Cost of and financial support for wave, tidal stream and tidal range generation in the UK

A report for the Department of Energy and Climate Change and the Scottish Government

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Ernst & Young LLP

Ernst & Young

Black & Veatch
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Executive summary

Background

The United Kingdom has considerable marine resource in its coastal waters and estuaries. The three main marine power generation technologies, wave, tidal stream and tidal range, have significant renewable energy potential. However, wave and tidal stream technologies are at an early stage of development, and little marine generation capacity has been installed at commercial scale to date. Tidal range technology is more mature, but has not been built to date in the UK.

A number of support mechanisms are currently available to marine technologies, ranging from grants to fund research and development, capital grants and revenue support to encourage commercialisation under the Marine Renewables Deployment Fund (MRDF), to revenue support for operational projects under the UK Renewables Obligation (RO) mechanisms.

As part of its Renewable Energy Strategy (RES) announced in July 2009, the UK Government included a pledge to develop a Marine Energy Action Plan to consider, amongst other things, the range of support available and the barriers to deployment. We understand that the results of this Study have been fed into the development of this Marine Energy Action Plan.

This Study was commissioned by DECC and the Scottish Government to provide:

- An assessment of the current (actual and best estimate) generation costs for wave, tidal stream and tidal range generation projects (excluding the Severn project) in the UK.
- An initial assessment of the likely downwards evolution of such costs on future demonstration and deployment to 2020, 2035 and 2050.
- An evaluation of the expected revenues available to future commercial marine projects from the sale of electricity, banded ROCs, LECs and other sources including Feed-in Tariffs (FiTs), through power purchase agreements.
- The level of financial support required at different points of development up to 2050 for early demonstration to large-scale deployment.

In carrying out our work and preparing our report, we have worked solely on the instructions of DECC and the SG and for DECC's and the SG's purposes. Our report may not have considered issues relevant to any third parties, any use such third parties may choose to make of our report is entirely at their own risk and we shall have no responsibility whatsoever in relation to any such use.

Our Report is based on certain publicly available information (as listed in Appendix A), capital and operating cost data from developers as obtained by Black & Veatch, resource and other proprietary data from Black & Veatch, project information obtained by DECC, Ernst & Young LLP (E&Y or Ernst & Young) proprietary data (where it has been legally possible to share it) and discussions with DECC and SG. We have not sought to verify the accuracy of the data or the information and explanations provided by any such sources. If you would like to clarify any aspect of this review or discuss other related matters then please do not hesitate to contact us.

Methodology

Black & Veatch led the population of a cost database, which contains the capital expenditure, operating costs and project characteristics for each of the technologies at the following stages of development: pre-demonstration, demonstration and commercial launch (Data) which vary for each technology.

The Data was sourced from other work already performed by Black & Veatch on the assessment of wave and tidal technologies, Black & Veatch proprietary data, data provided by DECC / Scottish Government (SG), as well as additional data gathered from current marine technology developers.

In addition to Data collection, the Study involved the following key tasks:

- Determining high, base and low case generic present costs within high, medium and low resource availability areas – undertaken by Black & Veatch.
- Identifying key cost drivers which could influence the future costs of each of the technologies (undertaken by Black & Veatch), and the extent to which each drives the technology costs. This included the establishment of learning rates to be applied to deployment (undertaken by Black & Veatch).
- Using estimated current and future project costs (calculated in January 2010 real terms), a discounted cash flow model (referred to herein as the 'Support Model') was built to calculate Net Present Value (NPV), Internal Rate of Return (IRR) and to derive levelised costs for pre-demonstration and demonstration projects reaching financial close respectively in 2020, 2035 and 2050.
- Given the range of estimates for forward wholesale power (as set out in Figure 72) and ROC revenue curves as provided by DECC, the Support Model was used to calculate the associated level of financial support using different mechanisms (eg ROC banding or FiT) that would be required to meet target post tax real IRRs as set out below. See Appendix D for Base Case assumptions.
- Though certain potential investors may require higher rates of return, we have applied the following target post-tax real discount rates (target IRRs) as suggested by DECC which are amongst other things more indicative of returns required for large infrastructure projects. Sensitivities with regards to target IRRs are set out in Appendices E, F and G.

Figure 1: Summary of post-tax real target IRRs
Source: Ernst & Young, DECC

As at valuation date	Under RO	FiT[1]	Notes
Pre-demonstration	14%	13%	pre-demonstration projects
Demonstration	12%	11%	demonstration projects (except for tidal range)
2020	10%	9%	becoming commercial
2035	9%	8%	all technologies are assumed to be commercial by 2035
2050	8%	7%	full commercial deployment

Summary of results

Black & Veatch provided us with capital and operating expenditure data (including error bands) by technology at pre-demonstration, demonstration and commercial launch dates,

[1] Due to the potentially more reliable nature of revenue under a Feed in Tariff, the required rates of return could be lower. We have been advised by DECC to reduce the RO target IRRs by a notional 100bp each to reflect such.

all for varying resource availability. The Base Case costs are expected to decline, largely due to the expected global deployment and the corresponding impact on learning (refer to Appendix D). Costs were separated out into the following elements:

Capex

- Construction costs
- Electrical systems infrastructure costs
- Pre-development costs

Opex

- Operating and maintenance costs (O&M)
- Insurance costs
- De-commissioning costs
- Other costs (including Crown Estate rent, Transmission Network Use of System (TNUoS) and national grid charges)

Black & Veatch provided the following generic estimates of costs at pre-demonstration, demonstration and commercial points of technological development for wave (combined near shore and offshore), tidal range, tidal stream shallow and tidal stream deep, based on their own proprietary data, publicly-available data sources and data collected directly from marine developers for this project. Note that the range of years at which these stages of development are assumed to be reached vary for each technology.

It is also important to note that the capacity factors vary significantly between technologies in the Base Case and hence the capital and operating costs in themselves are no indication of the resultant cost of energy.

Figure 2: Summary of costs (in real January 2010 terms) – Base Case costs at medium resource[2]

Source: Black & Veatch

Technology	Pre-demonstration project (low – high)	Demonstration project (costs for developer's first 10MW project) (low – high)	Commercial project costs for developer's 10MW project after 50MW deployed (low – high)
Wave			
Capex/MW	£7.3m (£6.1m - £8.6m)	£4.9m (£4.1m - £5.7m)	£3.4m (£2.8m - £3.9m)
Opex/MW/year	£0.63m (£0.52m - £0.74m)	£0.29m (£0.24m - £0.35m)	£0.2m (£0.17m - £0.24m)
Net load factor[3]	31%	33%	34%
Tidal Range			
Capex/MW	n/a	n/a	£2.7m (£2m - £3.2m)
Opex/MW/year	n/a	n/a	£0.03m (£0.03m - £0.04m)
Net load factor	n/a	n/a	20%

[2] Black & Veatch also estimated low, medium and high costs for low resource areas and for high resource areas.
[3] Load factors included in this table are dependent on the assumed resource and capacity mix for each technology at the specified stage of deployment. The load factors shown in Figure 54 show weighted average figures dependent on different resource assumptions.

Tidal Stream shallow			
Capex/MW	£11.2m (£7.5m - £12.4m)	£4.3m (£3.5m - £5.1m)	£3.2m (£2.7m - £3.9m)
Opex/MW/year	£0.47m (£0.32m - £0.56m)	£0.31m (£0.23m - £0.38m)	£0.15m (£0.12m - £0.19m)
Net load factor	53%	47%	33%
Tidal Stream deep			
Capex/MW	£8.6m (£7.3m - £9.9m)	£3.5m (£3m - £4.1m)	£3.3m (£2.8m - £4m)
Opex/MW/year	£0.31m (£0.27m - £0.39m)	£0.16m (£0.12m - £0.2m)	£0.12m (£0.09m - £0.16m)
Net load factor	36%	37%	35%

Taking the Base Case cost assumptions set out above, we have estimated the associated levelised costs of power generated. We have also estimated the level of Government support that would be required to generate the target IRRs as at demonstration stage[4], 2020 2035 and 2050, given these assumptions.

Figure 3: Summary of levelised costs (in real January 2010 terms)[5] under the Base Case (£/MWh)

Source: Ernst & Young analysis, Black & Veatch

Technology	Cost scenario[6]	2020	2035	2050
Wave	High	253	142	105
	Medium	214	118	86
	Low	177	97	71
Tidal Range	High	349	323	286
	Medium	279	258	229
	Low	205	190	168
Tidal Stream (Shallow)	High	211	199	166
	Medium	173	166	138
	Low	141	134	111
Tidal Stream (Deep)	High	250	159	129
	Medium	203	126	102
	Low	166	102	82

[4] The estimated costs at demonstration stage were calculated by reference to the date at which demonstration was assumed to occur, based on the assumption that demonstration occurs after the first 10MW farm.
[5] Levelised costs as at the relevant Valuation Date with assumed discount rate (target IRR) = Discounted total project capital and operating expenditure / Discounted total project output in MWh.
[6] High, Medium and low cost scenarios are based only on high, medium and low cost inputs as shown in Figure 2 above. This does not represent the absolute high or low of estimated levelised costs from expected errors resulting in sensitising other inputs (eg, deployment, resource, power prices or learning rates).

Figure 4: Summary of ROCs/MWh required under Base Case[7]

Source: Ernst & Young analysis, Black & Veatch

Technology	Cost scenario	2020	2035	2050
Wave	High	5.0	1.5	0.4
	Medium	3.8	0.8	neg
	Low	2.7	0.2	neg
Tidal Range	High	8.7	7.7	6.4
	Medium	6.4	5.6	4.6
	Low	3.3	2.8	2.2
Tidal Stream (Shallow)	High	3.7	3.2	2.2
	Medium	2.6	2.2	1.4
	Low	1.7	1.3	0.6
Tidal Stream (Deep)	High	4.9	2.0	1.1
	Medium	3.6	1.1	0.3
	Low	2.5	0.4	neg

Limitations of the analysis

The nature of the sector means that the Study incorporates a large number of assumptions (including present cost assumptions, uncertain learning rates and assumed deployment trajectories) around which there are varying degrees of certainty. It is also important to note that regardless of assumptions within the Report, any changes in the speed of device deployment or learning rates will change the projected outcomes and costs associated with the technology. Full details of the limitations of the analysis can be found in Section 2.3.

Conclusions

Given the key findings above, our conclusions are as follows:

- Given the early stage of the industry, costs are relatively high, however there is a potential for cost reduction assuming both the deployment and learning curves are deliverable and also that adequate support is given to the industry early on (to allow further developments later on).

- As projects reach commercial stage of deployment, our analysis suggests that under the Base Case, 2 ROCs/MWh may be an insufficient level of support for wave and tidal stream technologies, with 2 to 5 ROCs/MWh required to generate target IRRs. However, from 2035 between 1 and 3 ROCs/MWh would be a sufficient level of support and in the longer term (2050) these technologies are forecast to reach grid parity (except for tidal stream shallow). This depends on cost reductions continuing at the assumed learning rates; when wave and tidal stream reach technological maturity, these learning rates would be expected to slow and flatten out.

- Our analysis shows that tidal range is likely to need approximately 3 to 9 ROCs/MWh with no learning rate assumed, given that it is a well developed technology (based on tidal barrage).

[7] High, medium and low cost scenarios are based only on high, medium and low cost inputs as shown in Figure 2 above. This does not represent the absolute high or low of estimated levelised costs from expected errors resulting in sensitising other inputs (eg, deployment, resource, power prices or learning rates).

- Tidal stream seems to offer some early comparative advantages (especially tidal stream shallow at the demonstration stage of development with MRDF support), although wave technologies reach lower levelised costs in the long term.

- The assumptions used in this report are best estimates. However, they are highly uncertain and results should be considered as indicative.

Abbreviations

Bps	Basis points
Capex	Capital expenditure
COD	Commercial Operation Date
Commercial	Stage of development assumed to be reached for a 10MW project undertaken by developers after 50MW installed. Four developers have been assumed for each technology globally and this stage is therefore defined to be reached on average when 200MW is installed for each technology under the global deployment curve.
DECC	Department of Energy and Climate Change
Demonstration	Stage of development assumed to be reached when a developer installs their first 10 MW project. Four active developers have been assumed for each technology globally and this stage is therefore defined to be reached on average when 40MW is installed for each technology under the global deployment curve.
ESI	Electrical Systems Infrastructure
Ernst & Young or E&Y	Ernst and Young LLP
FCD	Financial Close Date
FiT	Feed-in Tariff
GW	Giga Watt
IRR	Internal Rate of Return (post tax in real terms)
k	Thousand
km	Kilometre
LEC	Levy Exemption Certificate
m	Metre/Millions
MW	Mega Watt
MWh	Mega Watt hour
MRDF	Marine Renewables Deployment Fund
NPV	Net Present Value
OFTO	Offshore Transmission Operator
Ofgem	Office of Gas and Electricity Markets
O&M	Operation and Maintenance
Opex	Operating expenditure
Pre-demonstration	First stage of project development before demonstration stage projects have been installed.
RES	Renewable Energy Strategy
R&D	Research and Development
Report or Study	Cost of and financial support for wave, tidal stream and tidal range generation in the UK
RO	Renewables Obligation
ROC	Renewable Obligation Certificate
SG	Scottish Government
TNUoS	Transmission Network Use of System
UK	United Kingdom
Vmsp	Mean tidal stream peak velocity

Contents

1. Introduction

The United Kingdom has considerable marine resource in its coastal waters and estuaries. As a result, marine power generation technologies, such as wave, tidal stream and tidal range, have significant renewable energy potential. However, wave and tidal stream technologies are at an early stage of development, and little marine generation capacity has been installed at commercial scale to date.

A number of support mechanisms are currently available to marine technologies, ranging from grants to fund research and development, capital grants and revenue support to encourage commercialisation under the Marine Renewables Deployment Fund (MRDF), to revenue support for operational projects under the UK Renewables Obligation (RO) mechanisms.

As part of its Renewable Energy Strategy (RES) announced in July 2009, the UK Government included a pledge to develop a Marine Energy Action Plan to consider, amongst other things, the range of support available and the barriers to deployment. We understand that the results of this Study have been fed into the development of this Marine Energy Action Plan.

2. Approach and methodology

2.1 Approach

The majority of the analysis was conducted over an eight-week period to 01 December 2009 and was based on data sourced from government commissioned and other work already done on the assessment of wave and tidal technologies, Black & Veatch proprietary data, data provided by DECC, SG, as well as additional data gathered from current marine technology developers.

As agreed with DECC, SG and Black & Veatch, our analysis encompasses the five identified technologies being: wave (combining offshore and near shore), tidal range and tidal stream (shallow and deep).

2.1.1 Work performed

The work performed involved the following key tasks:

Black & Veatch initially collected the input data for the Support Model:

- Black & Veatch reviewed existing literature covering resource, deployment, learning curve analysis and cost of energy for wave, tidal range and tidal stream projects. This information was used to sense check Black & Veatch's inputs into the Support Model. A summary of the literature review completed is included in Appendix A.

- Black & Veatch produced deployment scenarios for wave, tidal range and tidal stream technologies UK and Worldwide to 2050. The deployment to 2035 was estimated using developers' plans and potential success rates of both projects and technologies. The subsequent deployment from 2035 to 2050 was estimated using a (declining) growth rate based on the growth from 2020 to 2035. Base Case, optimistic and pessimistic deployment scenarios were created by varying the project and technology success rates. Growth was capped at the estimated total available resource (if reached). The pessimistic growth was constrained by grid.

- Black & Veatch reviewed the available resource sites in the UK and determined representative site conditions for a high, medium and low resource site (Figure 5). These conditions were provided to developers to develop their cost and performance data points. This allowed all the technologies for specific industries to be directly comparable and therefore aggregated.

Figure 5: Resource assumption data provided by Black & Veatch

Source: Black & Veatch

Description	High resource	Medium resource	Low resource
Wave	24 – 43 kW/m	22-35 kW/m	20-27 kW/m
Tidal range	N/A	700MW	150MW
Tidal stream shallow	3.6m/s	3m/s	2.4m/s
Tidal stream deep	3.8m/s	3.2m/s	2.8m/s

- Black & Veatch contacted the leading wave and tidal stream technology developers and tidal range project developers (excluding the Severn) and requested cost (capex & opex) and performance information.

- The analysis assumes that tidal range is a commercial technology and therefore the costs are well understood and defined. The high resource case is ignored as this is considered to be the Severn (not included in this study), the medium resource is based on project costs from the Mersey[8], and the low resource case is based on predicted costs for the Solway[9][10], Duddon[11] and Wyre[12]. Tidal range projects are considered individual civil engineering projects, similar to dams and bridges with little to no learning in costs between developments

- The wave and tidal stream industries are assumed to be in their infancy and therefore subject to initial high costs and high learning. To gain a higher level of confidence in the cost analysis of the wave and tidal industry, Black & Veatch collected data for three stages in the technologies development curve:

  1. Pre-demonstration: potential prototype costs which represent the starting point for the analysis.

  2. First 10MW farm: Represents large scale demonstration project costs. This stage assumed to be reached by the upper quartile of developers when the global installed capacity for each technology is as follows: (The upper quartile of developers will be expected to install devices at the date given brackets)

     - Wave – 50MW installed globally (2014)
     - Tidal stream shallow – 20MW installed globally (2014)
     - Tidal stream deep – 15MW installed globally (2018)

  3. A 10MW farm after technology developer has installed 50MW: Assumed to represent a project when the technology has fully commercialised. This stage assumed to be reached by the upper quartile of developers when the global installed capacity for each technology is as follows: (The upper quartile of developers will be expected to install devices at the date given brackets).

     - Wave – 160 MW installed globally (2016)
     - Tidal stream shallow – 100MW installed globally (2017)
     - Tidal stream deep – 60MW installed globally (2021)

- Black & Veatch aggregated the data collected from the developers and in house data with weightings applied to focus the data on validated data and information based on actual installations ie the leading technology developers. This provided a sense check of the data.

- To provide sensitivity to the data Base Case, optimistic and pessimistic cost and performance bands were developed for the identified technologies.

- Cost drivers (as set out in Appendix D) were applied to the data to forecast respective project free cash flows for projects with financial close in 2020, 2035 and 2050.

- Black & Veatch generated learning curves for the technologies. Tidal range is considered a commercial technology and therefore does not have a significant associated learning rate. The learning curves were used to devise progress ratios which

[8] Discussions with Iain Taylor (Peel Holdings) -23/10/09
[9] Solway Barrage Water Supply Scheme Desk Study, Babtie, Shaw & Morton, July 1966
[10] Discussions with Nigel Catterson (Solway Energy Gateway) Wednesday 21/10/09
[11] Tidal Power, A C Baker, 1991 (Table 11.2)
[12] River Wyre Preliminary Feasibility Study: Tidal Energy Barrage and Road Crossing Final Report, ETSU TID 4100, DoEN, 1991

in turn were used in conjunction with global deployment to develop the future cost of energy for the respective industries. These projections are inherently very uncertain.

The data generated by Black & Veatch was inputted into the Support Model, to forecast the future costs of the relevant industries, resulting in the following analysis:

- The calculation of current and future levelised costs at varying Valuation Dates (discussed below) for all technologies having regard to the characteristics and economics of each technology.
- The calculation of Base Case IRRs.
- The calculation of financial mechanisms (eg ROCs and FiTs) required to meet specific rates of return for all the technologies.
- The effect that varying deployment and other sensitivities and additional financial support mechanisms (capital grants and enhanced capital allowances) could have on the required ROC bandings and FiTs to meet the target IRRs.

2.1.2 Valuation dates and cost data as provided by Black & Veatch

In accordance with the invitation to tender (ITT), and DECC and SG requirements, we have used the following valuation dates (Valuation Dates) as part of our analysis. These dates correspond to financial close, ie just prior to the commencement of construction.

Figure 6: Agreed Valuation Dates

Source: DECC, SG, Ernst & Young, Black & Veatch

Valuation date	Relevant technologies and life cycle status
Pre-demonstration (1 January 2010)	► Pre-demonstration projects (except for tidal range)
Demonstration (1 January 2012-1 January 2016)	► Relevant for wave and tidal stream technologies (excluding tidal range as it is already commercial) ► Projects with capacity of 5 MW assumed to be deployed.
1 January 2020	► Relevant for all technologies; all of which are considered to be close to, if not commercial at this date. Farms of 10MW and over are assumed to be deployed.
1 January 2035	► All technologies have been assumed to have reached commercial stage with farms of 50MW and over being deployed.
1 January 2050	► Farms in excess of 100MW being deployed. ► Relevant for wave and tidal stream technologies

2.2 Methodology

2.2.1 Cost breakdown

Black & Veatch provided the cost categories for the analysis on the basis of DECC and SG's generation template as per Appendix C and summarized in Figure 7.

Figure 7: Capital expenditure and operating cost make-up

Source: Black & Veatch, DECC

Capital expenditure costs (capex)	Operating costs (opex)
Construction costs	Operations and maintenance (O&M) costs
Electrical systems infrastructure costs[1]	Grid costs[1]
Pre-development costs	Insurance costs
	De-commissioning costs

1. Grid costs and electrical systems infrastructure have been compiled by E&Y based on benchmarking against offshore wind transmission cost.

2.2.2 Forecast annual cash flows

We have forecast each of the respective capital expenditure and operating costs individually for each technology by:

- Identifying their respective cost drivers (eg, labour, installation vessels, steel, concrete, copper, electric motors and electricity distribution) and projected their implied forward curves based on historical trends of the identified cost indices. These forward curves were applied to the current costs to derive future cost trends. For further detail of how these drivers are applied refer to Appendix D - Base Case assumptions.
- Applying learning rates provided by Black & Veatch for the technologies based on each doubling in global capacity for each technology to determine the progress ratios. The progress ratios reflect the rate of cost reduction associated with industry learning and are applied to the costs to show the possible effects of increased industry experience on project costs (cost reduction) over time.

2.2.3 Base Case

For the purposes of this Study, we have applied Base Case assumptions (as summarized below and further detailed in Appendix D, herein referred to as the 'Base Case') in determining our conclusions for all wave, tidal range and tidal stream technologies. As summarized in the Appendices, we have run sensitivities on certain assumptions (brown power, deployment rates, enhanced capital allowances and target IRR).

Figure 8: Base Case assumptions

Source: DECC, SG

Base Case assumption	Value
Brown power	As provided by DECC (refer to Figure 72)
ROC (buy-out plus recycle)	2 ROCs /MWh under all Base Case scenarios. Forward curve as provided by DECC.
LEC	1 LEC under all Base Case scenarios. Forward curve as provided by DECC.
Generator share of revenues under PPA:	
► Wholesale power	► 90%
► ROC Buy-out	► 92.5%
► ROC Recycle	► 92.5%
► LEC	► 92.5%

Base Case costs, learning rates and capacity factor assumptions have all been provided for projects at high, medium and low resource sites. The Base Case resource assumption for each technology is a weighted average of the medium costs of each resource type (high, medium and low) according to the percentages set out below as provided by Black & Veatch.

Figure 9: Base Case available resource allocation assumptions

Source: Black & Veatch

Valuation date	Pre commercial			Demonstration			2020			2035 and 2050		
Available resource type	**High**	**Med**	**Low**	**High**	**Med**	**Low**	**High**	**Med**	**Low**	**High**	**Med**	**Low**
Wave	39%	23%	38%	39%	23%	38%	39%	23%	38%	39%	23%	38%
Tidal Range[13]	0%	50%	50%	0%	50%	50%	0%	50%	50%	0%	50%	50%
Tidal stream shallow	100%	0%	0%	100%	0%	0%	0%	100%	0%	5%	20%	75%
Tidal stream deep	100%	0%	0%	100%	0%	0%	0%	100%	0%	5%	20%	75%

The resource split as illustrated in Figure 9 above is based directly on the UK's available resource in the high, medium and low resource sites and the expected deployment over time.

According to Black & Veatch, the economics of these projects for early phase projects rely heavily on the deployment in the most economic sites. This will likely be largely based on proximity to grid, resource strength and site conditions. The analysis presented in this Study provides the average farm cost and therefore could potentially over estimate the costs of early phase projects.

2.2.4 Base Case target IRRs

Though certain potential investors may require higher rates of return, we have applied the following target post-tax real discount rates (target IRRs) as suggested by DECC which are amongst other things more indicative of returns required for large infrastructure projects:

Figure 10: Summary of post-tax real target IRRs

Source: Ernst & Young, DECC, SG

As at Valuation Date	Under RO	FiT[14]	Notes
Pre-demonstration	14%	13%	pre-demonstration projects
Demonstration	12%	11%	demonstration projects (except for tidal range)
2020	10%	9%	becoming commercial
2035	9%	8%	all technologies have been commercial by 2035
2050	8%	7%	full commercial deployment

2.2.5 Levelised costs

Using estimated current and future project costs and Base Case assumptions (as defined at Appendix D), a discounted cash flow (DCF or Support Model) model was used to derive levelised costs for projects reaching financial close as at the Valuation Dates using the target IRRs reflecting the operating status of each technology.

[13] The Severn Barrage was omitted from this study.

[14] Due to the potentially more reliable nature of revenue under a FiT, the required rates of return could be lower. We have been advised by DECC to reduce the RO target IRRs by a notional 100bp each to reflect such.

2.2.6 Key outputs and scenarios

Figure 11: Key outputs presented in the main body of this report (with Base Case resource assumptions)
Source: Ernst & Young

Base Case IRR (where positive)	Base Case levelised costs
All technologies at all Valuation Dates (unless technology is not deployed in the UK at that date)	All technologies at all Valuation Dates

2.2.7 Sensitivities

We have performed a number of sensitivities in analysing the costs and required financial support mechanisms across all technologies. For clarity, we have presented the sensitivities as follows:

Figure 12: Sensitivities presented in the main body of this report (with Base Case resources assumptions)
Source: Ernst & Young

Required ROC banding to earn target IRRs	► All technologies at 2020, 2035 and 2050 (unless resource is unavailable)
Required ROC banding to earn target IRRs with each separately: ► 10% / 25% capital grant ► enhanced capital allowances	► All technologies (unless resource is unavailable) at 2020
Levelised costs and Required ROCs/MWh with low/high capex and opex	► Low/High capex and opex ► All technologies at 2020
Required FiTs to earn target IRRs	► All technologies (unless resource is unavailable) at 2020 and 2035

Figure 13: Sensitivities presented in Appendix E to Appendix G of this report (with Base Case resource assumptions)
Source: Ernst & Young

Required ROC banding with target IRR sensitivity	► All technologies (except for tidal range) ► IRR of 12% (vs. 10%) at 2020
Required ROC banding with brown price sensitivity to earn target IRRs	► Tidal stream shallow ► Low/High brown power curve at 2020
Required ROC banding with deploy-ment sensitivity to earn target IRRs	► Wave and tidal stream deep ► Low and high deployment curves at 2035 and 2050
Required ROC banding to earn target IRRs with deployment sensitivity	► Wave and tidal stream deep ► Low and high deployment curves at 2035 and 2050

2.3 Limitations of the analysis

Readers should be aware of the following:

- The results are based on present industry cost assumptions, estimates of learning rates and assumed deployment trajectories which themselves depend on the level of support provided (all provided by Black & Veatch), uncertain cost escalation factors (applied by E&Y) and uncertain forward revenue curves (provided by DECC), and should therefore be treated with increasing caution with each future Valuation Date. Costs and the associated revenue support that would be required to generate required returns in 2035 and 2050 have been included in this Report to demonstrate the expected trends, given the current expectations of costs and have been included for illustrative purposes only.

- The economics of actual early phase projects are likely to rely heavily on the deployment in the most economic sites. This will be based on grid connection requirements, resource level and other site conditions. The analysis presented here provides the average project costs and is therefore potentially likely to overestimate the costs of the early phase projects.

- Varying these assumptions can produce large changes in the results. For example, referring to Appendix G, varying the deployment curve only, the tidal stream deep Base Case ROC requirement of 1.1 ROCs/MWh to achieve a 9% IRR in 2035 rises to 1.6 ROCs/MWh under the low deployment scenario and falls to 0.7 ROCs/MWh under the high deployment scenario. Similarly, for tidal stream shallow in 2020, the ROCs/MWh required to achieve a 10% IRR increases from 2.6 ROCs/MWh under the Base Case to 3.8 ROCs/MWh under the low wholesale power price scenario, and falls to 1.7 ROCs/MWh under the high wholesale price scenario.

- Black & Veatch's dataset for capital and operating expenditure included information provided by developers. While the project remit did not include full validation of this data, Black & Veatch completed partial validation and weighted the data based on its perceived strengths. Given the immaturity of the wave and tidal sector, the resulting data is inherently uncertain.

- While we have applied learning rates and other cost drivers to estimate costs up to 2090, we note that forecasts over a 40 year time period are inherently uncertain. Costs and the associated revenue support that would be required to generate required returns in 2035 and 2050 have been included in this Report to demonstrate the expected trends, given the current expectations of costs and have been included for illustrative purposes only.

- The literature review (see Appendix A) revealed that there is limited information available regarding the main cost drivers for key wave and tidal cost components, in particular regarding the contribution of these cost drivers towards overall capital and operating expenditure for a project. This analysis has had to rely on this limited information and has not involved a bottom-up analysis of 'fundamentals'.

- In order to highlight the variation in the level of support required, this Study includes sensitivities, as summarised in Section 2.2.7, on key assumptions including internal rate of return, cumulative MW deployment (provided by Black & Veatch), financial support mechanisms, revenue assumptions and the effects of lower/higher capital and operating expenditures.

- Taxation assumptions included in our forecasts have not taken into account any specific considerations of developers including, for example group or other relief. Our taxation calculations have all assumed projects are developed by standalone entities based in the UK.

3. Wave

3.1 Wave (combined offshore and near shore)

Waves are caused by the winds blowing over the sea. The longer the water distance (fetch) over which the wind blows, the greater the transfer of energy and the larger the waves. Waves are contained in the water nearest the surface; when they approach the shore some energy is lost as the waves meet with the seafloor.

Wave energy is easier to forecast (in the short-term) than wind energy, but is less predictable in the long-term than tidal stream.

The full extent of the wave resource which can be exploited for energy generation is dependent on many factors (eg device interactions, device spacing and cumulative impact) and as technologies develop, understanding of the available resource will improve. A commonly-used estimate of the practical resource level for wave energy in the UK waters is around 50TWh/year[15], (which is equivalent to the annual electricity demand of approximately 10 million UK households[16]. The wave resource assumptions[17] associated with this Study have been outlined in Appendix D.

The deployment location is the primary defining characteristic of wave devices. They can be divided into near-shore/onshore and offshore. Offshore wave energy converters are designed for deep sites (>c.20m and normally c.50m) while near shore sites (& shoreline) devices are intended for shallower water. Offshore and near shore wave energy converters are considered to be separate technologies, therefore learning and overlap between the two technologies is limited.

Figure 14 sets out the characteristics of a typical wave project for use as generic projects in our analysis.

Figure 14: Wave characteristics

Source: Black & Veatch

	Wave
Demonstration of first 10MW farm operational. (Assuming total global deployment of 50MW)	2014 (50MW)
Average 10MW commercial farm operational after 50MW installed. (Assuming total global deployment of 160MW)	2016 (160MW)
Distance from shore	3-7km
Water depth	>30m (offshore) <30m (near shore)
Mean power (energy density)	22-35KW/m
Mean Base Case capacity factor	28-42%
Typical project life	20 years
Typical construction period	2 years

[15] The Carbon Trust (2006) Future Marine Energy
[16] Calculated by dividing practical resource level for wave (TWh/yr) by average annual UK household electricity demand, adjusting for transmission losses (Source: DECC, Regional and Local Authority Electricity Consumption Statistics 2005-2008) http://www.decc.gov.uk/en/content/cms/statistics/regional/electricity/electricity.aspx).
[17] The wave resource assumptions for this study are based on the method referred to in footnote 16, but updated with recent developments in technology to provide a range of estimates for the practical resource. We are aware that other proposed methods of estimating the wave resource result in lower practical resource estimates. Carbon Trust is currently updating its 2006 Wave Resource work.

Figure 15 presents the cumulative deployment projections for wave[18] in the UK (as provided by Black & Veatch) to 2035 (the UK deployment growth flattens for wave post 2035).

Figure 15: Wave deployment – cumulative MW in the UK (FCD)[19]

Source: Black & Veatch

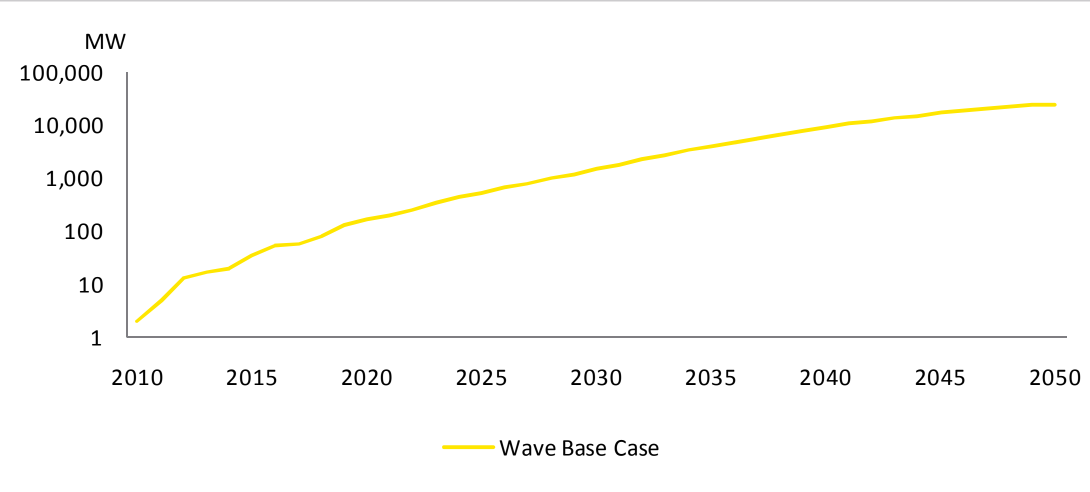


Figure 16: Wave High, Base Case and Low UK deployment projections

Source: Black & Veatch

UK cumulative MW deployed (FCD)	2020	2035	2050
COD[20]	2022	2037	2052
High	234	5,874	35,782
Base Case	156	3,917	23,857
Low	156	1,347	7,408

Figure 17: Wave High, Base Case and Low global deployment projections

Source: Black & Veatch

Global cumulative MW deployed (FCD)	2020	2035	2050
COD	2022	2037	2052
High	695	17,360	105,838
Base Case	463	11,572	70,550
Low	239	5,532	29,080

3.2 Costs: at pre-demonstration, demonstration and commercial stages

Figure 18 and Figure 19 show the total capital expenditure and operating costs for typical wave pre-demonstration, demonstration and commercial projects at varying dates (as per Figure 6). Construction costs and Operation and Maintenance (O&M) make-up over 90% and 60% of total capital expenditure and annual operating costs respectively.

[18] Wave deployment has been considered as the aggregate of offshore and near shore technologies
[19] Financial close date
[20] Commercial operation date

For the purposes of our analysis, these costs have been applied at an average date that corresponds with when a defined level of global deployment is reached. However, these stages are expected to be reached by individual developers over a range of dates. These average date ranges of Commercial Operation Date (COD) are as follows:

- Wave demonstration projects: 2013 to 2014
- Wave commercial projects: 2015 to 2017

Figure 18: Wave capex

Source: Black & Veatch

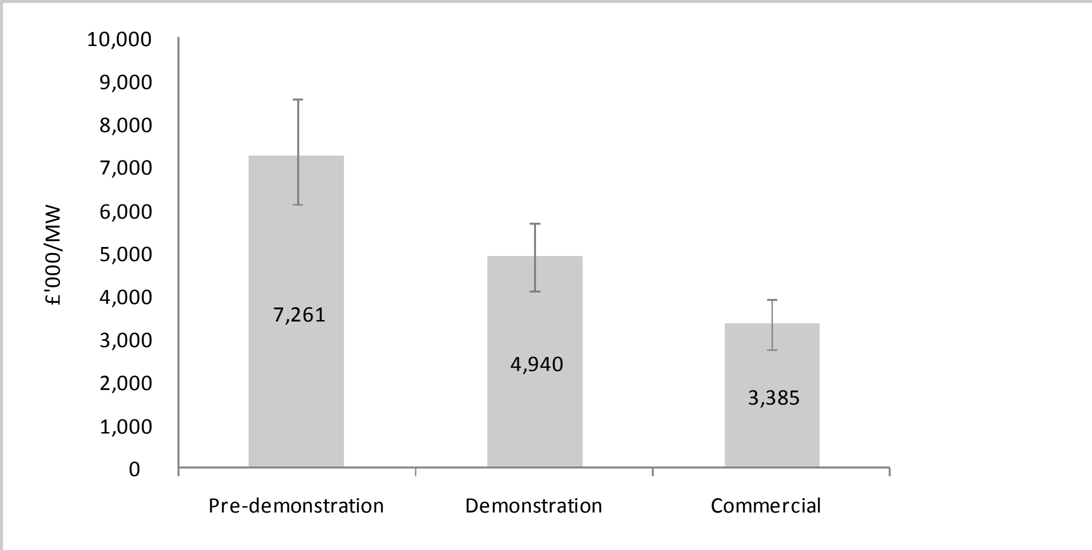
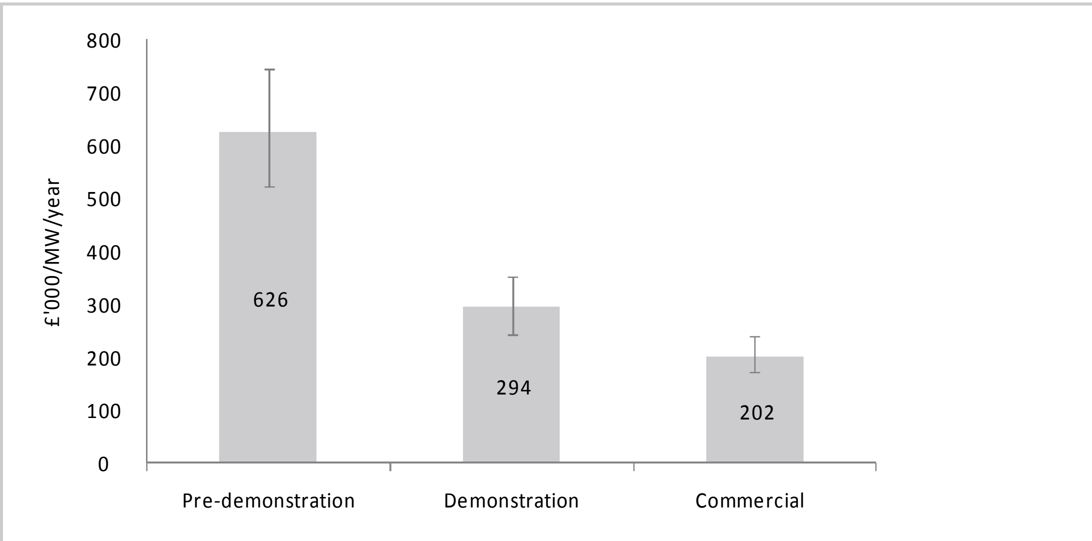


Figure 19: Wave opex

Source: Black & Veatch



Learning rates have been applied to these Base Case costs in a logarithmic correlation to the global deployment forecasts. For further details of learning rates, please refer to Appendix D. We note that these Base Case costs should be considered within the context of the appropriate capacity factors and relevant deployment forecasts.

3.3 Levelised costs[21]

As set out in Figure 20, though the levelised cost of wave is high today, it is assumed to fall by a net amount of c.70% by 2035 due to:

1. Expected learning rates in the sector as provided by Black & Veatch (as set out in Appendix D). The average learning rate that has been applied to costs, in logarithmic correlation to the commercial global deployment forecasts, is 12.4% from first commercial deployment. The underlying learning rate assumptions for capex components correspond to an overall learning rate for capex of around 11.1%.

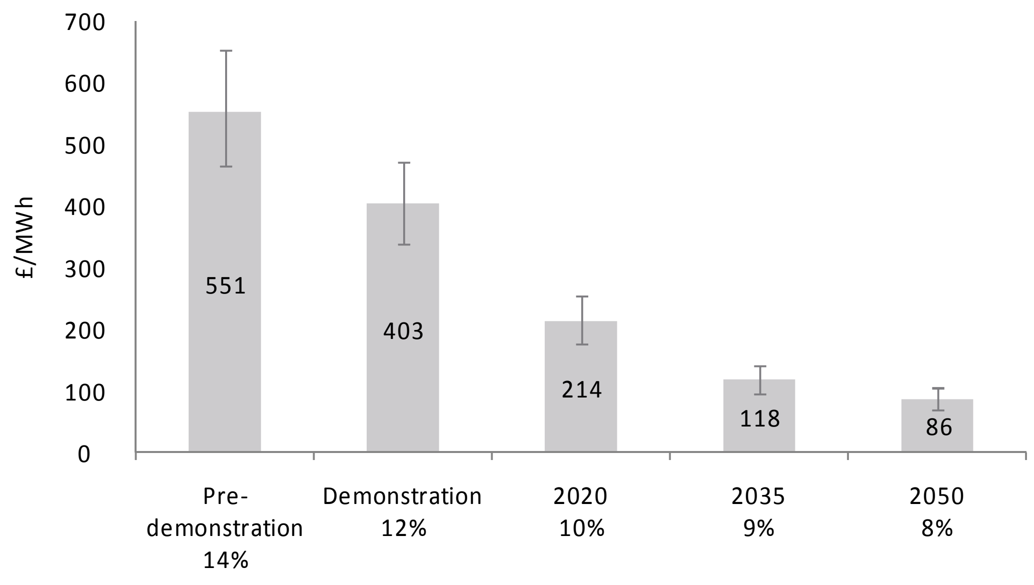
2. A declining rate of increase in underlying costs (eg metal and electrical manufacturing and labour). For example, metal and electrical manufacturing costs are driven by the All Carbon Steel Products Composite Price & Index which grows on average by 6.9% per annum from 2010 to 2020. Between 2020 and 2050, the same index grows on average by 0.7% per annum.

Wave technologies are expected to commence commercial operations around 2016 (when the upper quartile of developers are expected to install their first 10MW project each after having installed 50MW ie, with 150MW installed globally[22]).

Learning rates are assumed to be constant relative to doublings in deployment through time. In reality they are likely to be bumpy, and may slow down or fall to zero as the technology reaches technological and market maturity.

Figure 20: Wave levelised costs (with post-tax target IRRs as at Valuation Dates)

Source: Ernst & Young analysis, Black & Veatch



As shown above with the error bars and as set out below, we have observed the effect of cost uncertainty and have calculated the impact of high and low capital expenditure and operating costs on levelised costs for wave tec hnologies as at 2020, 2035 and 2050.

[21] Levelised costs as at the relevant Valuation Date with assumed discount rate (target IRR) = Discounted total project capital and operating expenditure / Discounted total project output in MWh.

[22] As per Black & Veatch global deployment forecast.

Figure 21: Wave levelised costs (with high and low capex / opex), £/MWh

Source: Ernst & Young analysis, Black & Veatch

	2020	2035	2050
High	253 (+19%)	142 (+20%)	105 (+22%)
Low	177 (-17%)	97 (-18%)	71 (-18%)

These levelised cost ranges do not represent the full range of uncertainty pertaining to levelised costs, but just that resulting from initial high/low capex and opex estimates. There is also uncertainty relating to deployment trajectories and learning rates which have significant impact on levelised costs.

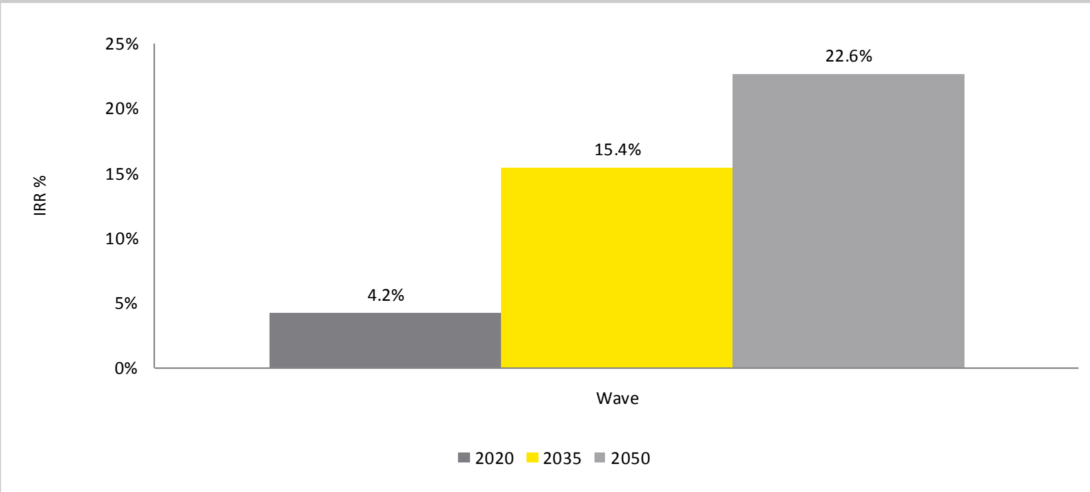
3.4 Base Case IRRs

Figure 22 shows the IRR for a typical project under all the Base Case assumptions, including current subsidy levels of 2 ROCs/MWh and 1 LEC/MWh. It is unlikely that deployment would proceed at the Base Case level if commercial project returns proved to be as low as 4%. The Base Case IRR exceeds the target IRR as at 2035 and 2050 due to the reduction in the levelised costs as a result of industry learning (as discussed in Section 3.3 above)[23]. Marine support levels would be expected to fall over time, taking advantage of this learning. This would avoid over-compensation of marine projects and imposing excessive costs on electricity consumers.

These Base Case IRRs are central estimates and do not take into account the significant uncertainty surrounding both costs and wholesale electricity revenues.

Figure 22: Wave Base Case IRRs on the basis of current levels of support

Source: Ernst & Young, Black & Veatch



3.5 Adjustment of financial support mechanisms

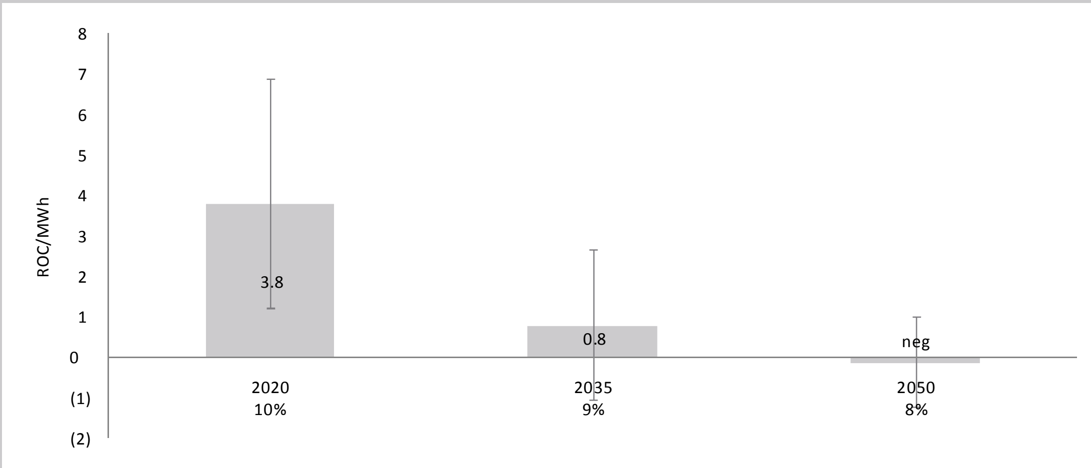
3.5.1 ROCs or FiT required to earn target IRRs

Figure 23 presents the number of required ROCs/MWh for wave project developers to earn the target IRRs. This equates to a FiT of £194/MWh and £67/MWh as at 2020 and 2035 respectively.

[23] Deployment levels are an exogenous assumption from Black & Veatch. If returns remained too low to meet target IRRs, deployment levels could be lower than those assumed by Black & Veatch.

Figure 23: Wave ROCs/MWh required to meet target IRRs as at Valuation Dates

Source: Ernst & Young analysis



As shown above with the error bars and as set out below, we have observed the effect of cost uncertainty and have calculated the impact of high and low capital expenditure and operating costs on ROCs/MWh required for wave technologies as at 2020, 2035 and 2050.

Figure 24: Wave ROCs/MWh required for target IRRs as at Valuation Dates (with high and low capex / opex)

Source: Ernst & Young analysis, Black & Veatch

	2020	2035	2050
High	5.0 (+30%)	1.5 (+86%)	0.4 (na)
Low	2.7 (-28%)	0.2 (-75%)	neg (na)

These ROC ranges do not represent the full range of uncertainty pertaining to ROCs/MWh required to meet target IRRs, but just that resulting from initial high/low capex and opex estimates. There is also uncertainty relating to deployment trajectories and learning rates which have significant impact on required ROCs/MWh.

We note that if a high deployment projection in 2035 is assumed for wave, the required ROCs/MWh to earn the target IRR of 9% are lower at 0.5. Furthermore, by 2050 our analysis indicates that virtually zero ROC support will be required under even the low deployment scenario for wave project developers.

3.5.2 2020: Capital grants and enhanced capital allowances

After MRDF support expires, there are two further financial support mechanisms the Government may consider introducing to assist marine developers:

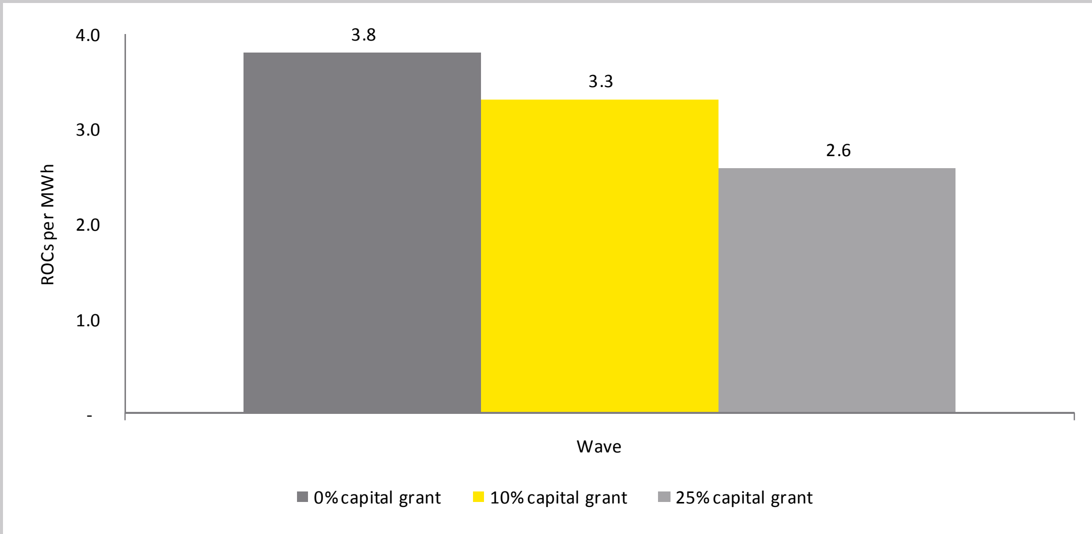
1. *Capital grants* are cash grants provided by the UK or Scottish Governments to offset the capital expenditure incurred in the development of wave, tidal range and tidal stream technologies.

2. *Enhanced capital allowances* assume the technology would be eligible for 100% of the capital costs to be written down in the first year of operation for tax purposes. We note that we have not considered the possible impact of group or other relief in regards to capital allowances and our analysis assumes the project is a standalone entity for taxation purposes.

Figure 25 shows that without such capital grants, wave projects require 3.8 ROCs/MWh to earn a target IRR of 10% in 2020 and this reduces to 2.6 ROCs/MWh with a 25% capital grant. The latter would equate to around £0.8m per MW under the Base Case.

Figure 25: Required ROCs/MWh with capital grant sensitivity as at 2020 with 10% discount rate

Source: Ernst & Young analysis



As set out in Appendix E, assuming the capital expenditure qualifies for enhanced capital allowances, the impact is almost immaterial. Under the Base Case, we have assumed that 96% of the capex falls within the general pool and a rate of 20% on a declining balance. As the proportion of capital expenditure that is an allowable deduction is not changed by this scenario, the rate at which the deduction can be claimed against taxable profits the scenario represents a timing benefit of the allowable deduction rather than an absolute financial benefit.

4. Tidal range

Tide formation is dominated by the interaction of the gravitational forces between the primary astronomical bodies in our solar system. The relative motions between sun, moon and earth are complex but the resulting tidal pattern is predictable. An advantage of tidal stream energy over other forms of renewable energy such as wind, wave or solar is this predictability. Tidal range is even more predictable than tidal stream.

Tidal barrages use the potential energy from the variance in height (tidal range) between a high and low tide. The technology is essentially a dam which stretches across an estuary, controlling the flow of water in and out between tides.

The UK has significant tidal range resource with the world's second highest tidal range site being located in the Severn Estuary with a benchmark energy output of 17TWh/yr from a Cardiff-Weston barrage. The other highest resource sites in the UK include the Mersey (1.4TWh/yr), Duddon (0.212TWh/yr), Wyre (0.131 TWh/yr) and Conwy (0.06TWh/yr). Through these tidal range projects and others that there is an opportunity to potentially provide up to 13% of the UK's electricity generation from tidal range alone. However, this study is based on the deployment projection of specific tidal range projects, these are detailed further, below.

Tidal range projects are considered to be large bespoke developments involving the use of mature engineering practices and accordingly, compared to wave and tidal stream technologies, have longer project lives. Tidal range development has already reached a commercial stage (unlike wave and tidal stream technologies). However, it is assumed that significant deployment in the UK does not occur for several years to come because of the long lead times.

Figure 26: Tidal range characteristics provided by Black & Veatch
Source: Black & Veatch

	Tidal range
Commercial stage	already commercial today
Distance from shore[24]	0km
Typical project capacity	100-700 MW
Average commercial capacity factor	20%
Typical project life	40 years financial life; 120 years design life
Typical construction period	3-6 years

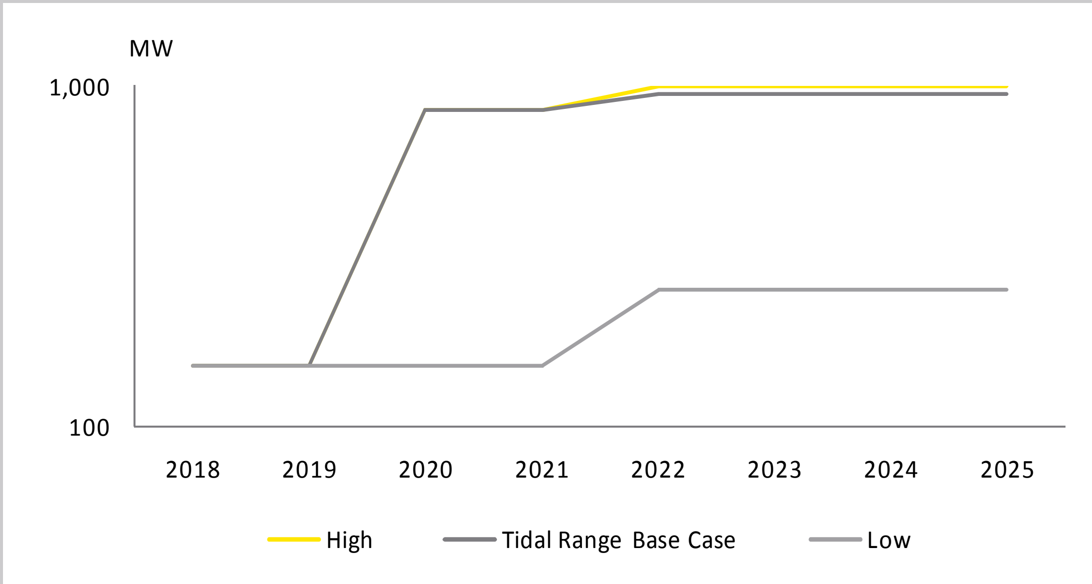
Figure 27, as set out below, presents the deployment projection for tidal range (as provided by Black & Veatch). Under the Base Case, 850 MW of tidal range capacity is expected to be deployed by 2020 in the UK. This is a result of the technology's relative mature status and long asset life (preventing the introduction of new projects).

These deployment curves (as set out below) are based on the following four potential projects: Mersey Tidal Power (700MW), Solway (150MW), Duddon (100MW) and Wyre (50MW) while excluding the Severn project. The deployment curves are based on varying sizes and numbers of projects going ahead. For the Base Case assumption we assume that a 150MW Solway project reaches financial close in 2018, a 700MW Mersey project in 2020 and a 100MW Duddon project in 2022. The Mersey project is assumed to take 6 years to construct and the other smaller projects 3 years to construct. The high case incorporates the Wyre. The low case is formed of the Solway followed by the Duddon.

[24] This Study excluded reference to offshore lagoons.

Figure 27: Tidal range deployment – cumulative MW in the UK (FCD)

Source: Black & Veatch



4.1 Costs: commercial

For the purpose of this analysis, tidal range technology is not considered to be at the pre-commercial or demonstration stages. Hence, its current central cost estimates (capex of £2.7m/MW and opex of £34k/MW per annum), reflecting a commercial stage equivalent technology, are lower than the other wave and tidal stream technologies.

We have observed the effect of high and low capital expenditure and operating costs on levelised costs of tidal range as at 2020. The results are as follows.

- An increase of 17% in total costs: levelised costs increase by 33%
- A decrease of 21% in total costs: levelised costs fall by 35%

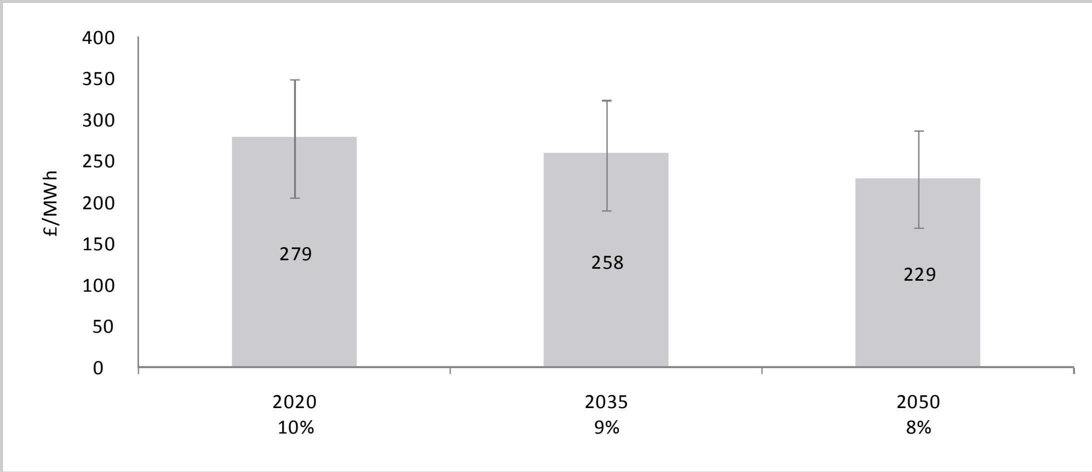
4.2 Levelised costs

As discussed, due to the relative mature nature of this technology, deployment in the UK is expected to commence at a commercial stage. However according to Black & Veatch, no projects are expected to be operational prior to the 2020 Valuation Date and therefore costs have not been forecasted prior to this date.

As set out in Figure 28, the levelised costs of tidal range are expected to be £279/MWh in 2020. This is based on an equal split between the comparatively lower cost (Mersey) and higher cost (Solway, Duddon and Wyre) scenarios. In the long term, due to the heavy capital nature of the technology and lack of learning potential as well as limited sites for deployment, tidal range has been found to be the most expensive of the marine technologies.

Figure 28: Tidal range levelised costs (with post-tax target IRRs as at Valuation Dates)

Source: Ernst & Young analysis



The declining discount rate over time was used for consistency with wave and tidal stream. It is possible that as a more mature technology, the risk (and hence the cost of capital) associated with tidal range projects does not fall this much over time.

As shown above with the error bars and as set out below, we have observed the effect of cost uncertainty and have calculated the impact of high and low capital expenditure and operating costs on levelised costs for tidal range technologies as at 2020, 2035 and 2050.

Figure 29: Tidal range levelised costs (with high and low capex / opex), £/MWh

	2020	2035	2050
High	349 (+33%)	323 (+55%)	286 (+66%)
Low	205 (-35%)	190 (-58%)	168 (-70%)

These levelised cost ranges do not represent the full range of uncertainty pertaining to levelised costs, but just that resulting from initial high/low capex and opex estimates. Even considering that this technology is already in its commercial stage, there is still some uncertainty relating cost drivers.

4.3 Base Case IRR

Under the Base Case costs and revenues, (ie, with current levels of financial support being 2 ROCs/MWh for 20 years and 1 LEC/MWh), tidal range does not generate a positive IRR in 2020. As no learning is assumed for this technology, the costs are only subject to cost drivers including the manufacture of metal structures index which is forecast to increased at an average of 24% from 2020 to 2050 resulting in negative IRRs as at all Valuation Dates to 2050. As shown above, there is significant uncertainty surrounding the levelised costs of tidal range even though it is a more mature technology.

We note that the actual operating life can be up to 120 years however for the purpose of this analysis we have modelled the first 40 years for the following reasons:

- Significant re-fitting costs are required sometime after 40 years.
- Discounted cash flows are insignificant beyond 40 years.

- Revenues depend on support mechanisms being available for this time period (it is difficult to accurately predict the financial support mechanisms that will be in place in 40 years time).

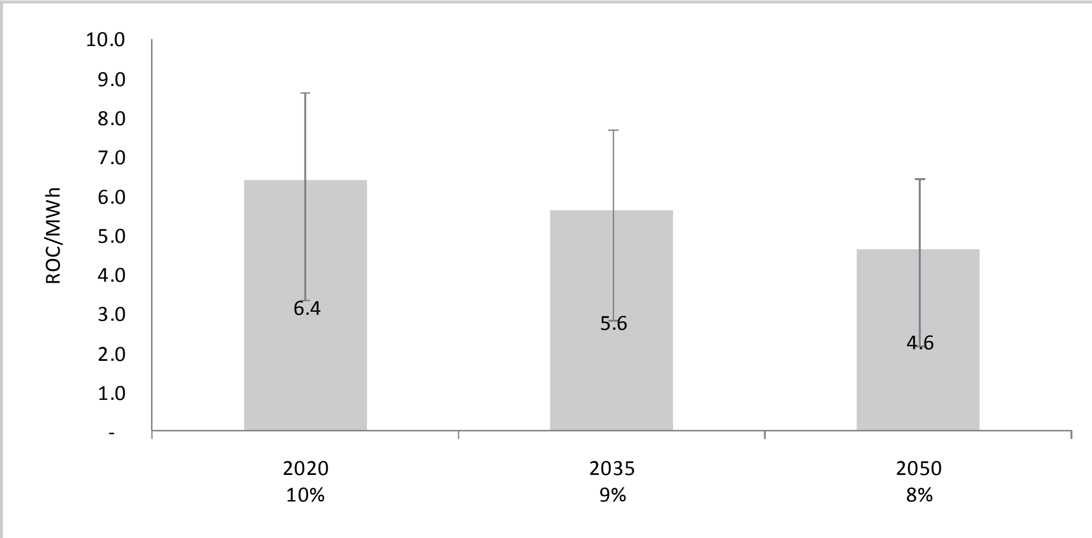
4.4 Adjustment of financial support mechanisms

4.4.1 ROCs or FiT required to earn target IRRs

Figure 30 presents the number of ROCs/MWh that tidal range technology developers would likely require in order to earn the target IRRs. This equates to a FiT (for the financial life of the project) of £248/MWh and £221/MWh as at 2020 and 2035 respectively.

Figure 30: Tidal range ROCs/MWh required to meet target IRRs as at Valuation Dates

Source: Ernst & Young analysis



As shown above with the error bars and as set out below, we have observed the effect of cost uncertainty and have calculated the impact of high and low capital expenditure and operating costs on ROCs/MWh required for tidal range technologies as at 2020, 2035 and 2050.

Figure 31: Tidal range ROCs/MWh required to meet target IRRs as at Valuation Dates (with high and low capex / opex)

Source: Ernst & Young analysis, Black & Veatch

	2020	2035	2050
High	8.7 (+35%)	7.7 (+37%)	6.4 (+39%)
Low	4.0 (-37%)	3.4 (-39%)	2.7 (-41%)

These ROC ranges do not represent the full range of uncertainty pertaining to ROCs/MWh required to meet target IRRs, but just that resulting from initial high/low capex and opex estimates. There is also uncertainty relating to deployment trajectories and learning rates which have significant impact on required ROCs/MWh.

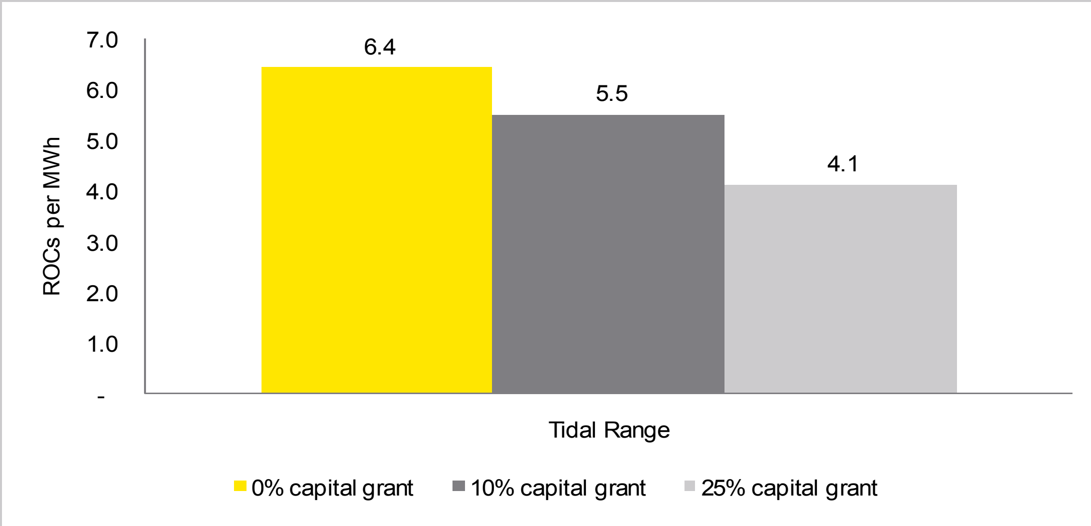
Referring to Appendix F, if the cost of capital is assumed to be 12% rather than 10% in 2020, this raises the ROCs/MWh required from 6.4 to 8.5.

4.4.2 2020: Capital grants and enhanced capital allowances

See Section 3.5.2 for an overview of capital grant and enhanced capital allowances. Figure 32 shows that without such capital grants, tidal range requires 6.4 ROCs/MWh for projects to earn a target IRR of 10% in 2020. With a 10% or 25% capital grant, this ROC requirement declines. For a 700 MW project, under the Base Case capex assumption a 25% capital grant would amount to £600m.

Figure 32: Required ROCs/MWh with capital grant sensitivity as at 2020 with 10% discount rate

Source: Ernst & Young analysis



Furthermore, as set out in Appendix F, assuming the capital expenditure for tidal range qualifies for enhanced capital allowances, the required ROCs/MWh fall by 6.5% to 6.0 in 2020.

5. Tidal stream

5.1 Tidal stream shallow and tidal stream deep

The tides as highlighted in Section 4 are also the energy source for tidal stream. Sea level variations are accompanied by the movement of very large quantities of water. This flow of water is known as a tidal stream.

The full extent of the tidal stream resource which can be exploited for energy generation is dependent on many factors (eg turbine interactions, device spacing and cumulative impact) and as technologies develop, understanding of the available resource will improve. The UK has a unique level of tidal stream resource and estimates indicate that the practical tidal stream resource is indicated to be in the order of 17TWh/year[25],[26],[27]. (which is equivalent to the annual electricity demand of approximately 4 million UK households[28]). This is derived from a method that provides the most conservative estimate[29] and although there are a number of methodologies to estimate the values of tidal stream resource, it is accepted by the sector as an appropriate analysis technique in some tidal energy conditions. Other methods of estimating the tidal stream resource result in higher technical potentials [30], [31], [32], [33]. There are uncertainties regarding these pieces of work but the potential resource they suggest is sufficiently large to justify urgent further research by Government. The tidal stream resource assumptions associated with this study have been outlined in Appendix D.

Generally, only tidal streams with mean spring peak velocities of >c. 2.5m/s (5kts) are of relevance to energy extraction, since below this level energy extraction becomes increasingly uneconomic. Velocities of this magnitude are very site specific, and are found only in certain areas where land formations create natural restrictions, for example where tidal flows are forced through relatively narrow boundaries. Both reasonably high tidal ranges and narrow channels are generally required to cause significant tidal stream currents. Tidal streams flow in two directions on each semi-diurnal tide; in one direction on the flood tide and in the reverse direction on the ebb tide. The velocities are not necessarily bi-directional and can vary through the tidal cycle; in some cases this can have implications for power capture by a turbine with a fixed orientation. Generally the velocities in the UK are lower on the ebb tide, although this is not always the case.

The tidal stream resource is generically split into shallow (<40m) and deep (>40m). This split is considered to be in line with the deployment method required to install in deeper sites compared to shallow. However, unlike wave the shallow and deep technologies are potentially the same apart from the structure, foundation or moorings. The technologies therefore benefit from learning, from each other. Black & Veatch envisage that shallow water sites will be the easiest to deploy in the short term with deeper sites following on naturally as the economics improve.

Tidal stream technology, comprising tidal stream shallow and tidal stream deep technologies, converts the energy of tides into electricity using under water turbines. These

[25] SKM (2008) Quantification of Constraints on the Growth of UK Renewable Generating Capacity.
[26] Black & Veatch (2005) Phase II UK Tidal Stream Energy Resource Assessment, Carbon Trust.
[27] Sustainable Development Commission (2007) Turning the Tide, Tidal Power in the UK.
[28] Calculated by dividing total tidal stream potential (TWh/yr) by average annual UK household electricity demand (Source: DECC, Regional and Local Authority Electricity Consumption Statistics 2005-2008, http://www.decc.gov.uk/en/content/cms/statistics/regional/electricity/electricity.aspx).
[29] Blunden, L.S., Bahaj, A. S.,(2006) Tidal Energy resource assessment for tidal stream generators.

[30] Houlsby, G.T., Oldfield, M. L. G., Draper, S. "The Betz Limit and Tidal Turbines". Report commissioned by Lunar Energy (2008).
[31] Taylor, G. I. "Tidal Friction in the Irish Sea", Philosophical Transactions in the Royal Academy, 1918.
[32] Salter, S. H., Taylor, J. R. M. T. (2007) Vertical-Axis Tidal –Current Generators and the Pentland Firth, Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy.
[33] Mackay, D. J. C. (2008) Sustainable Energy: Without the hot air. UIT Cambridge, 2008. www.withouthotair.com

technologies have generally been considered to have less of an environmental impact (compared to the large tidal range barrages) and are expected to be cheaper to build and maintain, in the medium and long term as they benefit from learning.

Figure 33: Tidal stream shallow and tidal stream deep characteristics

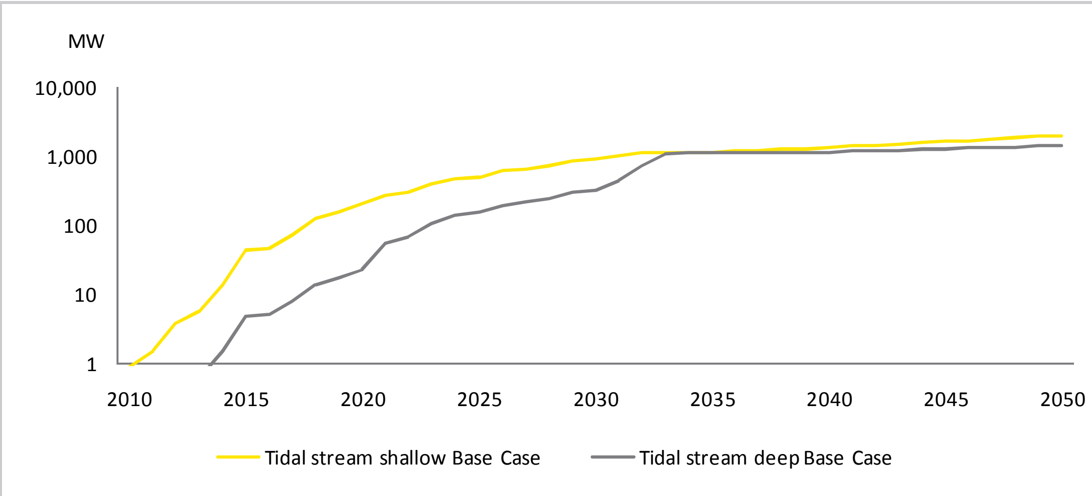
Source: Black & Veatch

	Tidal stream shallow	Tidal stream deep
Demonstration of first 10MW farm operational. (Assuming one developer per 10MW and at global deployment specified)	2015 (20MW)	2018 (15MW)
10MW commercial farm operational after 50MW installed. (Assuming one developer per 10MW and at global deployment specified)	2017 (100MW)	2020 (60MW)
Water depth	<50m	>50m
Mean power (energy density)	3m/s	3.2m/s
Mean Base Case capacity factor	35%	37%
Typical project life	20 years	20 years
Typical construction period	3 years	2 years

Figure 34, as set out below, presents the deployment projections for both tidal stream shallow and tidal stream deep technologies in the UK (as provided by Black & Veatch). In the medium term, with tidal stream shallow technology being more developed, its deployment is greater than tidal stream deep. Under the Base Case, 200 MW of tidal stream shallow capacity is expected to be deployed globally by 2019 vs. only 23 MW for tidal stream deep. However, in the long term (from 2031), tidal stream deep deployment is expected to exceed tidal stream shallow, both globally and in the UK, due to greater resource levels overall.

Figure 34: Tidal stream shallow and deep deployment – cumulative MW in the UK[34] (FCD)

Source: Black & Veatch



[34] Includes re-powering.

Figure 35: Tidal stream shallow and tidal stream deep high, Base Case and low UK deployment stages

Source: Black & Veatch

UK cumulative MW deployed (FCD)	Demonstration	2020	2035	2050
Tidal stream shallow (COD	2015	2023	2038	2053
High	65	304	2,621	4,071
Base Case	44	203	1,136	1,980
Low	44	180	587	942
Tidal stream deep (COD)	2018	2022	2037	2052
High	20	34	1,727	3,217
Base Case	13	23	1,104	1,413
Low	13	20	460	660

These deployment assumptions, developed by Black & Veatch, are fundamentally based on a bottom-up assessment of developers' growth plans, combined with assessments of technological, grid and the conservative resource constraints outlined earlier. They do not consider project finance, ie they assume that projects finances are not a limiting factor on deployment.

They predict a fairly low level of deployment up to 2020, and quick acceleration in the 2020s. Other forecasts have assumed a higher level tidal stream of deployment by 2020 may be possible[35], reflecting the high degree of uncertainty surrounding future deployment rates.

Figure 36: Tidal stream shallow and tidal stream deep high, Base Case and low global deployment stages

Source: Black & Veatch

Global cumulative MW deployed (FCD)	Demonstration	2020	2035	2050
Tidal stream shallow (COD)	2015	2023	2038	2053
High	80	895	6,818	13,025
Base Case	53	597	3,812	7,480
Low	48	471	1,663	3,043
Tidal stream deep	2018	2022	2037	2052
High	27	156	5,406	11,360
Base Case	18	104	2,871	6,913
Low	16	83	1,197	2,491

5.2 Costs: at pre-demonstration, demonstration and commercial stages

Figure 37 and Figure 38 show the total capital expenditure and operating costs for typical pre-demonstration, demonstration and commercial projects. We note that construction

[35] SKM (2008) Quantification of Constraints on the Growth of UK Renewable Generating Capacity

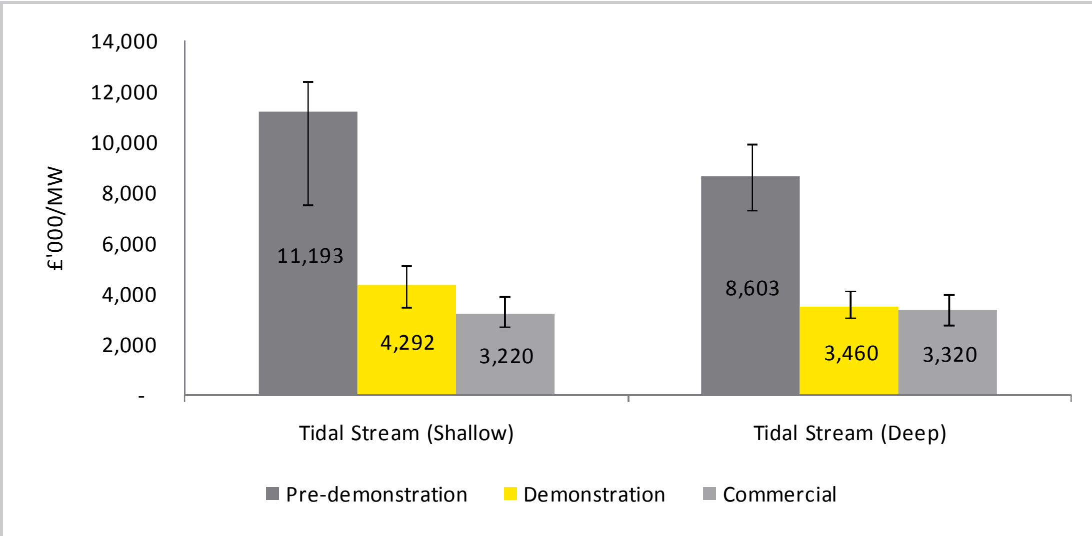
costs and O&M make-up over 80% and 50% of total capital expenditure and annual operating costs respectively.

We note that for the purposes of our analysis, these costs have been applied at an average date that corresponds with when a defined level of global deployment is reached. However, these stages are expected to be reached by individual developers over a range of dates. These average date ranges for operation date are as follows:

- Tidal stream shallow demonstration projects: 2012 FCD, 2015 COD
- Tidal stream shallow commercial projects: 2014 FCD, 2017 COD
- Tidal stream deep demonstration projects: 2016 FCD, 2018 COD
- Tidal stream deep offshore commercial projects: 2018 FCD, 2020 COD

Figure 37: Tidal stream shallow and deep capex

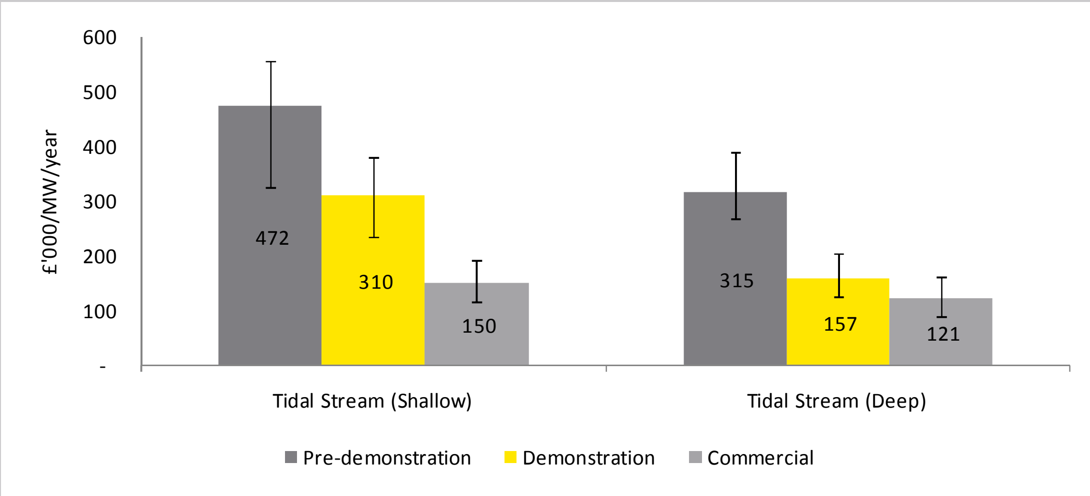
Source: Black & Veatch



While the costs for tidal stream deep are less than for tidal stream shallow, we note that, tidal stream shallow is considered to develop earlier than tidal stream deep. Therefore the learning curve ensures that tidal stream deep costs are lower in the longer term as tidal stream deep is assumed to learn from tidal stream shallow, resulting in lower costs at the milestones shown above

Figure 38: Tidal stream shallow and deep opex

Source: Black & Veatch



Learning rates have been applied to these Base Case costs in a logarithmic correlation to the global deployment forecasts. For further details on learning rates, please refer to Appendix D. We note that these Base Case costs should be considered within the context of the appropriate capacity factor and relevant deployment forecasts.

5.3 Levelised costs[36]

As set out in **Figure 39** and Figure 40, though the levelised costs of tidal stream shallow and tidal stream deep are high today, it is assumed that they will fall by a net amount of 70% and 55% respectively by 2035 due to:

1. Expected learning rates in the sector as provided by Black & Veatch (as set out in Appendix D). Average learning rates that have been applied to costs, in logarithmic correlation to the commercial global deployment forecasts, is 13.0% and 12.5% from first commercial deployment for tidal stream deep and shallow respectively. The underlying learning rate assumptions for capex components correspond to an overall learning rate for capex of around 17.1% (shallow) and 13.2% (deep).

2. A declining rate of increase in underlying costs (eg metal and electrical manufacturing and labour). For example, metal and electrical manufacturing costs are driven by the All Carbon Steel Products Composite Price & Index which grows on average by 6.9% per annum from 2010 to 2020. Between 2020 and 2050, the same index grows on average by 0.7% per annum.

Learning rates are assumed to be constant relative to doublings in deployment through time. In reality they are likely to be bumpy, and may slow down or fall to zero as the technology reaches technological and market maturity.

Due to tidal stream technologies being deployed at the most commercial sites first, the levelised costs are lower than for wave technologies although costs level out by 2035.

Tidal stream shallow projects are assumed to be deployed before tidal stream deep, however in the long run (ie, 2050), due to greater deployment potential, tidal stream deep's levelised costs (£102/MWh) are assumed to be below tidal stream shallow (£138/MWh).

[36] A minor change in resource assumptions as at the 2035 and 2050 valuation dates has resulted in a small difference between levelised costs from initial analysis quoted in the 'Marine Energy Action Plan' and the final results quoted in this report.

Figure 39: Tidal stream shallow levelised costs (with post-tax target IRRs as at Valuation Dates), £/MWh
Source: Ernst & Young analysis, Black & Veatch

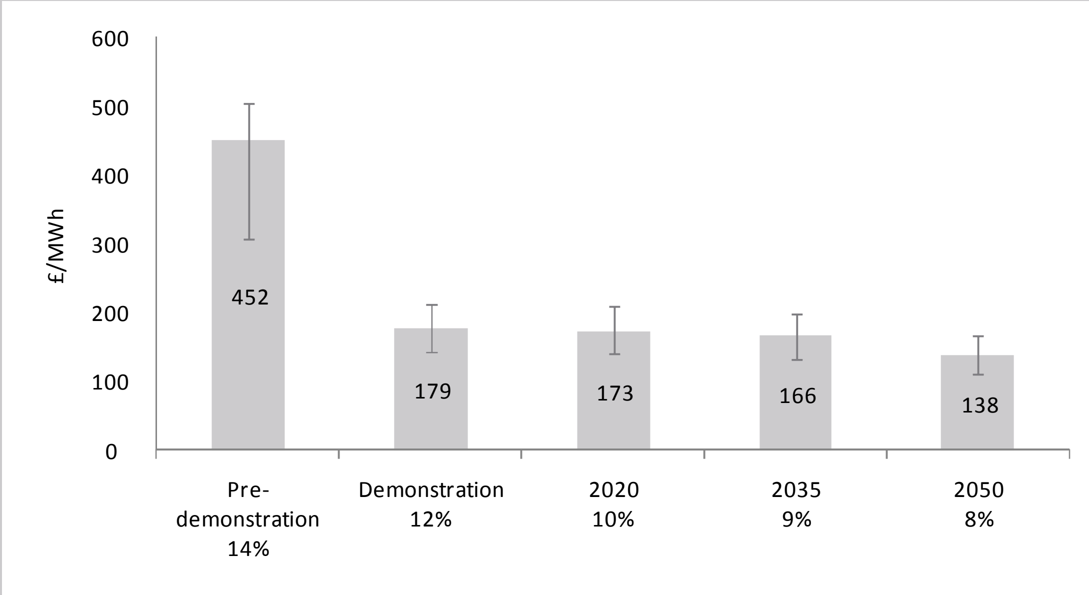
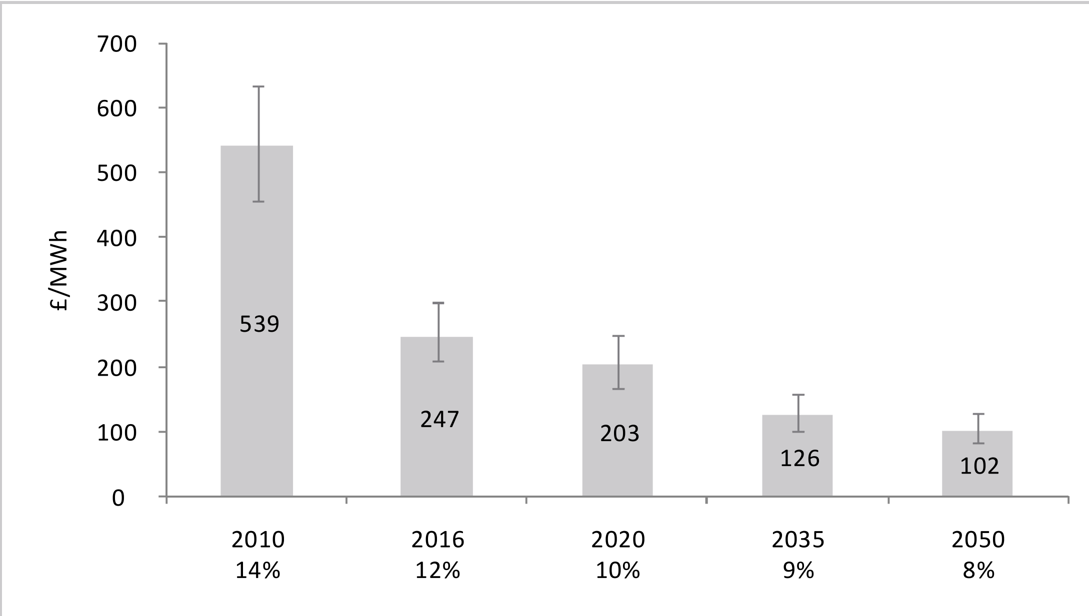


Figure 40: Tidal stream deep levelised costs (with post-tax target IRRs as at Valuation Dates), £/MWh
Source: Ernst & Young analysis, Black & Veatch



As shown above with the error bars and as set out below, we have observed the effect of cost uncertainty and have calculated the impact of high and low capital expenditure and operating costs on levelised costs for tidal stream technologies as at 2020, 2035 and 2050.

Figure 41: Tidal stream shallow levelised costs (with high and low capex / opex), £/MWh

Source: Ernst & Young analysis, Black & Veatch

	2020	2035	2050
High	211 (+22%)	199 (+20%)	166 (+20%)
Low	141 (-18%)	134 (-19%)	111 (-20%)

Figure 42: Tidal stream deep levelised costs (with high and low capex / opex), £/MWh

Source: Ernst & Young analysis, Black & Veatch

	2020	2035	2050
High	250 (+23%)	159 (+26%)	129 (+27%)
Low	166 (-18%)	102 (-19%)	82 (-20%)

These levelised cost ranges do not represent the full range of uncertainty pertaining to levelised costs, but just that resulting from initial high/low capex and opex estimates. There is also uncertainty relating to deployment trajectories and learning rates which have significant impact on levelised costs.

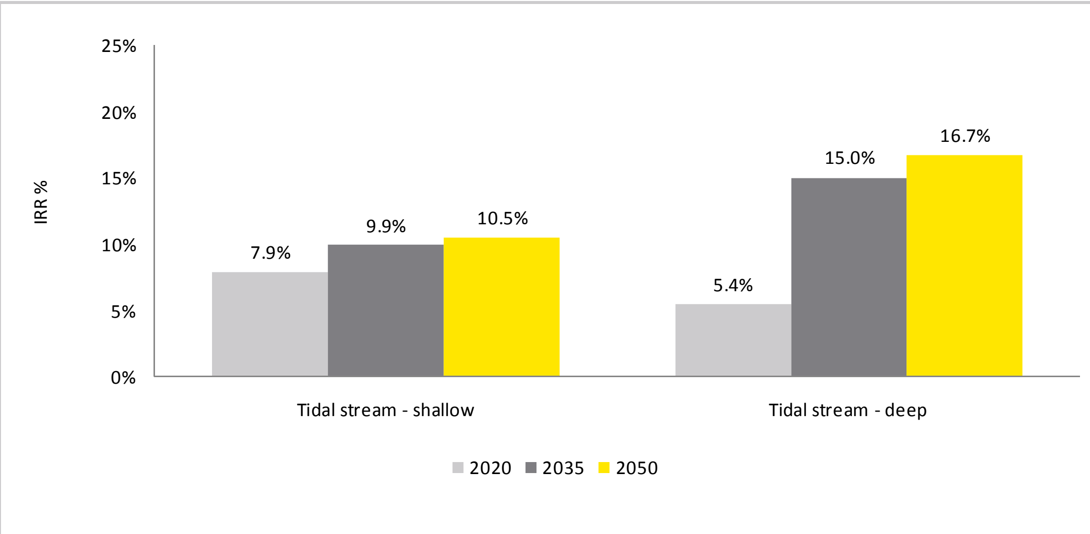
5.4 Base Case IRRs

Figure 43 shows the IRRs for a typical project under all the Base Case assumptions, including current subsidy levels of 2 ROCs/MWh and 1 LEC/MWh. At 2020 under the Base Case assumptions, tidal stream deep and shallow technologies earn an IRR of 7.9% and 5.4% respectively. It is unlikely that deployment would proceed at the Base Case level if commercial project returns proved to be as low as 5%. The Base Case IRR exceeds the target IRR as at 2035 and 2050 due to the reduction in the levelised costs as a result of industry learning. Marine support levels would be expected to fall over time, taking advantage of this learning. This would avoid over-compensation of marine projects and imposing excessive costs on electricity consumers.

These Base Case IRRs are central estimates and do not take into account the significant uncertainty surrounding both costs and wholesale electricity revenues.

Figure 43: Tidal stream deep Base Case IRR to 2050 on the basis of current levels of support

Source: Ernst & Young analysis



5.5 Adjustment of financial support mechanisms

5.5.1 ROCs or FiTs required to earn target IRRs

Figure 44 and Figure 45 present the number of required ROCs/MWh for tidal stream developers to earn target IRRs. Due to levelised cost movements as discussed above, the required ROCs/MWh for tidal stream deep projects are greater than those for tidal stream shallow in the short term. However in the long term (by 2035), tidal stream shallow requires more support.

Figure 44: Tidal stream shallow ROCs/MWh required to meet target IRRs as at Valuation Dates

Source: Ernst & Young analysis

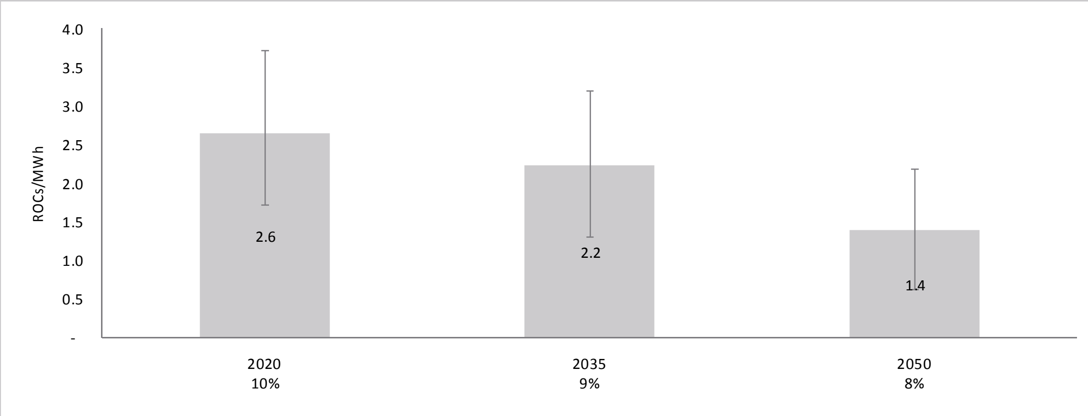
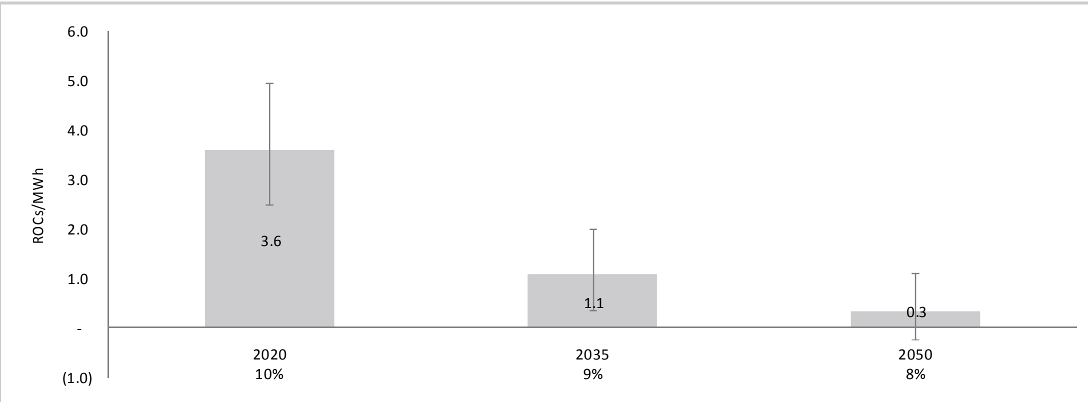


Figure 45: Tidal stream deep ROCs/MWh required to meet target IRRs as at Valuation Dates

Source: Ernst & Young analysis



As shown above with the error bars and as set out below, we have observed the effect of cost uncertainty and have calculated the impact of high and low capital expenditure and operating costs on ROCs/MWh required for tidal stream technologies as at 2020, 2035 and 2050.

Figure 46: Tidal stream shallow ROCs/MWh required to meet target IRRs as at Valuation Dates (with high and low capex / opex)

Source: Ernst & Young analysis, Black & Veatch

	2020	2035	2050
High	3.7 (+41%)	3.2 (+43%)	2.2 (+58%)
Low	1.7 (-35%)	1.3 (-41%)	0.6 (-55%)

Figure 47: Tidal stream deep ROCs/MWh required to meet target IRRs as at Valuation Dates (with high and low capex / opex)

Source: Ernst & Young analysis, Black & Veatch

	2020	2035	2050
High	4.9 (+38%)	2.0 (+86%)	1.1 (+225%)
Low	2.5 (-30%)	0.4 (-65%)	neg (-168%)

These ROC ranges do not represent the full range of uncertainty pertaining to ROCs required to meet target IRRs, but just that resulting from initial high/low capex and opex estimates. There is also uncertainty relating to deployment trajectories and learning rates which have significant impact on required ROCs/MWh.

The Base Case deployment scenario includes repowering of projects which are expected from 2035.

Referring to Figure 44 and Figure 45, tidal stream deep ROCs/MWh required in 2035 (1.1) fall below that of tidal stream shallow (2.2) which is consistent with the expected decline in levelised costs in 2035 (where tidal stream deep has the lowest levelised costs of all wave and tidal technologies at £126/MWh).

Prior to 2035, the expected global deployment of tidal stream deep is much lower than that of tidal stream shallow. For example, in 2020, it is assumed that only 32 MW will be deployed globally for tidal stream deep compared to 203 MW for tidal stream shallow. However, after 2035, due to the assumed increase in global deployment and corresponding impact on underlying costs, tidal stream deep requires relatively less ROCs than tidal stream shallow to generate the target IRRs.

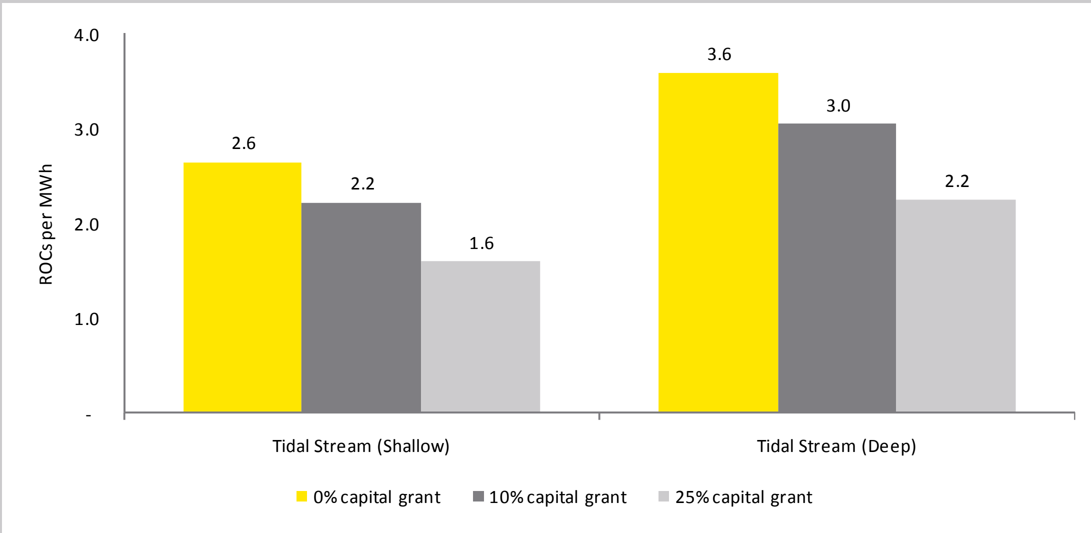
The ROCs/MWh required shown in Figure 46 and Figure 47 (as set out above) equates to a FiT of £127/MWh and £118/MWh for tidal stream shallow as at 2020 and 2035 respectively; £159/MWh and £77/MWh for tidal stream deep at 2020 and 2035 respectively (see Appendix G for more details).

5.5.2 2020: Capital grants and enhanced capital allowances

See Section 3.5.2 for an overview of the capital grant and enhanced capital allowances support mechanisms. Figure 48 below shows that without such capital grants, tidal stream shallow projects require 2.6 ROCs/MWh and tidal stream deep projects require 3.6 ROCs/MWh to earn a target IRR of 10% in 2020. With a 10% or 25% capital grant, this ROC requirement declines. A 25% grant under base case capex for 2020 financial close would cost approximately £0.7m per MW for or £0.9m per MW for tidal stream deep.

Figure 48: Required ROCs/MWh with capital grant sensitivity as at 2020 with 10% discount rate

Source: Ernst & Young analysis



As set out in Appendix G, assuming the capital expenditure for both tidal stream technologies qualifies for enhanced capital allowances, the impact is almost immaterial as it is a timing benefit rather than a financial benefit. We note that we have not considered the possible impact of group or other relief in regards to capital allowances and our analysis assumes the project is a standalone entity for taxation purposes.

Appendix A Sources

BERR ETSU Statistic, as reported in: www.bwea.com/marine/resource.html

BWEA/npower juice: Path to Power (2006)

BWEA/Redpoint: The Benefits of marine technologies within a diversified renewables mix (2009)

Cost indices sourced from Office for National Statistics, Bloomberg and Eurostat

Carbon Trust: Future Marine Energy Results of the Marine Energy Challenge: Cost competitiveness and growth of wave and tidal stream energy (2006); Focus for Success: A new approach to commercialising low carbon technologies (2009)

Developer information as provided by Black & Veatch

Douglas Westwood: Supply Chain Constraints on the Development of Renewable Electricity Technologies (2008)

Electric Power Research Institute Inc. (EPRI): EPRI Ocean Energy Program;

Electric Power Research Institute Inc. (EPRI): System Level Design, Performance and Costs – Oregon State Offshore Wave Power Plant

Electric Power Research Institute Inc. (EPRI): System Level Design, Performance and Costs for San Francisco California Pelamis Offshore Wave Power Plant

Electric Power Research Institute Inc. (EPRI): System Level Design, Performance and Costs – San Francisco California Energetech Offshore Wave Power Plant

Ernst & Young: Impact of Banding the Renewables Obligation – Costs of electricity production (2007)

Pöyry: Compliance Costs for meeting the 2020 EU Renewables Target (2008)

Redpoint/Trilemma: Implementation of the EU 2020 renewables target in the UK electricity sector: RO reform (2009)

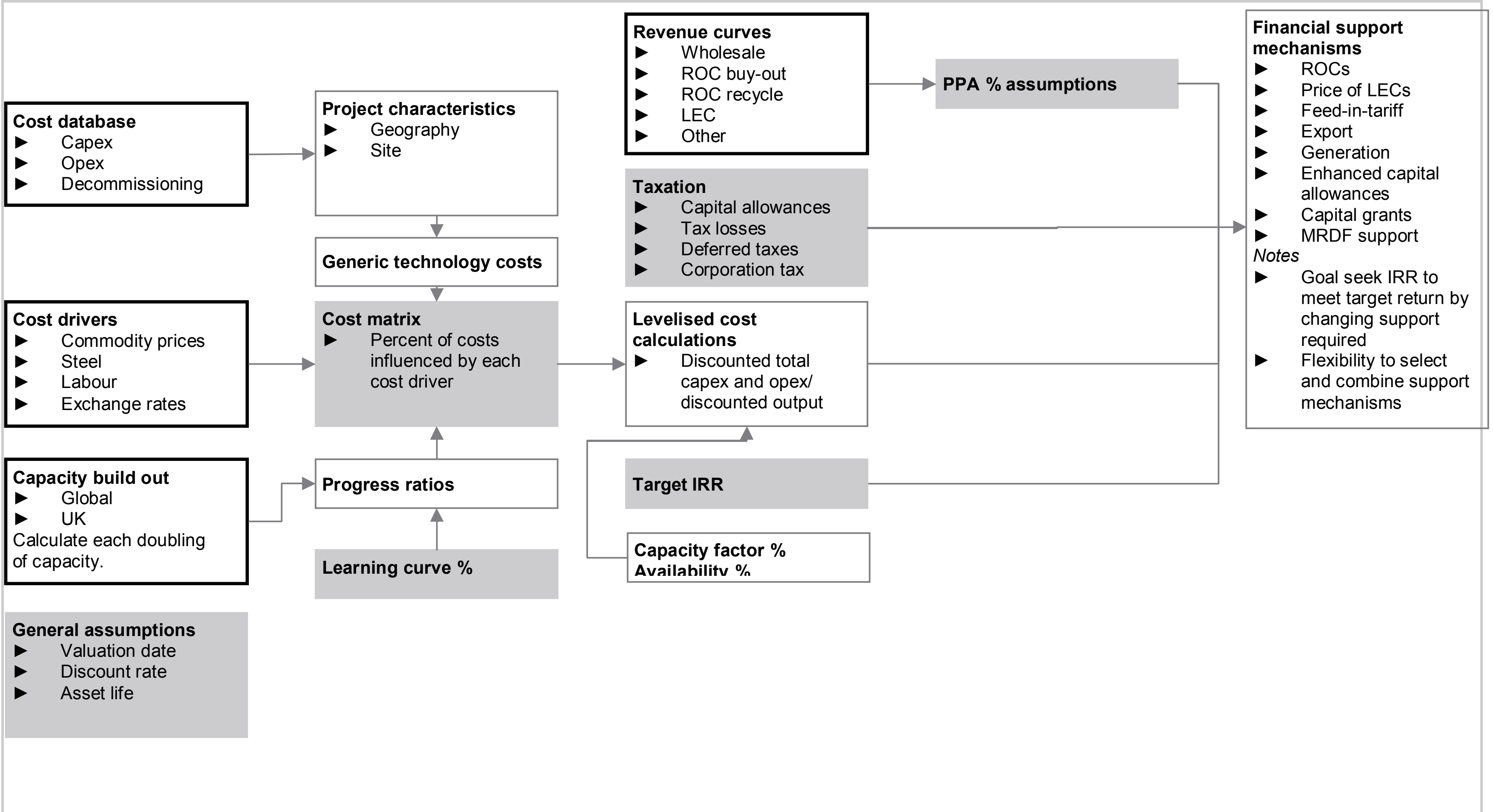
SKM: Growth Scenarios for UK Renewables Generation and Implications for Future Developments and Operation of Electricity Networks (2008); Quantification of Constraints on the Growth of UK Renewable Generating Capacity (2008)

Sustainable Development Commission: Tidal Power in the UK (2007)

Appendix B Modelling methodology

Figure 49: Modelling methodology

Source: Ernst & Young, Black & Veatch



Appendix C Data requested from developers

The following is a template for categories of costs that were requested from developers.

The assumptions can be grouped into five broad areas:

- Pre-development costs:
  - Pre-licensing - cost and time period.
  - Public enquiry and planning - cost and time period.
  - Technical development (including design selection).
  - Distribution of the costs over the pre-development period.

- Construction costs:
  - Overnight Capital cost - £/kW installed.
  - Construction period.
  - Owner's cost.
  - Waste disposal costs.
  - Interest during Construction (IDC) cost.
  - Distribution of the costs over the construction period.
  - Infrastructure costs, for example grid reinforcement and connection, compliance with environmental regulations.

- Operational costs:
  - Total operation and maintenance (O&M) cost - £/kW.
  - Fixed O&M cost (split down into major categories) - £/kW.
  - Variable O&M cost - £/kWh.
  - Grid use of service costs.
  - Short-run marginal cost - £/MWh
  - Decommissioning fund cost - £/kW.

- Technical assumptions:
  - Plant capacity.
  - Plant availability. Load factors should be differentiated between steady state and load factors before fully operational.
  - Technical life.
  - Decommissioning fund cost and timing - £/kW.
  - Learning effects resulting in cost reduction to 2035.
  - Optimism bias.

- Financial assumptions:
  - Commercial life of plant

Appendix D Base Case assumptions

Unless specifically highlighted in the main body of this Report, the Base Case scenarios were calculated using the following assumptions:

Figure 50: Base Case assumptions

Black & Veatch

Base Case assumption	Value
Valuation dates	As specified in Report
Post tax real discount rates (under RO; FiT)	2010 (14%, 13%), 2014 (12%, 11%), 2020 (10%, 9%), 2035 (9%, 8%), 2050 (8%, 7%)
Project life	Wave and Tidal stream: 20 years; Tidal range: 40 years financial life and 120 years design life
Construction periods	Wave and tidal stream deep: two years; Tidal range: five years; Tidal stream shallow: three years
Brown power	Low, medium and high scenarios as provided by DECC
ROC (buy-out plus recycle)	Two ROCs/MWh under all Base Case scenarios. Forward curve as provided by DECC.
LEC	One LEC under all Base Case scenarios. Forward curve as provided by DECC.
Generator share of revenues under PPA:	
► Wholesale power	► 90%
► ROC Buy-out	► 92.5%
► ROC Recycle	► 92.5%
► LEC	► 92.5%
MW capacity deployment	
► UK 2020	Wave – 156MW, Tidal range- 850MW, Tidal stream shallow – 203MW, Tidal stream deep - 27MW
► UK 2035	Wave –3,917MW, Tidal range- 950MW, Tidal stream shallow –1,236MW, Tidal stream deep – 1,104MW
► UK 2050	Wave – 23.9GW, Tidal range- 950MW, Tidal stream shallow – 1,980MW, Tidal stream deep – 1,413MW
► Global 2020	Wave – 742MW, Tidal range- n/a, Tidal stream shallow – 597 MW, Tidal stream deep - 104MW
► Global 2035	Wave – 16,5GW, Tidal range- n/a, Tidal stream shallow – 3,812 MW, Tidal stream deep - 2,871MW
► Global 2050	Wave –70.6GW, Tidal range- n/a, Tidal stream shallow – 7,480MW, Tidal stream deep – 6,913MW
Load factor	Wave - 35%; Tidal range 20%; Tidal stream shallow - 35%; Tidal stream deep 37% (refer to Figure 54 and discussion below)
OFTO/National Grid cost of capital	10%
Capital costs of offshore transmission and substations	£17,500 per MW/km
Distance from shore	Wave 3km-7km Tidal stream shallow: 4km; Tidal stream deep: 7km
Onshore annual TNUoS	£7,500 per annum
Corporation tax rate	28%
Capital allowances (wave and tidal stream)	► 96% of fixed assets @ 20% reducing balance ► 4% of fixed assets do not qualify for capital allowances
Capital allowances (tidal range)	► 96% of fixed assets @ 10% reducing balance ► 4% of fixed assets do not qualify for capital allowances

Figure 51: Base Case resource type allocation

Black & Veatch

Valuation date	Pre commercial			Demonstration			2020			2035 and 2050		
Available resource type	High	Med	Low	High	Med	Low	High	Med	Low	High	Med	Low
Wave	39%	23%	38%	39%	23%	38%	39%	23%	38%	39%	23%	38%
Tidal Range[37]	0%	50%	50%	0%	50%	50%	0%	50%	50%	0%	50%	50%
Tidal stream shallow	100%	0%	0%	100%	0%	0%	0%	100%	0%	5%	20%	75%
Tidal stream deep	100%	0%	0%	100%	0%	0%	0%	100%	0%	5%	20%	75%

The Base Case is a weighted average of the medium costs of each resource type (high, medium and low) according to the percentage above, provided by Black & Veatch.

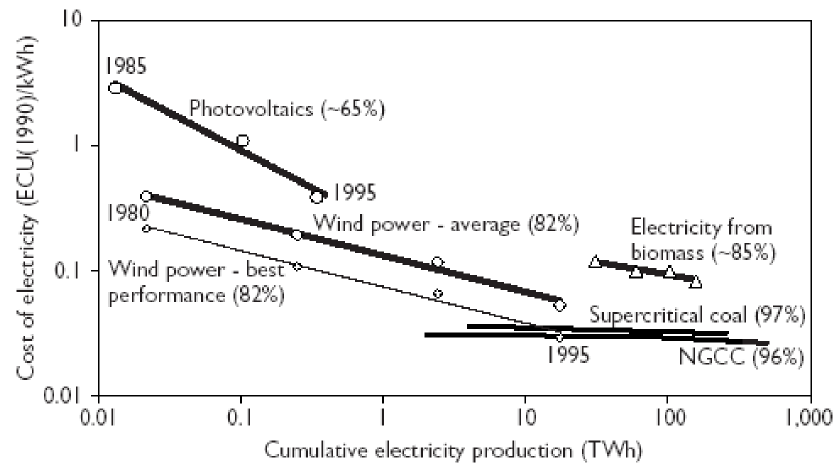
Learning rates

The learning rates assumed in our analysis have been derived by Black & Veatch on the basis of learning experience from other similar developing industries, in conjunction with observations and comparisons of the wave and tidal stream industries with other renewable energy technologies as described below.

In order to form a judgement as to the likely learning rates that can reasonably be assumed for wave and tidal stream technologies, it is appropriate to first consider empirical learning rates from other emerging renewable energy industries. Figure 52 shows observed learning rate data for a range of emerging renewable energy technologies.

Figure 52: Learning in renewable energy technologies

Source: International Energy Agency



Price and cumulative capacity are observed to exhibit a straight line when plotted on a log-log diagram and mathematically this straight line indicates that an increase by a fixed percentage of cumulative installed capacity gives a consistent percentage reduction in price. For example the progress ratio for photovoltaics over the period 1985 to 1995 was ~65% (learning rate ~35%) and that for wind power between 1980 and 1995 was 82% (learning rate 18%).

[37] We note that the Severn Barrage was omitted from this study.

The likely learning rates that may be experienced in the wave and tidal stream energy industry will be subjective. The closest analogy for the wave and tidal stream industry has been assumed to be the wind industry. However, the progress ratio for the wave industry is expected to be higher than observed in wind energy (82%) for the following reasons:

- In wind, much of the learning was a result of doing "the same thing bigger" or "upsizing" rather than "doing the same or something new". This has probably been the single most important contributor to the progress ratio for wind, contributing c. 7% to the 18% learning rate[38]. Most wave energy devices (particularly resonant devices) do not work in this way. A certain size of device is required for a particular location in order to minimise the energy cost and simply making larger devices does not reduce energy costs in the same way. Nevertheless, wave devices can benefit from economies of scale achieved by building farms with more devices, as well as the actual energy capture becoming closer to that theoretically achievable (the gap between theory and practice for many wave technologies is significantly larger than for early wind turbines).

- With wind energy, the agreed technical solution has consolidated (3-bladed horizontal-axis turbine). However, for the wave industry there is a plethora of different options for devices and little indication at this stage as to which is the best solution. This indicates that learning rate reductions will take longer to realise when measured against the cumulative industry capacity. Tidal stream devices appear to be converging on a horizontal axis turbine, however a number of alternative concepts are still being developed.

- Much of the learning in wind power occurred at small scale with small scale units (<100kW), often by individuals with very low budgets. Wave and tidal stream on the other hand requires large investments to deploy prototypes and therefore requires a smaller number of more risky steps to develop. This tends to suggest that the learning will be slower (and the progress ratio higher).

The learning rates for the wave and tidal (shallow and deep) have been developed by Black & Veatch as per the observations above. Tidal range is considered a commercial technology and therefore does not have an associated learning rate. The average learning rates are illustrated in Figure 53.

Figure 53: Average learning rates

Source: Black & Veatch Base Case

Average learning rates for each doubling in global MW capacity	Base Case	Pessimistic	Optimistic
Wave	13.2%	9.9%	16.9%
Tidal Range	0%[39]	0%	0%
Tidal stream shallow	13.0%	9.0%	16.9%
Tidal stream deep	12.5%	9.6%	16.4%

[38] See, for example, http://www.electricitypolicy.org.uk/pubs/wp/eprg0601.pdf, which calculates an 11% learning rate for wind excluding learning due to 'upsizing'.

[39] Assuming limited learning rates compared to tidal stream and wave, though this does not include innovative and hybrid tidal range/stream technologies such as those progressed under the Severn Embryonic Technologies Scheme (SETS)

Load factors

Black & Veatch developed generic site conditions for wave and tidal sites. These site conditions were provided to technology developers, so that they could develop comparable cost and performance inputs for the study. The load factors for the analysis were developed directly from the aggregated load factors provided by the technology developers; therefore the load factors match the aggregated costs. It is important to remember that load factors are technology dependent and must be interpreted in association with the costs and should therefore not be considered either in isolation or as an industry standard.

The tidal range load factors for the base and pessimistic cases were based on the proposed Mersey and Solway projects respectively.

Example load factors indicative of those used in this analysis are illustrated in Figure 54. The analysis is based on a range of leading technologies; each technology has a different optimum capacity factor, therefore the numbers presented are averaged based on the technologies considered, and are not representative of any given technology in any particular site.

Figure 54: Average load factors

Source: Black & Veatch

	Base Case		Optimistic Case		Pessimistic Case	
	Resource	Load Factor	Resource	Load Factor	Resource	Load Factor
Wave	32kW/m	35%	39kW/m	50%	26kW/m	25%
Tidal range	700MW	20%	N/A	N/A	150MW	19%
Tidal stream shallow	3m/s	35%	3.6 m/s	49%	2.4 m/s	24%
Tidal stream deep	3.2 m/s	37%	3,8 m/s	53%	2.8 m/s	27%

Maximum Feasible Resource

Set out in Figure 55 below are the assumptions for the maximum feasible resource estimated for the UK in MWs.

Figure 55: Maximum feasible resource

Source: Black & Veatch

	High	Medium	Low
Wave	41,000	30,000	19,000
Tidal stream shallow	2,750	1,100	550
Tidal stream deep	2,750	1,100	550

Cost indices

The cost indices shown below are applied to the base cost data, in addition to learning rates as described above. Each component of capital or operating expenditure are expected to be exposed to various cost drivers in specified proportions eg, 38% of construction element of capex costs for tidal stream (shallow) are exposed to the movement in the "manufacture of metal structures or part of structures" cost index. A remaining proportion of the costs are assumed to be comprised of fixed prices. The proportions of each cost that is exposed to the drivers were provided by Black & Veatch. Indices used and the calculations performed are all in nominal terms.

Both the cost drivers that have been identified and the specific index used as a proxy of this driver have been given in the titles to each figure below.

Figure 56: Installation vessels - Baltic Dry Index

Source: Bloomberg

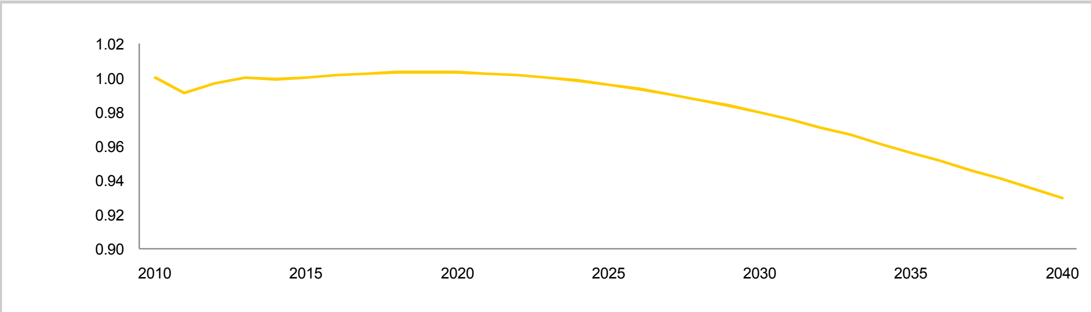


Figure 57: Labour - Average Earnings Index: Electricity, Gas & Water Supply NSA excluding bonus

Source: Bloomberg

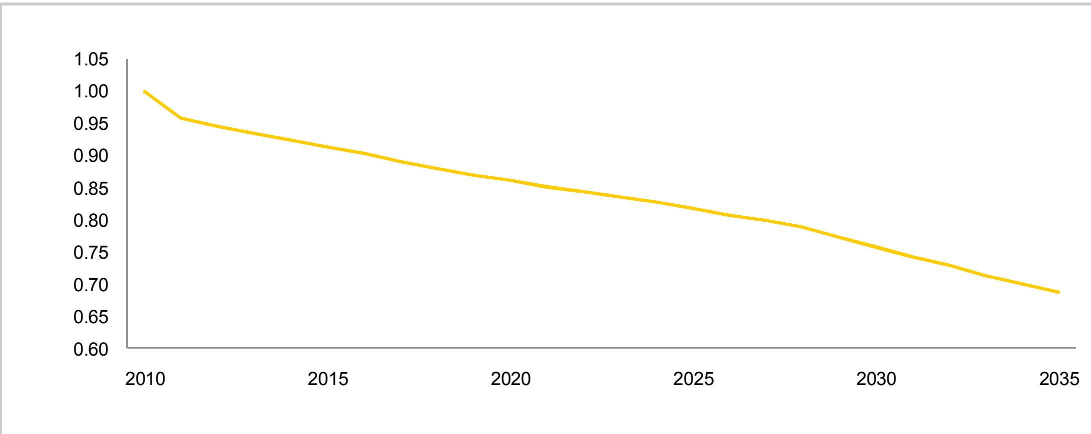


Figure 58: Electric motors, generators and transformers - Industry - Producer price indices, Manufacture of electricity distribution and control apparatus

Source: Bloomberg

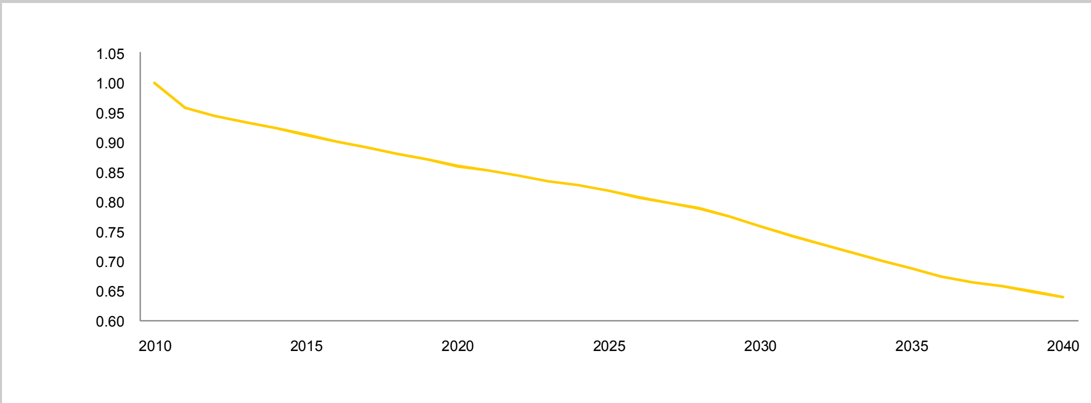


Figure 59: Manufacture of metal structures or part of structures - MEPS: All Carbon Steel Products Composite Price & Index

Source: Bloomberg

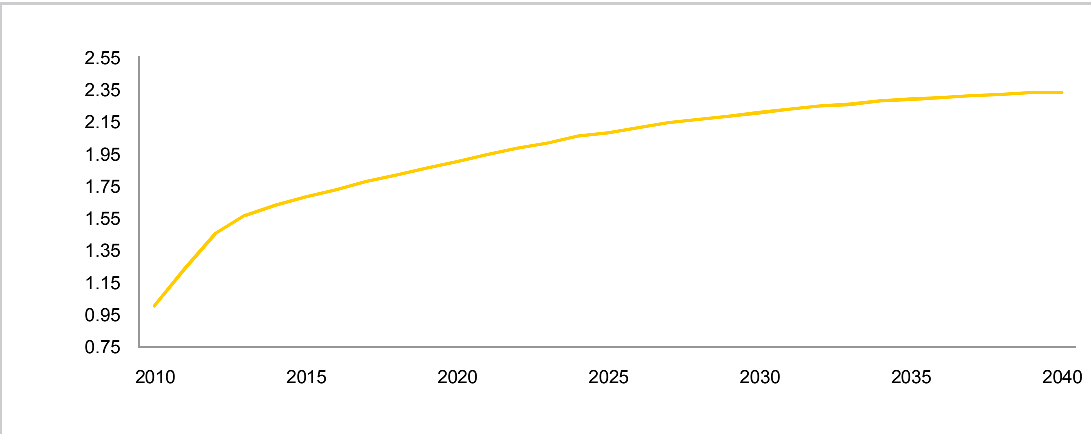


Figure 60: Concrete price index - Industry - Producer price indices, Manufacture of concrete products for construction purposes

Source: Bloomberg

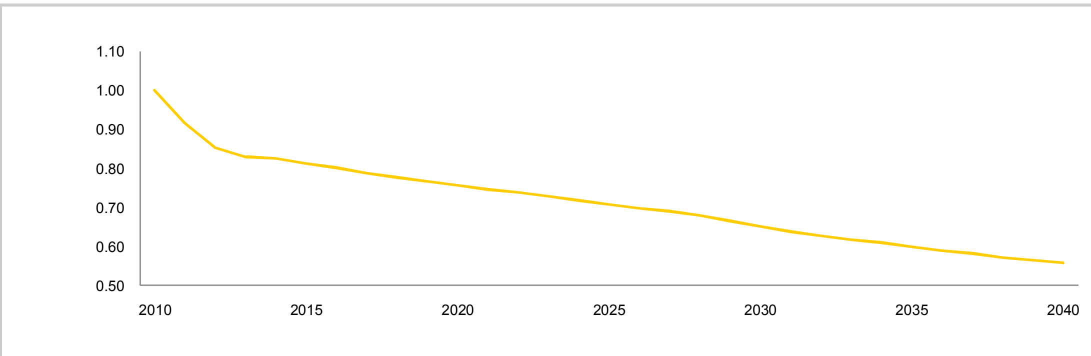


Figure 61: Electricity distribution and control apparatus - Industry - Producer price indices, Manufacture of electricity distribution and control apparatus

Source: Bloomberg

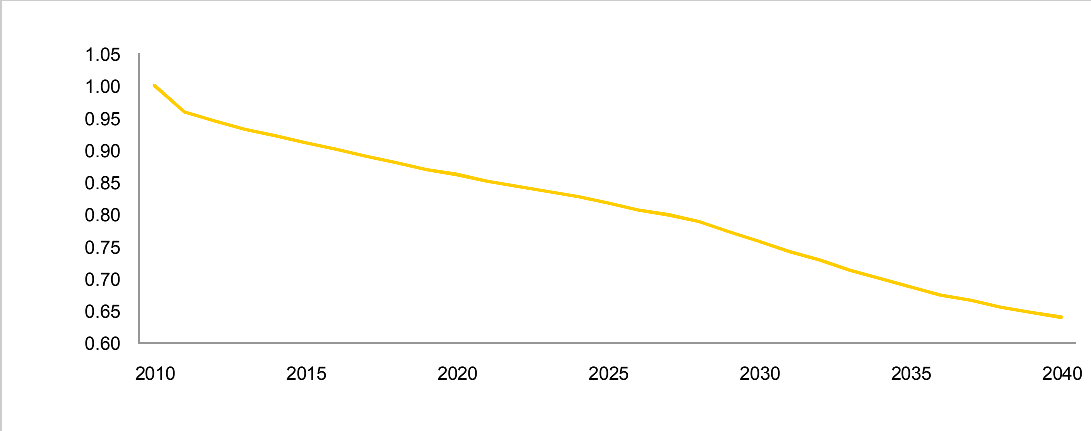
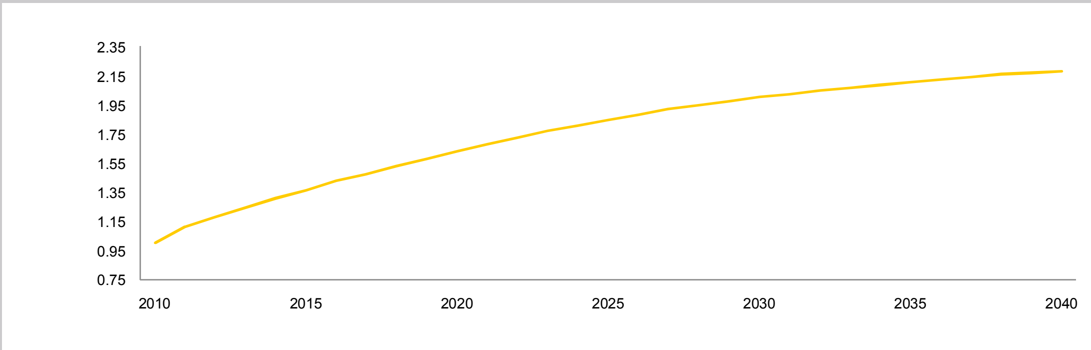


Figure 62: Copper index - S&P GSCI Copper Spot – price index

Source: Bloomberg



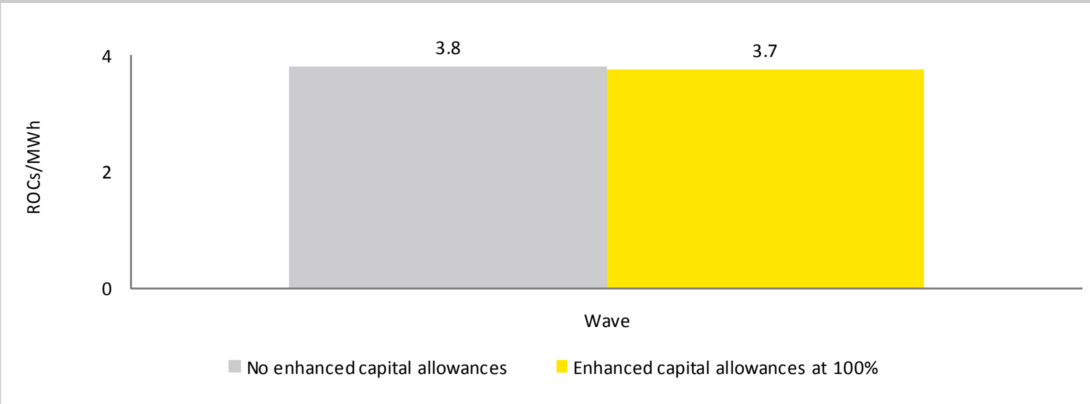
Appendix E Wave sensitivities

Enhanced capital allowances as at 2020

As set out in Figure 63 below, assuming the capital expenditure for both wave technologies qualifies for enhanced capital allowances. We have not assumed any group relief in our analysis. We note that as the capital expenditure is fully tax deductable under the Base Case over a period of five years (20%), the impact is almost immaterial as it is more a timing benefit rather than an absolute financial benefit.

Figure 63: Required ROCs/MWh with enhanced capital allowances sensitivity as at 2020 with 10% discount rate

Source: Ernst & Young analysis

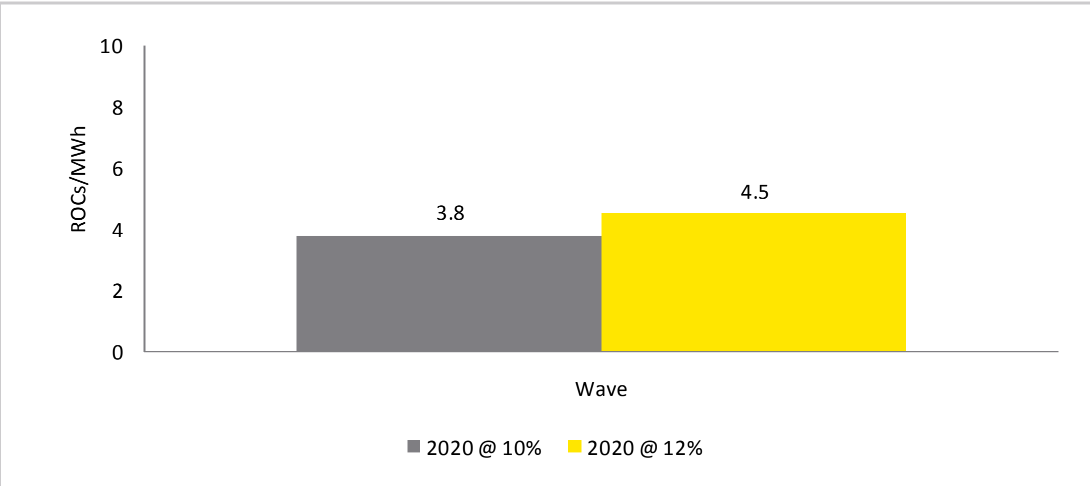


ROCs/MWh required with target IRR sensitivity

As set out below, Figure 64 presents the implied ROCs/MWh required, with a sensitivity on the target IRR as at 2020 (12% vs. a Base Case target IRR of 10%).

Figure 64: Wave ROCs/MWh required with IRR sensitivity as at 2020

Source: Ernst & Young analysis

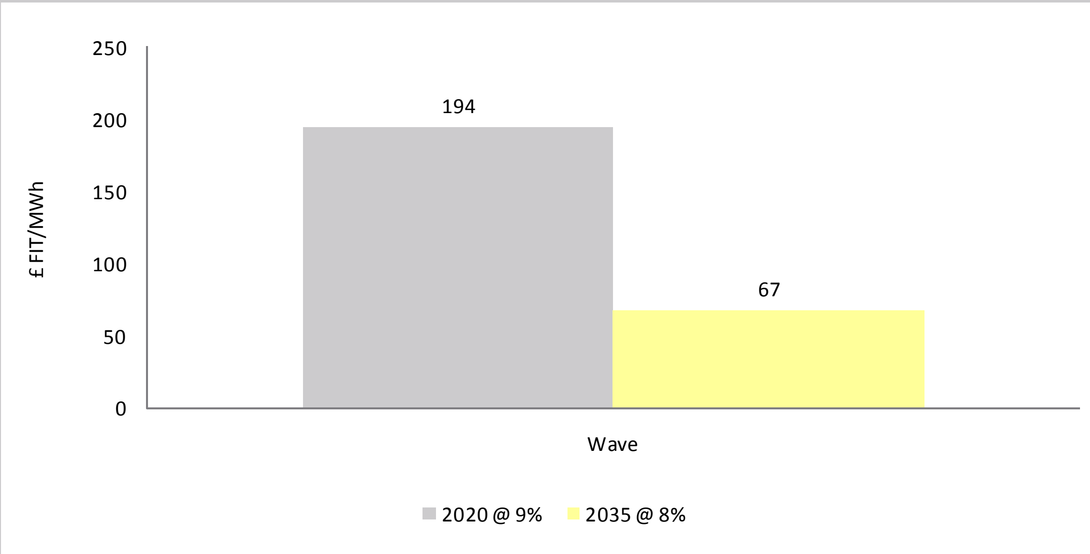


FiTs required to earn target IRRs

Figure 65 presents the expected required FiT for wave technology developers to earn target IRRs as at 2020 and 2035.

Figure 65: Wave FiTs (£/MWh) required to earn target IRRs at 2020 and 2035

Source: Ernst & Young analysis

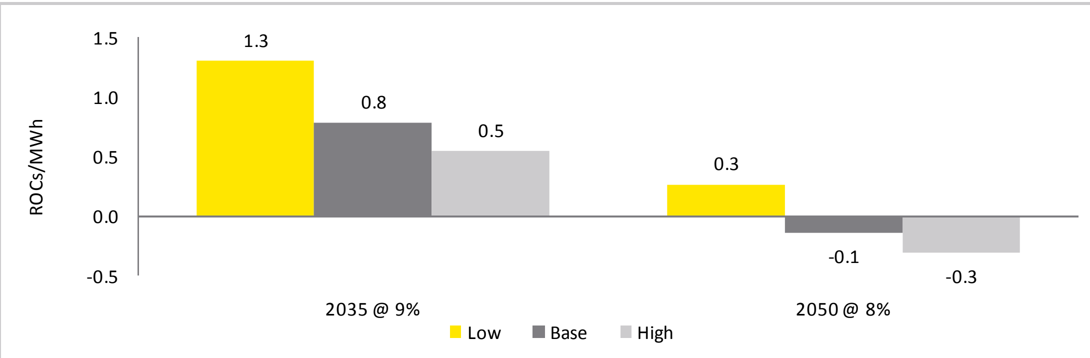


ROCs/MWh required with high/low deployment

Figure 66 below illustrates the number of ROCs/MWh that would be required for wave technologies to reach the target IRR if low or high level deployment assumptions are used. Under higher deployment the cost benefits of learning by the industry are realised more quickly resulting in a reduced level of financial support.

Figure 66: Wave ROCs/MWh required to earn target IRRs at 2035 and 2050 under high, low and Base Case deployment scenarios

Source: Ernst & Young analysis



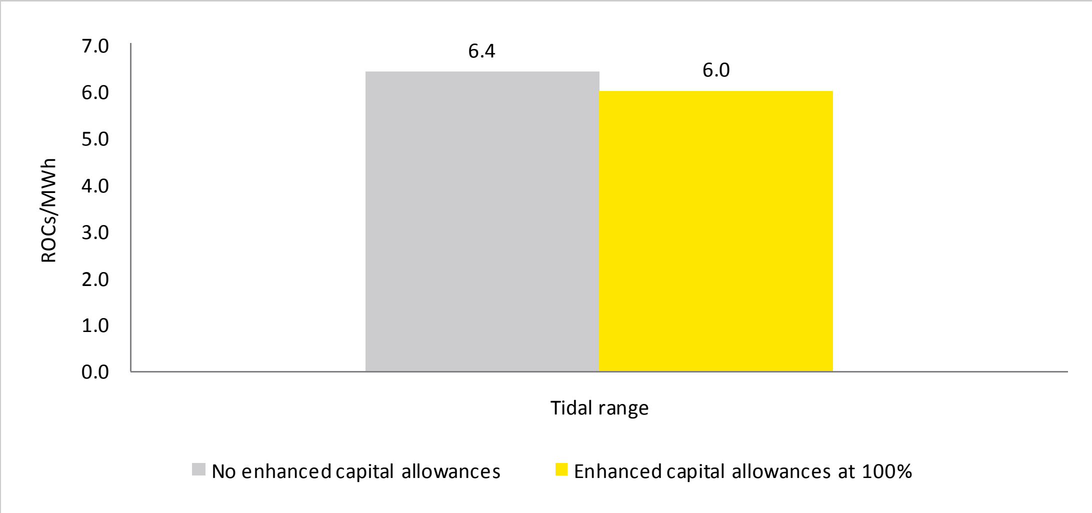
Appendix F Tidal range sensitivities

Enhanced Capital Allowances as at 2020

As set out in Figure 67, assuming the capital expenditure for tidal range qualifies for enhanced capital allowances, the required ROCs/MWh fall by 6.3% to 6.0 in 2020.

Figure 67: Required ROCs/MWh with enhanced capital allowance sensitivity as at 2020

Source: Ernst & Young analysis

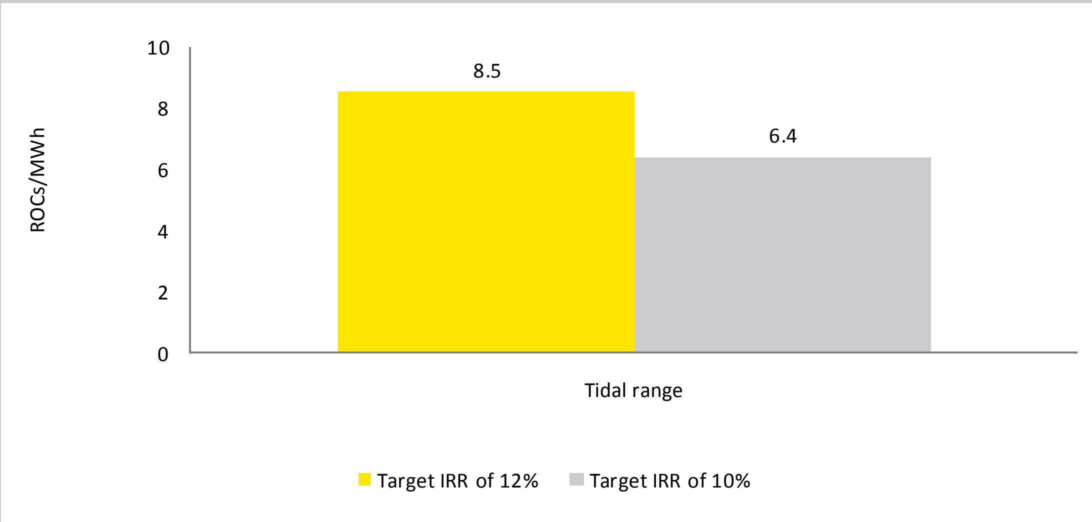


ROCs/MWh required with target IRR sensitivity at 2020

Figure 68 presents the implied ROCs/MWh required, with increasing the target IRR at 2020 (12% vs. a Base Case target IRR of 10%).

Figure 68: Tidal range ROCs/MWh required with IRR sensitivity as at 2020

Source: Ernst & Young analysis

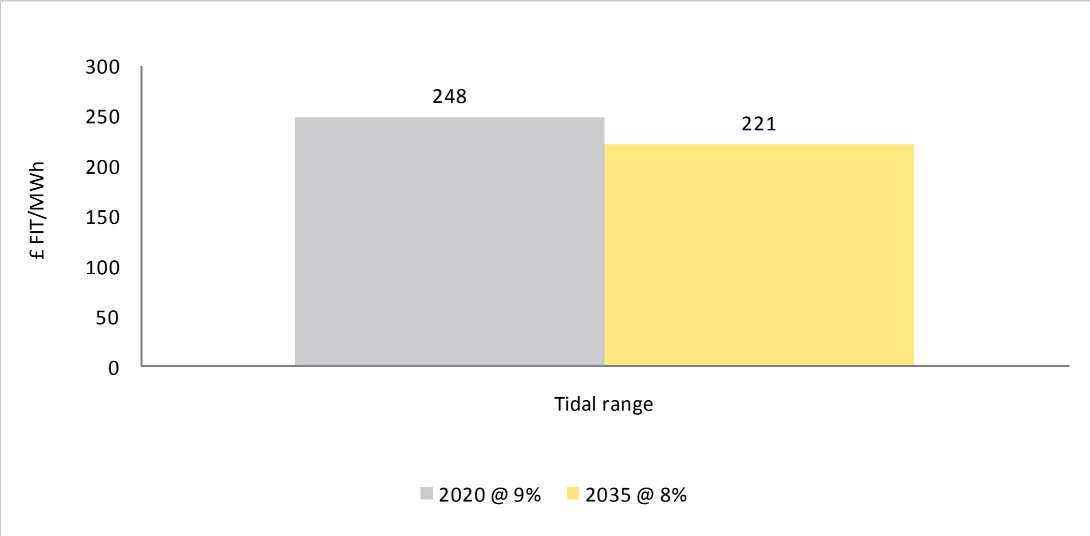


FiTs required to earn target IRRs

Figure 69 presents the expected required FiT for tidal range developers to earn target IRRs as at 2020 and 2035.

Figure 69: Tidal range FiTs (£/MWh) required to earn target IRRs at 2020 and 2035

Source: Ernst & Young analysis



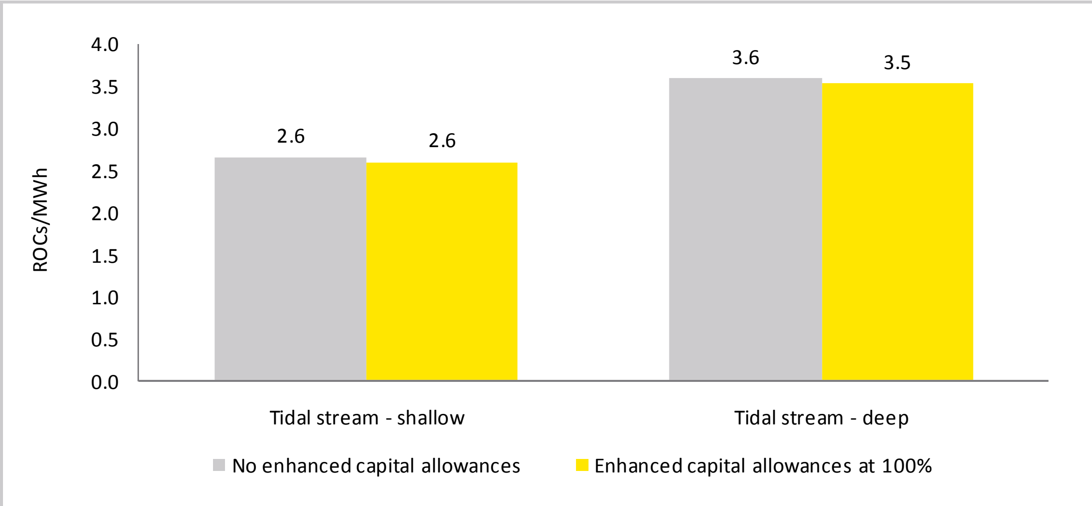
Appendix G Tidal stream sensitivities

Enhanced Capital Allowances as at 2020

Similar to the other wave and tidal range technologies, as set out below, the effect of the enhanced capital allowances have an immaterial impact on the required ROCs/MWh.

Figure 70: Required ROCs/MWh with enhanced capital allowance sensitivity as at 2020

Source: Ernst & Young analysis

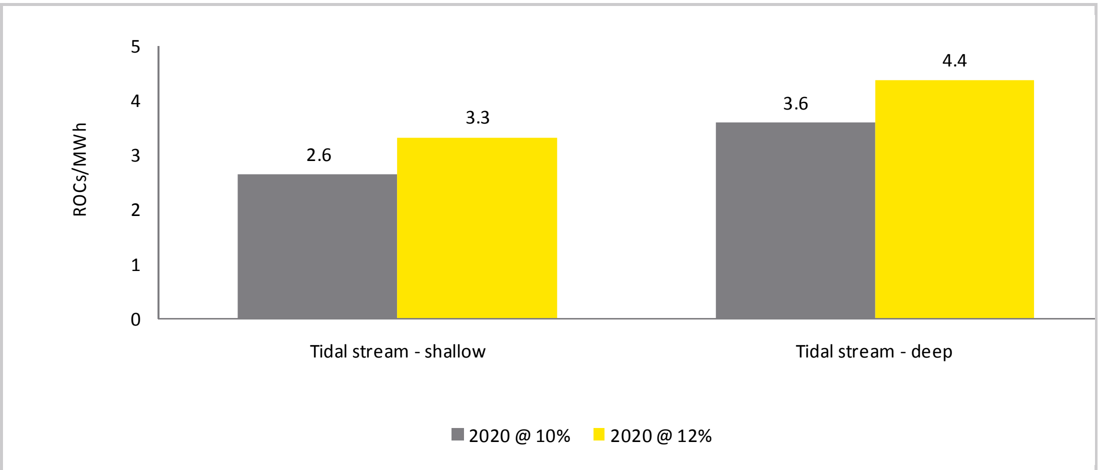


ROCs/MWh required with target IRR sensitivity at 2020

Figure 71 presents the implied ROCs/MWh required, with increasing the target IRR at 2020 (12% vs. a Base Case target IRR of 10%).

Figure 71: Tidal stream shallow and tidal stream deep ROCs/MWh required with IRR sensitivity as at 2020

Source: Ernst & Young analysis



ROCs/MWh required with brown power price sensitivity at 2020

Figure 72: Brown power curves (in real terms)

Source: DECC

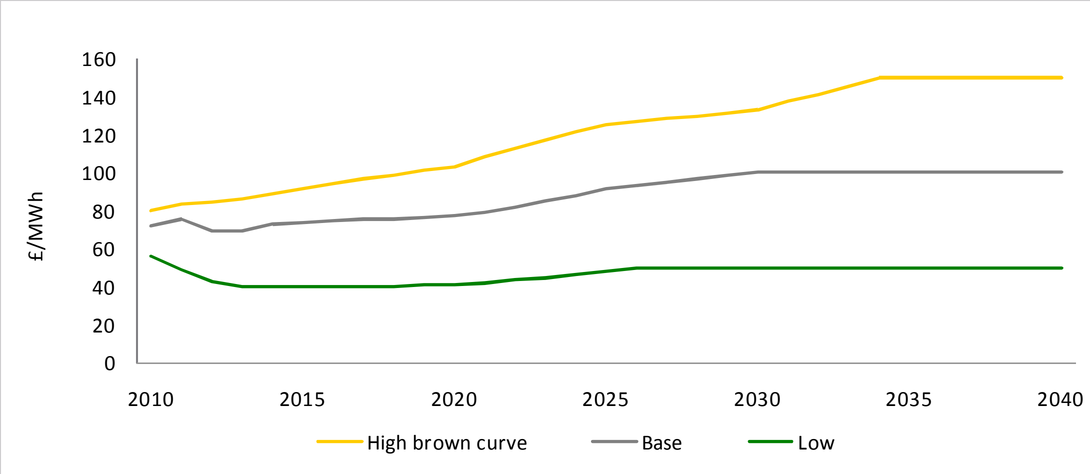
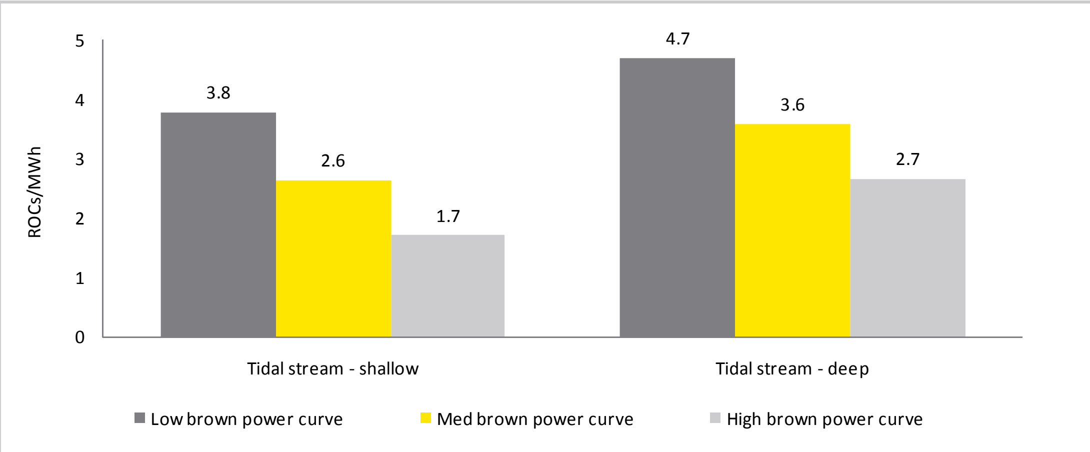


Figure 73 presents the implied ROCs/MWh required to earn the target IRR of 10% at 2020 under varying brown power curves as provided by DECC and set out above.

Figure 73: Required ROCs/MWh with brown price sensitivity as at 2020 with 10% discount rate

Source: Ernst & Young analysis

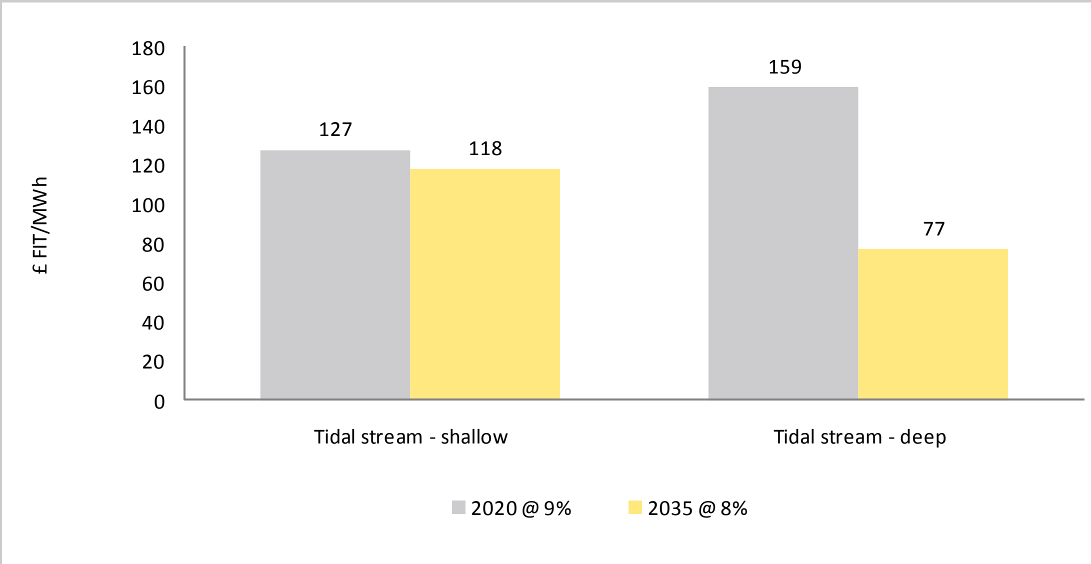


FiTs required to earn target IRRs

Figure 74 presents the expected required FiT for wave technology developers to earn target IRRs as at 2020 and 2035.

Figure 74: Tidal stream shallow and tidal stream deep FiTs (£/MWh) required to earn target IRRs at 2020 and 2035

Source: Ernst & Young analysis



Similarly with the required ROCs/MWh as at 2020 and 2035, the FiT required under tidal stream deep is lower in 2035 than for tidal stream shallow due to the lower long term levelised costs expected for tidal stream deep.

ROCs/MWh required with high/low deployment

Figure 75 presents the required ROCs/MWh for tidal stream deep under low, Base Case and high deployment projections.

Figure 75: Tidal stream deep ROCs/MWh required to earn a target IRRs at 2035 and 2050 under high, low and Base Case deployment scenarios

Source: Ernst & Young analysis