Role and Value of Tidal Stream Generation in the Future UK Energy System

Further Sensitivity Studies

A REPORT FOR OFFSHORE RENEWABLE ENERGY CATAPULT

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Executive Summary

A range of studies has been undertaken to understand how the penetration of Tidal Stream (TS) technologies will benefit the broader energy system, not only the electricity system but also the hydrogen and carbon infrastructure and operation), shape the portfolio of low-carbon energy resources, and understand what is needed to facilitate the cost-effective integration of such technologies and other technologies in the future of UK's 2050 net-zero energy system. The studies aim to provide modelling evidence to inform UK policy regarding the role and value of tidal stream power generation in the future UK low-carbon energy system and assess the cost-efficient deployment of tidal stream technologies across various energy system development scenarios. The key findings of initial studies can be found in the published report "Role and Value of Tidal Stream Generation in the Future UK Energy System"[1].

Since then, several other factors have been identified that may influence the system value of TS. The new set of studies investigates various aspects, such as different assumptions on the levelised cost of variable Renewable Energy Sources (RES) in 2050, the inclusion of extreme weather events in energy system planning, high deployment of nuclear capacity, high cost of nuclear, high gas prices, reduction in the cost of electrolysers and BESS. A spectrum of additional sensitivity analyses has been conducted to analyse how these aspects may affect the future energy system and influence the value of TS.

Key findings

The key findings can be summarised as follows:

- In the future net-zero energy system dominated by low-carbon technologies, extreme weather events, high gas prices, and high-power generation costs are the main drivers for the increased system costs. TS' system benefits are higher in those situations.

- TS' system benefits are robust across all scenarios – in all studies analysed, integrating 11.8 GW (39 TWh) of TS saves the annual system costs by 1.7- 2.6 £bn/year[2]. Therefore, the target cost of TS is between 43.59 and 66.67 £/MWh to be justified. The variation of TS' system benefits across different scenarios is shown in Figure E- 1.

- TS improves energy resilience by diversifying renewable energy sources to cope with extreme weather events. TS' benefits increase when the UK's energy system is designed to cope with a longer duration of low-RES output during winter peak conditions. The highest TS benefit in

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[1] Reference: https://ore.catapult.org.uk/?industryreports=tiger-report-role-and-value-of-tidal-stream-generation-in-the-future-uk-energy-system

[2] All cost figures are based on the 2050 projected costs expressed as undiscounted, real figure in 2020.

these studies is when TS is integrated into a system designed to cope with two weeks of low-RES output during winter peak demand.

- Higher gas prices incentivise diversified renewable sources. High gas prices reduced natural gas usage for heating, power and hydrogen for electricity production. Increasing the installed capacity of offshore or solar PV will further increase their system integration cost. Complementary to those technologies, TS can enhance the diversity of renewable energy resources to be more resilient against uncertainty in gas prices.

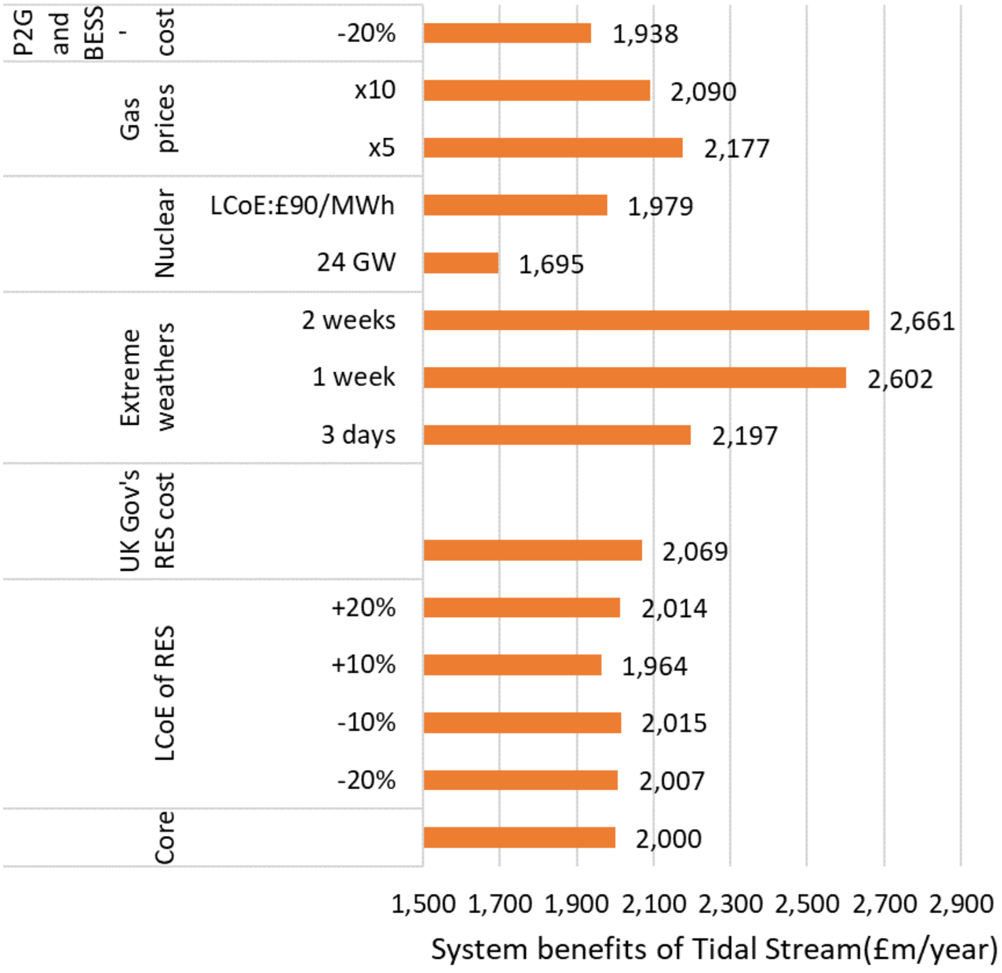

Figure E- 1 Annual system benefits of Tidal Stream under different conditions

- TS benefits are 15% less if the future system has substantial nuclear power (i.e. 24 GW) in its energy mix. Nuclear is a firm, low-carbon power generation technology and dispatchable, although not as flexible as other thermal generators. It reduces system balancing requirements and capacity from other technologies and the need for carbon removal technologies.

The lower cost of electrolysers and BESS reduces TS' value as the electrolysers, and BESS improve system flexibility. The result is aligned with the findings in the Phase 1 report that the value of TS will be lower in a system with higher flexibility.

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Abbreviation

ATR	Auto Thermal Reformer that produces hydrogen from natural gas
BECCS	BioEnergy plants with CCS. BECCS produces hydrogen or power
BESS	Battery Energy Storage System
BF	Bottom-fixed offshore wind
CCGT	Combined Cycle Gas Turbine (natural gas)
CCS	Carbon Capture and Storage. In power generation, it refers to CCGT with CCS
CE	Continental Europe
DACCS	Direct Air Carbon Capture and Storage
DNO	Distribution Network Operators
DR	Demand response
DH	District heating
H2	Hydrogen
HP	Heat Pumps
HHP	Hybrid heating (natural gas boiler + heat pump)
IE	Ireland
IWES	Integrated Whole Energy System model
LCoE	Levelised cost of electricity
NG OCGT	Open Cycle Gas Turbine (natural gas)
ORE	Offshore Renewable Energy
OSW	Offshore Wind farms
PV	Photovoltaic
Reformer	Methane reformer (Auto Thermal) with CCS
RES	Renewable Energy Source
TS	Tidal Stream

Chapter 1. Introduction

1.1 Context

The emergence of new low-carbon technologies, such as Tidal Stream (TS) generation, opens opportunities to harness the full potential of renewable energy resources in UK waters. According to the Offshore Renewable Energy Catapult (ORE Catapult), the UK has potential sites to connect 6 to 17 GW of TS, supplying 21 – 60 TWh/year of electricity, which is about 6% - 17% of the current annual UK electricity demand, i.e. around 350 TWh. TS technologies are important in the future UK energy mix for several reasons:

- These technologies can improve the diversity of low-carbon resources to supply the electricity demand needed by the UK and be exported to neighbouring regions to support decarbonisation and energy security in Europe and gain economic benefits through energy trading. Diversity of energy resources improves energy resilience against disruption in a particular energy source, and it also reduces the volatility of aggregate outputs, system balancing, and operating reserve requirements.
- TS energy is a renewable energy source that is predictable and consistent, unlike wind and solar energy, which vary on more volatile weather conditions.
- TS energy has a very low or zero carbon footprint and does not produce greenhouse gas emissions.
- TS energy is high density, which means it can generate significant energy from a relatively small area, minimising the underwater sea area used for power generation.
- TS systems can be manufactured and deployed using the UK's indigenous supply chain contributing to energy security and levelling up agenda.

Since TS is on the verge of commercialisation, a range of studies have been undertaken to understand how the penetration of such technology will impact the overall energy system and what is needed to facilitate the cost-effective integration of such technologies and other technologies in the future of Great Britain's 2050 net-zero energy system. The key findings of our Phase 1 study[3,4] are:

- TS technologies provide alternative low-carbon energy sources, which can work in synergy with other low-carbon technologies in net-zero emission systems.
- While TS can be operated in synergy with other technologies, it also competes and can displace a mix of generation technologies such as offshore wind, PV, biomass with CCS, gas and hydrogen power generation but not nuclear. The variability of TS means that it could not replace the role of nuclear, which can provide zero-carbon energy with a firm capacity and a

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[3] D.Pudjianto, G.Strbac, "Role and Value of Tidal Stream Generation in the Future UK Energy System," a report prepared for Offshore Renewable Energy Centre Catapult, Dec 2022 <Link>

[4] D. Pudjianto, C. Frost, D. Coles, A. Angeloudis, G. Smart, and G. Strbac, "UK studies on the wider energy system benefits of tidal stream," *Energy Adv.*, 2023, doi: 10.1039/d2ya00251e.

certain extent of grid services and flexibility. TS variability could be firmed with energy storage or greater build-out of tidal range, but this will incur additional costs and energy losses, and therefore, it may not be cost-optimal from the system perspective.

- The gross energy system benefits of TS are around 49 – 55 £/MWh. The results indicate a cost range for TS to compete against other low-carbon technologies. The figures are system-specific and depend on the assumptions of other technologies.
- Most of the benefits are related to savings in energy infrastructure investment costs, indicating the long-term value of TS. The long-term predictability of TS energy with high accuracy also provides certainty on its long-term benefits. This contrasts with renewable technologies such as wind and solar PV, whose annual energy outputs vary substantially.
- While TS affect mostly the electricity system, where most system benefits are derived, the studies also demonstrate and quantify the indirect impact of TS technologies on the hydrogen system, gas usage, and carbon removal and storage requirements. TS reduces residual emissions and volume of sequestered carbon; therefore, offsetting emissions and storing carbon costs become less. The results highlight the sector coupling between electricity and other system components. Therefore, the value of TS (or any new) technologies should be assessed holistically, considering their impact on the whole energy system.

We also identified several conditions that affect the value of TS technologies, those are:

- **Locations** - The gross system benefits of TS are location specific. TS in England and Wales has around 2.5% - 4% higher value than in Scotland. The TS value of Scotland is slightly lower due to transmission investment requirements to transport power from Scotland to England, where the bulk of demand is located.
- **Electrification strategy** - The gross system benefits of TS will also depend on how heat demand will be decarbonized in future. The benefits of TS in the pathways with high electricity demand, such as deep electrification and hybrid heating, are higher than in the hydrogen pathway.
- **Cost of offshore wind** - Lower offshore wind capacity factor intensifies the system benefits of TS and vice versa. The gross system benefits of TS with a 52% offshore wind capacity factor are 40% higher than those in a system with the median wind (60% average). On the other hand, having a 64% offshore wind capacity factor will reduce the system benefits of TS by 20%.
- **System flexibility** - The gross system benefits of TS are the highest when the energy system flexibility is low. The results also suggest that the storage requirements to maximise the value of TS is relatively small from the system perspective.
- **Cost of TS** - If the cost of TS is low, e.g. £40/MWh, the model proposes 20.8 GW installed capacity, demonstrating that it is competitive against offshore wind and other technologies (although the LCOE of offshore wind is £35/MWh[5]) and still brings a net benefit of £0.6bn/year savings in system costs.
- **Interconnection development** - Increasing interconnection capacity will reduce the gross system benefits of TS from £2bn/year to £1.7bn/year as the system flexibility increases.

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[5] The model proposed around 80 GW of offshore wind by 2050.

- **Hydrogen export** - The studies considering the possibility of exporting hydrogen under various prices demonstrate that the hydrogen market may bring uncertainty on the TS deployment as it will also affect the capacity of other renewables
- **Tidal Range** – Energy systems based on controlling impounded water flow through low-level turbines could be matched around the UK with TS systems, collectively offering a more consistent national energy output. This warrants additional new studies.

However, there are many other uncertainties, such as the impact of extreme weather conditions, nuclear deployment and costs, natural gas prices and rapid development of electrolysers and battery technologies which drive down those technologies' costs. The impacts of those were not fully understood.

1.2 Objectives

In this context, further sensitivity studies were conducted with the following objectives:

- To expand the sensitivity studies by including the factors identified after the Phase 1 report[6] was published that may influence the system value of TS
- To evaluate and understand the system implications of having different key assumptions
- To determine the range of TS' system benefits considering various uncertainties.

1.3 Summary of case studies

A range of case studies has been further analysed to meet the objectives and facilitate the investigation of the value of predictable tidal stream technologies, focusing on the 2050 net zero-emission system. In summary, the case studies look into various aspects, such as:

- **Levelised Cost of variable RES in 2050** - The value of TS is influenced by the cost of technologies being displaced, and there is uncertainty in the levelised cost of electricity for different variable Renewable Energy technologies in 2050.
- **Extreme weather event -** It is envisaged that TS technologies may provide greater energy security during extreme weather events, such as low RES output during winter peak demand conditions. Therefore, the value of TS may increase if the system is designed against more stringent weather conditions.
- **Nuclear capacity** - High levels of nuclear deployment driven by Government policy to ensure the reliability of the UK's energy supply may compete with TS, and the impact on its value is unclear.
- **High cost of nuclear** – in contrast to the previous scenario with high nuclear capacity, in this scenario, nuclear plants will have a higher cost. A higher nuclear cost should drive more RES and may affect the value of TS.

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[6] D.Pudjianto, G.Strbac, "Role and Value of Tidal Stream Generation in the Future UK Energy System," a report prepared for Offshore Renewable Energy Centre Catapult, Dec 2022 <Link>

- **Gas prices** – the recent geopolitical events in Ukraine provide evidence that gas prices can be very volatile in future. Considering this aspect may affect how the future energy system will evolve and influence the value of TS.
- **Cost of electrolysers and BESS** – those technologies have received special attention as the technologies are being developed swiftly, and the cost of those technologies is expected to reduce.

Detailed parameters used in the sensitivity analysis will be described in the next chapter.

1.4 Tidal stream scenarios

We use the same TS scenarios ORE Catapult and the University of Plymouth provided to facilitate the sensitivity studies. The TS installed capacity, costs and locations across the UK are shown:

Project name	Country	Array power capacity (MW)
Orkney		
Westray Firth	Scotland	260
North Ronaldsay Firth	Scotland	70
Pentland Firth		
Pentland Firth Shallow	Scotland	352
Pentland Firth Deep	Scotland	4700
Northern Ireland		
Strangford Lough	Northern Ireland	40
East Raithlin Sound	Northern Ireland	35
Raithlin Island	Northern Ireland	62
West Coast		
West Islay + Islay	Scotland	690
Kyle Rhea	Scotland	20
Mull of Kintyre	Scotland	120
Mull of Galloway	Scotland	100
Wales		
Holyhead (Morlais)	Wales	560
Ramsey Island	Wales	130
Uwchmynydd (Bardsey)	Wales	6
England		
Bristol Channel - Minehead	England	125
Bristol Channel - Barry & Mackenzie Shoal	England	65
English Channel		
Portland Bill	England	30
Isle of Wight	England	300
Alderney Race	Channel Islands	3600
Big Russel	Channel Islands	11
East Casquets	Channel Islands	425
West Casquets	Channel Islands	140
TOTAL (all projects)		11841

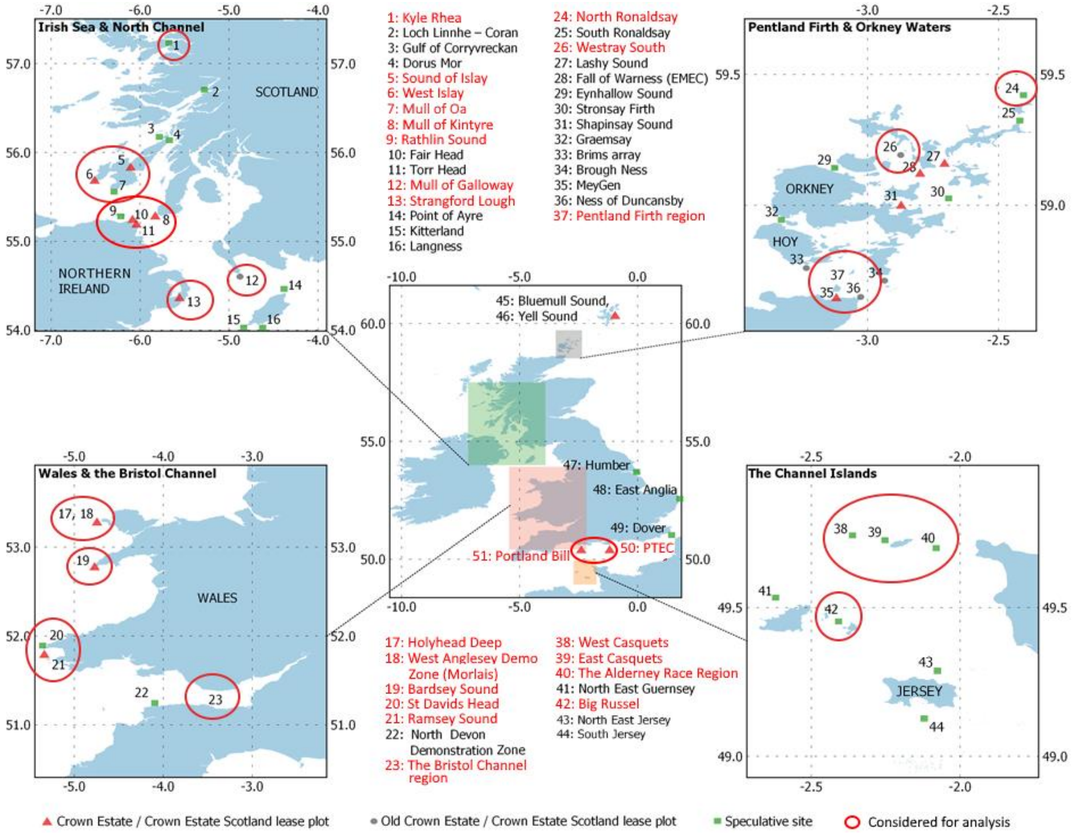


Figure 1-1 Installed capacity and locations of Tidal Stream. Sites considered for the core scenario are shown in red.

The locations and capacities were selected according to the Carbon Trust study "UK Tidal Current Resource and Economics Study". Published in 2011, this was the last national-level resource study conducted. It provides locations and estimated annual production for about 30 sites across the UK, subject to environmental constraints. Since this resource study, there have been improvements in technology, with turbine ratings now reaching 2MW (Orbital Marine O2 and Magallanes ATIR in 2021), double what was available pre-2020, and plans for 5MW+ turbines. Moreover, there are developments or additions to the demonstration zones in Wales. In addition, Nova Innovation is also doubling the size of the Shetland Tidal Array.

Depth-averaged tidal flow speed data with a duration of 1 month was obtained for each site from regional scale hydrodynamic models. Harmonic extrapolation was implemented to extend the data sets to 1 year with a 30-minute resolution. The annual flow speed data sets were used to derive the power time series for each farm. The rated power of each farm dictated its maximum power output. The total swept area of each farm was chosen such that each farm achieved a capacity factor of 40%. A turbine cut-in speed of 1 m/s was implemented. This work, carried out by the Universities of Plymouth and Edinburgh, resulted in a baseline installed capacity of 11.8 GW.

The locations of TS were then mapped into 14 Distribution Network Operator regions modelled in the energy system optimisation tool described shortly in section 1.5. For each site, 10-minute output profiles were provided. The profiles were converted to one hourly resolution maintaining the daily maximum and minimum output of TS and the daily energy output.

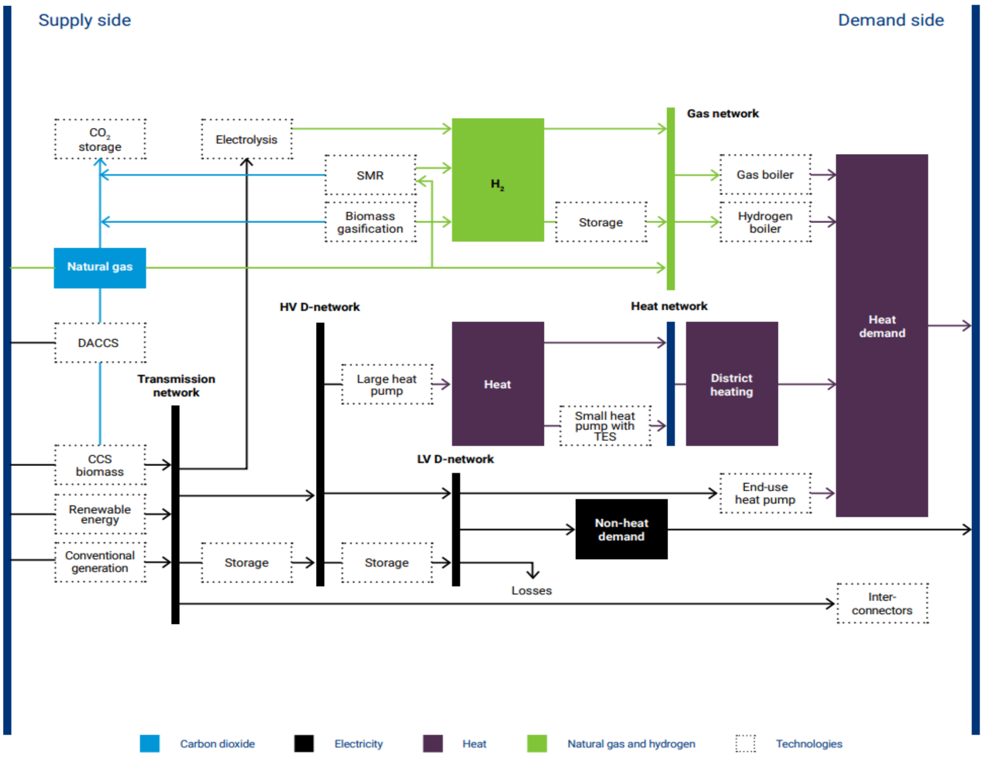
1.5 Summary of the approach

As in the Phase 1 study, we also used the integrated whole energy systems model (IWES) to quantify the system impacts of different scenarios. IWES is a least-cost optimisation model that minimises long-term investment and short-term operating costs across multi-energy systems (electricity, heating, hydrogen) from the supply side, and energy network to the end-customers while meeting the required carbon targets and system security constraints. IWES also optimises the deployment of flexibility technologies such as energy storage (thermal, electricity, hydrogen), demand response technologies (e.g. smart electric vehicle charging system with and without vehicle-to-grid capability, industrial and commercial sector demand response), interconnection with Europe, electrolysers, and generation flexibility to ensure adequate generation capacity during the peak demand with low renewable outputs.

Figure 1-2 illustrates the interactions across different system components considered in IWES. The model also considers the energy system from the local district level to a national system and the UK and European energy systems' interactions. IWES also considers the system's operational requirements, such as frequency response and reserves (which has a timeframe of milliseconds to minutes), dispatch problems (hours, days or seasons), and long-term investment problems (years) simultaneously.

Annual system costs and the energy system infrastructure proposed by the model in different scenarios can be compared to analyse the factors influencing TS' system benefits and implications. In order to identify the system benefits and impacts of TS, the optimal design of the system with TS in question is compared with the one without TS. The latter will serve as a reference or counterfactual scenario.

A more detailed description of the model can be found in the appendix of our Phase 1 report.



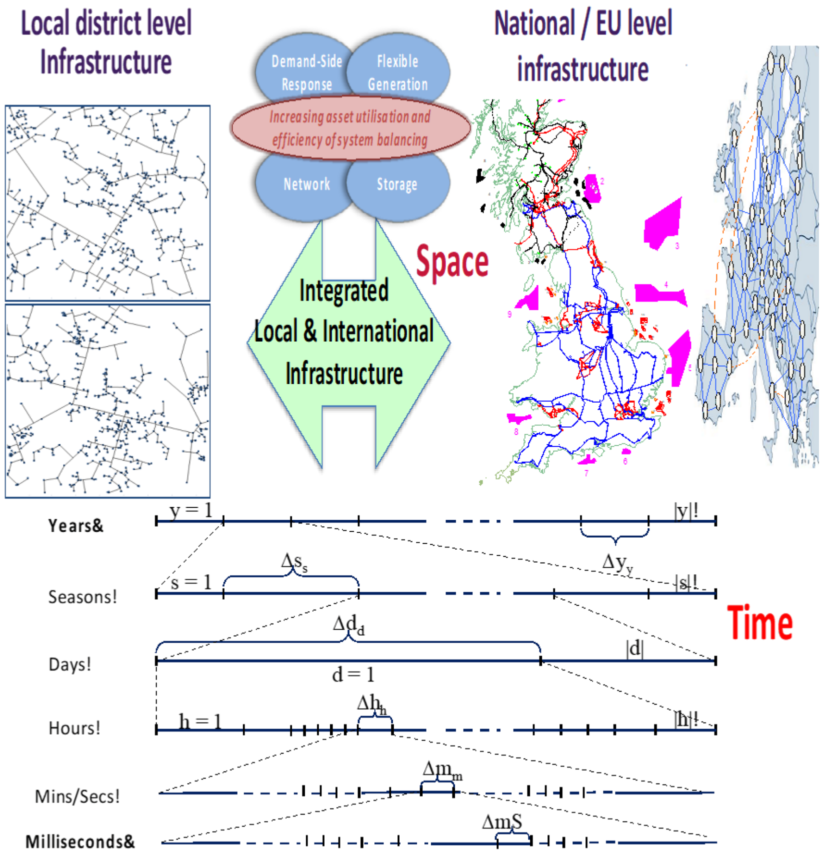


Figure 1-2 Integrated whole-energy system model

Chapter 2. Whole System Benefits ofTidal Stream in Different Future Scenarios

A spectrum of sensitivity studies has been conducted and analysed to identify and understand the implications of different scenarios on TS value as defined in section 1.3. The case studies are summarised in Table 2-1, where the values used in the base case are compared with those used in the sensitivity studies.

Table 2-1 List of scenarios being studied

Assumptions	Base	Sensitivity
LCoE of vRES in 2050	BF: £35/MWh FW: £35/MWh Solar: £44/MWh Onshore wind:£30/MWh	(1) LCOE of RES: +/- 10%,20% (2) Based on the UK government's Energy Generation Cost projection BF: £40/MWh FW: £40/MWh Solar: £33/MWh Onshore wind:£44/MWh
Extreme event	No wind drought during winter peak	3 days, 1 and 2 weeks
Nuclear capacity	Optimised	24 GW
LCOE of Nuclear in 2050	Nuclear: £60/MWh	£90/MWh
Gas prices	£21.6/MWh	5x, 10x
Cost of electrolysers and electricity storage	SOE: £700/kW Alkaline: £455/kW PEM: £340/kW BESS: £55/kWh	-20%

In total, 13 scenarios have been analysed. For each scenario, two simulations were carried out: (i) a system without TS (No Tidal), which acts as the counterfactual, and (ii) a system with 11.8 GW TS (Core), as shown in Figure **1-1**. So, the analysis involved 26 simulation runs.

2.1 Overview of the sensitivity study results

Unless otherwise stated, this report's annual costs and benefits are expressed as real value in 2020.

The impacts of different scenarios on the annual system costs for a system with and without TS are shown in Figure 2-1.

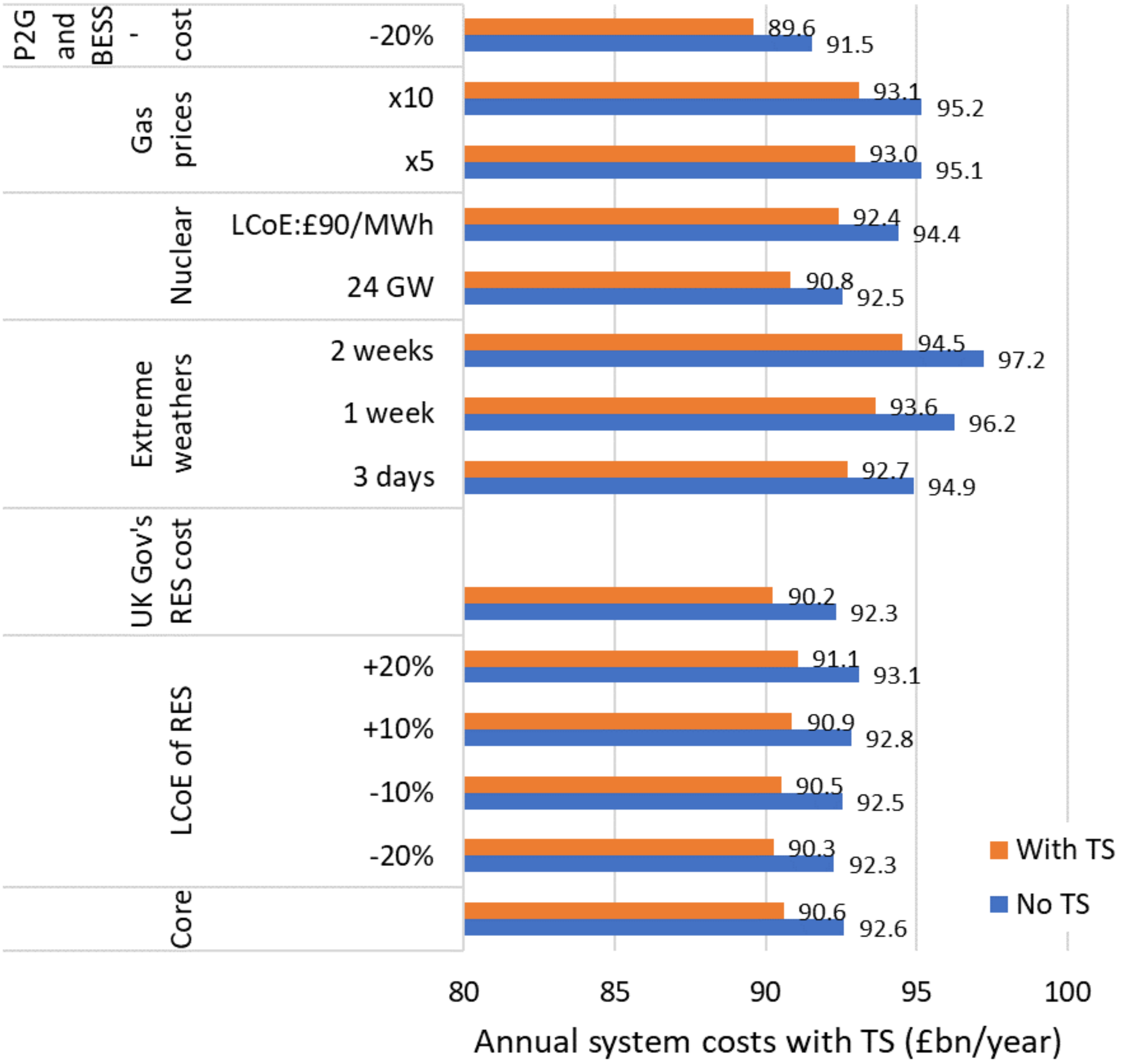


Figure 2-1 Annual system costs of the system with and without Tidal Stream under different conditions

There are some key findings from the modelling results:

- The conditions that increase the system costs are extreme weather conditions and high gas prices. The longer the severe weather the system must cope with, the higher the cost. For example, the system cost increases by £4.6bn/year from £92.6bn/year to £97.2bn/year if extreme events are two weeks long.

- The impact of five times or ten times gas prices is very similar because, at five times gas price, the energy system uses no natural gas and, therefore, increasing further the gas prices does not have a substantial impact.
- When the cost of vRES decreases or decreases, the annual system costs will follow accordingly, but the impact is relatively marginal.
- The cost of the system with 24 GW nuclear is relatively similar to the core scenario indicating that RES can be an alternative to nuclear.
- When the LCoE of nuclear is set to £90/MWh, the annual system cost increases by £1.8bn/year as nuclear is replaced by other low-carbon power technologies with a slightly higher cost.
- 20% cost reduction of electrolysers and BESS reduce the annual system cost by £1.1bn/year.
- TS reduces annual system costs in all cases, but the gross benefits vary.

System benefits of TS are derived by calculating the cost difference between the system without and with TS. The TS cost is excluded from the total system costs. The gross system benefits of TS across all scenarios considered are shown in Figure 2-2.

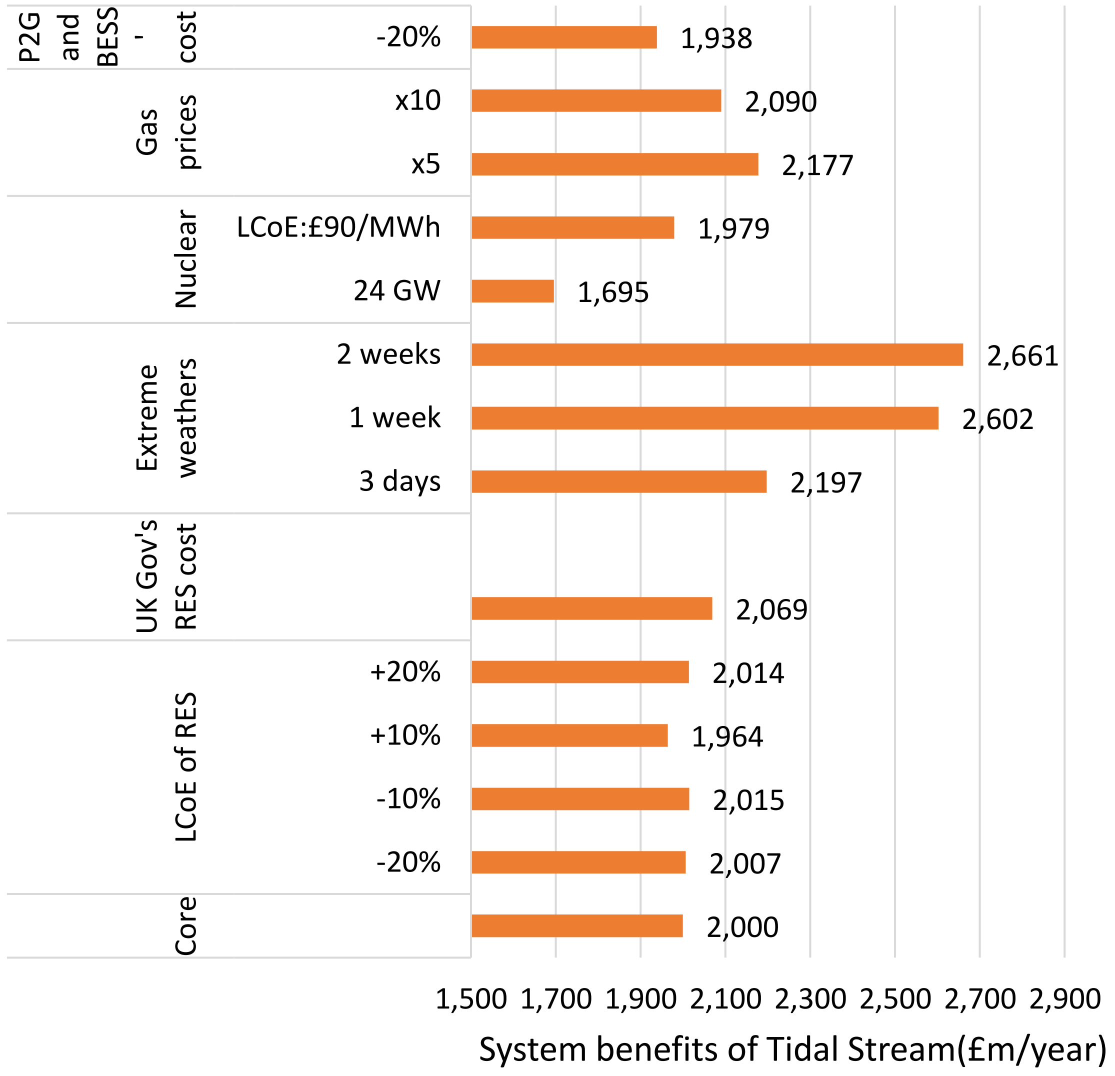


Figure 2-2 Annual system benefits of Tidal Stream under different conditions

The results demonstrate:

- In most cases, the gross benefit of TS remains around £2bn/year. It proves that the TS benefits are quite robust and relatively indifferent to the uncertainty in the cost of variable RES (within the range of uncertainty being studied, including the use of the UK Government's assumptions on projected electricity generation cost), higher cost of nuclear, and gas prices.
- TS will improve energy resiliency against extreme weather conditions. Increased duration of extreme weather events will increase TS' system benefits by up to 33%. The value rises rapidly when extreme weather events are considered in the system design; however, after having one week of low RES output with peak demand, the incremental cost of having another week is relatively lower.
- The value of TS will be lower in a system with a high nuclear capacity because nuclear is a firm low-carbon capacity. The value of TS is lower by 15% in the scenario with 24 GW nuclear plants.
- Surprisingly, higher gas prices only increase TS benefits by 5% - 9%.
- Reduction of electrolysers and BESS costs also do not boost the value of TS. As electrolysers and BESS improve system flexibility, the TS benefits are 3% less.

We will focus our subsequent analyses and discussions on the three identified main drivers of TS' system value, i.e.

- Extreme weather events
- Gas prices
- High deployment of nuclear

2.2 Impact of extreme weather events

In a system with high penetration of variable RES, especially wind, like in the UK, cold snaps coinciding with wind stills across wide geographical areas become a major concern. The electricity system capacity will be stressed due to increased heat-led electricity loads while the electricity production from wind and solar PV is low for a long period. Sufficient dispatchable power generation capacity, such as from nuclear, gas or hydrogen-fired power plants, will be needed to ensure energy security during those events. In combination, the mix of energy sources could be optimised to maximise the diversity and reduce the reliance on particular sources during those events to minimise the impact. Integrating TS into the future energy mix may enhance energy resilience in this context.

The modelling results, shown in Figure 2-3, demonstrate that TS' system benefits increase by 35% from £2bn/year to £2.7bn/year if the system is designed to cope with two weeks of extreme winter weather events. Marginal increased TS' benefits between the results for 1 and 2 weeks indicate that the benefits are relatively saturated when the system is already designed with sufficient dispatchable capacity. The majority of benefits are in reducing the cost of electricity infrastructure, such as the investment cost of power generation, transmission and Opex of electricity. Increased savings in Capex of non-low-carbon generation indicates the capacity value of TS as a reliable and consistent renewable energy source. Other savings include reducing carbon offset infrastructure costs such as DACCS and Capex of hydrogen infrastructure.

Figure 2-4 shows the impact of considering extreme weather events in optimal power generation planning. More than 25 GW of additional thermal power generation capacity is added when three days of severe weather are considered. If longer extreme weather events are considered, more thermal power generation capacities are added. At the same time, the diversity of the energy mix is improved by reducing the offshore wind capacity and increasing onshore wind, PV, and biomass.

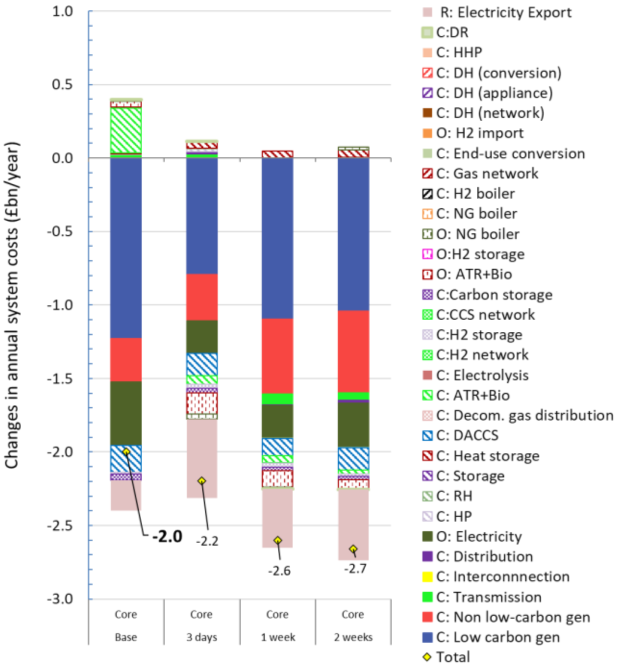
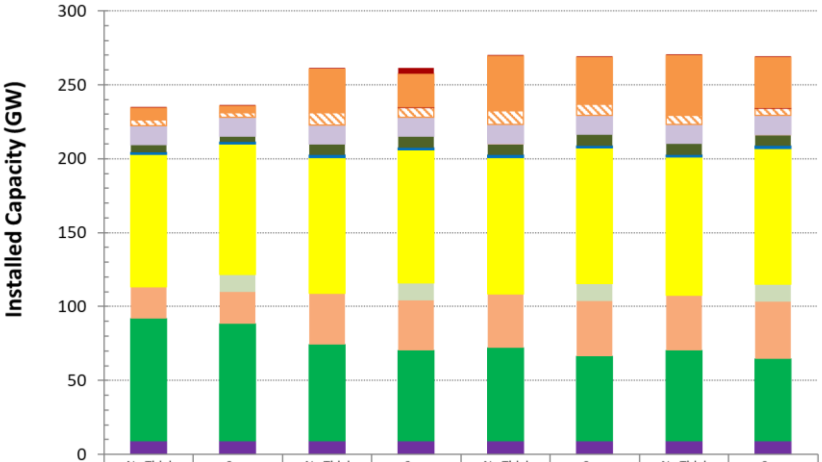


Figure 2-3 Annual system benefits of Tidal Stream integrated into a system designed for extreme weather conditions.



	No Tidal	Core	No Tidal	Core	No Tidal	Core	No Tidal	Core
		Base		3 days		1 week		2 weeks
■ NG OCGT	0.0	0.1	0.2	4.0	0.4	0.4	0.2	0.2
■ NG CCGT	8.1	4.9	29.6	22.7	37.4	31.9	40.9	34.5
▨ H2 OCGT	0.0	0.0	0.0	0.2	0.2	0.2	0.2	0.2
▨ H2 CCGT	4.2	3.0	8.3	6.7	9.2	7.4	6.1	5.1
■ Storage	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7
■ CCS	0.0	0.0	0.0	0.1	0.2	0.1	0.2	0.2
■ Biomass CCS	5.2	4.0	7.7	7.6	7.7	7.7	7.7	7.7
■ Hydro	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
■ PV	89.3	88.1	91.9	89.9	92.5	91.6	93.3	92.1
■ TS	-	11.8	-	11.8	-	11.8	-	11.8
■ Onshore Wind	21.5	21.5	35.0	33.7	36.3	37.4	37.7	38.6
■ Offshore Wind	82.7	79.1	64.8	61.3	62.9	57.1	60.9	55.2
■ Nuclear	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3

Figure 2-4 Impact of considering extreme weather events for optimal power generation planning

The modelling results demonstrate that the integration of TS will affect the optimal generation mix. TS can displace some capacity of wind, solar PV, hydrogen and conventional gas combined cycle gas turbines (CCGT). Unlike wind or solar PV, which could not displace firm generation capacity, TS can displace the CCGT capacity indicating that this technology could support energy security. However, the capacity value of TS is half of the conventional generation's. To a certain extent, improving the system flexibility could improve the capacity value of renewables, including TS'.

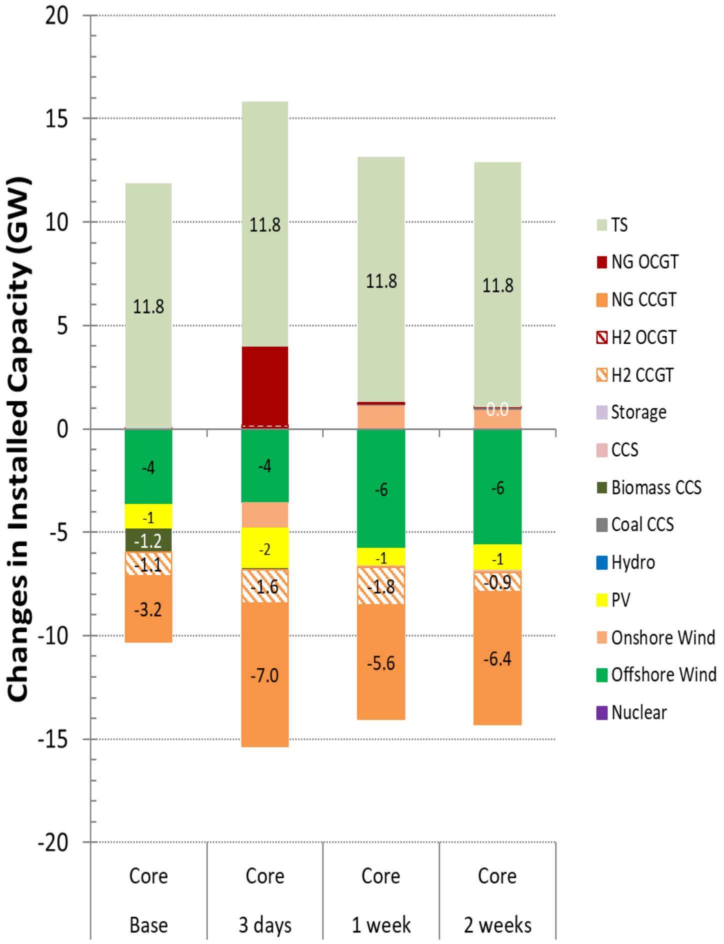


Figure 2-5 Impacts of TS on the optimal power generation mixes

In low electricity output from wind and solar PV, hydrogen and gas power plants will increase production, increasing natural gas consumption. The system requires less natural gas with TS as TS's energy is always consistent. The consumption also increases in the heating sector as gas boilers will operate longer during cold snaps to minimise the use of electric heating to reduce peak demand. The impacts of considering extreme weather events on methane consumption can be seen in Figure 2-6.

Increased methane consumption will increase residual carbon emissions, which need to be offset by additional investment in carbon removal technologies, such as Direct Air with CCS (DACCS). With TS, methane consumption is less; therefore, the system also requires less DACCS. The savings in DACCS investment attributed to TS can be seen in Figure 2-3. The results are shown in Figure 2-7.

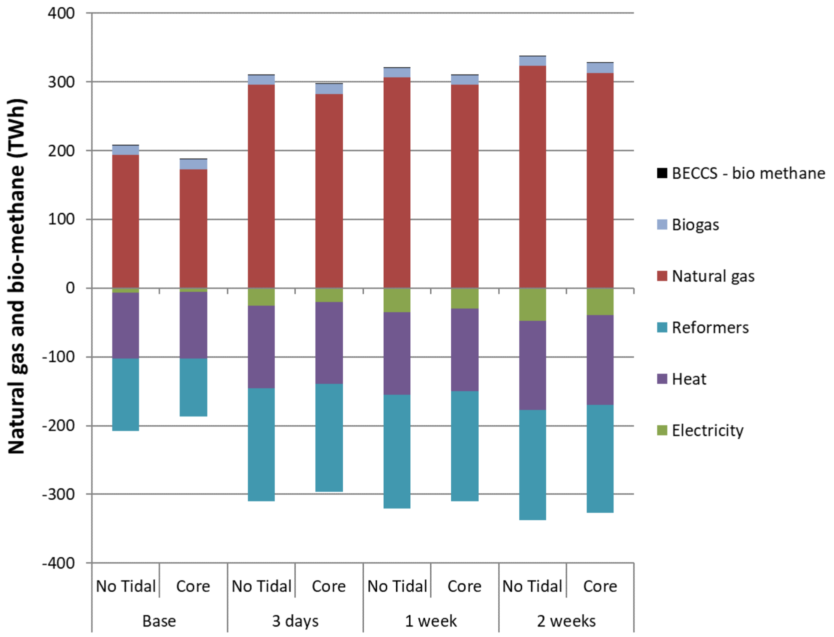


Figure 2-6 Annual supply and methane consumption considering extreme weather.

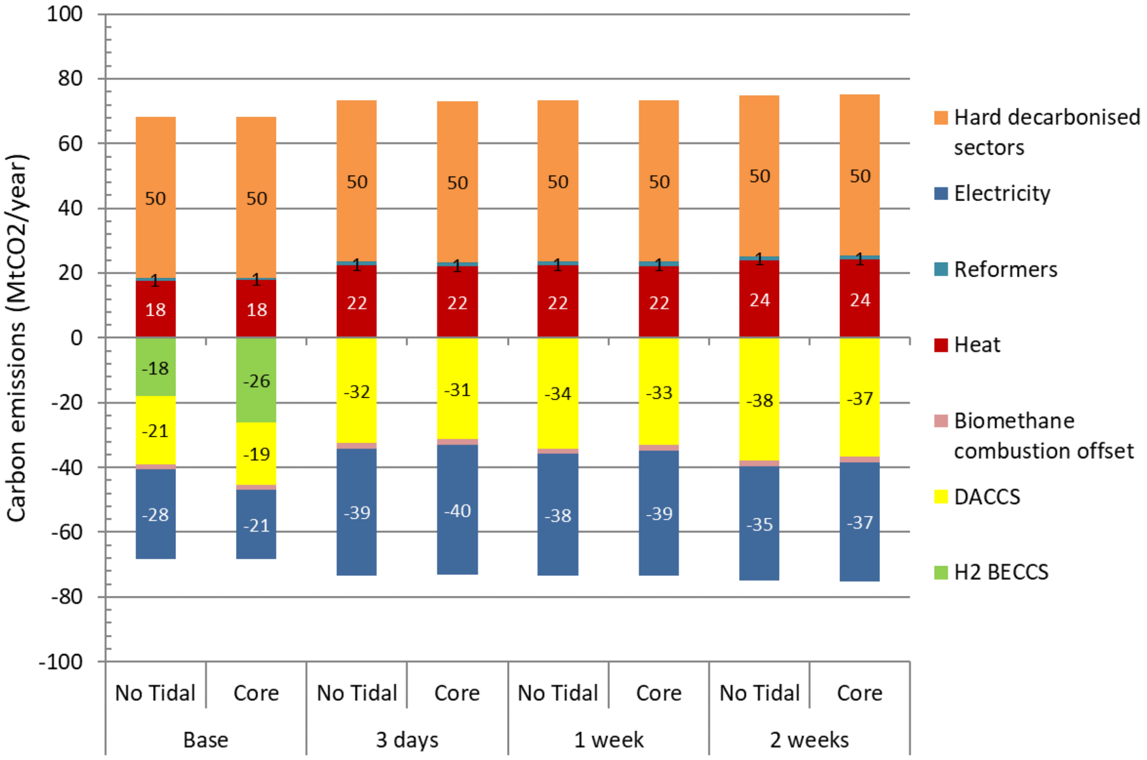


Figure 2-7 Annual carbon emissions and carbon removal from different sectors

The results also demonstrate that the net emissions are zero in all cases. All residual emissions from hard decarbonised sectors, electricity, and reforming processes are offset by negative emissions from BECCS in power and hydrogen systems and DACCS.

2.3 Impact of higher gas prices

Gas supply disruption from countries with large gas reserves due to recent geopolitical turmoil between Europe and Russia caused gas price spikes in 2022. It increases uncertainty about future gas prices. Therefore, two cases were analysed using very high gas prices (x5, x10 higher than the assumption in the base scenario). The model stops using natural gas once the gas price is increased by five times. Increasing further the gas price does not change the results. However, the model still proposes a small volume of methane produced from biogas and BECCS to fuel conventional boilers. Figure 2-8 shows the impact of gas prices on gas supply and consumption. The effects of TS on reducing natural gas consumption in the base scenario can also be observed.

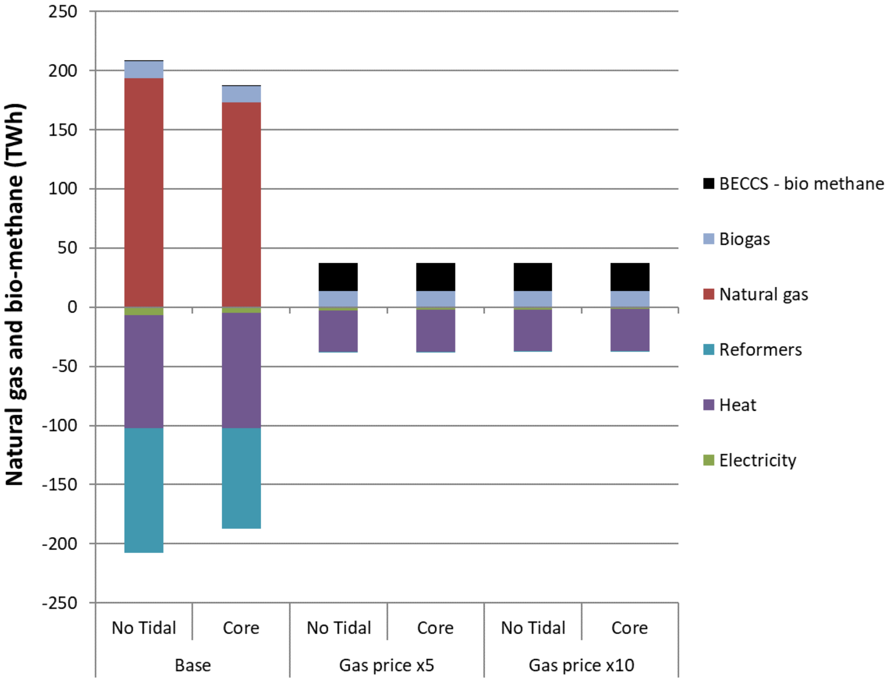
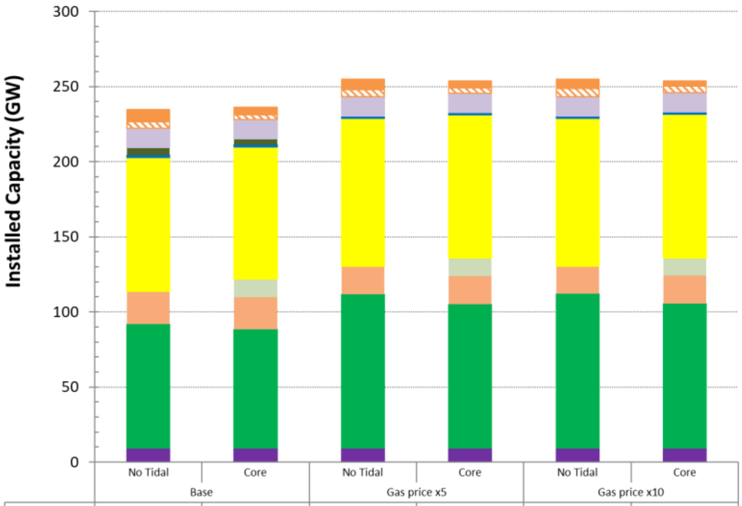


Figure 2-8 Annual supply and methane consumption considering different gas prices.

Higher gas prices will reduce the utilisation of gas-fired power plants, blue hydrogen production, and gas for heating. The system will require more capacity for renewable energy sources to compensate for gas usage reduction. For example, offshore wind capacity increases from 83 GW to 103 GW when the gas price increases by five times. Solar PV also increases from 89 GW to 99 GW. However, the capacity of CCGT only decreases slightly as some capacity will need to be maintained to meet the security requirements. The impact of gas prices on the optimal power generation portfolio is seen in Figure 2-9.

Figure 2-10 shows that the integration of TS will displace offshore wind and PV. The volume of displaced capacity increases in the scenario with high gas prices, as the additional capacity of wind and PV triggered by high gas prices will increase their system integration cost. In this situation, TS becomes a better renewable source alternative. However, the volume of firm generation capacity that TS can displace decreases since the installed capacity of firm generation is already less in the case without TS. The impact of increasing further the gas price on how much TS can displace is relatively modest.



	Base		Gas price x5		Gas price x10	
	No Tidal	Core	No Tidal	Core	No Tidal	Core
🟧 NG CCGT	8.1	4.9	7.0	4.6	6.2	3.6
▨ H2 CCGT	4.2	3.0	4.7	3.7	5.4	4.5
■ Storage	12.7	12.7	12.7	12.7	12.7	12.7
■ CCS	0.0	0.0	0.0	0.0	0.0	0.0
■ Biomass CCS	5.2	4.0	0.0	0.0	0.0	0.0
🟦 Hydro	1.5	1.5	1.5	1.5	1.5	1.5
🟨 PV	89.3	88.1	98.6	95.5	98.5	95.5
■ TS	-	11.8	-	11.8	-	11.8
■ Onshore Wind	21.5	21.5	18.6	18.6	18.6	18.6
🟩 Offshore Wind	82.7	79.1	102.5	96.0	102.6	96.3
🟪 Nuclear	9.3	9.3	9.3	9.3	9.3	9.3

Figure 2-9 Impact of high gas prices on the optimal power generation portfolio

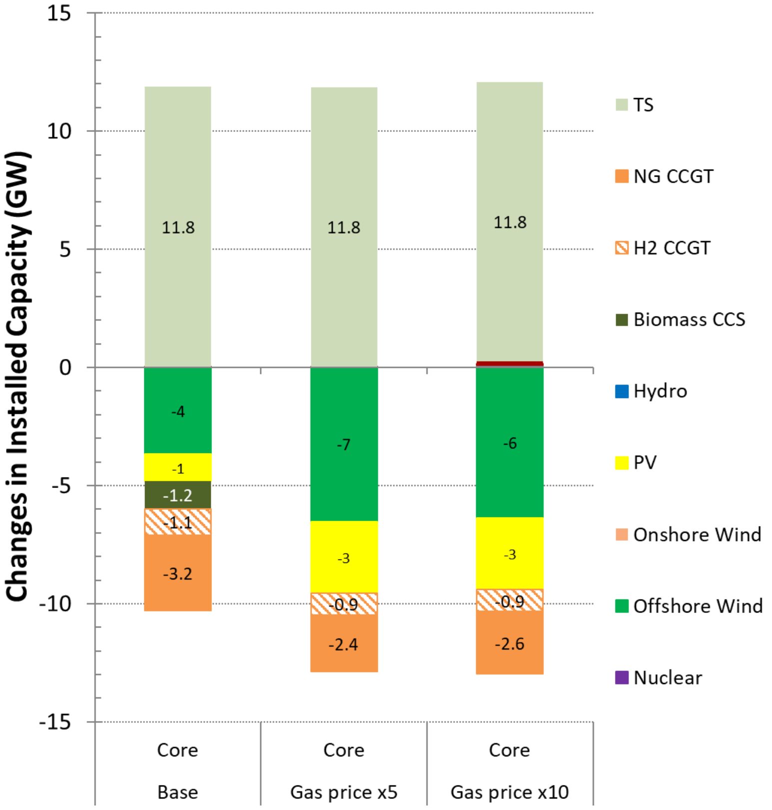


Figure 2-10 Generation capacity that Tidal Stream can displace in systems with different gas prices

TS' system benefits are 4.5% - 9% higher in the system with high gas prices, as depicted in Figure 2-11. Due to substantially reduced gas usage, the residual emissions decrease, so DACCS are also less required, even in the system without TS. In this case, TS's benefit for reducing the DACCS requirement disappears.

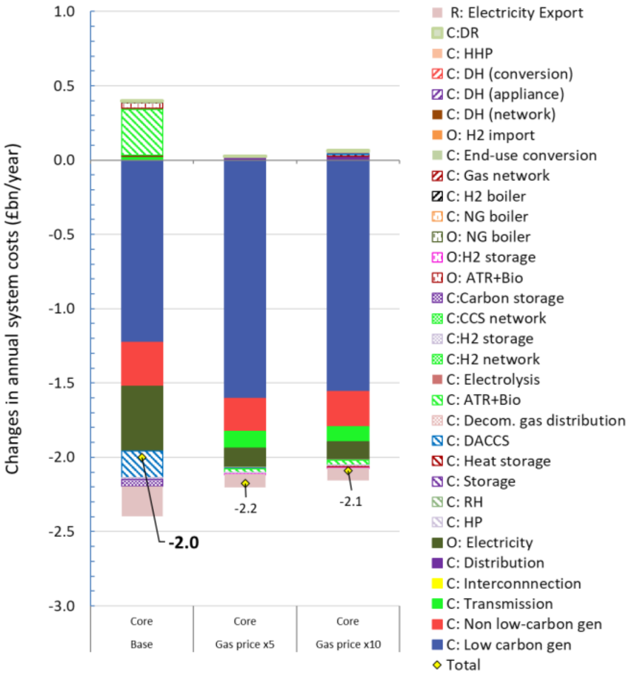


Figure 2-11 Impact of gas prices on the system benefits of Tidal Stream

2.4 Impact of high nuclear deployment and cost

Nuclear power provides firm low-carbon energy sources; this technology supports energy decarbonisation and provides energy security. While nuclear costs are high, it relies on the government's financing support and energy policy. There is high uncertainty on how nuclear should be included in the future UK's energy mix. In this context, two case studies were conducted investigating the impact of having 24 GW of nuclear in the system and high-cost nuclear. The modelling results of TS' system benefits are shown in Figure 2-12.

In a system with 24 GW of nuclear power, TS' benefits are less than in the base case—the savings in reducing firm capacity, Opex of electricity and investment in DACCS decrease. With so much nuclear power, the need for additional firm power capacity becomes less, and as nuclear can provide low-carbon energy sources continuously, the need to use other thermal plants becomes less, reducing the Opex of electricity and natural gas consumption. This also reduces residual emissions and investment needed in DACCS. Therefore, the integration of TS brings 15% less benefit to this system.

In contrast, with a higher cost of nuclear (£90/MWh[7]), TS' total system benefits are relatively the same compared to the core scenario, although the breakdown of the benefits is slightly different. As nuclear becomes more expensive, no nuclear power is used in the generation mix (Figure 2-13), but the capacity of wind and PV cannot be increased due to balancing issues. As an alternative to nuclear, gas CCS is used. The capacity of CCS increases from 0 to 5.9 GW in the system without TS. With TS, the capacity of gas CCS needed can be reduced to 4.3 GW. Hence, the operating cost of electricity driven by fuel cost can be reduced. However, the total savings are the same as in the base case due to trade-offs from other system component costs, as shown in Figure 2-12.

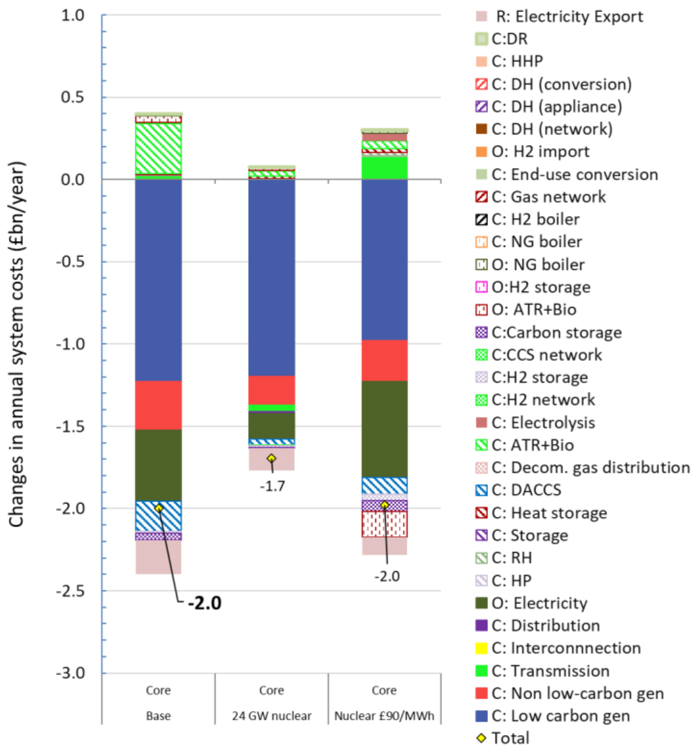


Figure 2-12 Impact of different nuclear deployment and costs on Tidal Stream

Figure 2-13 shows the optimal power generation portfolio in different scenarios. With 24 GW nuclear capacity, the volume of vRES needed becomes less. The impact of TS on the optimal power generation portfolio is shown in Figure 2-14.

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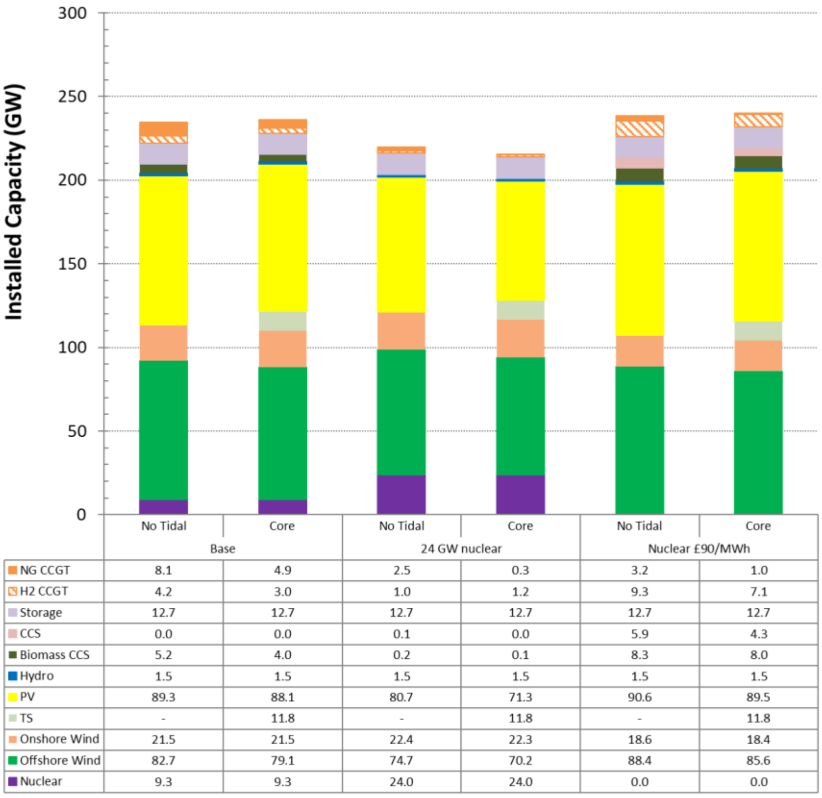
[7] Compared to £60/MWh in the base case



	No Tidal	Core	No Tidal	Core	No Tidal	Core
	Base		24 GW nuclear		Nuclear £90/MWh	
NG CCGT	8.1	4.9	2.5	0.3	3.2	1.0
H2 CCGT	4.2	3.0	1.0	1.2	9.3	7.1
Storage	12.7	12.7	12.7	12.7	12.7	12.7
CCS	0.0	0.0	0.1	0.0	5.9	4.3
Biomass CCS	5.2	4.0	0.2	0.1	8.3	8.0
Hydro	1.5	1.5	1.5	1.5	1.5	1.5
PV	89.3	88.1	80.7	71.3	90.6	89.5
TS	-	11.8	-	11.8	-	11.8
Onshore Wind	21.5	21.5	22.4	22.3	18.6	18.4
Offshore Wind	82.7	79.1	74.7	70.2	88.4	85.6
Nuclear	9.3	9.3	24.0	24.0	0.0	0.0

Figure 2-13 Impact of different nuclear deployment and costs on optimal generation portfolio

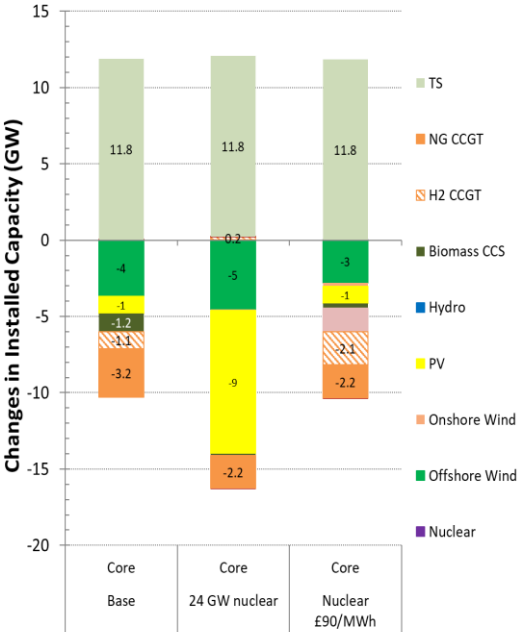


Figure 2-14 Capacity that Tidal Stream can displace in different nuclear scenarios

Chapter 3. Conclusions

A spectrum of additional sensitivity studies has been conducted to include the factors identified in the discussions after the published Phase 1 study report of Tidal Stream's energy system benefits. The case studies look into various aspects, such as different assumptions on the levelised cost of variable RES in 2050, the inclusion of extreme weather events in energy system planning, high deployment of nuclear capacity, high cost of nuclear, high gas prices, reduction in the cost of electrolysers and BESS. Considering these aspects may affect how the future energy system will evolve and influence the value of TS.

3.1 Key findings

The key findings can be summarized as follows:

- Extreme weather events, high gas prices and high power generation costs are the main drivers for the increased system costs.
- TS' system benefits are robust across all scenarios – in all studies analysed, the integration of TS saves the annual system costs by 1.7- 2.6 £bn/year.
- TS improves energy resilience by diversifying renewable energy sources to cope with extreme weather events. TS' benefits increase when the UK's energy system is designed to cope with extreme weather events. The highest TS benefit in these studies is when TS is integrated into a system designed to cope with two weeks of low RES output during winter peak demand.
- Higher gas prices incentivise diversified renewable sources. High gas prices reduced natural gas usage for heating, power and hydrogen for electricity production. Increasing the installed capacity of offshore or solar PV will further increase their system integration cost. Complementary to those technologies, TS can enhance the diversity of renewable energy resources to be more resilient against uncertainty in gas prices.
- TS benefits are 15% less if the future system has substantial nuclear power (i.e. 24 GW) in its energy mix. Nuclear is a firm, low-carbon power generation technology and dispatchable, although not as flexible as other thermal generators. It reduces system balancing requirements and capacity from other technologies and the need for carbon removal technologies.
- Improved system flexibility due to lower cost of electrolysers and BESS reduces TS' value. The result is aligned with the findings in the Phase 1 report that the value of TS will be lower in a system with higher flexibility.

3.2 Future work

The work described in this report flags several areas that need to be studied in more detail in future, including:

- Another area for strong planning and operation coordination is the North Sea energy integration, which involves integrating hydrogen and electricity and multi-national energy and offshore transmission islands.
- There is also potential strong synergy with other marine technologies such as tidal lagoon and wave power. Having coordinated development of marine renewable technologies may reduce the system integration challenges of those technologies and allow more cost-effective utilisation of the infrastructure built to support those developments.