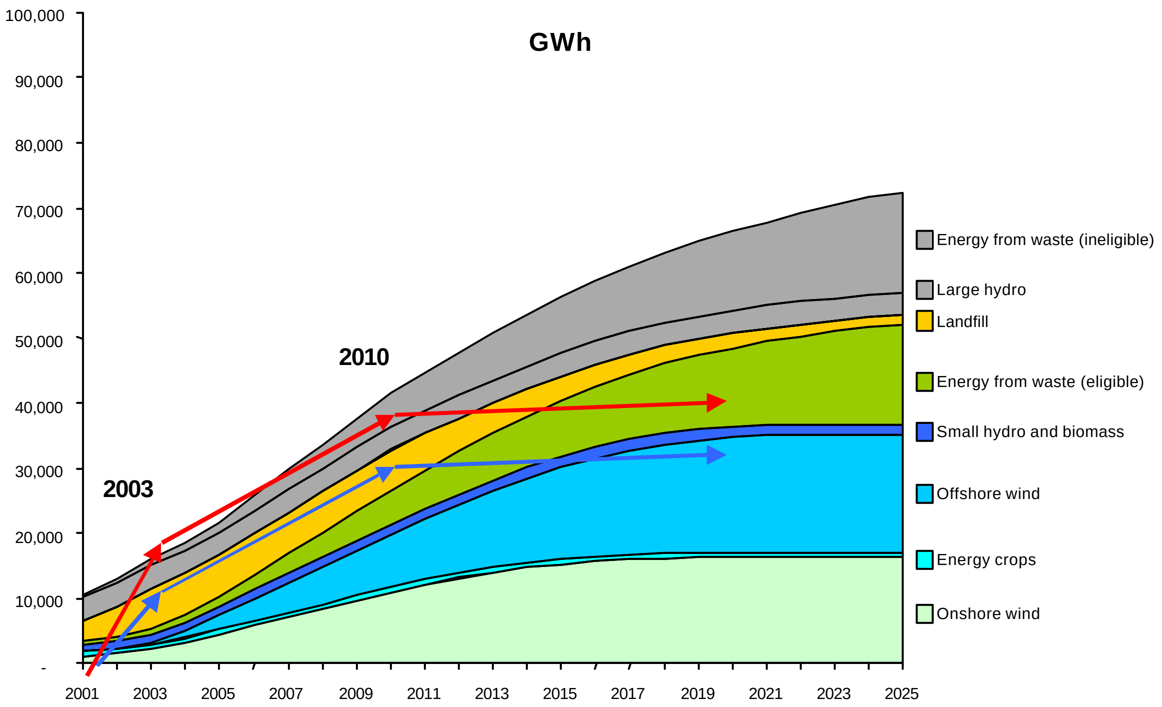
[16] The contribution from imports is not shown.

[17] *Post script*: Grant-funding of energy crops may guarantee entry exogenous to the modelled entry.

Figure 3.4: Scenario 4, obligation frozen at 10% after 2010



Under this scenario, the target is achieved in 2010 and thereafter, and entry stabilises at a level above 10%.[18]

3.3 Conclusions

The conclusions of the Renewables Obligation modelling are as follows.

- Build rates in the order of 500 MW per annum are required from onshore and offshore wind, and beyond 2010, from energy crops, in order to meet the target of generation of 10% of electricity available from renewable sources, and to pursue a target of 20% in 2020. The constraint to achieve these build rates is likely to be partly in the private sector and partly in the public sector. The capacity to process and approve plans, the organisation of network connection and reinforcement (which, in part, depends on the regulatory arrangements for the transmission and distribution networks), and the allocation of subsidies where these apply, are three restrictions where very high increases in throughput must be achieved in order to deliver the national target.
- Under the central assumptions about the costs of entry, of ROCs appropriated by generators, and the level of imbalance charges faced by wind generators, both

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[18] *Post script*: In this early version of the model, entry continues after 2010 due to a simplification in the model equations. In practice, little entry would be expected once the 2010 had been fulfilled.

onshore and offshore wind are economically viable under the Renewables Obligation without supplementary support from capital grants. This means that the certain binding constraint in reaching the 2010 target is the delivery of volume of build, and the provision of the institutional arrangements to enable this rate of build. The cost reductions which allow rapid entry of offshore wind after 2005 may be dependent on build between 2001 and 2005.[19]

- The announcement of targets beyond 2010 affects the expected value of ROCs to be generated from new build today.

- The price of ROCs is extremely sensitive to the supply of eligible electricity through interconnectors from other countries, particularly early on. An interconnector supply of 4 GW from 2004 would effectively exclude offshore wind and energy crops from entry, and limit the build of onshore wind.

- If the Renewables Obligation was not continued in its present form, but was instead united with a European trading scheme for renewables or carbon emissions, then the value of a ROC might fall to a small fraction of the value computed in the model. If generators discount the value of ROCs as a consequence, then the predictions of the model might not be borne out in practice. The presumption that the Renewables Obligation will be insulated from other trading schemes is crucial, and generators would have to be convinced that the government is committed to this position, and that it is legally sound.

- The two most important technologies contributing to targets beyond 2010 are energy crops and offshore wind, which offer the largest resources. The model does not predict energy crop entry before 2010 because the cost of entry is too high. It is possible to achieve the 2010 target without the contribution of energy crops, but meeting the 2020 target is assisted by a contribution from this source. Energy crops are not cost-competitive at present, and would require direct support. Of the other major technologies modelled, offshore wind is the most marginal economically, and would be the most sensitive to reductions in the value of ROCs. One argument for the provision of direct financial support of offshore wind is that uncertainties in the ROC price weigh heavily in the commercial decision for offshore wind generators to enter the market, and the policy-maker would have more confidence that entry will take place if direct support is provided.

These model results are dependent on the realisation of cost reductions in the marginal technologies of offshore wind and energy crops over time. The annual rate of cost reduction would be governed in part by the cumulative learning-by-doing gained by building new capacity. If this capacity does not come on stream, then the cost reductions may not materialise. The second part of this paper explores the concept of learning-by-

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[19] *Post script*: This build may depend upon financial support.

doing, and its relevance to renewables policy. The conclusion that is most important to read across to the results of the entry model is that the entry of energy crops, and possibly also offshore wind, could be dependent on early direct financial support.

Post-2010, the scenarios assume no annual cost reductions, except for energy crops, for which it is assumed that costs fall at 3% per annum between 2010 and 2013 and stabilise thereafter. The extended period of cost-reduction for energy crops, at a reduced rate after 2010, is intended to reflect both the initial high potential for cost saving and the diminishing marginal cost reduction from learning-by-doing as cumulative production increases.

4. Evaluation of Additional Support for Renewables

4.1 Observations from the Renewables Obligation model

4.1.1 Onshore wind

Onshore wind is unlikely to require additional support outside the Renewables Obligation under the central scenario (2).

4.1.2 Offshore wind

Offshore wind does not require additional support under the ‘achieve target’ scenario (1), but entry may be delayed if the ROC price is reduced—for example, by imports of eligible renewables. Later entry is still partly dependent on cost savings achieved by learning, so the assumption that later entry does occur might not be valid if early projects do not take place.

It may be concluded that it is not certain whether offshore wind is viable early in the period (and therefore at all) without additional support. In order to avoid the cost of the provision of a subsidy that generates no additional entry, a means of revealing the true cost of entry is required. One possible mechanism is a negative auction—participants bid for the amount of subsidy they require to enter the market, perhaps in £/kW capacity constructed. The winners are those who place the lowest bids. There would have to be a commitment to build in order to attract only genuine bids (unlike the NFFO auctions), a commitment which might be obtained through a bond that would be forfeited if the project were not completed. The auction might be limited to a ceiling capacity, or a total dispensation of support, whichever is the appropriate constraint. [20]

4.1.3 Energy crops

Energy crops play an important role in contributing to output after 2010. The model predicts entry after 2010, based on cost reductions assumed to take place between now and 2010. Insofar as these may depend on learning-by-doing, then some build is required in advance of 2010 to permit entry thereafter.

The output charts from the model show clearly the major contribution that energy crops could make after 2010, because of the size of the available resource.

4.1.4 Energy from waste

Energy from waste is assumed to be a relatively low-cost resource, limited in entry by permitted build rate alone. It has the potential to make a major contribution to the UK target in both 2010 and 2020. In the longer term, it is limited by the volume of waste likely to be available after minimisation and recycling.

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[20] *Post script*: More information on offshore wind costs has become available since this paper was written. These have not been included here.

4.2 Emerging technologies

4.2.1 Photovoltaics

Photovoltaics (PV) is the most expensive of all the technologies considered. It has not been modelled because the learning curve models suggest that it would not become commercially viable, even under the Renewables Obligation, by 2020, although with continued cost reductions it would gain greater penetration in specialist markets.

4.2.2 Wave and tidal

Wave and tidal technologies have secured funding from the Scottish Renewables Obligation and the Northern Ireland Obligation. The technology is embryonic, and the plant being built is the first of its kind. At present it has high capital costs, unproven output and maintenance costs, and does not yet offer the scope for large-scale deployment, so it has been excluded from the Renewables Obligation model.

4.3 Other technologies

Since the capacity of energy from small-scale hydro, chicken litter and straw has been assumed to be fixed, there are no observations from the model.

5. Analysis

5.1 Targeted support

Given that there is an earmarked sum of £100m available to support the generation of renewable energy, there are also the questions of (i) where best to target the support, and (ii) which instruments to use to deliver it. This section discusses one aspect of evaluation: the benefits of learning-by-doing. It describes the combination of learning curves with a simple computation of benefits in a spreadsheet calculator. This calculator is used to illustrate the process of evaluation, although it was found that the learning-curve data were insufficient to permit quantitative conclusions to be drawn from the exercise. Thus the following discussion focuses on the process of making the evaluation.

Before launching into that discussion, it is worth setting out the context more fully. The learning benefits calculator would be only one of several dimensions of evaluation for the policy-maker. Thus it is acknowledged that, in building the calculator, a narrow definition of benefits has been adopted. This definition takes only the potential benefits that might accrue to UK electricity customers and excludes non-market benefits. It also excludes benefits to customers outside the UK, and considerations of UK employment, exports, training, expertise in higher education, and spill-over benefits to other sectors. It is not within the scope of this paper to assess the magnitude of these other components, to determine their hierarchy or to weight their importance in the value of the outcome. It is assumed that there are several objectives: first, to provide renewable generation at least-cost in the long term; second, to provide a diversity of renewable energy sources; and third, to provide sources that might contribute sources of fuel as well as electricity, potentially for use as transport fuels.

There is a constraint: the £100m is to be committed over a period of three years, and there are also likely to be constraints on when it may be spent.

The elements of good instrument design should be considered. These include:

- additionality, in that the result of support is an outcome that would not have been delivered without that support;
- competition to be used where possible, to reveal information about market prices and to provide solutions at least cost—ie, if subsidies are to be given, they should be dispensed in a competition;
- maintenance of market structure, by offering support to all players in a market, and to sufficient players to avoid market concentration which would reduce the level of competition in future rounds;[21]
- transparency, so that the purpose of the instrument is clear and its performance can be observed; and

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[21] *Post script*: A further purpose is to address market failures.

- complementarity with other policy objectives, which suggests that the instrument should be focused on the objective and should not be tailored to achieve other objectives simultaneously, resulting in unforeseen distortions in other areas of policy.

The first objective is to provide renewable generation at least-cost in the long term. In the period to 2010, the Renewables Obligation appears broadly sufficient to deliver the 10% target. In order to achieve a 20% target in 2020, it is anticipated that the cheapest mix of renewables will include substantial contributions from energy crops and offshore wind. The long-term perspective stretches beyond 2010 to 2020, and to low-carbon future scenarios where targets are set to reduce per capita CO_2 emissions dramatically, perhaps to achieve a 60% reduction in emissions by 2050.[22] In these scenarios, the accessible resources that are likely to have to be exploited include resources that have not yet been exploited in the UK, and do not appear to be stimulated by the Renewables Obligation because their entry costs are presently too high.

The potential benefit to consumers from renewables support is primarily from the reduction in the future cost of achieving a tough, binding renewables or greenhouse gas emissions target. It is expected that cost reductions would be derived from the process known as learning-by-doing. This process is continuous throughout the development of a technology, from research and development, through demonstration, to commercial deployment. Empirical evidence has shown that the cost of production falls with the cumulative volume of production over time. This relationship is found to be linear when expressed as the log of cumulative production and the log of costs. Hence the production of one additional unit reduces the cost of production of the next unit and each subsequent unit in turn. The benefits in terms of future cost reductions due to the production of an additional unit can be calculated if the learning index from the log–log model of learning-by-doing is known. This relationship has been estimated empirically for onshore wind and for PV by the PIU, using data from the IEA and elsewhere. For wind and wave, offshore wind and energy crops, the learning index could only be estimated by decomposing the potential for learning and making comparisons with other technological applications or to be assumed to be the same as for wind. This decomposition has not been carried out—instead, simple averages have been assumed.[23]

This study attempts to calculate the benefits from supporting those technologies which are not supported by the Renewables Obligation, or which are not commercially viable in the early years of the obligation, and whose commercial availability might be advanced in time.

The rationale for support is that there are some investments that the market will not make because a firm would be unlikely to make a commercial return on its investment, but

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[22] *Post script*: A reference to the report of the Royal Commission on Environmental Pollution.
[23] *Post script*: OXERA has since carried out further examination of learning-by-doing.

nevertheless would generate benefits to society (from learning-by-doing). These would typically be projects where:

- the learning benefits from undertaking the project are appropriated largely by society, and only in a small part by the firm, such that a project offering a net benefit to society offers a negative net benefit to the firm. This could include offshore wind or energy crop technologies that become widely available;
- a substantial time delay between investment and revenues makes apparent the wedge between the commercial cost of capital and the public-sector discount rate, such that the project passes the public-sector cost–benefit test but fails the private-sector cost–benefit test, for example, the delay between planting crops and harvesting;
- there are capital or management resource constraints that limit the opportunities that can be pursued, which means that some projects are not pursued even though they may offer net private and public returns, because other opportunities offering higher private returns are available. For example, a company or sector may invest in one technology such as onshore wind, and not another, such as offshore wind, until the best opportunities for the former have been exhausted.

The model maximises the learning benefits purchased by financial support, given the investments that other countries are carrying out. Where the UK does not invest in a technology, the model assumes the ability to free-ride on the learning benefits generated by the production of renewable electricity outside the UK. This has an important effect on the learning benefits accruing to the UK, but may have a much lesser effect on some of the other components of benefits mentioned above.

Free-riding is one aspect of the game theoretic aspects of learning benefits. Another important aspect is the potential to stimulate counter-investment in learning through investment in substitute technologies which threaten to reduce the value of the physical and intellectual property assets of companies. This is an attractive option where there is the potential to establish new technologies that are genuine substitutes for established technologies. PV is a promising target because its costs are high, and there are alternative PV cell substrates that might offer much lower production costs. It is possible that support for research into new PV substrates would not only offer learning benefits *per se*, but could also leverage counter-investment from the PV manufacturers. The PV manufacturers would adopt this strategy in order to be in a position to compete in the manufacture of a new substrate if a successful substrate should emerge from the research.

5.2 A calculator of learning benefits

In order to inform the allocation of financial support for renewable electricity technologies, it would be useful to identify those technologies offering the greatest benefits in terms of learning-by-doing per pound of support. To recap, these are the technologies whose entry would be supported by the Renewables Obligation, but could be advanced in time, or those which would not be commercially viable at any time under the Renewables Obligation.

As the focus of the policy is the UK, only the benefits from learning-by-doing that accrue to UK consumers are calculated. Having chosen a UK focus, there is a limit to the benefits that can be accrued when the UK adopts any particular technology—this is defined by the technology's technically accessible resource in the UK. The benefit from a unit cost reduction is the value of bringing forward in time a unit cost reduction factored by the remaining accessible resource. These benefits have to be discounted over time.

The size of the unit cost reduction is given by the learning index, which is determined empirically for technologies that have a history of development—ie, wind and PV—and are assumed to be an average figure for other technologies. The learning index is the exponent, I, in the formula 'unit cost is proportional to cumulative production^{-I}'. The learning index should reflect an engineering assessment of the potential for cost reductions and capture:

- economies of scale in component manufacture;
- cost savings through standardisation of design;
- cost savings through standardisation of contracting;
- empirical data on maintenance costs and operational risks; and
- innovations in design which reduce cost and improve performance.

In summary, for the technologies of interest, illustrative opportunities for learning are summarised in Table 5.1. This breakdown illustrates how an engineering assessment might be presented to a policy-maker, to relate the components of learning to the value of the learning index, and ultimately to decompose the learning index into its constituent parts. OXERA has not undertaken an engineering assessment.

While this decomposition of the learning index does not appear to be useful in estimating the index from an empirical data set, for most policy situations the index will have to be forward-looking. When a forward-looking assessment of the learning index is made, there is the possibility that the rate of learning may be different from the historic index. In order to establish whether this is possible, or even likely, it may be helpful to decompose the opportunities for learning into components such as those listed above.

Table 5.1: Opportunities for learning

	Onshore wind	Offshore wind	Wave and tide	Energy crops	PV
Scale in manufacture	Low	Med	High	Low	High
Standard design	Low	Med	High	Med	Low
Standard contracts	Low	Low	Low	High	Med
Performance and risks	Med	High	High	High	Med
Design innovation	Low	Med	High	Low	High

The following paragraphs discuss the opportunities for learning listed in Table 5.1.

5.2.1 Onshore wind

Wind turbines are already manufactured on a large scale to standard designs, and contractors have experience of building and operating wind farms. Manufacturers have had to absorb the costs of design flaws, and amassed a large number of operating hours. There may be further design innovations available: turbines now achieve a high proportion of their theoretical maximum efficiency, but use a range of designs and may be able to adopt new power handling techniques.

5.2.2 Offshore wind

Offshore wind turbines will have aspects of design which are different from on-shore wind turbines, and the costs which will fall as the scale of production increases. At the same time, designs may become more standardised. One might expect the contractual arrangements to be similar to onshore wind, with few opportunities for learning. In contrast, the risks of offshore operation offer opportunities for learning in both operation and design.

5.2.3 Wave and tide

Wave and tide technologies have never been deployed on a large scale. They offer substantial opportunities for learning in all but contracting, where the arrangements might be similar to wind turbines.

5.2.4 Energy crops

The fuel supply chain offers substantial scope for learning—in crop growing, handling and processing. The pyrolysis and gasification technology is also novel in this application, so costs would be expected to fall with scale of manufacture, standardisation of design, and experience in the operation of plant.

5.2.5 Photovoltaics

PV is manufactured in relatively small volumes at present. The contracts for installation, sales of electricity, and maintenance would be novel and likely to provide opportunities for learning. While operational experience is limited, the devices require little maintenance and hence their performance is established, but the substrates are expensive to manufacture, and there are opportunities for major reductions in substrate cost.

The spreadsheet model applies the learning index numbers to each technology, and calculates the benefits to UK consumers from the support of additional units of production. The model optimises the expenditure of support such that support is targeted on those technologies that offer the highest benefits to consumers per pound spent.

The assumptions in the model are shown in Table 5.2.

Table 5.2: Learning model assumptions

Technology	Maximum possible investment (£m)	Cumulative world output (GWh)	Expected growth in cumulative output (GWh)	Current average cost (p/kWh)	Learning index	Accessible UK resource (GW)	Likelihood of eventual commercial viability (%)
Onshore wind	50	200,000	40,000	4.6	0.3	20	100
Offshore wind	50	10,000	4,000	5.5	0.3	30	75
Wave and tide	10	50	20	15	0.3	30	10
Energy crops	50	10,000	2,000	8.5	0.3	8.5	55
PV	50	1.2 GW	0.3 GW	£2,400/ peak kW	0.8	10 peak GW	40

Source: learning index figures for PV and onshore wind estimated by the PIU.

In the model, the maximum possible investment is restricted to £10m for wave and tide, to reflect a likely limited pool of research projects available for this technology, but not based on any analysis of the size of this pool. For the other technologies, it is assumed that the government would be unwilling to spend more than half the subsidy on any one type of technology. The figures for cumulative world output and current average cost give the current position of each type of technology on its learning curve. The expected build rate (not shown) gives the rate at which the technology would move along its learning curve in the absence of subsidy by the UK government, and the learning index is related to the slope of the curve. The UK resource gives the ultimate potential benefit of each type of technology to the UK, in terms of meeting the country's energy needs. Finally, the likelihood figure, which should be based on an engineering assessment (though no such assessment was available for this report), gives the probability of costs falling to a commercially viable level, and hence enabling the UK resource to be exploited.

The quality of information available varies between different technologies. For technologies for which learning curves cannot be estimated from historical data (such as offshore wind, wave and tidal, and energy crops), the figures should be treated with special caution. The uncertainty over all these figures means that the model outputs should be treated with some caution.

The likelihood figure scales the benefits that accrue from learning. It is partly endogenous to the level of support. The larger a programme of support, the greater the learning, and therefore the more likely that learning is going to deliver cost reductions down to the level of commercial viability. In considering a support measure, it is important to assess whether the scale of support is sufficient to bring the unit cost down to a level where it can compete in the market with no further assistance. While the model can be used to consider this, the case would probably have to be supported by a business case in the form of a long-term support plan, linked to the engineering assessment, to allow the merits of the case to be judged.

The likelihood figure also recognises that innovation is a stochastic process, especially for research and development (rather than deployment). In other words, the benefits in these early stages of innovation are not linearly related to effort, except in a statistically large set of cases. As any investment in research could have an uncertain pay-off, then its *ex ante* value depends on the investor's attitude towards risk. The learning-benefit calculator assumes that the investor (the UK public purse) is risk-neutral.

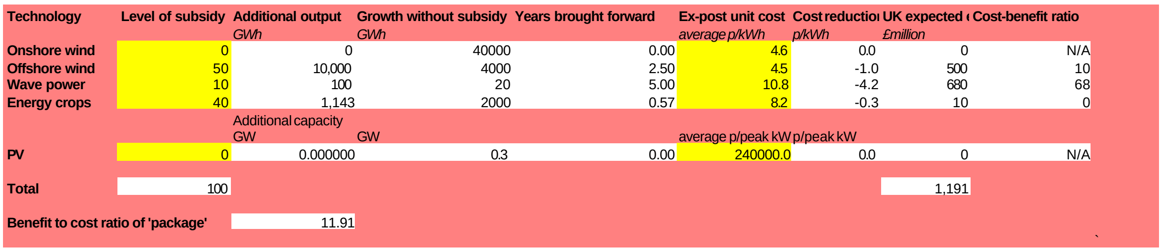
The likelihood figure could be decomposed into the following elements:

- the extent to which the assumed rate of learning and the assumed growth in cumulative production will be sufficient to bring costs down to a commercially viable level for each technology;
- the uncertainty surrounding the data on which the learning curves are based; and
- the stochastic nature of the innovation process.

It is assumed that the financial support contributes the difference between the unit cost of the technology and the revenue available in the market. In this case, the relevant revenue per unit is the wholesale price of electricity plus approximately 3p/kWh, which is the value that a generator might appropriate from the sale of certificates for the Renewable Obligation and Climate Change Levy exemption. The generator would meet the unit costs covered by this level of revenue.

The output of the model appears in the form shown in Figure 5.1. The cost-benefit ratio figures in the right-hand column are rounded to the nearest unit.

Figure 5.1: Output of learning model



Technology	**Level of subsidy**	**Additional output**	**Growth without subsidy**	**Years brought forward**	**Ex-post unit cost**	**Cost reductio**	**UK expected**	**Cost-benefit ratio**
		GWh	*GWh*		*average p/kWh*	*p/kWh*	*£million*	
Onshore wind	0	0	40000	0.00	4.6	0.0	0	N/A
Offshore wind	50	10,000	4000	2.50	4.5	-1.0	500	10
Wave power	10	100	20	5.00	10.8	-4.2	680	68
Energy crops	40	1,143	2000	0.57	8.2	-0.3	10	0
		Additional capacity GW	GW		average p/peak kW	p/peak kW		
PV	0	0.000000	0.3	0.00	240000.0	0.0	0	N/A
Total	100						1,191	
Benefit to cost ratio of 'package'		11.91						

The model quantifies the effect of ongoing private and non-UK investment. The investment is assumed to take place through, or have the equivalent effect of, new build, and is captured in the 'expected build rate'. Research and development programmes exist that are focused on particular components of a technology or particular technologies, and may provide cost reductions unrelated to the expected build rate. Where these programmes exist, they may deliver some of the learning benefits that otherwise (although perhaps less cost-effectively) could be delivered by new build. It may be appropriate to discount the benefits accorded to learning-by-doing for technologies for which substantial research programmes exist.

The model exhibits the property of diminishing marginal returns to support. The hierarchy of benefit per pound spent is wave power, followed by offshore wind, then energy crops and PV. The order of the first three is robust to changes in the model assumptions, but the ranking of energy crops and PV is very sensitive to small changes in the assumptions. Relaxing the constraint that only £10m can be spent on wave power leads to more money being allocated to wave and less to energy crops or PV, with a significant increase in overall learning benefits.

The model behaves in a flip-flop fashion. It allocates support to one technology until it is not permitted to allocate any more to that technology, and then begins the allocation to the next technology and so on. It does not distribute support to several technologies in a mixed portfolio. This behaviour may be caused by the solving method used by Excel Solver and the static nature of the analysis. Further development of the model might be able to improve its behaviour in this area.

The construction and operation of the model has provided some valuable lessons.

- In order to make decisions about the benefits of learning-from-doing accruing from funding support, additional information is necessary: namely, a more detailed understanding of the composition of the learning index in terms of the components listed in Tables 5.1 and 5.2, and the cumulative output of relevant component technologies.
- The cost–benefit ratio from investment in technologies that currently have low cumulative build (ie, are emerging) can be high, such that they may be a priority area for support.
- There appear to be grounds to believe that the benefits accruing from support of onshore wind and PV build are much lower per pound spent than support for offshore wind, wave and tide, and energy crops, but more information is required to confirm this result. Nevertheless, there may be a case for supporting research and development, rather than deployment, in these areas.

5.3 Further observations

The greatest benefit would be obtained from supporting renewable technologies that are not (or are only marginally) viable under the Renewables Obligation; that offer a substantial future resource; and that offer significant benefits from learning (ie, where there is little investment being undertaken overseas). Offshore wind, energy crops, and wave and tide fit this description.

For **offshore wind**, the costs of operation are not well established, and the reliability of large turbines offshore has not been recorded. Furthermore, there are some fixed costs that have to be borne before installation can begin, such as the construction of specialist drilling and lifting barges. Once the fixed costs have been recovered and the risks associated with uncertain costs and reliability established, the risk premia and up-front costs of entering the market could recede, and entry costs could fall. As it will be several years before the first UK farms can be installed, and a further few years before reliability data begin to indicate the long-term performance of the turbines, the risks are unlikely to be discounted from new project appraisals for the next five or six years, possibly longer. If this reasoning is correct, offshore wind would remain economically marginal under the Renewables Obligation, and direct support might be required to stimulate construction for at least the first half of this decade.

Energy crops are a more distant prospect than offshore wind for widespread development. The entry cost is higher, and the prospects are less well understood. Nevertheless, the modelling shows that with assumed reductions in cost, energy crops could play an important role in reaching the 2020 target if it is above 10%. Given that energy crops will be too expensive to be stimulated by the Renewables Obligation alone between 2002 and 2010, additional support would be needed if energy crops are to achieve cost reductions by 2010 and are therefore able to play a role in the 2020 renewable generation mix. The question of the origin of the greatest potential opportunities for savings should be examined. The future stage might be to consider the best means to support learning. Support need not be purely financial. As an example of non-financial support, the public sector, having experience in managing contracts with farmers, may be able to provide a service in brokering, consolidating and enforcing energy-crop supply contracts with farmers, making the construction and operation of energy-crop plant more attractive.

The reliability premium might be reduced once experience of running plant has been obtained. In order to provide experience, a future programme could include a small number of plant, perhaps with a range of technologies, to allow the reliability of the plant to be tested and to provide a statistical sample for analysis. Similar to offshore wind turbines, the plant probably has to be run for several years before its performance can be assessed with confidence. A support mechanism might even specify a competition for contracts to build, own and operate a series of energy crop plant.

Wave and tidal energy offer high but very uncertain benefits per pound spent. It offers high benefits because of the substantial early cost reductions, potential ultimate cost-competitiveness of the technology, and very large accessible resource. Expenditure on these technologies is probably limited by the small number of manufacturers and research groups operating in this field. Several designs have reached the demonstration phase, but over the next three years the opportunities for funding are likely to remain in research or demonstration for the purposes of reliability testing and output recording.

PV attracts substantial international investment in deployment, and the marginal benefit from UK support funding for deployment is therefore likely to be small. Cost savings from implementing PV technologies in the UK may only be realised across small volumes since the volume of future PV build in the UK is expected to be small. The best opportunity for benefits that would not be realised by other research programmes on PV is innovation—probably at the early stages of research and development—that has the potential to offer dramatic reductions in manufacturing cost. Cost reductions in the manufacture of the current substrates are likely to be realised by the ongoing and increasing levels of build occurring internationally. The threat of production of a new, lower-cost substrate could result in a response from industry to increase its own research into lower-cost substitute technologies.

Appendix 1: Assumptions Used in Renewables Modelling

Table A1.1: Assumed suppliers' obligation (achieve target scenario)

	Supplier's obligation (GWh)
2002	10,366
2003	14,041
2004	16,548
2005	19,104
2006	21,242
2007	23,405
2008	25,594
2009	27,806
2010	30,041
2011	33,635
2012	37,217
2013	40,865
2014	44,579
2015	48,361
2016	52,210
2017	56,129
2018	60,118
2019	64,177
2020	68,307
2021	68,278
2022	68,254
2023	68,236
2024	68,223
2025	68,223

Table A1.2: Assumed maximum build rates (reduced figures were used for scenario 2 and for energy from waste in scenario 8), MW/year

Year	Onshore wind	Energy crops	Energy from waste	Landfill	Offshore wind
2001	150	100	0	200	10
2002	250	500	50	200	10
2003	400	500	50	200	200
2004	500	500	100	200	400
2005	500	500	100	200	400
2006 onwards	500	500	200	200	400

Appendix 2: Availability of Energy from Waste

A2.1 Introduction

This note summarises a review of several sources undertaken by OXERA Environmental for two purposes:

- to feed into the project on Regional Renewable Assessments; and
- to check the assumptions used in the OXERA Renewables Obligation model in modelling work for the Cabinet Office.

The sources reviewed were:

- the Energy from Waste Association web site.
- the regional renewable assessments (those published by September 1st 2001);
- House of Commons Environment, Transport and Regional Affairs Select Committee (2001), 'Delivering Sustainable Waste Management, Volume 1';
- the Environment Agency's Strategic Waste Management Assessments;
- DETR (2000), 'Waste Strategy 2000: England and Wales';
- Biffa (1997), 'Great Britain plc: The Environmental Balance Sheet';

The assumption for the Cabinet Office work was that about 2 GW of energy from waste capacity would be technically available in 2010—'technically available' means without taking into account economic or planning constraints. The recent review of sources reported in this note showed that it would be reasonable to assume that energy from waste might contribute between 300 MW and 3,000 MW.

A2.2 Estimates of Energy Available from Waste

A2.2.1 Approach

In order to make the estimates from different sources comparable, they have been converted into a common indicator of capacity—number of energy-from-waste plant of 200,000 tonne per annum size. This indicator was chosen because it was referred to by a number of contributors to the House of Commons select committee, and has been used by the Energy from Waste Association.

It has been assumed that, in the presence of the Renewables Obligation, new energy-from-waste plant would only use 'advanced technologies', as defined in the draft Renewables Obligation Order, and could accept a mixed waste stream, where only 50% of the electricity produced would be eligible. The eligible component would be derived from biomass waste. No evidence has yet been sought to substantiate that 50% is the appropriate figure.

A2.2.2 Energy from Waste Association

The Energy from Waste Association maintains lists of projects in operation, under construction, with planning permission, seeking planning permission, and at a feasibility or pre-feasibility stage. These lists are published on its web site.

The lists contain 3,771 kt/annum of capacity in operation or with planning permission, and a total of 6,991 kt/annum of capacity if proposed projects are included. This is equivalent to 35 plant of 200 kt/annum capacity. It is assumed that the 3,771 kt/annum which is at an advanced stage of planning or has already been commissioned would use incineration technology, and would be unlikely to be considered eligible generation under the Renewables Obligation.

The Association's figures can be converted into an energy-recovery rate of 575 kWh/t if an 85% load factor is assumed. This gives an output of 4,000 GWh/yr, and an electrical capacity of 500 MW. In comparison, in 1993 the DoE published figures for electrical output for energy-from-waste schemes, quoting a range from 575 to 754 kWh/t. The lower figure seems to reflect an assumption of 25% efficiency of conversion of heat to electricity.

A2.2.3 Regional Renewables Assessments

For the five regional renewables assessments that have been examined so far, a total of 660 MW of energy-from-waste capacity has been proposed. This can be translated into 5,300 GWh/yr, or 46 plant of 200 kt/annum size in 2010.

A2.2.3 Evidence to the Environment, Transport and Regional Affairs Select Committee

In volume 1 of the Select Committee's report on waste management, the Committee reviews the evidence it received on the likely number of energy-from-waste plant. It noted that the DETR's Waste Strategy 2000 quoted a figure of 166 plant. Robin Murray of the DETR gave a figure of 100 in his evidence, as did Biffa; the Energy from Waste Association were more cautious, however, quoting 50 plant.

2.2.5 Strategic Waste Management Assessments

In 2000, the Environment Agency published a suite of documents called the Strategic Waste Management Assessments—one for each region in England and Wales. These contained estimates of waste management activity for several scenarios. In the high energy-from-waste scenario, the assessments showed an increase from the current capacity of 2,500 kt/annum of all waste energy recovery and incineration (with and without recovery), to 12,000 in 2010, and 22,500 in 2020. Excluding the current capacity, which will not use advanced technologies, gives the equivalent of 48 plant in 2010, and 100 in 2020.

2.2.6 Waste Strategy 2000

The DETR's Waste Strategy 2000 provides basic waste statistics which can be used to make an approximate assessment of combustible waste. The document provides a breakdown of commercial and industrial waste, and a separate breakdown of household waste. The figures exclude Scotland.

Of a total of 78 Mt/annum of commercial and industrial waste, approximately 28 Mt/annum is not available for energy recovery because it is recycled, and a further 20 Mt/annum is not combustible, leaving 40 Mt/annum available for energy recovery.

The Strategy document does not give any data for sewage sludge. Sewage sludge data must be handled with care because its calorific value per tonne is determined by its water content, which varies considerably. Biffa's 1997 report states a figure of 1.3 Mt/annum, whereas the DoE's 1993 report states a figure of 4.8. A further potential source of sludge figures is OFWAT, but OFWAT is unlikely to include farm wastes in its data. It is assumed here that a figure of 2 Mt/annum dry weight is correct, which includes arisings in Scotland.

Household waste totals about 25 Mt/annum, of which only about 10 Mt/annum would be combustible and available for energy recovery once recycling and composting targets for 2015 have been met.

Together, the waste streams available for energy recovery total 51 Mt/annum, equivalent to 255 plant. Unlike the regional assessments, this top-down analysis does not exclude waste arisings from areas of low population, where the scale of waste arisings is small, and may be insufficient to make the costs of energy recovery competitive with other forms of disposal. This figure is based on historical data: it does not take into account trends in waste arisings. It remains to be seen whether economies of scale are similar for advanced technologies and for conventional incineration. It is assumed in the calculation in sub-section 2.7 that 12 plant or 2.5 Mt/annum have already been commissioned and use incineration technology.

2.2.7 Summary

Table 2.1 presents the calculation of potential electrical generation capacity. The estimates range from 300 to 3,000 MW. A figure of at least 1,000 MW seems to be feasible, especially if plant can be built at a small scale without a large unit cost penalty relative to alternative disposal routes.

Table 2.1: Calculation of energy-from-waste potential

Range of assumptions	**Low**	**Medium**	**High**
Number of plant of 200 kt/annum	**40**	**100**	**243**
Total tonnes of waste processed (Mt/annum)	8	20	49
Thermal efficiency (%)	25	30	40
Energy recovered (GWh—at 575 kWh/t)	4,600	13,800	44,700
Load factor	80	80	80
Generation capacity (MW)	656	1,969	6,380
Proportion of power of biomass origin and eligible (%)	50	50	50
Eligible power generated (GWh)	2,300	6,900	22,360
Eligible capacity installed (MW)	**328**	**985**	**3,190**