Institution of MECHANICAL ENGINEERS

Lancaster University

Tidal Range Energy Opportunity for the UK

IMechE NW Power Industries

Tuesday 8th November 2022

EUR ING Professor

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Questions

1. Which UK estuaries are suitable for tidal range schemes?
2. How much electricity can be generated using tidal range?
3. What are the costs of tidal range projects?
4. When could tidal range power be delivered?
5. Where should tidal range power sit in terms of UK generating options?

LUREG
Lancaster University
Renewable Energy Group

Lancaster University

ENERGY - LUREG Research

- Research on Renewable Energy & Fluid Machinery
  - Generic & Applied

- Energy & Renewables
  - Computational & Experimental Modelling
  - Device Development & Power take off
  - Computational Fluid Dynamics & Control
  - Economics, Resource & Condition Monitoring

- Novel Topology Fluid Machinery & Turbines
  - Computational Fluid Dynamics, Turbine Design & Analysis
  - Direct Drive & In Line Turbines
  - Siphonic Low Head & Low Cost Turbine Research
  - Fluid Machinery reliability & Energy Efficiency

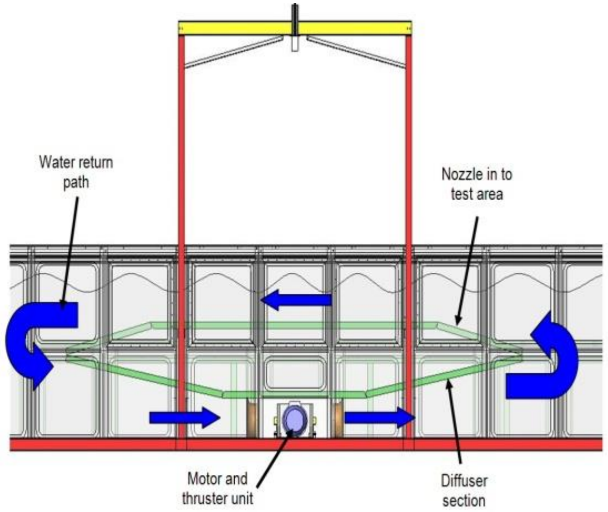
- Funded by EPSRC, Carbon Trust, EU, RDAs, Utilities and Industry

Lancaster University Engineering Building

Lancaster University
Renewable Energy Group

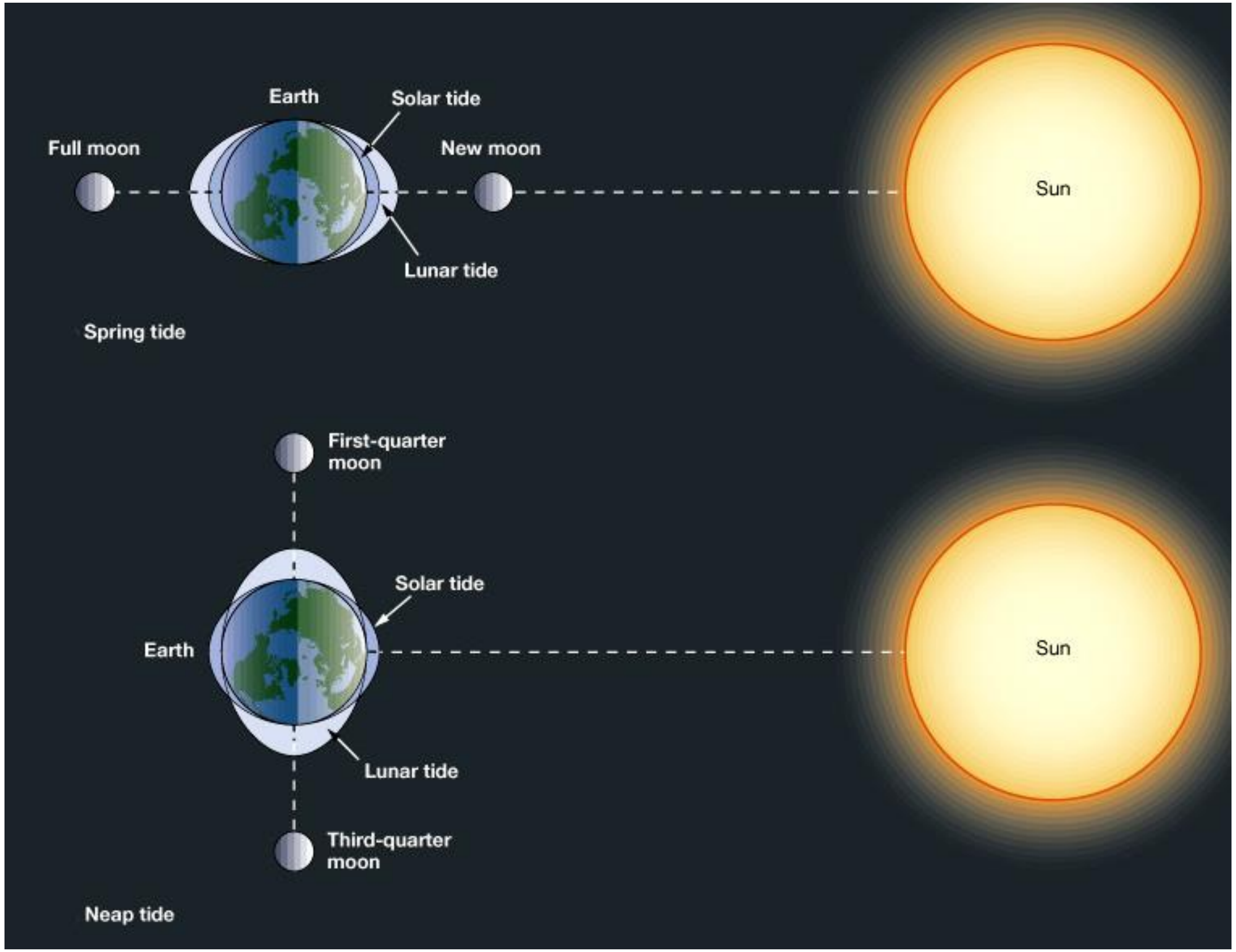
Lancaster University

ENERGY Research Facilities



Earth-Moon-Sun Gravity

Tidal energy exploits the **natural ebb & flow** of coastal tidal waters caused principally by the interaction of the **gravitational fields of the earth, moon and sun.**



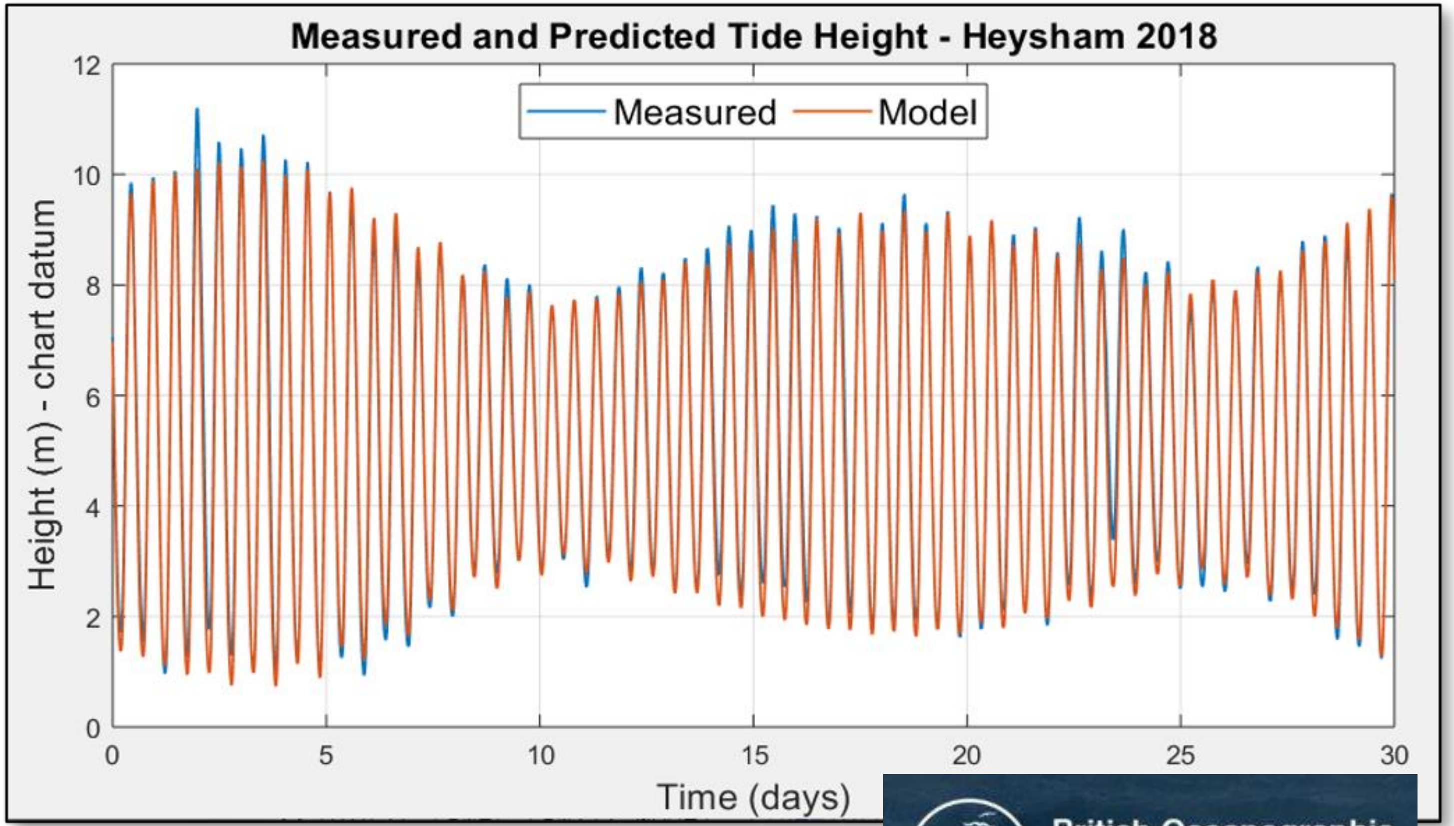
Tidal Range Power

- Cyclical - modelled (red)
  - Twice daily – ebb/flood
  - Monthly (lunar) cycles
  - Seasonal cycles

} spring/neap

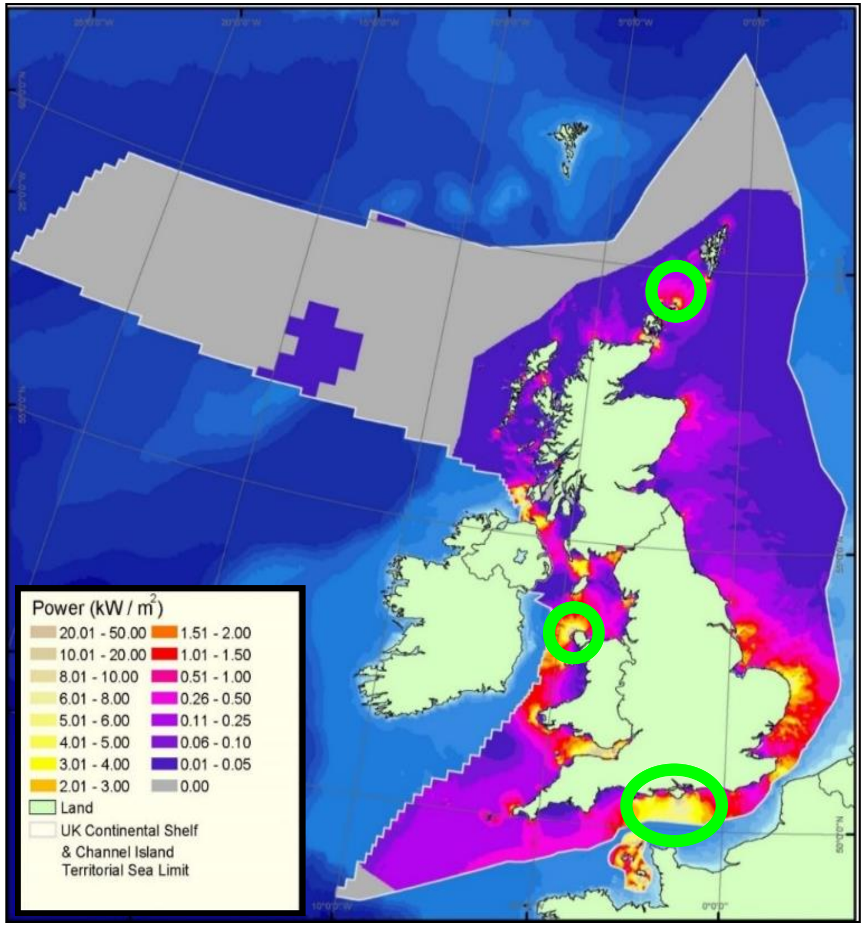
- Modified – show reality (blue), by
  - Atmospheric pressure
  - Wind
  - Climate change

Results are largely (but not perfectly) predictable long into the future!

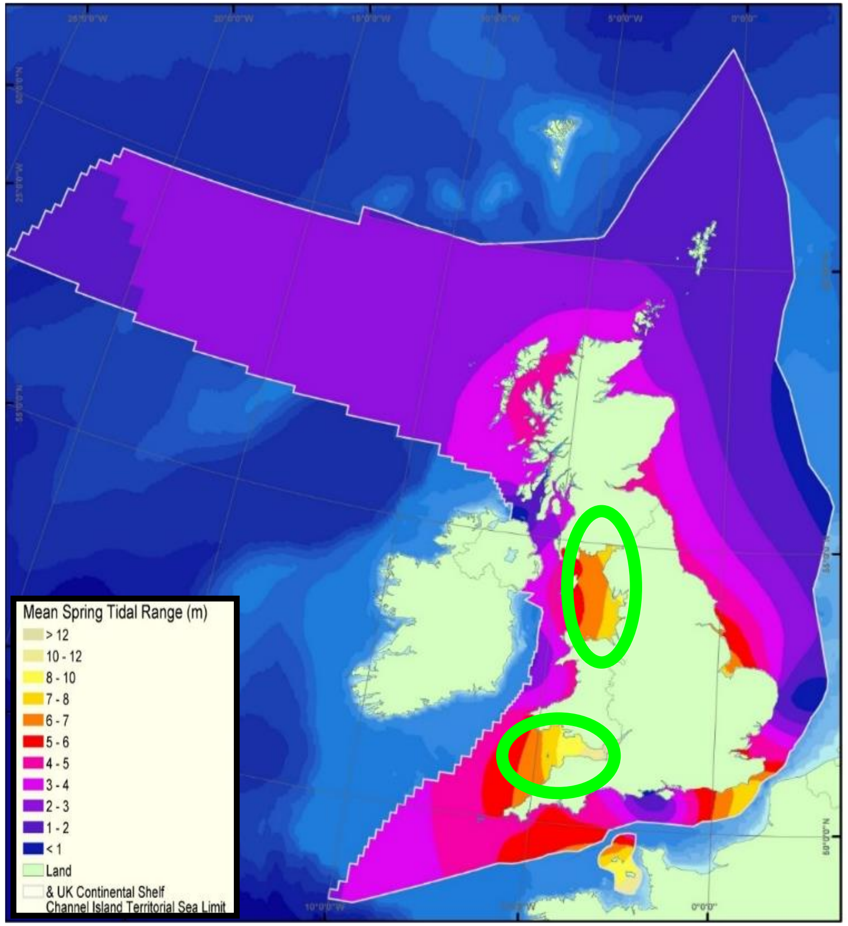


British Oceanographic Data Centre
National Oceanography Centre

U.K. Tidal Resource



Tidal Stream



Tidal Range

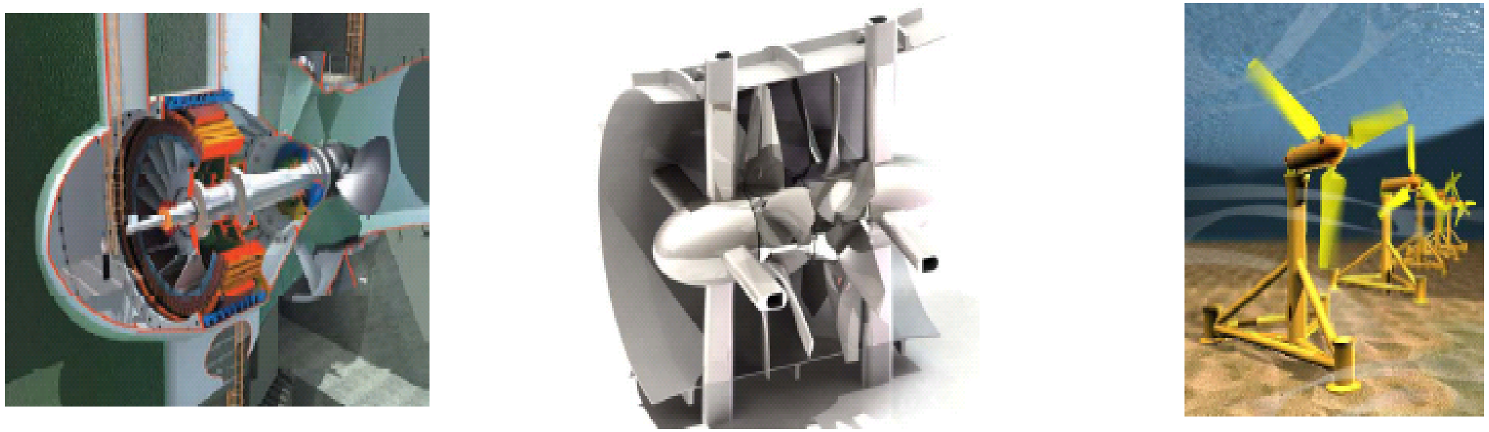
Source – DTI Atlas of Marine Renewable Energy Resources

Professor G A Aggidis

Tidal Technologies

Both forms of energy (potential & kinetic) can be harvested by tidal energy technologies as renewable energy.

Increasing environmental impact



Uni-directional operation.	Bi-directional operation.	Bi-directional operation.
High axial flow speed.	Low axial flow speed.	Low axial flow speed.
50 metre downstream diffuser.	Straight walled support structure.	No enclosing support structure.
High solidity rotor.	Twin low solidity rotors.	Low solidity rotor.
Steady flow conditions.	Steady flow conditions.	Unsteady flow conditions.
Deep cavitation submergence.	Modest cavitation submergence.	Modest cavitation submergence.

Decreasing power density

Waters, S. and Aggidis, G., 2016. Tidal range technologies and state of the art in review. *Renewable and Sustainable Energy Reviews*, *59*, pp.514-529.

Lancaster University Renewable Energy Group

Where else in the world?

- Europe
  - La Rance – France’s cheapest electricity 50-years operation to date 240 MW
- Canada
  - Annapolis – decommissioned after 34-years operation 20 MW
- S Korea
  - Sihwa - 10-years operation to date 254 MW

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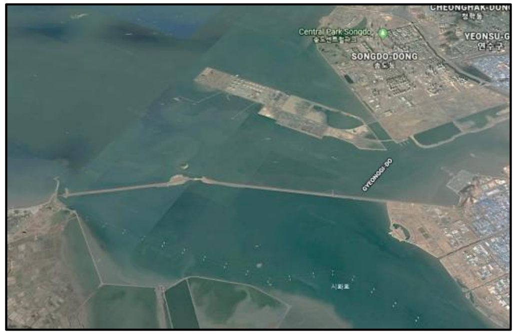


Professor G A Aggidis

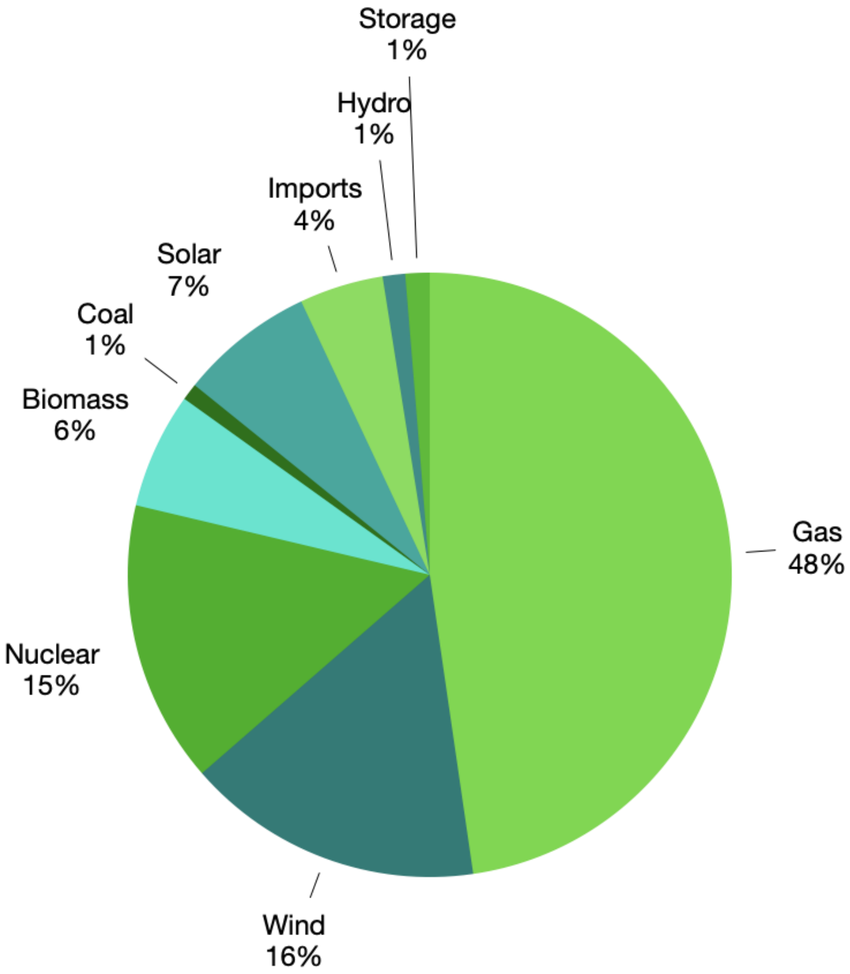
UK’s current generating capacity

Installed capacity	76.6 GW
Annual generation	308.7 TWh
Demand (consumption)	334.2 TWh
Import	28.7 TWh

Digest of United Kingdom Energy Statistics (DUKES)
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1094628/DUKES_2022_Chapter_5.pdf

Approximate breakdown by source

Source	Percent
Gas	47.7
Wind	15.9
Nuclear	15.1
Biomass	6.2
Coal	0.9
Solar	7.2
Imports	4.5
Hydro	1.2
Storage	1.3



August 2022

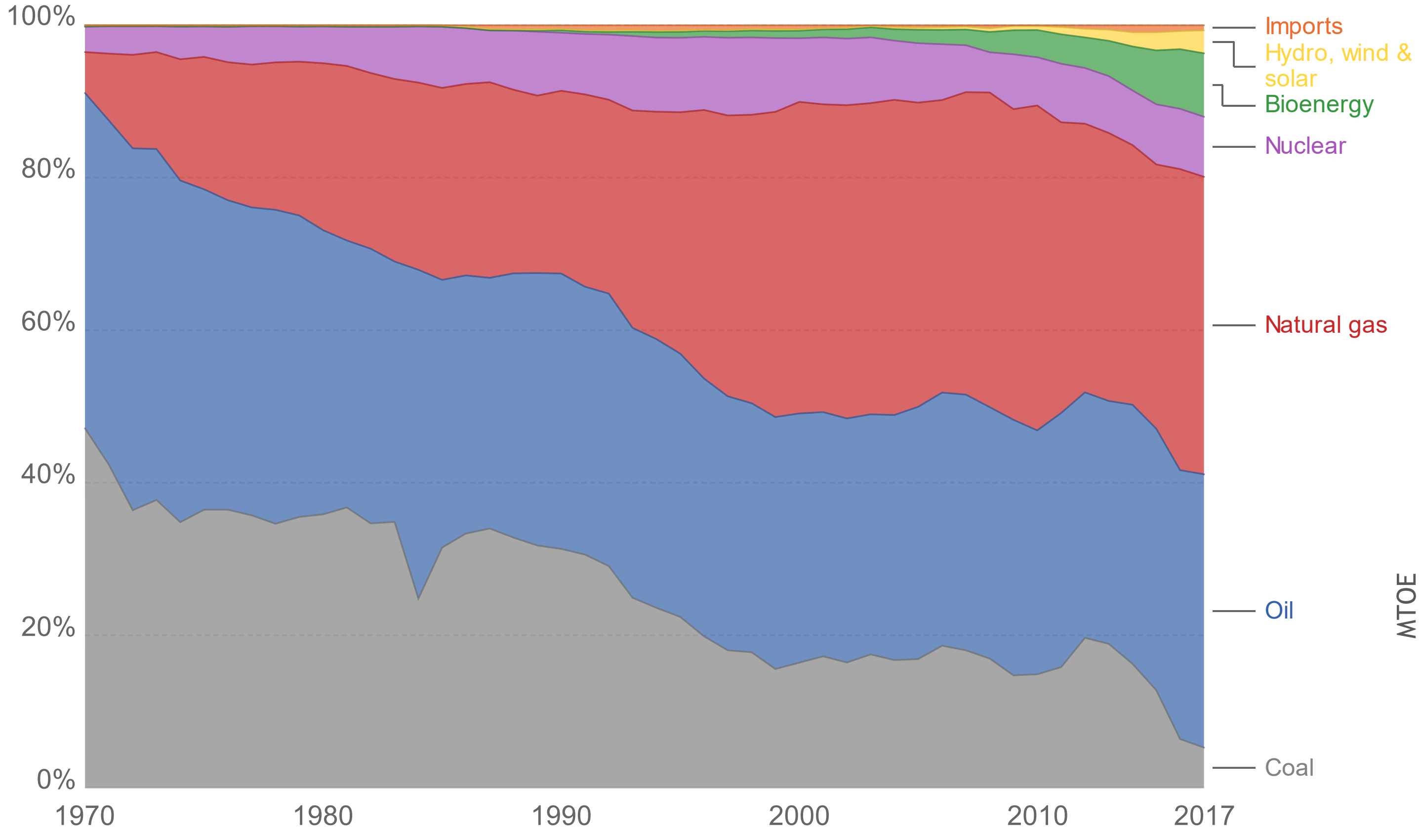
https://www.nationalgrideso.com/electricity-explained/electricity-and-me/great-britains-monthly-electricity-stats

The past

All energy

Primary energy mix in the United Kingdom

Primary energy mix in the United Kingdom, differentiated by energy source. This is based on domestic inland consumption, and does not include exported energy.



Source: Digest of UK Energy Statistics (DUKES, 2018)

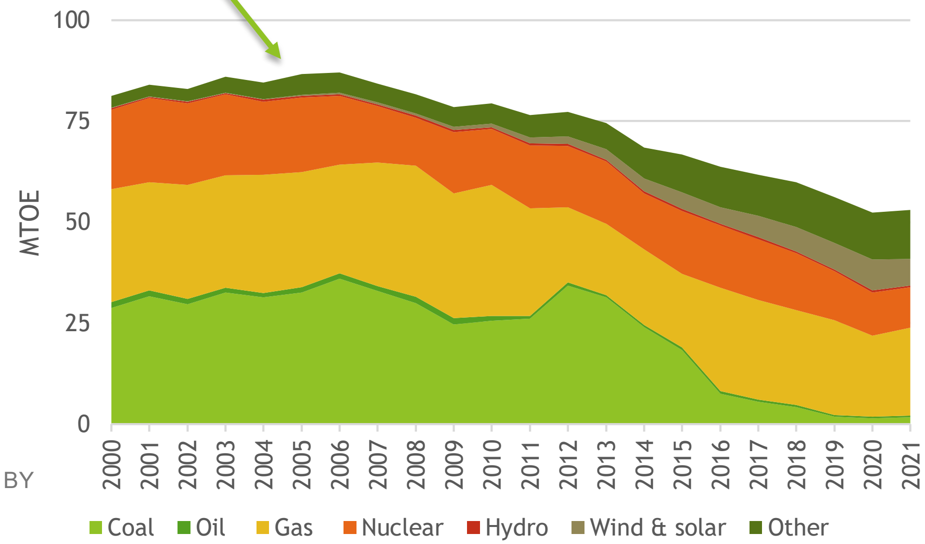
CC BY

- ➢ Our electricity use has declined since the peak in 2005, despite population increase.

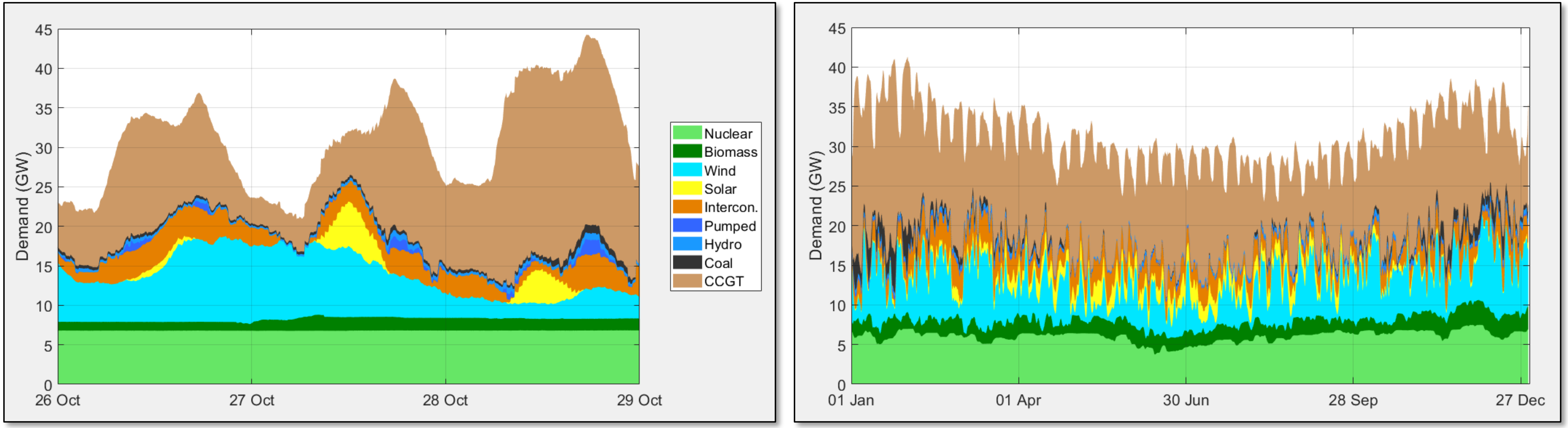
This is because of:

- energy efficiency regulations
- energy efficient lighting
- changing consumer habits
- (including the continuing decline of heavy industry)

Electricity



UK Electricity supply mix (2019)



- Nuclear and biomass provide baseload
- Wind and solar are fully utilised when available
- Pumped storage used for peak demand
- Interconnectors, hydro (~seasonal), coal and gas (CCGT) are used to satisfy the remaining demand

- No sun and wind => compensate by burning gas
- Installing more solar and wind capacity does not change this without an alternative approach

The future....

UKERC Energy 2050 (2009)

The project addressed two of the Government's toughest energy policy goals – delivering reliable energy to consumers while meeting its legal commitment to reduce $C0_2$ emissions by 80% by 2050. Conclusions:

- *Decarbonise electricity totally by 2050*
- *Improve energy efficiency (i.e. reduce use)*
- *Change lifestyles*
- *Early action essential*

… which is now

- *The bullets appear to be happening (i.e. action is taking place), link to decline in electricity use.*
- *There are other studies, this is just an example, but maybe research is having an effect and being listened to!*

UKERC Energy 2050 (2009!) also said:

"Major gas shocks could have cost impacts measured in £billions, mainly through lost supplies to industrial consumers. More investment in gas storage or import facilities could mitigate these impacts"

Our gas storage facilities have shrunk!

Government White Papers

- *Continued and appropriate ambition*
  - *Energy White Papers (2003, 2007 and 2020)*
- *Legislation and plans*
  - *Climate Change Act (2008)*
  - *Low Carbon Transition Plan (2009)*
  - *Energy Bill (2012-13)*
- *...but still no serious consideration of tidal range*

ENERGY WHITE PAPER

Powering our
Net Zero Future

December 2020 | CP 337

HM Government

TOGETHER FOR OUR PLANET

dti

ENERGY WHITE PAPER

Our energy future -
creating a low
carbon economy

HM Government

Meeting The Energy Challenge A WHITE PAPER ON ENERGY

dti

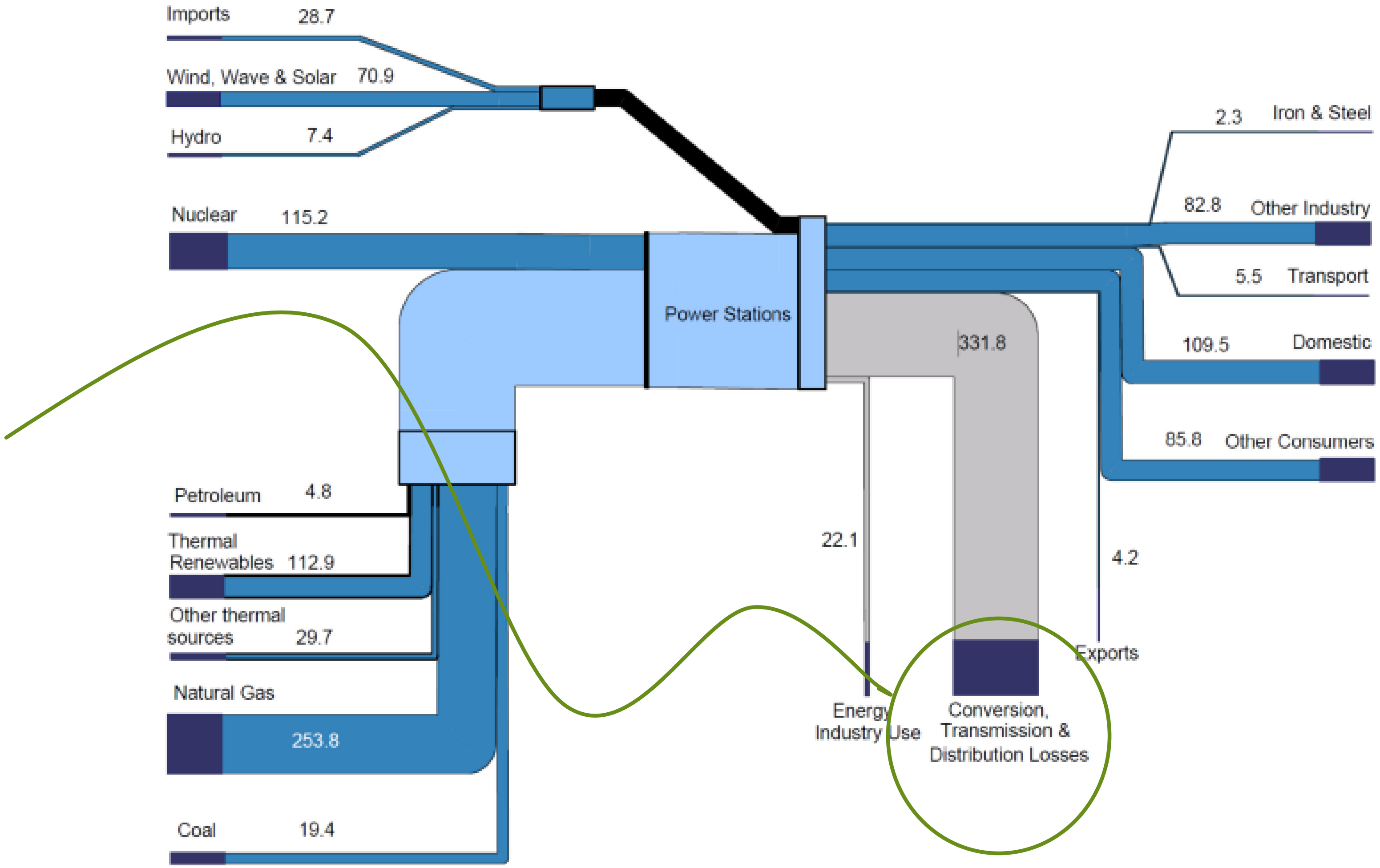
MEETING THE ENERGY CHALLENGE

A White Paper on Ene

MAY 2007

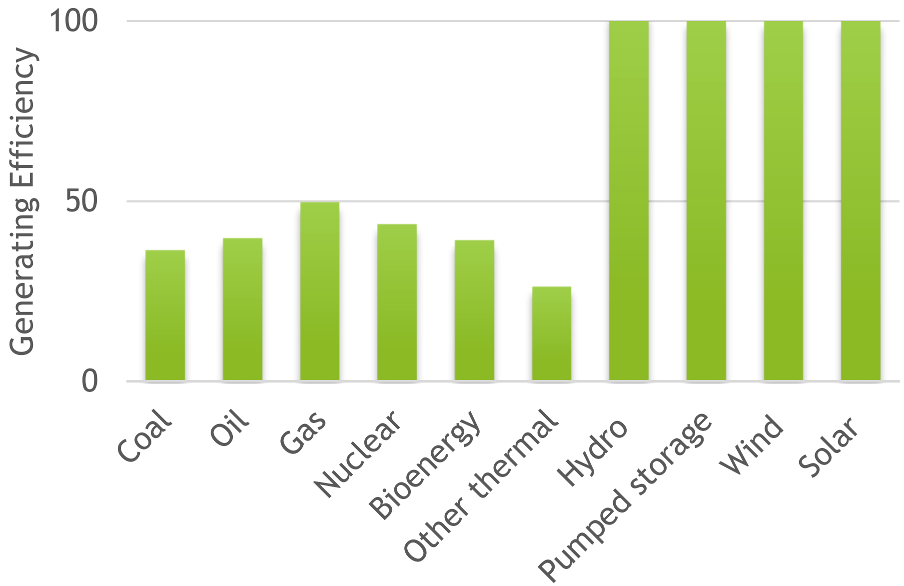
Electricity generation and usage 2021 (TWh)

Over half the energy used is lost!



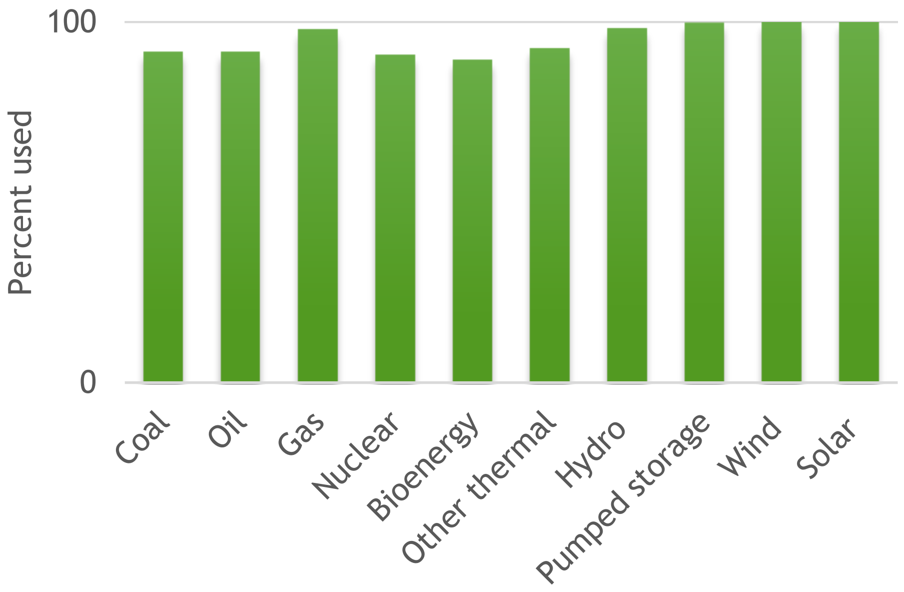
Digest of United Kingdom Energy Statistics (DUKES)

Losses



Thermal inefficiencies

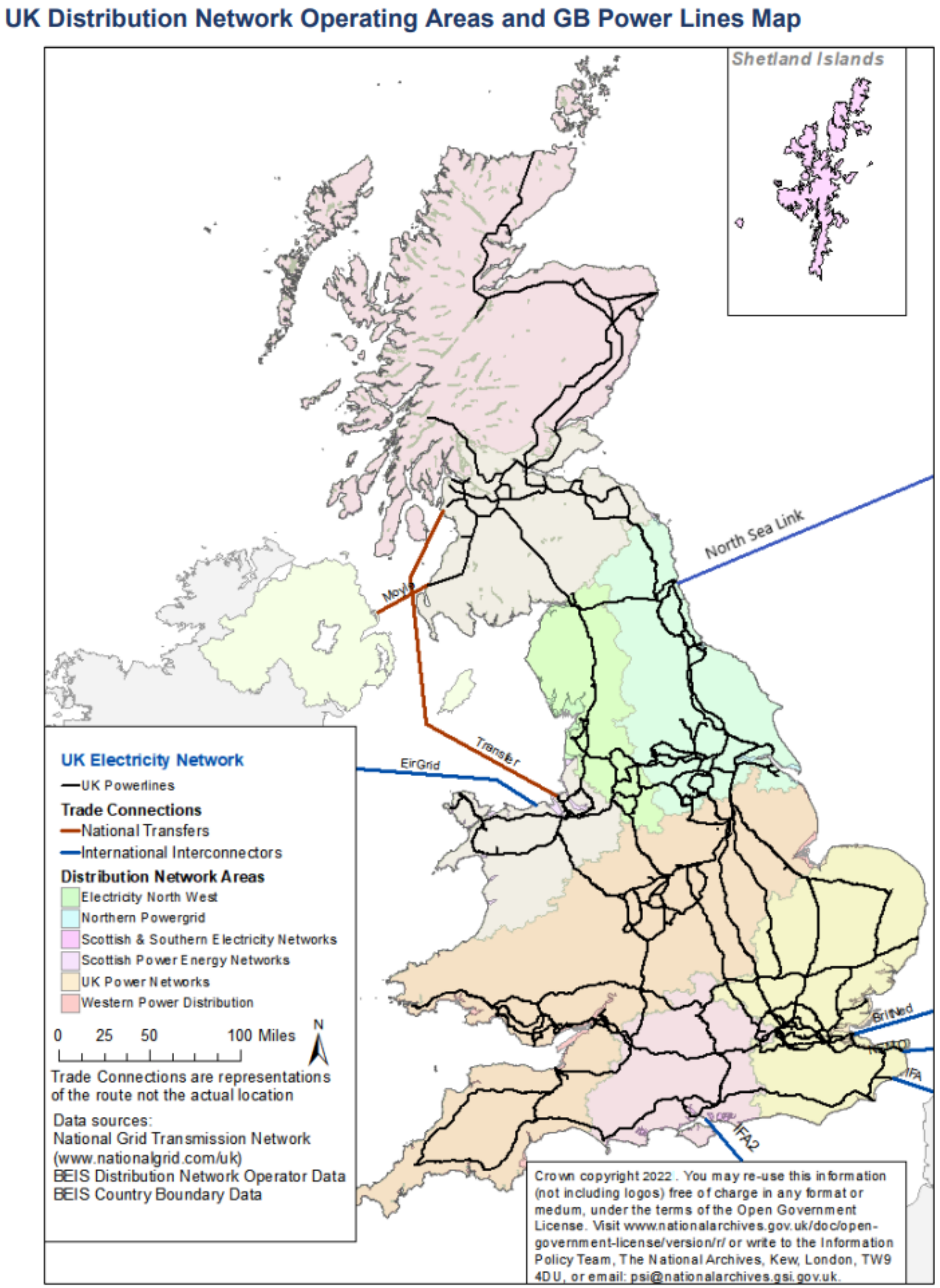
Use it or lose it!



https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1094460/DUKES_5.6.xlsx

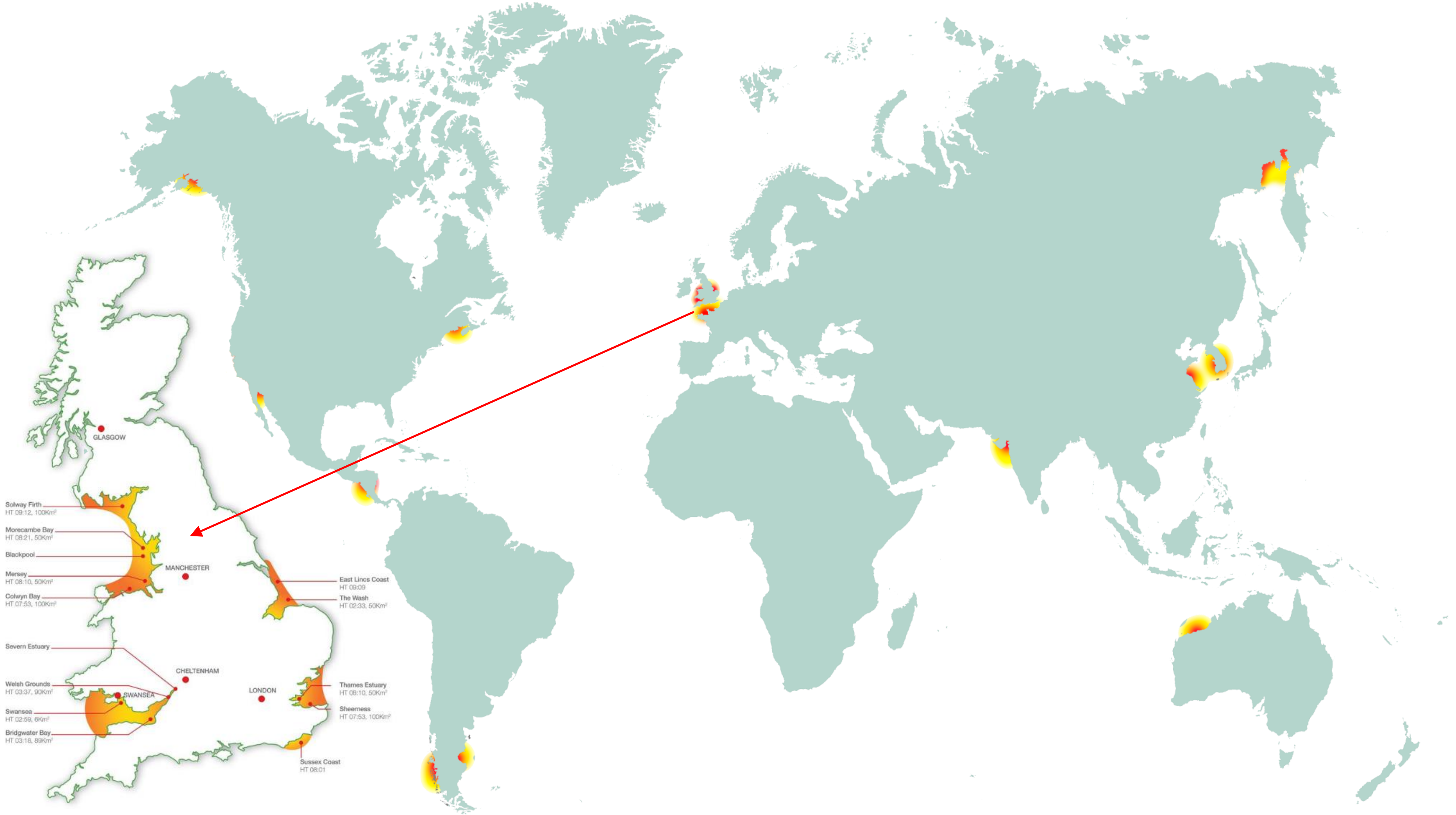
The electricity network

- Nearness to major power lines and connectors essential



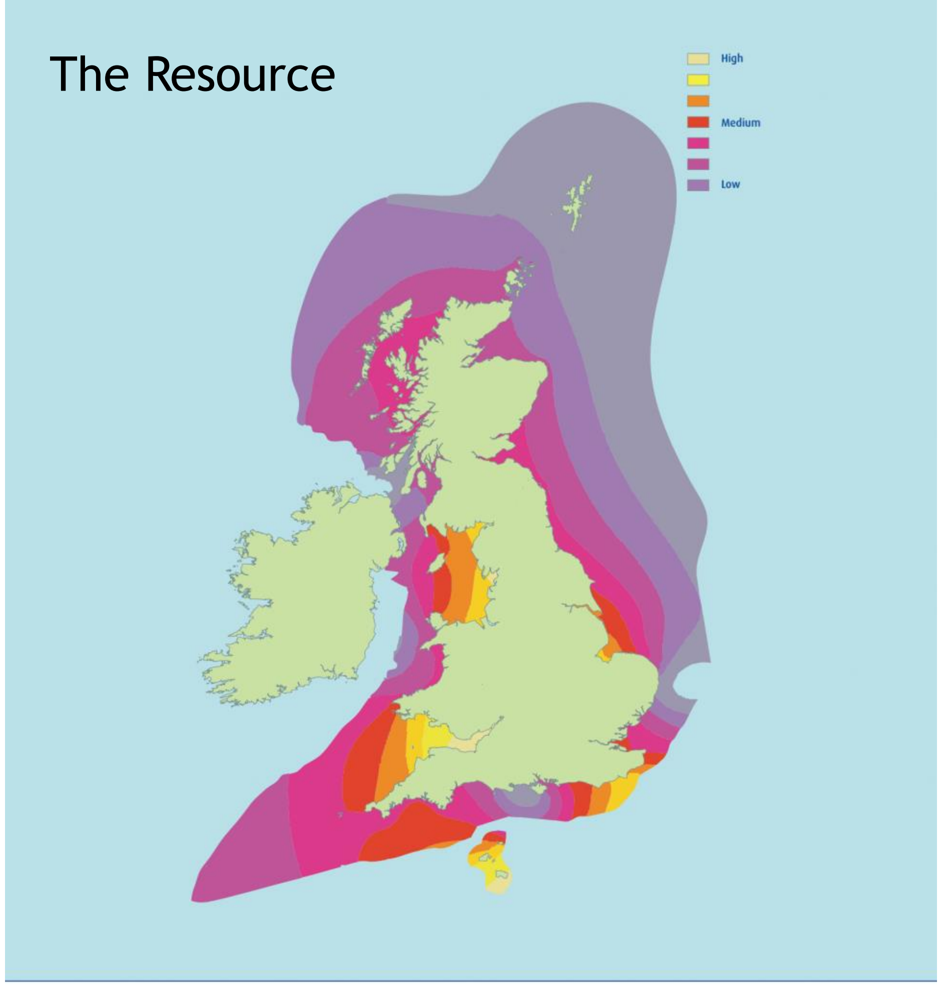
Digest of United Kingdom Energy Statistics (DUKES)

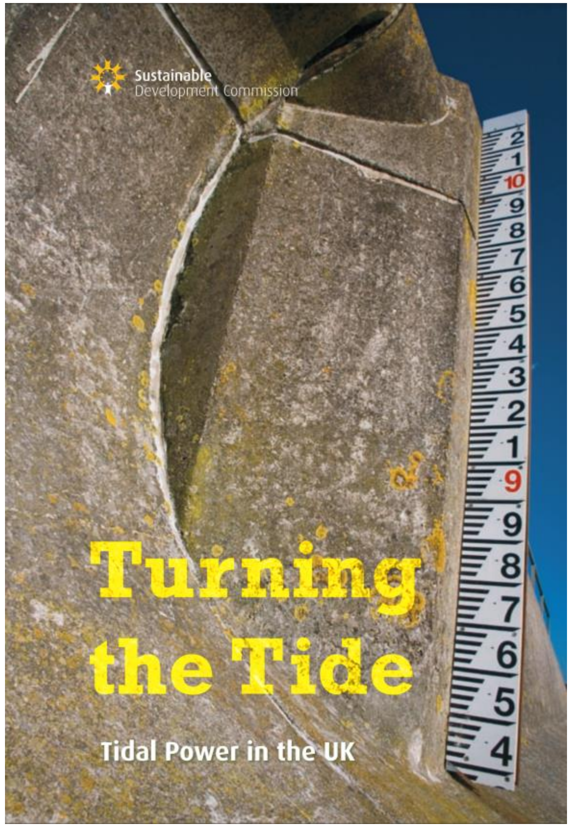
Tidal Range Energy Resource



Neill, S.P., Angeloudis, A., Robins, P.E., Walkington, I., Ward, S.L., Masters, I., Lewis, M.J., Piano, M., Avdis, A., Piggott, M.D. and Aggidis, G., 2018. Tidal range energy resource and optimization–Past perspectives and future challenges. *Renewable energy*, *127*, pp.763-778.

Where could tidal range schemes be built?




Sustainable Development Commission

Turning the Tide

Tidal Power in the UK

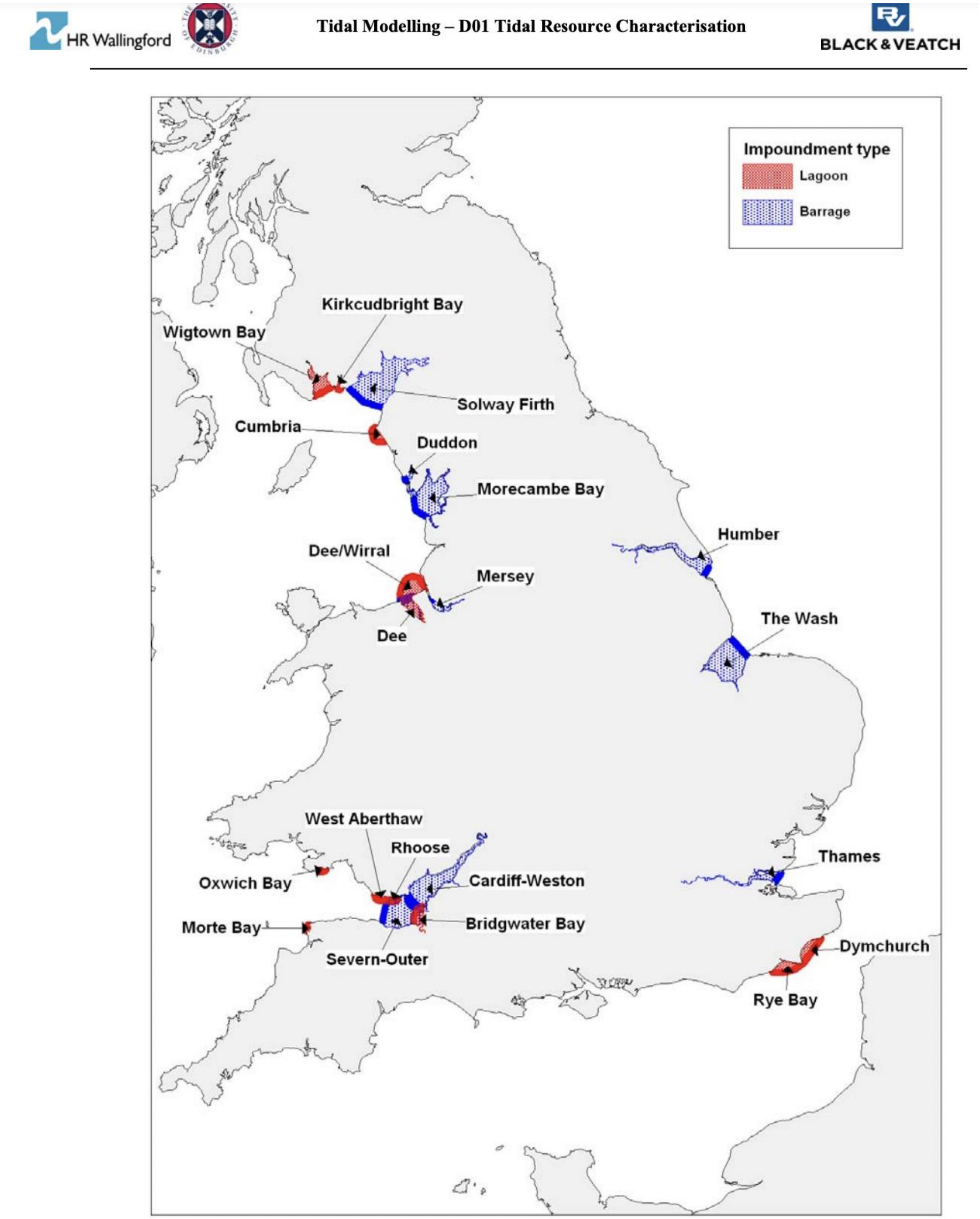
Turning the Tide
https://www.sdcommission.org.uk/data/files/publications/Tidal_Power_in_the_UK_Oct07.pdf

ETI Report

Black & Veitch (2011)
Tidal Resource
Characterisation
and Feasible
Schemes Report

13 December 2011

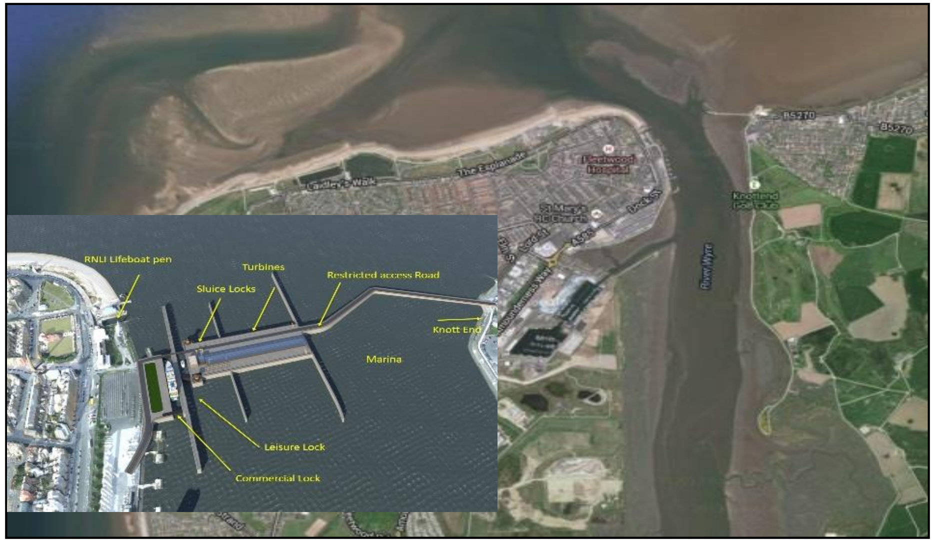
MRN_MA1009_15.pdf (dl.ac.uk)



HR Wallingford
Tidal Modelling – D01 Tidal Resource Characterisation
BLACK & VEATCH

Which UK estuaries are suitable for tidal range?

- **Estuaries**
- Approximately 15% of UK capacity
- More smaller estuaries (e.g. Wyre)



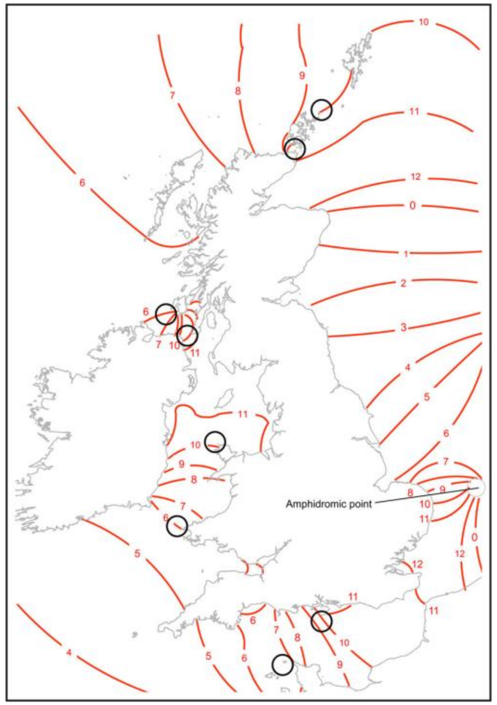
- Solway Firth
- Morecambe Bay
- Mersey
- Dee
- Severn
- Wash
- Humber
- Thames
- Forth
- Tay

Thames Barrier – flood protection and an opportunity missed

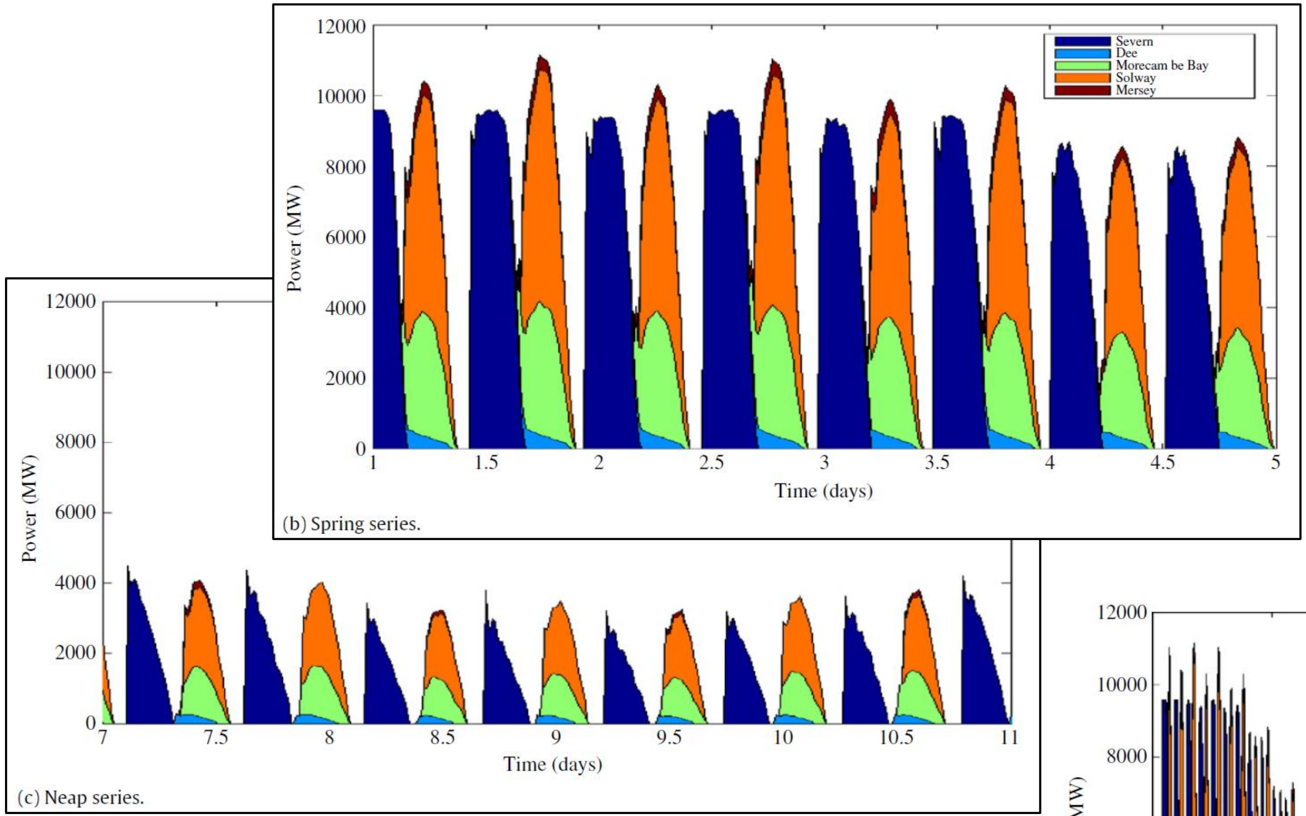
Yates, N., Walkington, I., Burrows, R. and Wolf, J. (2013) Appraising the extractable tidal energy resource of the UK's western coastal waters *Philosophical Transactions: Mathematical, Physical and Engineering Sciences* **371**(1985) 1-14

Tidal Resource Complementarity

Variability and phasing of tidal current energy around the United Kingdom. Iyer *et al* 2103



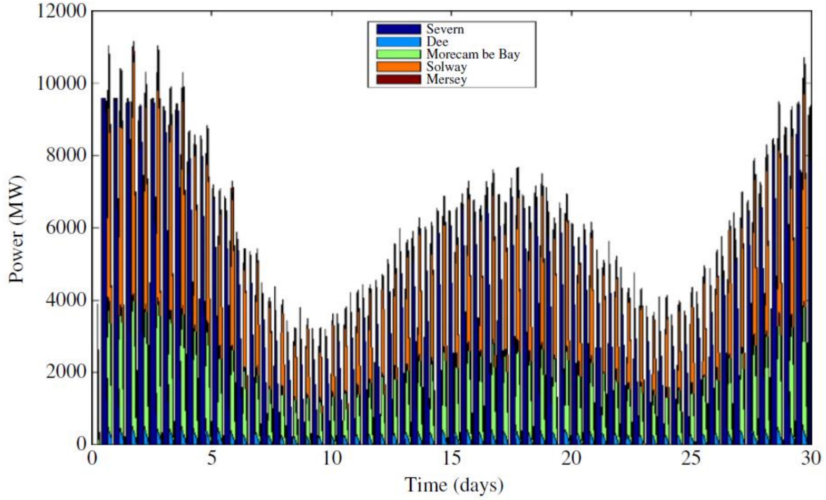
Co-tidal lines for the coast of UK.



(b) Spring series.

(c) Neap series.

The tidal range energy potential of the West Coast of the United Kingdom. Burrows *et al*, 2009



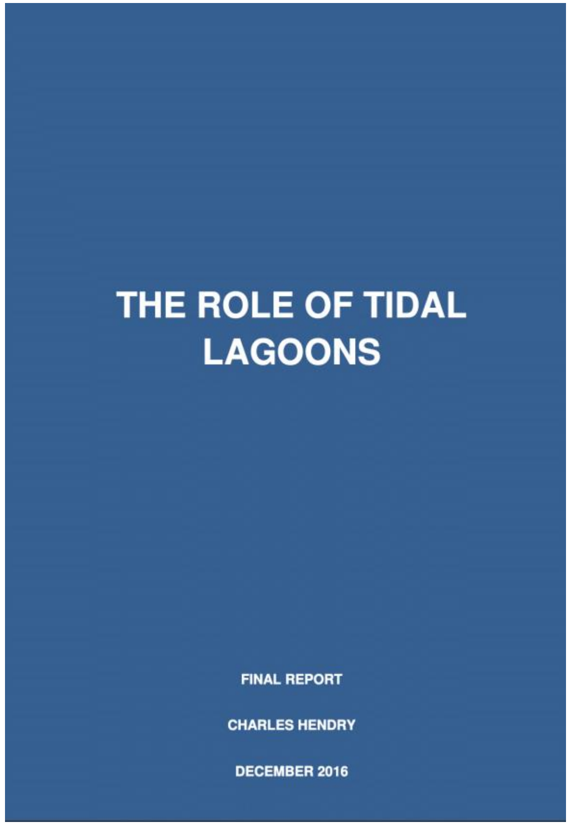
(a) Full 30-day power series.

Where else could they go?

- Tidal Lagoons
- Hendry Report
  - 37 GW capacity from 18 sites
  - 4 sites in NW England
  - ~ 50% of UK current capacity

… but not positive about current proposals

Offshore Lagoons
No-one
has assessed
their potential!



THE ROLE OF TIDAL LAGOONS

FINAL REPORT

CHARLES HENDRY

DECEMBER 2016

Site	Installed Capacity (GW)
Swansea Bay	0.3
Stepping Stones	0.8
Cardiff	3.4
Newport	1.4
Bridgwater Bay	6.5
Conwy	0.7
Colwyn Bay	3.2
Sefton	2.6
Wirral / Liverpool	1.6
West Cumbria	2.2
Blackpool	2.6
Wyre	3.0
Barrow in Furness	1.6
The Wash	0.7
East Lincs Coast	1.9
Sheerness	1.3
Thames Estuary	0.5
Sussex Coast	2.4
Total	36.9

Hendry Review – The website for the independent review of tidal lagoons, led by Charles Hendry (wordpress.com)

Hendry, 2016

The case for a Tidal Lagoon Programme

- *"I conclude that the potential impact on consumer bills of large scale tidal lagoons appears attractive, particularly when compared to nuclear projects over a long time period."*
- *"A new body (Tidal Power Authority) should be established at arms-length from Government, with the goal to maximise UK advantage from a tidal lagoon;"*
- *"Sites with the highest tidal ranges are in the Severn Estuary, followed by North Wales / Liverpool Bay and the North West."*
- *"the theoretical scale of opportunity in the UK is around 37 GW of installed capacity, from a tidal lagoon programme of 18 potentially feasible schemes, generating 55 TWh of electricity per year."*

Neill et al, 2018

"The potential for using tidal range to generate electricity was originally proposed for the Severn Estuary in Victorian times".
"a total potential energy of 366 TWh per annum … is found in UK waters,

Site Type	Mean tidal range (m)	Basin area (km^2)	Proposed Capacity (GW)	Estimated annual output (TWh)
Severn Barrage	7.0	520.0	8.64	17.00
Mersey Barrage	6.5	61.0	0.70	1.50
Wyre Barrage	6.0	5.8	0.05	0.09
Conwy Barrage	5.2	5.5	0.03	0.06
Swansea Lagoon	-	11.7	0.32	1.00
Newport Lagoon	-	-	0.75	–
Bridgewater Lagoon	-	-	2.00	–
Cardiff Lagoon	-	-	1.80-2.80	–
Colwyn Bay Lagoon	-	-	1.50	–
Blackpool Lagoon	-	-	1.00	

Table extracted from S.P. Neill et al. / Renewable Energy 127 (2018)

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Lancaster University Renewable Energy Group

Wholesale Electricity Prices

Lancaster University

- Pre-2021 ~ £45/MWh
- 2021 post Covid bounce
- 2022 Putin *Special Military Operation*
- Swansea Bay *CfD* £95/MWh

Year	Sell price, £/MWh		
	Average	Maximum	Minimum
2016	40.0	1,528.7	-100.0
2017	45.1	1,509.8	-73.1
2018	57.4	990.0	-150.0
2019	41.9	375.0	-88.0
2020	34.9	2,242.3	-70.5
2021	113.2	4,037.8	-70.0
2022	201.7	4,036.0	-90.3
Average	76.3	2,102.8	-91.7

Half-hourly wholesale system sell price from Elexon best view prices

https://www.elexon.co.uk/data/open-settlement-data/

Professor G A Aggidis

Tidal Range Alliance

Mission

- Promote the multi-disciplinary features and benefits of tidal range projects to key stakeholders across Government, industry and the media

Key Messages

- Multi-functional, multi-generational benefits beyond energy alone
- Security and stability of supply to help meet future energy needs
- Sustainability and contribution to decarbonisation
- Geographical spread of projects

BHA Tidal Range Alliance

LUREG
Lancaster University
Renewable Energy Group

TRA project estimates

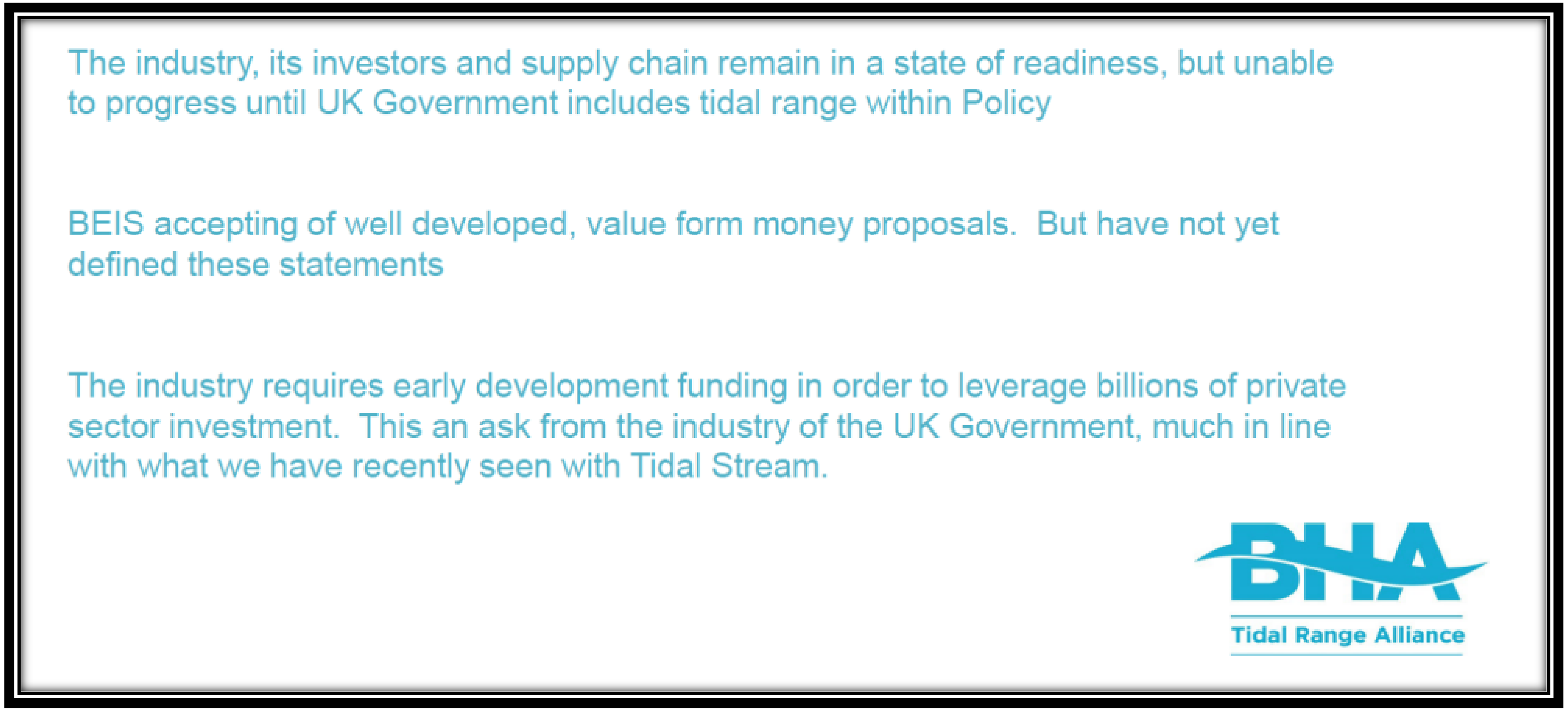
Lancaster University

Project	Cap. Ex.	GW	Construction
Mersey Tidal Power	£9 billion	3.8	7 years
West Somerset Lagoon	£8.5 billion	2.5	5 years
Wyre (Fleetwood)	£.15 billion	0.1	3 years
Blue Eden (Swansea)	£1.7 billion	0.35	5 years
Norther Tidal Power Gateway	£9.8 billion	4.0	7 years
Mostyn SeaPower	£0.6 billion	0.2	4 years
North Wales Tidal Lagoon	£7.5 billion	2.5	5 years
TOTAL:	**£37.52 billion**	**13GW**	**7 years**

BHA
Tidal Range Alliance

- ➢ Perhaps their sum of construction time is overoptimistic!
- ➢ It suggests that in 7 years we could have 13 GW of tidal power.
- ➢ Perhaps here we require a more realistic value of years that is significantly higher.

Barriers to success



The industry, its investors and supply chain remain in a state of readiness, but unable to progress until UK Government includes tidal range within Policy

BEIS accepting of well developed, value form money proposals. But have not yet defined these statements

The industry requires early development funding in order to leverage billions of private sector investment. This an ask from the industry of the UK Government, much in line with what we have recently seen with Tidal Stream.

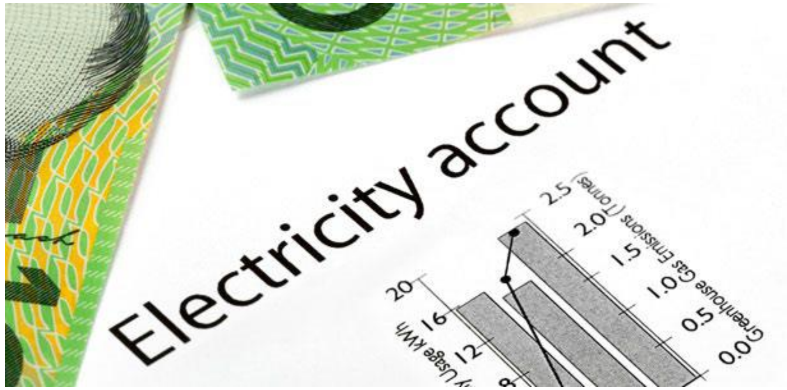
BHA
Tidal Range Alliance

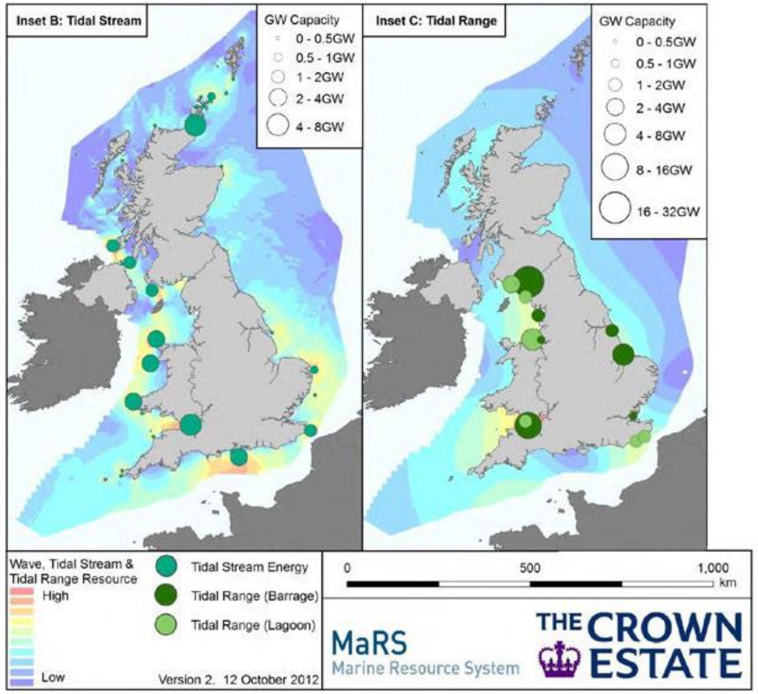
Time Frame

Step	Stage	Time (Years)	Potential
1.	Initial examination (proposal)	2-3	0.5
2.	Detailed analysis and full costings	2-3	2.5
3.	Planning approval	5	2
4.	Construction deployment	8	6
1-4		***18***	***11***
5.	Operation	130	130
6.	Decommissioning	5	5

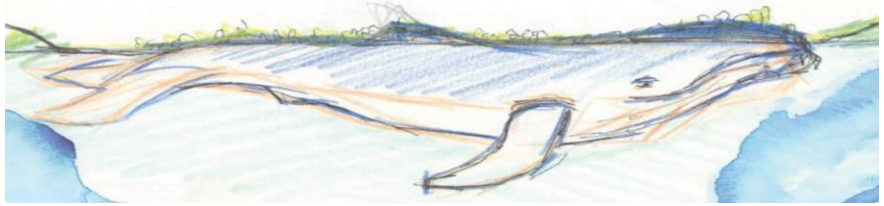
Objectives (Power)

- Sustainability
- Zero carbon
- Independence (from international markets)
- Balance of supply
- Storage





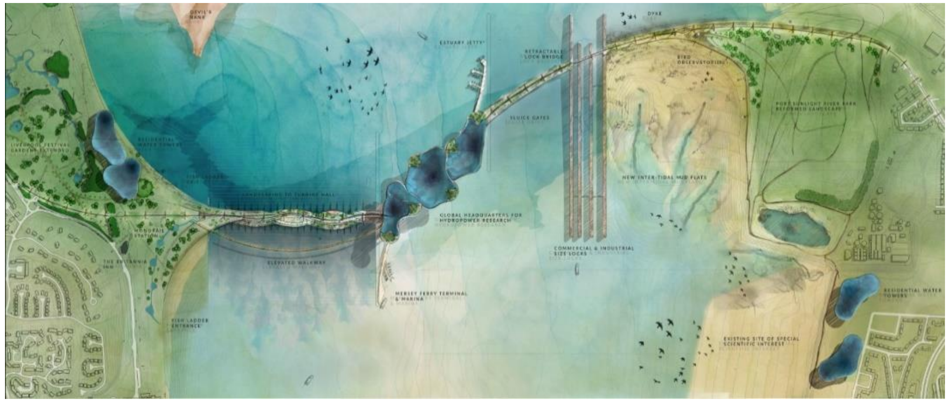
Objectives (other functions)



THE GREEN WHALE (2017)

- **Environmental**
  - Carbon emission reduction (including carbon capture in saltmarsh)
  - Flood protection (marine from sea level rise and terrestrial from rainstorms)
  - Habitat creation/management (including Spartina grass an invasive)
  - Species conservation (esp. birds, marine mammals and fish)
- **Socio-economic**
  - Jobs
  - Transport
  - Power management (e.g. grid network connections)
  - Recreation
  - Tourism

Petley, S., Starr, D., Parish, L., Underwood, Z. and Aggidis, G.A., 2019. Opportunities for tidal range projects beyond energy generation: Using Mersey barrage as a case study. *Frontiers of Architectural Research*, *8*(4), pp.620-633.



Latest relevant research at Lancaster

Models

- Lancaster 0-D Generation Model
- Lancaster Cost Model

Publications

- Lancaster 0-D Generation Model (in prep)
- A Model of the Costs for Tidal Range Power Generation Schemes (in press *ICE Energy*)
- The Value of Tidal Range Power Generation (submitted *ICE Energy*)
- Tidal range electricity generation: A comparison between estuarine barrages and coastal lagoons (*Heliyon* - DOI: 10.1016/j.heliyon.2022.e11381)

Lancaster 0-D Generation Model

Underpinning data

- Turbine
  - Efficiency (Hill chart)

- Water
  - Tidal cycle (timing & head)
  - Bathymetry (volume)

Variables

- Turbine
  - Size
  - Number
  - Operation
    - flood., ebb or 2-way
    - double/triple regulation
    - pumping
- Generator rating
- Sluices

Lancaster Cost Model

$$Capital\ Cost = N_{t+g}C_{t+g} + N_{t+g}C_p + N_sC_s + L_cC_c + L_bCb$$

Where
C_{t+g} = **turbo-generating equipment** cost
C_p = **powerhouse** cost
C_s = **sluices** cost
C_c = **cofferdam** cost
C_b = **bund** cost
N_{t+g} = number of turbo-generators and powerhouse sections
N_s = number of sluices
L_c = length of the cofferdam.
L_b = length of the bund.

Where does UK tidal range power sit?

Hurdle rates and decisions

- What investors expect to risk before they will invest (i.e. the lower the more favourable)
- Balances risks, competing opportunities, inflation, interest rates, etc.
- Sometimes seem counter intuitive rejecting larger projects with higher total returns
- Must involve economists!

Levelised Cost of Energy (LCoE)

- Technology specific hurdle rates (2018)
- Still complicated
- No tidal barrage!

- Kwasi Kwarteng (then Chancellor) suggested that Swansea Bay would be. He said 8.00% (range between 6.20% and 9.00%)

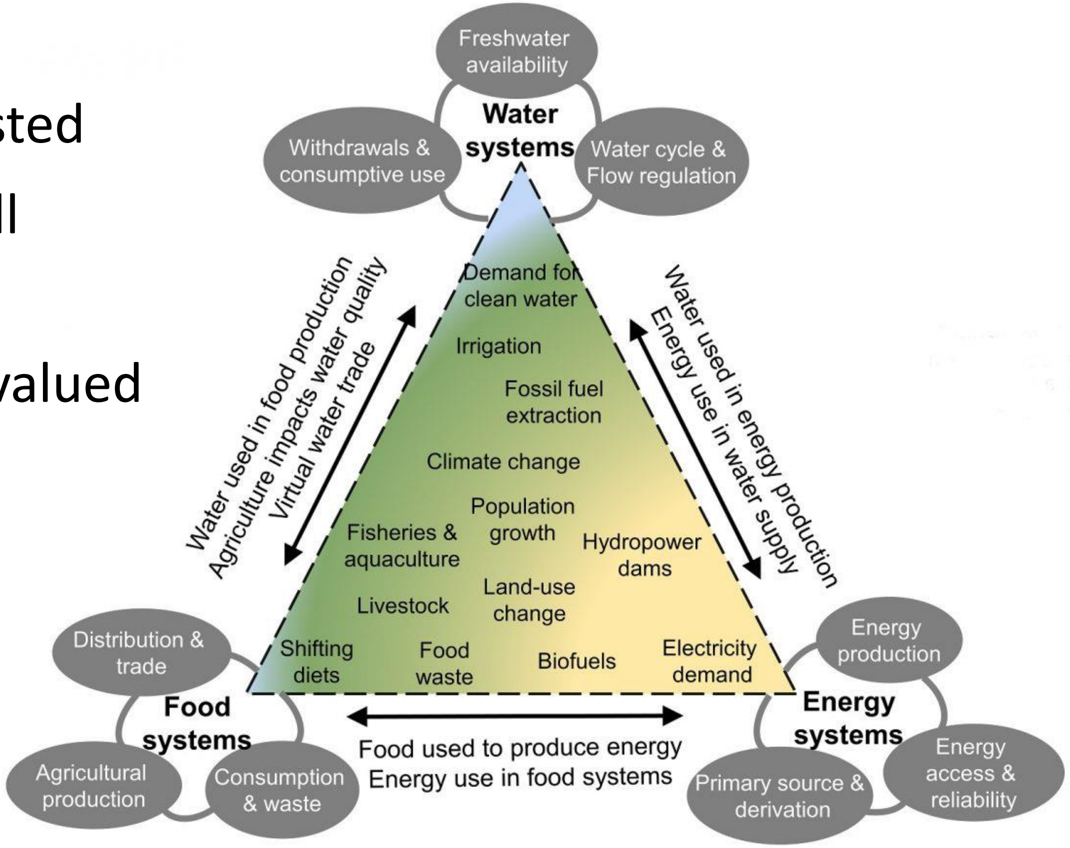
Technology	Hurdle rate
Solar PV	5.00%
Onshore wind	5.20%
Hydro	5.40%
Hydro large storage	5.40%
Landfill	6.10%
Offshore wind	6.30%
EfW	6.50%
Sewage gas	7.10%
Gas/diesel reciprocating engine	7.10%
OCGT	7.10%
ACT standard	7.20%
CCUS gas nth of a kind	7.30%
CCGT	7.50%
EfW CHP	7.60%
Dedicated biomass 5-100MW	7.90%
Dedicated biomass >100MW	8.10%
ACT advanced	8.10%
AD	8.30%
Wave	8.60%
ACT CHP	8.90%
CCUS gas first of a kind	9.00%
CCGT CHP	9.00%
CCUS biomass	9.10%
Biomass conversion	9.20%
Tidal stream	9.40%
Biomass CHP	9.90%
AD CHP	9.90%
Geothermal CHP	18.80%

Electricity Generation Costs 2020 (publishing.service.gov.uk)

Other issues….

Questions are not simple

- Energy generation may be compromised by conservation, flood protection/management, recreational requirements – all need to be costed
- Sea level rise is a major issue that threatens all estuaries and coastlines
- Multifunctional benefits need to be properly valued
  - Transport
  - Economy/employment
  - Pollution
  - Etc.
- Consider the nexus of our requirements



The Challenges of Meeting Future Food, Energy, and Water Needs - Eos

but….

Negatives

- It hasn't happened yet
- It's low on the financiers list
- There are still concerns about the environment…

Positives

- Power generation may not be the main driver
- Sea level rise needs an urgent response
- Protecting habitats and species reverses conservation concerns
- It's gaining popularity.

Conclusions

- Needs to be thought of as part of the UK’s whole energy system
  - 10% rising to a maximum of 20-25% total for security
- Multi-functional so other benefits must be costed in
  - Socio-economic
  - Environmental
- Research ongoing, but more needed
  - Construction options
  - Environmental consequences
  - Economic and political research

Lancaster University
Renewable Energy Group

What can we do?

- Robust and sound research both focussing on the engineering and its interactions with other disciplines.
- Publish beyond standard scientific literature.
- Seek funding to address questions such as the brief given today.
- Press politicians to support (and co-fund) a proof of concept barrage in Britain.
- **ACT NOW!**

Thank you

IMechE NW Power Industries

Tuesday 8th November 2022

Tidal Range Energy Opportunity for the UK

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