in collaboration with
Ken Kasriel

Offshore Wind Economics For Complete Beginners

Self-paced online course for those new to project economics, offshore wind, or both

Including Excel exercises and case studies

https://ore-catapult-school.thinkific.com

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What is this course?

Offshore Wind Economics for Complete Beginners is a self-paced, hands-on, detailed pathway course into the subject for those who are new to offshore wind energy, cashflow modelling, or both.

Through hands-on Excel case studies and preparatory exercises (all with solved and unsolved versions); approximately 12 hours of wide-ranging, often conversational video lectures (averaging around 3-4 minutes each); and various quizzes and tangents, this course is Version 2.0 of a successful pilot given in 4Q 2020 (please see "Student Feedback", below).

It comes from a nearly 18-month collaboration between two experienced, plain-spoken energy valuation analysts – both Big 4 alumni, one deeply experienced in offshore wind (OSW), the other a Wiley Finance Excel textbook author, oil & gas valuation practitioner and visiting MSc. economics professor.

Assuming no renewables background or Excel cash flow modelling experience, the course first gradually immerses students in the relevant high-level issues framing OSW (based on early 2020s technology).

Then, in rolled-up-sleeves-with Excel mode, we'll see how to simulate wind speed patterns and power generation for different notional OSW wind farm sites. Solved and unsolved versions of exercise and model files are provided and coded for clarity.

Finally, in a realistic case study, we'll combine this with detailed cost and other technical guidance, with all jargon explained, to arrive at our own estimates of commercial value creation or destruction, and use variance analysis to explain the differences between them.

Who should enrol

Lateral-thinking or merely curious, new or experienced analysts seeking a hands-on introduction to offshore wind energy, through an Excel lens, within a broader renewables context.

Certificate of completion

Students will receive a digital certificate of completion once all course videos have been viewed and end of section quizzes completed.

Prerequisites

Students need Microsoft Excel, an internet connection for watching online video, and an interest in offshore wind economics.

Comfort with how dollar signs are used in Excel formulas, and with basic IF, AND etc. statements, are useful but not essential. All coding is detailed clearly in non-academic language.

No renewables energy background or valuation experience is assumed. Pilot version students with the latter, however, say they still got insights from lectures on discounting and picked up useful Excel techniques.

Course overview

The course's first unit introduces many OSW/broader renewable power issues, some within, and some beyond, the context of the multi-option site selection case study and exercises which come in in the fifth and final unit.

The remaining, mainly hands-on units swap Unit I's macro lens for a micro one, to prepare us in careful stages for Unit V's modelling and analysis, where we have to pick the best of several competing wind farm development options.

Unit I: Where's good for offshore wind?

We start with a wide-roaming, sometimes conversational world tour of what's needed for a commercially viable OSW farm with early 2020s technology (as well as a peek beyond, at emerging floating wind and energy storage techno-economics).

Broader utilities and renewables backdrop topics, such as grid balancing requirements, intermittency, onshore transmission, and the "experience curve" view of industry cost trends, all get treated here.

This unit makes good use of a handy, global OSW technical resource potential map, custom designed for the course, produced by industry consultants AquaTerra, and free to all enrolees.

Unit II: Wind-to-Watts: Resource estimation

Here you will be guided through building an Excel-based simulation model of annual wind speed patterns at different locations, from first principles, using what's called the Weibull function.

We'll then see how to combine this windy result with turbine-specific data, to work out annual gross annual electricity production (**AEP**) and capacity factors (a measure of utilisation) for a single turbine.

Next, we'll use this new know-how to pick the winners of two turbine beauty contests – which are best for the case study site? Choose wisely, as the winners will determine which ones will be used in the case study model, directly affecting its revenue line. So, no pressure. And just for fun, we'll also learn to estimate how different turbine rotor hub heights change AEP.

For students new to simulation modelling, the theory and mechanics are laid out clearly. Those with more experience and who have used only third-party simulation add-ins, might like the cheap and cheerful, checkable, 100% native Excel, non-VBA approach.

We'll also take an accessible look at the underlying physics behind wind turbine generation, and the roles played by wind speed, rotor blade length, natural limits and other factors. Maybe we'll be surprised, only a few lessons after being introduced to a turbine "power curve" – basically a lookup table of how much power is generated at different wind speeds – how straightforward it is to nearly replicate the curve of a turbine spec published by International Energy Agency, et al., based on just a few of their key inputs and some basic maths. This material is non-core, and not used directly in the case study model, but merits knowing as it explains the basics behind how wind becomes electricity.

Unit III: Cashflow-based valuation basics in Excel

This unit gets you up to speed on the basics of valuation: the what, why and how of plain vanilla project-level, post-tax net cashflow modelling. It breaks calculations and logic into small, clearly captioned/otherwise explained steps, with asides on good and useful Excel techniques/habits braided in as we go.

Excel and valuation novices are well supported in this unit. To let us first focus just on generic project and cashflow modelling and discounting theory/practice, without the complexities of wind-specifics just yet, here we roll out a more compact and accessible "mini model" for this unit's walk-through. This way, by the time we're on top of these basics, we'll recognise most of the formulas when we get to the Unit V case study model, and so can focus there on the wind-specific content, playing "what-if", and analysing results.

While designed for newbies, more experienced analysts in pilot course feedback say they benefitted from Unit III's discussions of

- what we really mean when we "discount" cashflows to reach net present value (NPV);
- exercises showing how NPV and its troublesome twin, internal rate of return, sometimes "act funny";
- and how to explain these, or any other valuation, to yourself and others, with an analytical method which sheds much more light than Excel's NPV function, which sometimes acts like a single-celled black box.

Unit IV: Case Study: Outlining options and their costs

If online courses had broad steel support foundations, Unit IV would be ours. It offers a fundamental, yet layperson-friendly and perhaps uncommonly granular walkthrough of detailed case study assumptions. These cover a wide array of modern, utility-scale OSW technical items and services required across our projects' assumed 25-year operating life cycle.

These include turbines, foundation types, array cables, substations, HVAC vs HVDC transmission kit (if these terms don't mean anything to you now, they will), export cables, site conditions, operations and maintenance costs, service lives, and decommissioning.

Special emphasis is placed on explaining not only the cost assumptions used in the various case-study scenarios, but also why and how they might differ in other circumstances, as well as the unique economic trade-offs posed by different development concepts.

This broader understanding won't make you a wind farm cost estimation specialist, but it will give you plenty of good questions to ask one!

Professional footage, used courtesy of a number of major OWS industry companies, helps drive home the sometimes mind-blowing scale and mass of the very, very tangible capital items behind the mild-mannered Excel cost line item captions.

Unit V: Multi-option case study model: Full model and analysis

Here we'll arrive with

- the gross, single-turbine power generation results we got in Unit II,
- the cashflow modelling savvy (including how to make flexible timing assumptions) from Unit III, and
- an understanding of over a dozen principal cost categories from Unit IV.

After just a bit more preparation, covering the likes of

- power losses (some of which arise when our single turbine gets multiplied by 100 or more, and arrayed in a farm); this is how we get from gross, single-turbine AEP, to net project AEP, and
- pricing (feed-in tariffs vs market pricing, over user-specified periods)

we'll now see all these key ingredients as moving parts in one modelling frame, designed to help us choose the best of several wind farm development options.

Case study details

The case study premise is that you, a developer, are ready to start a 1 gigawatt (we'll put that into context for you) project, off the coast of a windy, fictitious country which takes its net-zero commitments seriously, and so is generally receptive to the idea.

Some local stakeholders, however, object that the farm would be visible from beach developments, which contribute a lot to the local economy. Worried mainly about how tourists might react to the view, they win an injunction, stopping your project until either a court can rule, or for some reason they withdraw their petition.

They tell you, in fact, what would make them do so: if you were to agree to move to a site in the same permitted farm development zone, but too far to be seen from shore, they'd drop the claim.

This offer raises some options for you to consider. Going further out means somewhat higher costs, due to longer transmission-to-shore power cables, all other things being equal.

But in fact, all else is *not* equal:

- on the one hand, this farshore site is in deeper water, which is usually not a good omen for OSW costs.
- on the other, there are higher wind speeds further out, and so higher generation potential.

Whether this plus outweighs those minuses is not obvious. You have to run the numbers!

But not just yet, as there are other nuances to factor in. One is time-related. You believe that a court case could take 1-3 years to resolve. As you are not being asked to go altogether, but rather, just out of site, your options are to:

- agree now to go further out, meaning local stakeholders would drop their claim, and you could get started today
- contest in court and lose; meaning that apart from walking away, your only option is to develop the farshore site, but starting the project up to three years later than planned
- contest in court and win; meaning you could develop either the nearshore or farshore site, but again, up to three years late.

Having seen in Unit III

- how sometimes, discounting can shrink economic profits, the longer they are delayed (just like butter melts more, the longer it's under the sun), and
- how to quickly shift things in time in Excel,

we'll now be able to quantify the total "discounted", or "net present" value effects of any delays on the options where they apply.

And just to keep life interesting, each of the options – near or far, early or late – can vary in yet another way: whether our 1 GW farm has 100 large turbines, or 166 smaller ones, to see whether any economies of scale emerge.

The case study model determines the best option as the one generating the highest discounted post-tax cashflow, or NPV. It has various features to encourage playing "what-if" by making it easy to compare options – not only the results at a glance, but if needed, a visual breakdown behind the "why".

It also has a simple VBA macro, coded with notes for non-coders, to estimate any option's Levelised Cost of Energy, a key industry metric which gets its own lecture.

Results of the solved version of the model are explained in detail and interrogated step by step in a comprehensive case study analysis discussion. Follow-on exercises and written material, for the hard-core, explore further scenario nuances.

Endorsements from students of the 4Q 2020 pilot course

Version 1.0 of this course was given online in October/November 2020 for the Petroleum Exploration Society of Great Britain. Here is what students said.

"I found it extremely helpful and perfect for someone like me - lots of upstream cash flow experience but no renewables … [It's a] broad introduction to the economics of offshore wind generation, with emphasis on breaking down the cash flow into its parts - energy production, tariffs, revenues, capital and operating costs….

Very credible presenters, ability to get hands-on and to take away a simplified model … The waterfall charts were some of the best tools I've seen used in explaining some of the factors that impact NPV!"

- Stewart Williams, VP, Energy Research, Wood Mackenzie

"Overall the course has been great. I am a newcomer to wind energy but found it very accessible. The level of detail in the lectures for me has been unparalleled by other courses that I've attended. The content was information-rich, and the level of difficulty of the exercises was well pitched and sufficiently hands-on to understand the theory from the lectures.

The course significantly improved my understanding of offshore wind economics and economic principles in general, and following the course I was able to expand and transition my role into renewable project economic modelling. I am certain that the understanding of the wind industry I gained from this course directly contributed to this."

- Toya Latham, Analyst, GlobalData Energy

"Would recommend… An excellent introduction to wind power economics which exceeded my expectations for the amount and quality of materials…. A good balance was struck between general economic concepts and wind specific ones.

The Socratic method worked well. You make a good double act.

Having been on the receiving end of economics spreadsheets for many years, it was good to be walked through how they are made. In addition, the tips on quality control and tracing preceding cells were generally useful. Particular credit to you for the Monte Carlo simulation without expensive software; I will use this again."

- Philp Rawstron, Subsurface Advisor, OGL Geothermal

“Excellent, well organised course. It did a good job of "lifting the bonnet" on the workings of the spreadsheets.

The key to delivering online courses is to keep the interest of the audience especially when the content is technical and that was certainly achieved. Strikes a really good balance between delivering knowledge without it being too ‘heavy’….

As a newcomer to offshore wind, I found the course extremely useful and a great introduction. Would recommend without hesitation. Good content, well delivered, strong self-study examples to reinforce lecture content, and presented by two really passionate presenters.”

-Roshan Khan, Petroleum Engineer, TRACS International

“Overall, useful and insightful. Pitched at the right level for a total wind novice…. the Weibull function and how this is used with the power curves was the fundamental learning for me.

- Tim Davies, Group Exploration Manager International, Harbour Energy

“An outstanding introduction to the fundamentals of wind power generation and economic modelling. It was authoritative, focused and instructive, and where appropriate witty.

I would recommend this as a taster for Petroleum Economists, Explorers and economists, investors, scientists"

- Colin Clarke, Senior Geophysicist, Lloyd's Register Energy

“Most wind courses are too basic. This course got advanced enough to offer insight, without getting bogged down in engineering details”

(Name withheld)

“[Level of exercises was] good. As with any exercise you can always make it more difficult yourself, but not simple to make it easier when you are struggling!”

(Name withheld)

“I thought the material was put together in a very thoughtful and fun way. There was a good balance between theory and practical modelling examples in Excel. In all cases, the course instructors explained the technical jargon to avoid any confusion. The modelling was very well explained and there were several levels of complexity offered for the homework depending on the participants capacity…

I felt the fun, humorous and sounding-board nature of conversations between Gavin and Ken kept the audience very engaged throughout the course, especially after what for many had already been a long day in the day-job!

Would recommend, an excellent learning pathway for people looking to get into offshore wind technical and/or commercial roles"

(Name withheld)

Course leaders' biographies

Gavin Smart has 10 years of wide-ranging experience in financial analysis and economic modelling of offshore renewables, spanning project appraisal, business planning, budgeting and financial management. A qualified Management Accountant (ACMA, CGMA), Gavin held a number of traditional finance roles before moving into valuation and business modelling with Ernst & Young in the Middle East, working across a range of industries and delivering valuation modelling training to EY graduates.

He moved into offshore renewables in 2010 as a senior valuation modeller with ScottishPower Renewables, where he was part of cross-disciplinary teams working on UK and European offshore wind and marine energy projects, compiling the business cases and multiple scenario analyses for Board-level review of projects including East Anglia One, Wikinger and St Brieuc and bringing the West of Duddon Sands project to successful Final Investment Decision (FID).

Gavin joined the Offshore Renewable Energy (ORE) Catapult, the UK's leading technology innovation and research centre for offshore renewable energy, in 2014, where he is currently Head of Analysis & Insights. He leads a team of financial and strategy analysts and is responsible for developing and maintaining financial and economic modelling, which feeds directly into the organisation's commercial strategy and for generating insights from ORE Catapult projects.

He has led a number of high-profile, industry-level projects, including: lead author on the International Energy Agency's IEAWind Programme Task 26 "Offshore Wind Farm Baseline" report, 2016; "Macroeconomic Benefits of Floating Offshore Wind in the UK", 2018; co-author on "Tidal Stream and Wave Energy Cost Reduction & Industrial Benefit", 2018; and led quantitative analysis workstream of the Offshore Wind Cost Reduction Monitoring Framework (CRMF) 2014-2017.

Gavin and his team also work with a number of innovative companies helping to quantify the benefits of their products and services, and identifying pathways to commercialisation.

In addition to conducting and documenting detailed and complex analysis, Gavin regularly presents project findings and industry thought leadership at various offshore renewables conferences, including Global Offshore Wind, Wind Energy Hamburg, Reuters Offshore & Floating Wind Europe.

Ken Kasriel is an independent petroleum economist and Associate Principal Economist with ERCE Energy in London. His 25-year career in petroleum finance also includes working in oil and gas equities research (including at Robert Flemings, now part of JP Morgan), as Senior Analyst with PwC's global petroleum practice, and Senior Petroleum Economist with RPS Energy.

He has built upstream economic models in 27 fiscal regimes in Africa, Asia, Europe, the Former Soviet Union, the Middle East and the Americas, for the purposes of valuation, fiscal/legal due diligence, investment screening, portfolio optimization, negotiation, commercial arbitration and regulatory reporting. Mid-case resources involved have ranged from a few million to over a billion barrels of oil equivalent, from pre-drill exploration scoping through to brownfield development option valuation.

He has co-authored papers presented to the Society of Petroleum Engineers/published in *The Oil & Gas Journal*, as well as the textbook, *Upstream Petroleum Fiscal and Valuation Modeling in Excel: a Worked Examples Approach*, which student bookstore sales data indicate has been adopted by 21 US universities and colleges since its publication in 2013 by Wiley Finance. Editorial and Amazon reviews give it good marks for accessibility / laymen-friendliness.

He has taught a short course in petroleum economics and risk analysis to non-economist Petroleum Geoscience MSc students at University of London, Royal Holloway. He has also taught upstream valuation modelling at the French Institute of Petroleum (IFP School); privately trained new oil and gas company and investment banking staff before starting their first economic modelling roles; and built courseware used in training petroleum law students, simulating fiscal contract negotiations among governments and international/national oil companies.

Originally a journalist (including a role as a multi-sector business editor of a business magazine published by the Economist Group), he prefers plain English to academic speak, and likes cross-disciplinary grazing, learning and explaining.

Course pricing

The course is priced at £820 + VAT

Check out our video on the course page

For more information, and a feel our presentation style, please visit https://ore-catapult-school.thinkific.com for video overviews and free sample lectures.

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To give you the full flavour of what the course has to offer, see the full table of contents here in super-summary view, summary view and detailed view.

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- Unit I.A.2: Introduction to Wind Speed Distributions
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- Unit I.A. 6: What's Big for an Offshore Wind Farm?
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- Unit I.B.2: Transmission Costs and Distance: a UK Example
- Unit I.B.3: Onshore Transmission Charging
- Unit I.B.4: Getting Power Not Only Where, But When It's Needed
- Unit I.B.5: Electricity - Balancing Supply and Demand
- Unit I.B.6: When a Grid Wobbles
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- Unit I.B.8: Introduction to Utility-Scale Power Storage
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- Unit I.C.1: Back to the Present - Avoid Long Distance Transmission Where Possible
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- Unit II.A.9: Programming a Fair Die
- Unit II.A.10: Preliminary sense check of our programming
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- Unit III.C.5: Maximum Exposure and Breakeven; Pivoting Away from the NPV Function
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- Unit III: Space for Potential Future Resources

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- Unit IV.B.8: Cost Impact of Different Seabed Conditions
- Unit IV.B.9: Seabed Installation Terminology: Reminders/Explainers (1/2)
- Unit IV.B.10: Seabed Installation Terminology: Reminders/Explainers (2/2)
- Unit IV.B.11: Site Parameters Summary
- Unit IV.B.12: Design Life
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- Unit IV.B 14: Quiz - Case Study Assumptions

Unit IV.C: Case Study Costs - Devex

- Unit IV.C.1: Introduction to Development Expenditure (Devex)
- Unit IV.C.2: Development Risk and Environmental Surveys
- Unit IV.C.3: Environmental Protection and Standards
- Unit IV.C.4: Devex Costs

Unit IV.D: Case Study Costs - Capex, Turbines Focus

- Unit IV.D.1: Offshore Wind Turbine Costs Overview
- Unit IV.D.2: Transition Pieces
- Unit IV.D.3: Structural Notes
- Unit IV.D.4: Turbine Supply - Wrap-Up
- Unit IV.D.5: Note re Turbine Size and Economies of Scale
- Unit IV.D.6: Turbine Installation Costs
- Unit IV.D.7: Turbine Installation Footage

Unit IV.E: Case Study Costs - Capex, Foundations Focus

- Unit IV.E.1: Offshore Wind Foundations - Introduction
- Unit IV.E.2: Foundations Cost Variances
- Unit IV.E.3: Monopile Fabrication and Installation
- Unit IV.E.4: Monopiles - a Sense of Scale
- Unit IV.E.5: Different Offshore Wind Foundation Types Compared
- Unit IV.E.6: Monopile and Jacket Foundation Supply Costs - 10 MW Turbines
- Unit IV.E.7: Monopile and Jacket Foundation Installation Costs - 10 MW turbines
- Unit IV.E.8: Monopile and Jacket Cost Comparison - 6MW Turbines
- Unit IV.E.9: Comparing the Mass of Monopiles and Jackets
- Unit IV.E.10: Jacket Fabrication
- Unit IV.E.11: Case Study Foundation Cost Assumptions

Unit IV.F: Other Capex and Wrap-Up

- Unit IV.F.1: Array Cables and Transmission (1/2)
- Unit IV.F.2: Array Cables and Transmission (2/2)
- Unit IV.F.3: Other Capex
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Unit IV.G: Operations & Maintenance, Decom

- Unit IV.G.1: Operations & Maintenance (O&M) Costs Overview
- Unit IV.G.2: Other Operating Costs
- Unit IV.G.3: Decommissioning Overview
- Unit IV.G.4: Decommissioning and Scrap Value
- Unit IV.G.5: Decommissioning, Recycling and Responsible Disposal of Components
- Unit IV.G.6: Cost Assumptions Wrap-Up
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Unit IV.H: Transmission Focus

- Unit IV.H.1: Transmission Assets - Refresher
- Unit IV.H.2: Transmission Assets (2)
- Unit IV.H.3: HVAC or HVDC - That Is The Question
- Unit IV.H.4: International inter-connections (1)
- Unit IV.H.5: International inter-connections (2)
- Unit IV.H.6: Enablers for Inter-connection
- Unit IV.H.7: Quiz - Transmission Focus

Unit IV: Space for Potential Future Resources

- Unit IV: Space for Potential Future Resources

Unit V Overview: Multi-option Case Study Model: Full Model and Analysis

- Unit V Overview: Multi-option Case Study Model: Full Model and Analysis

Unit V.A: Download the Case Study Model Here

- Unit V.A.1: Download the Case Study Model

Unit V.B: Pricing (Tariff) Assumptions

- Unit V.B.1: Feed-in Tariffs vs Market pricing; Thoughts on Forecasts
- Unit V.B.2: Merit Order Pricing
- Unit V.B.3: Adding Wind to the Mix: Good times, Bad times
- Unit V.B.4: Our Model's Tariff Regimes

Unit V.C: Losses

- Unit V.C.1: Losses Overview; Wake Losses

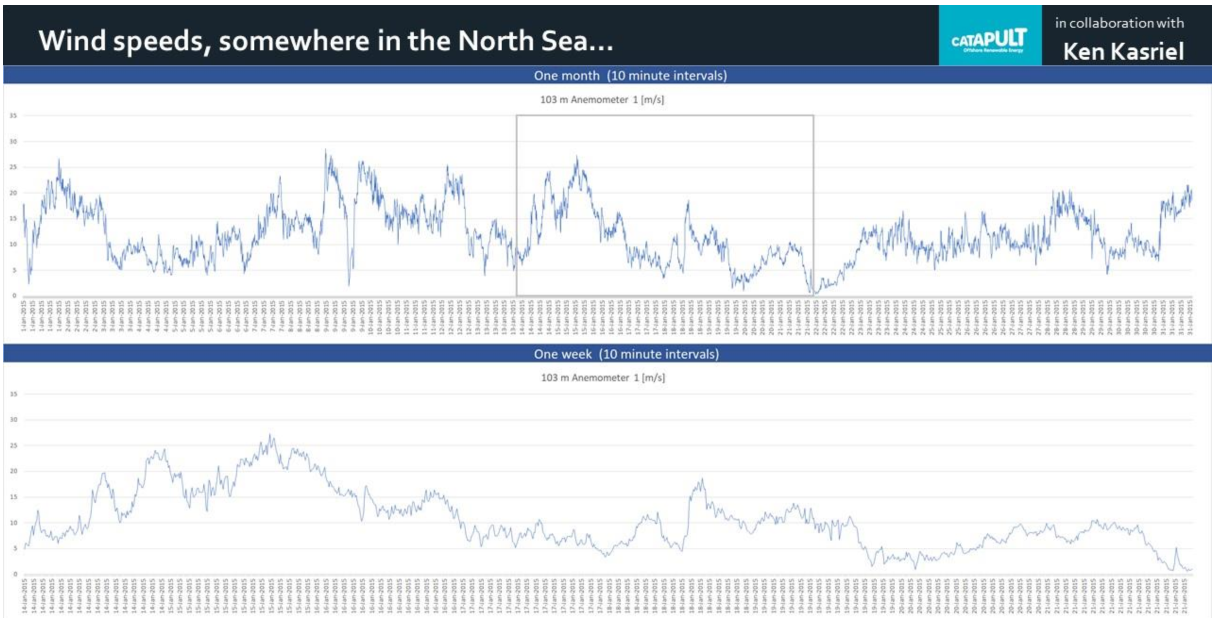
Unit V.D: Case Study Results

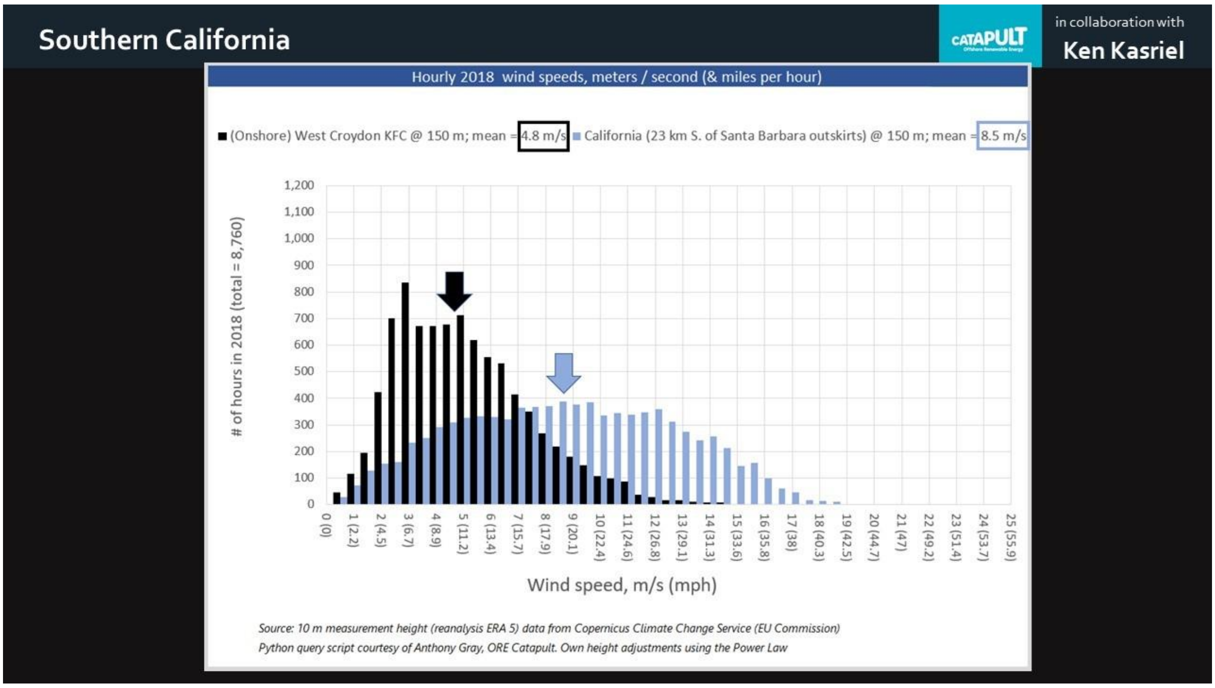
Unit V.E: Levelised Cost Of Energy (LCOE)

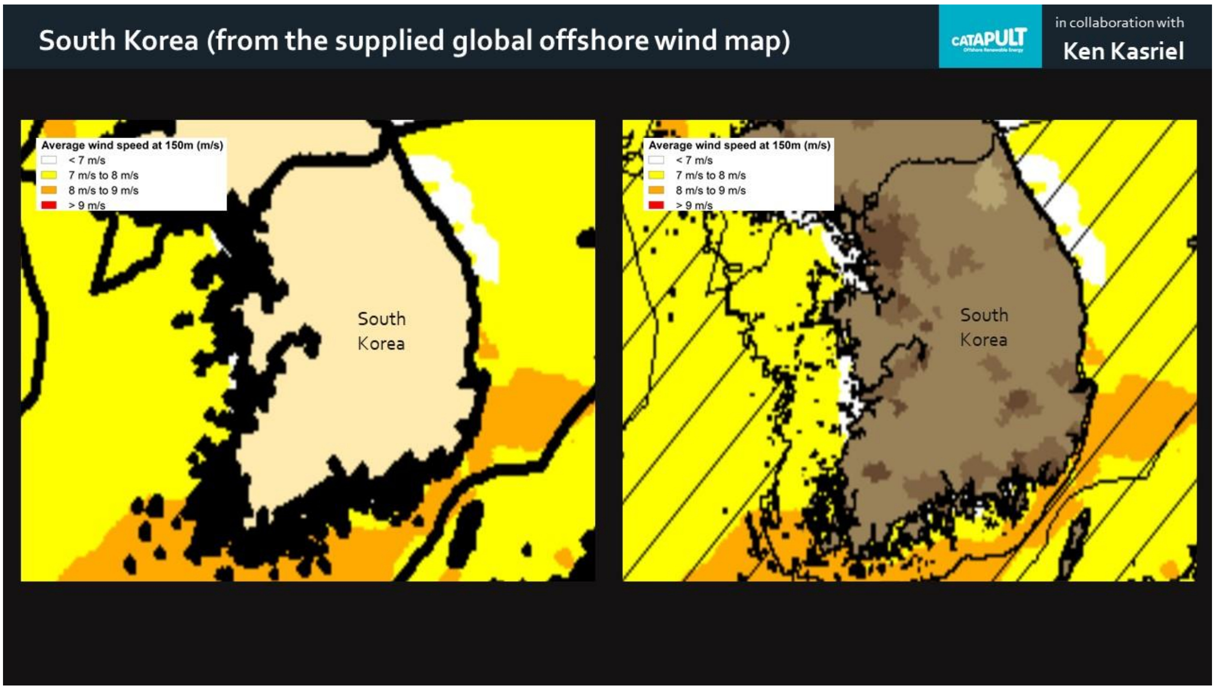
Unit V.F: Exercises Using the Case Study Model

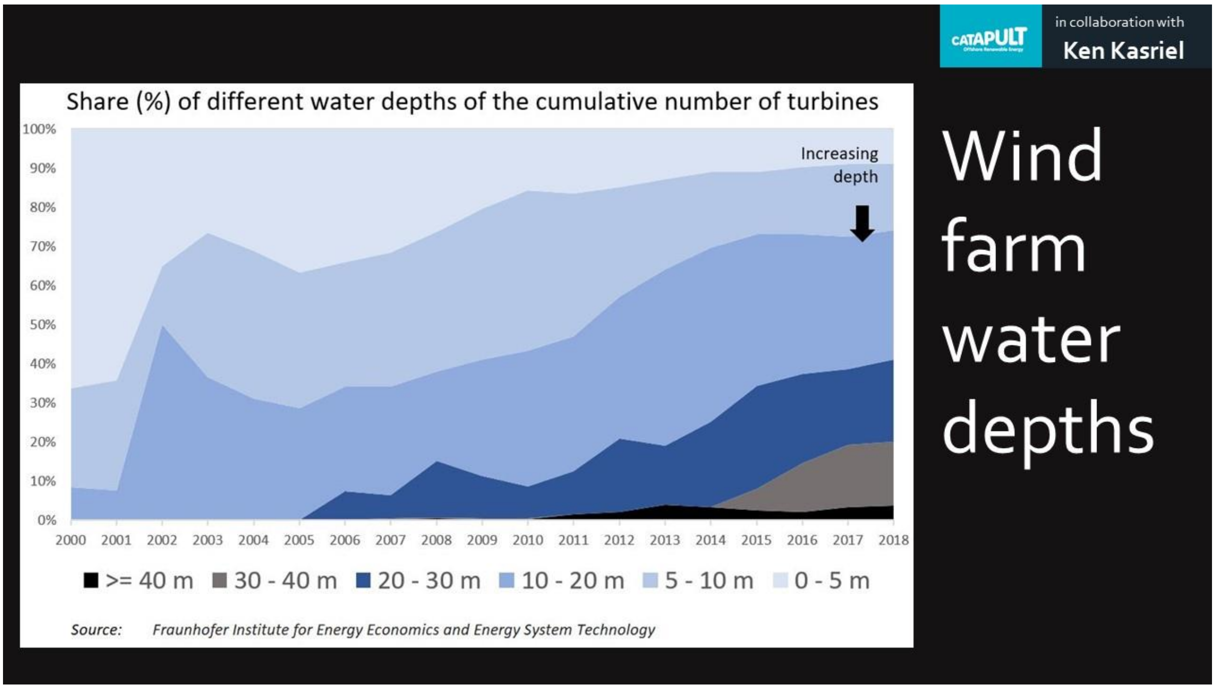
Unit V: Space for Potential Future Resources

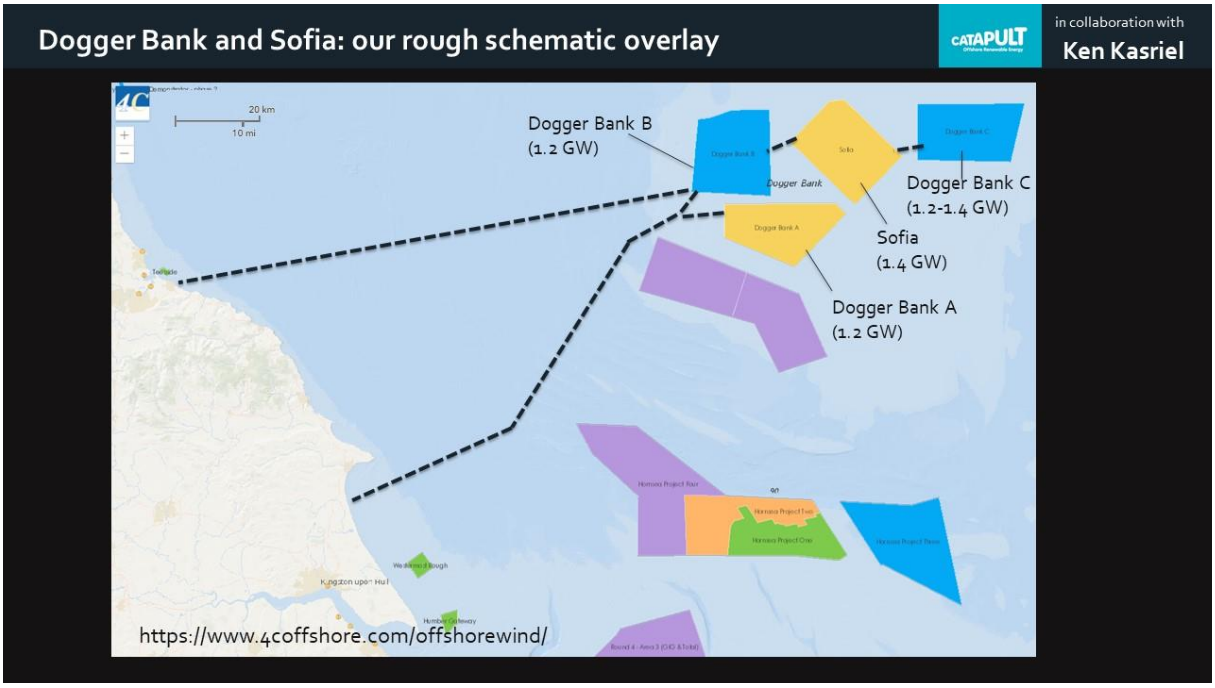
Gallery of lecture and exercise screenshots




Southern California
in collaboration with
Ken Kasriel
Hourly 2018 wind speeds, meters / second (& miles per hour)
(Onshore) West Croydon KFC @ 150 m; mean = 4.8 m/s
California (23 km S. of Santa Barbara outskirts) @ 150 m; mean = 8.5 m/s
# of hours in 2018 (total = 8,760)
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
0 (0)
1 (2.2)
2 (4.5)
3 (6.7)
4 (8.9)
5 (11.2)
6 (13.4)
7 (15.7)
8 (17.9)
9 (20.1)
10 (22.4)
11 (24.6)
12 (26.8)
13 (29.1)
14 (31.3)
15 (33.6)
16 (35.8)
17 (38)
18 (40.3)
19 (42.5)
20 (44.7)
21 (47)
22 (49.2)
23 (51.4)
24 (53.7)
25 (55.9)
Wind speed, m/s (mph)
Source: 10 m measurement height (reanalysis ERA 5) data from Copernicus Climate Change Service (EU Commission)
Python query script courtesy of Anthony Gray, ORE Catapult. Own height adjustments using the Power Law


South Korea (from the supplied global offshore wind map)
in collaboration with
Ken Kasriel
Average wind speed at 150m (m/s)
< 7 m/s
7 m/s to 8 m/s
8 m/s to 9 m/s
> 9 m/s
South Korea
Average wind speed at 150m (m/s)
< 7 m/s
7 m/s to 8 m/s
8 m/s to 9 m/s
> 9 m/s
South Korea

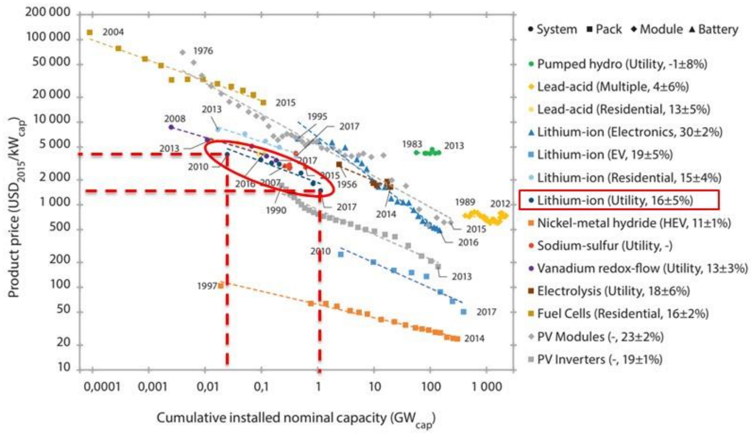

in collaboration with
Ken Kasriel
Wind farm water depths
Share (%) of different water depths of the cumulative number of turbines
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Increasing depth
>= 40 m
30 - 40 m
20 - 30 m
10 - 20 m
5 - 10 m
0 - 5 m
Source: Fraunhofer Institute for Energy Economics and Energy System Technology


Dogger Bank and Sofia: our rough schematic overlay
in collaboration with
Ken Kasriel
20 km
10 mi
Dogger Bank B
(1.2 GW)
Dogger Bank C
(1.2-1.4 GW)
Sofia
(1.4 GW)
Dogger Bank A
(1.2 GW)
Dogger Bank
https://www.4coffshore.com/offshorewind/

Experience Curves: power storage technology

CATAPULT in collaboration with Ken Kasriel

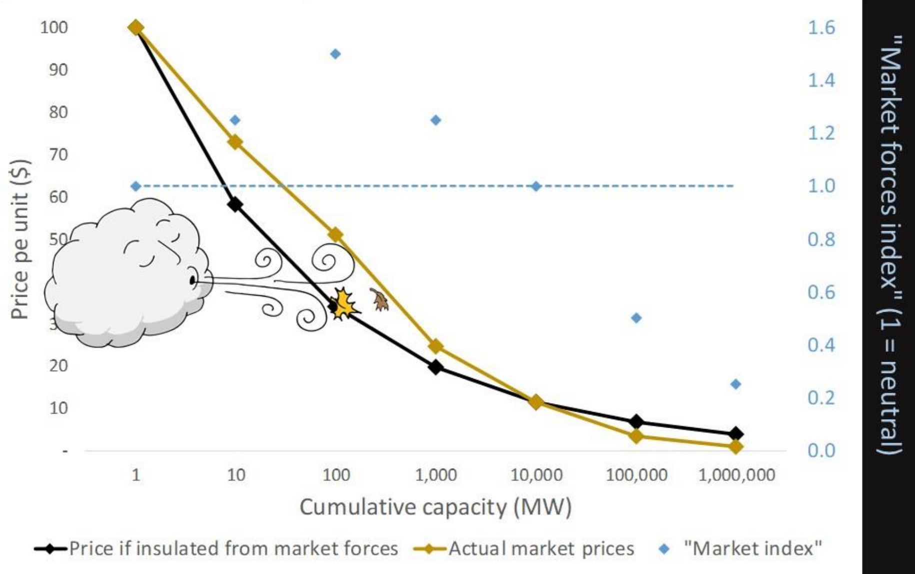
Figure 6.1: Experience curves for electrical energy storage (EES) technologies per nominal discharge power capacity, in different uses



Note: The percentage terms in brackets express the Experience Rate ER ± uncertainty.[9] Fuel cells and electrolysers must be considered together.
Source: Schmidt et al. (2018).

Experience curve vs actual prices in a non-neutral market environment

CATAPULT in collaboration with Ken Kasriel



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Balancing the Grid

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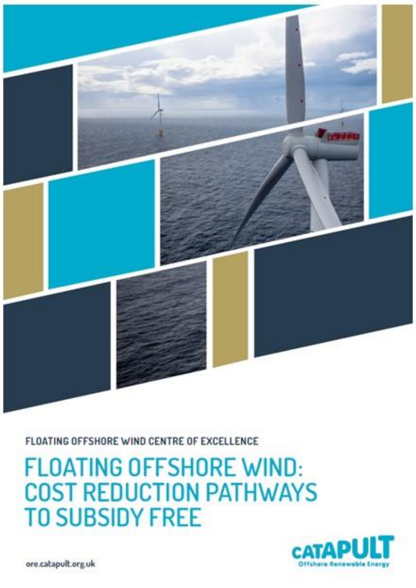
https://commons.wikimedia.org/wiki/File:Dublin_Philharmonic_Orchestra_performing_Tchaikovsky%27s_Symphony_No_4_in_Charlotte,_North_Carolina.jpgBy Derek Gleeson. - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=15602176

Floating wind cost outlook

CATAPULT Offshore Renewable Energy in collaboration with Ken Kasriel



CONTENTS

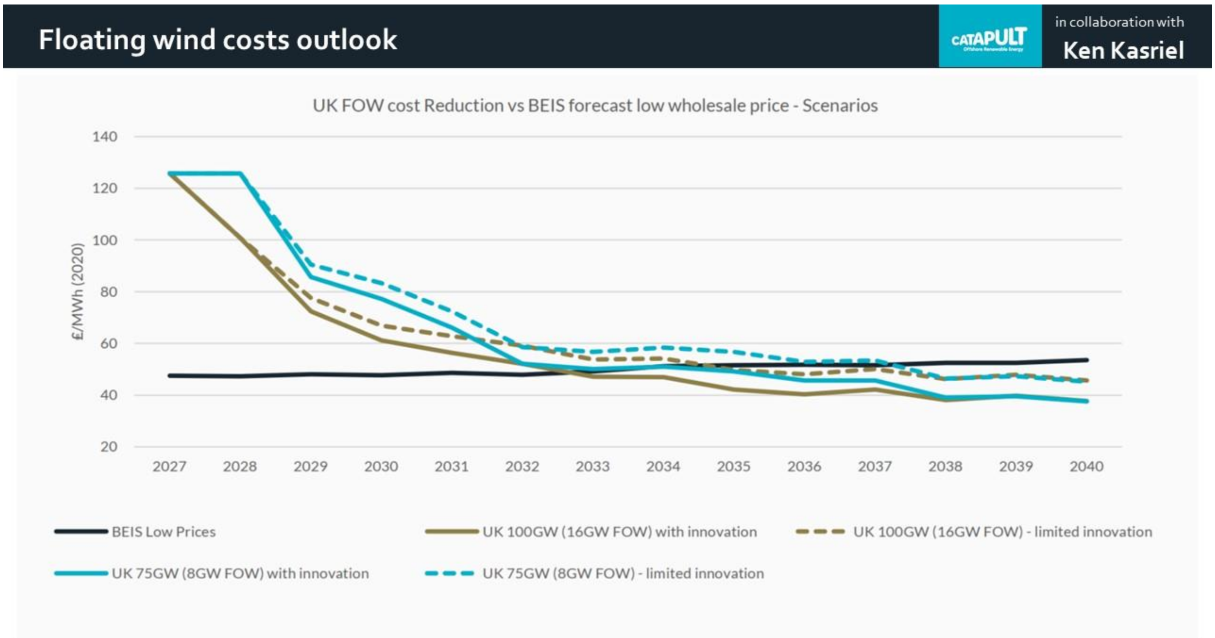
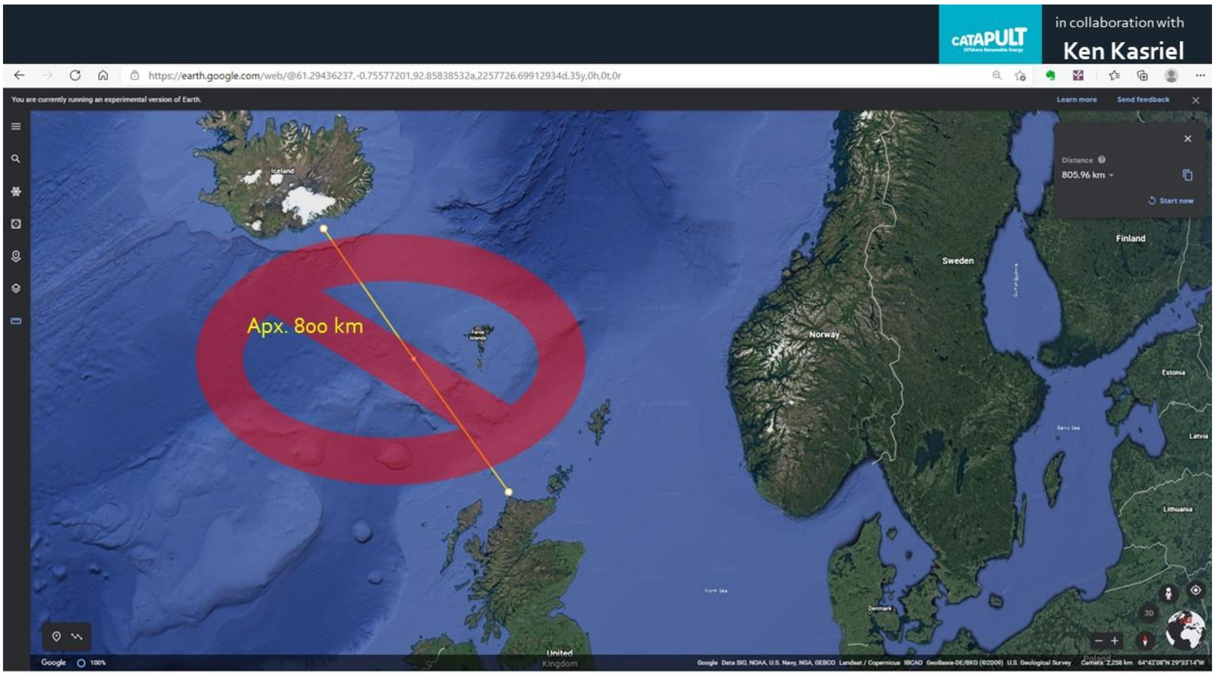
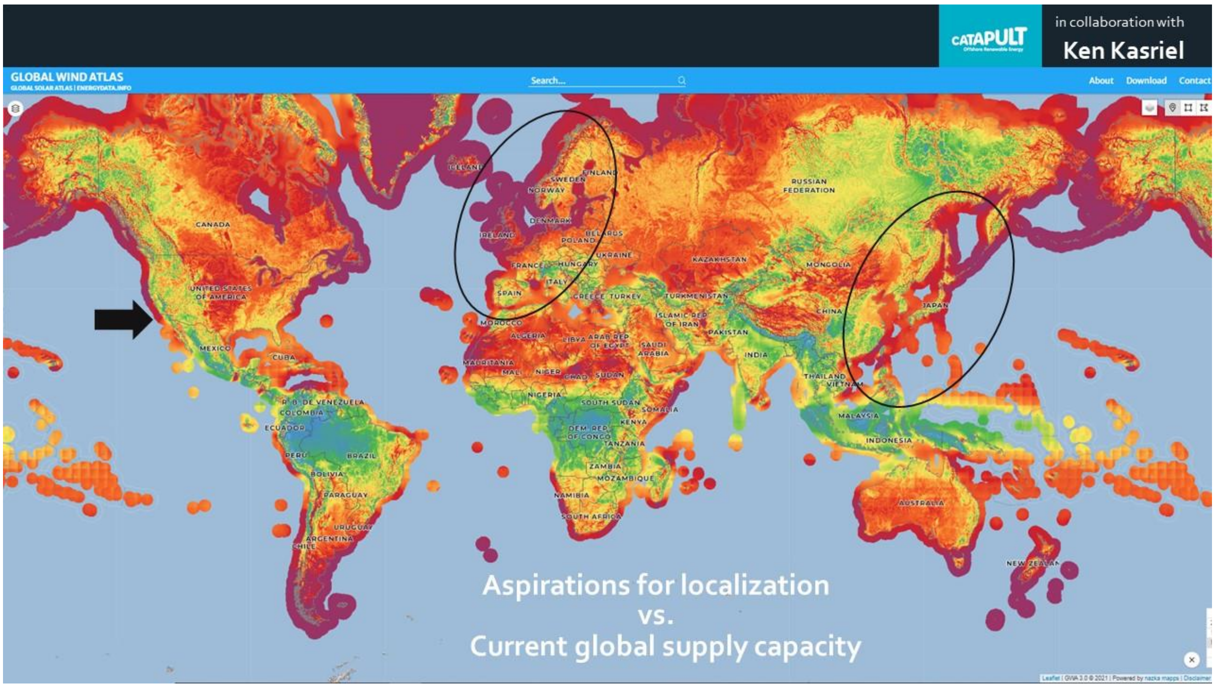
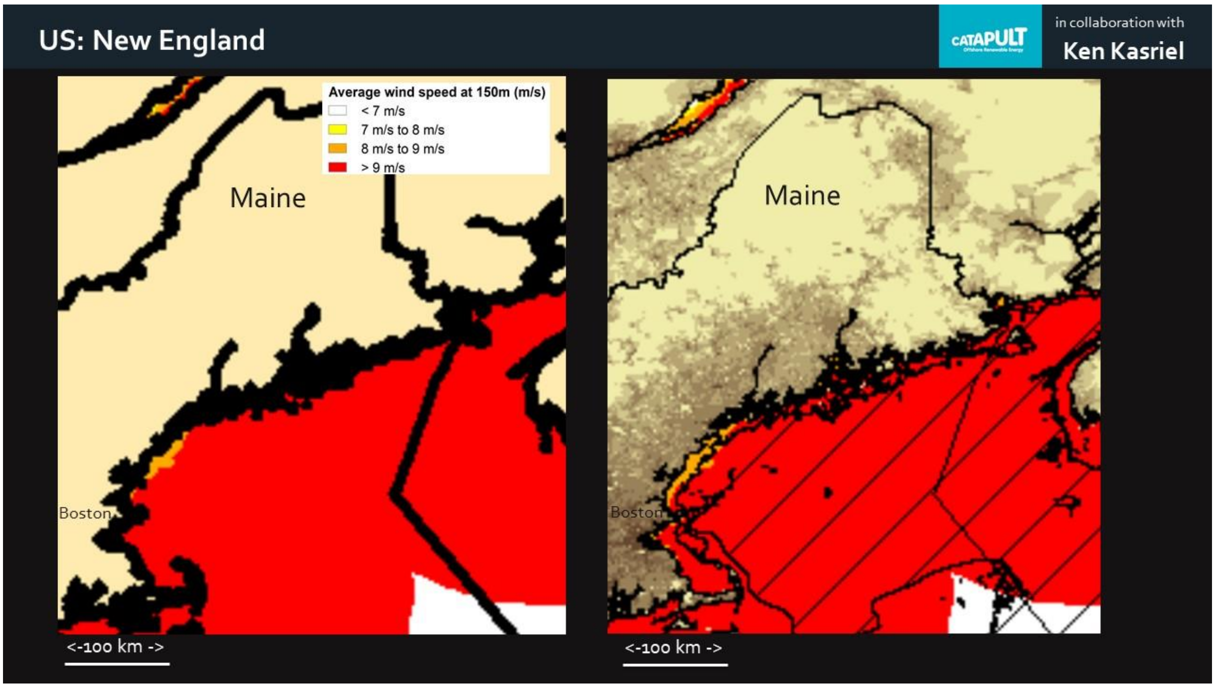
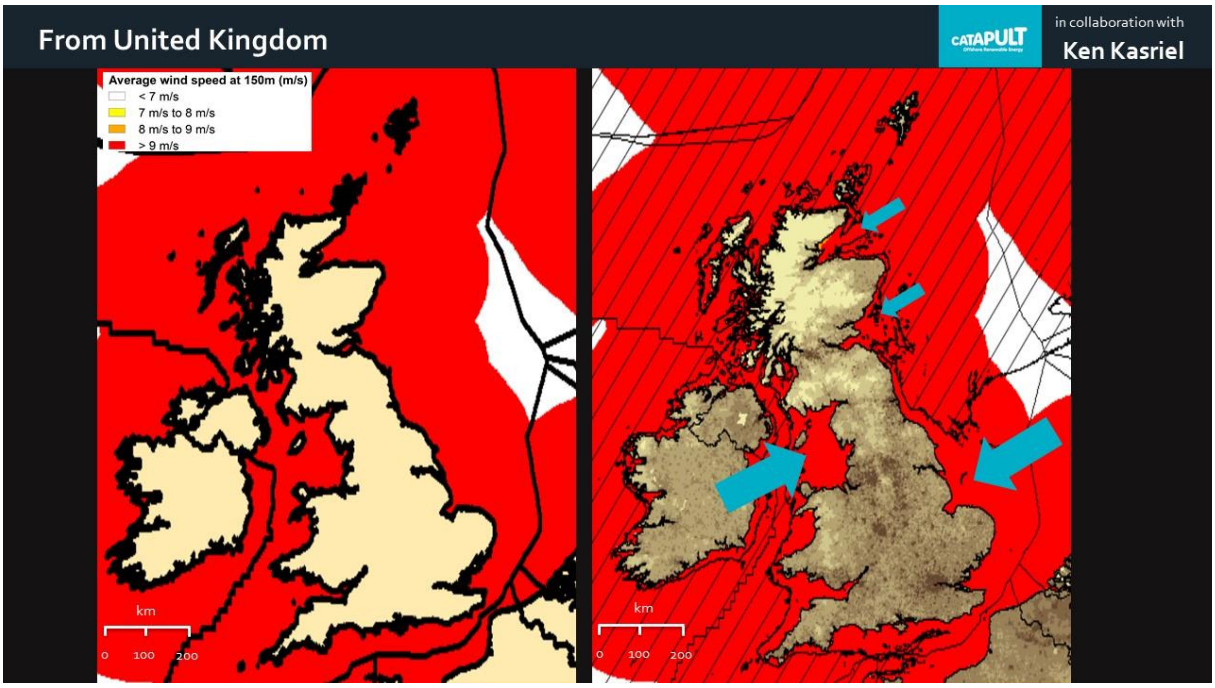


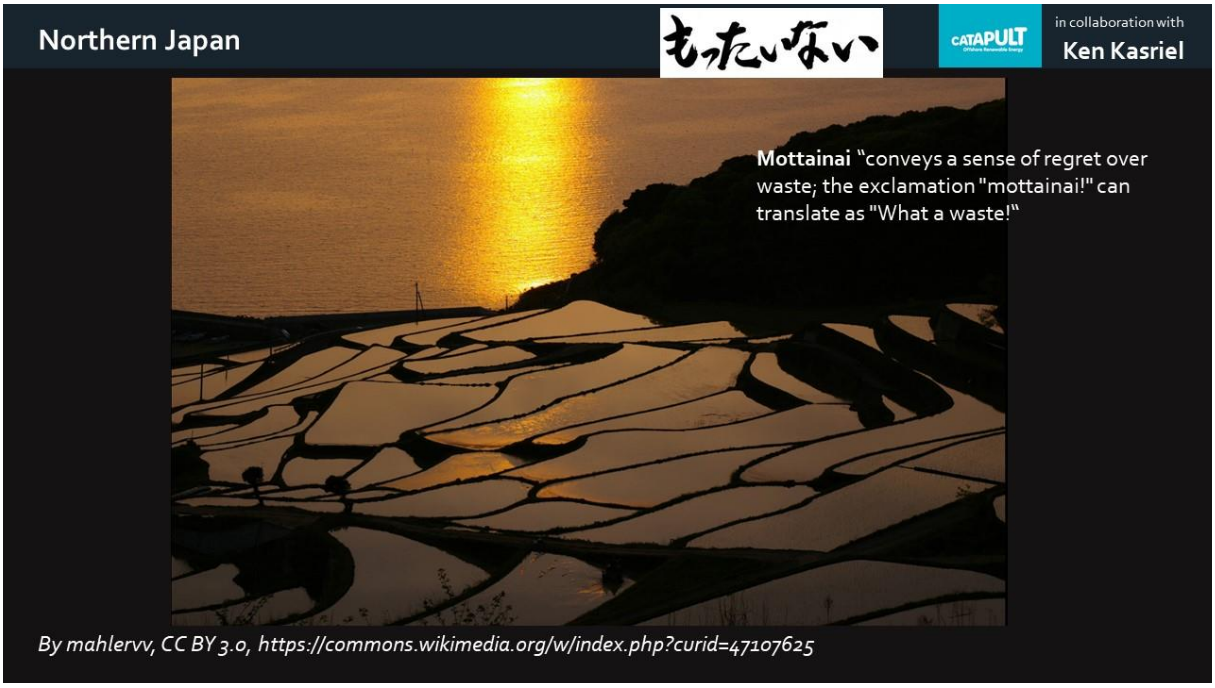
Figure 6: UK FOW cost reduction vs BEIS forecast wholesale electricity price

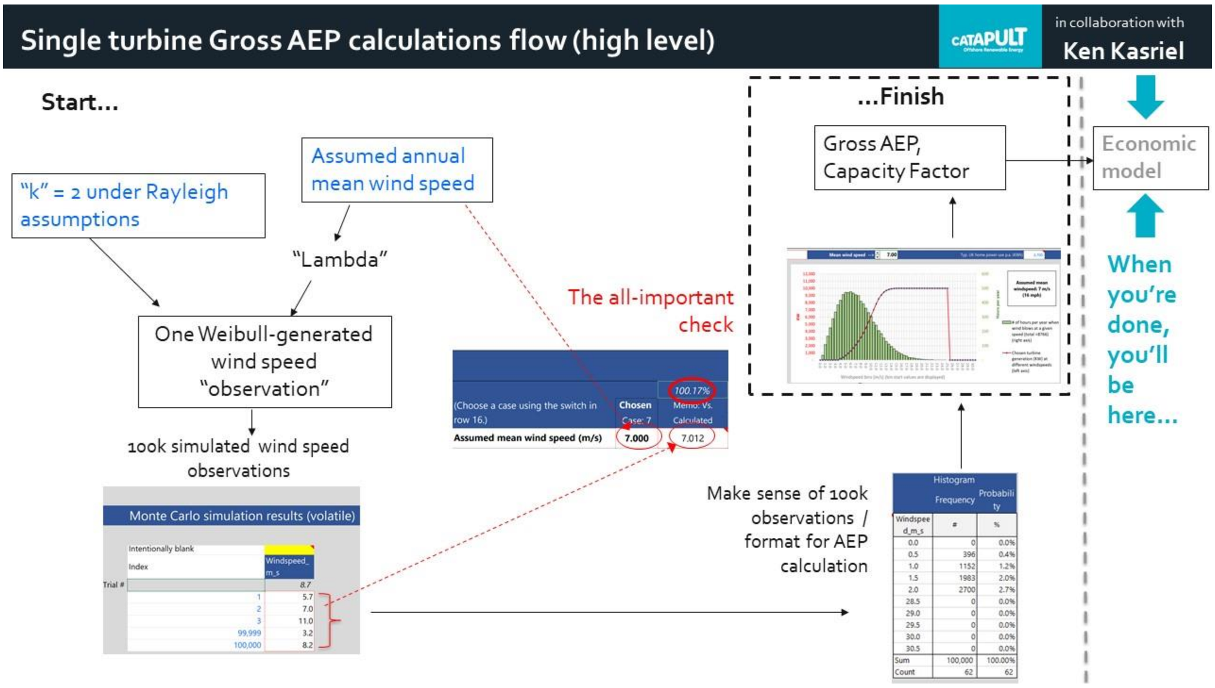



CATAPULT
in collaboration with
Ken Kasriel
GLOBAL WIND ATLAS
Search...
About
Download
Contact
Aspirations for localization
vs.
Current global supply capacity

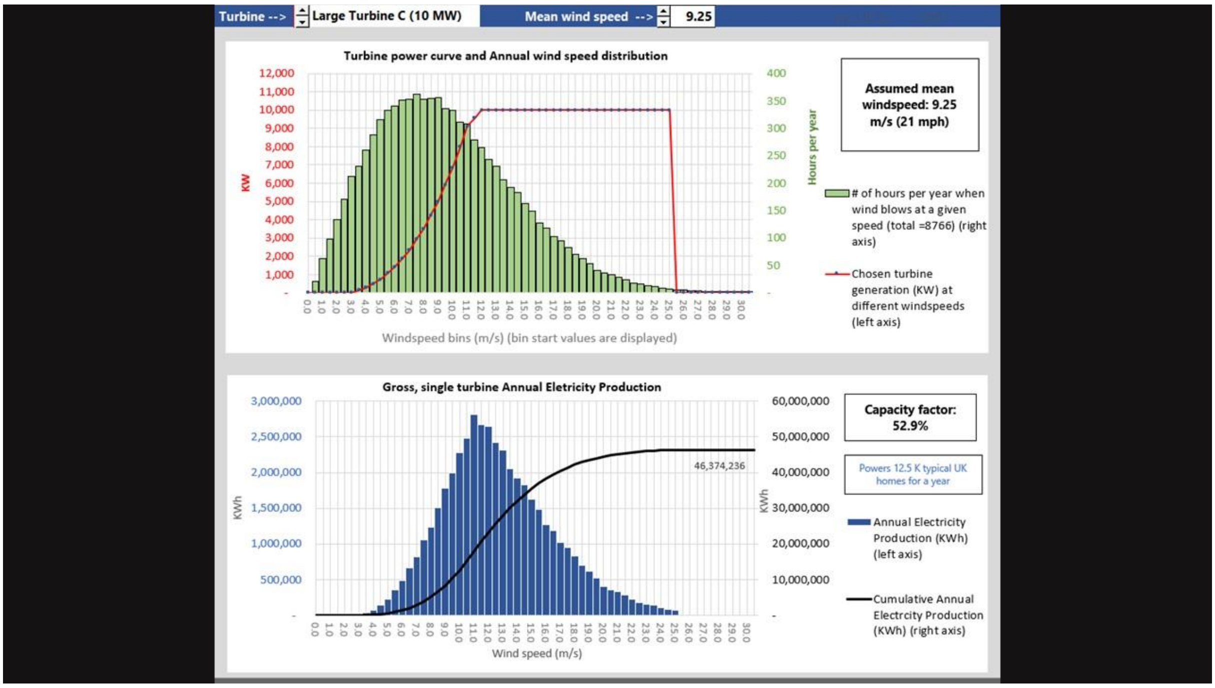

US: New England
CATAPULT
in collaboration with
Ken Kasriel
Average wind speed at 150m (m/s)
< 7 m/s
7 m/s to 8 m/s
8 m/s to 9 m/s
> 9 m/s
Maine
Boston
<-100 km ->
Maine
Boston
<-100 km ->

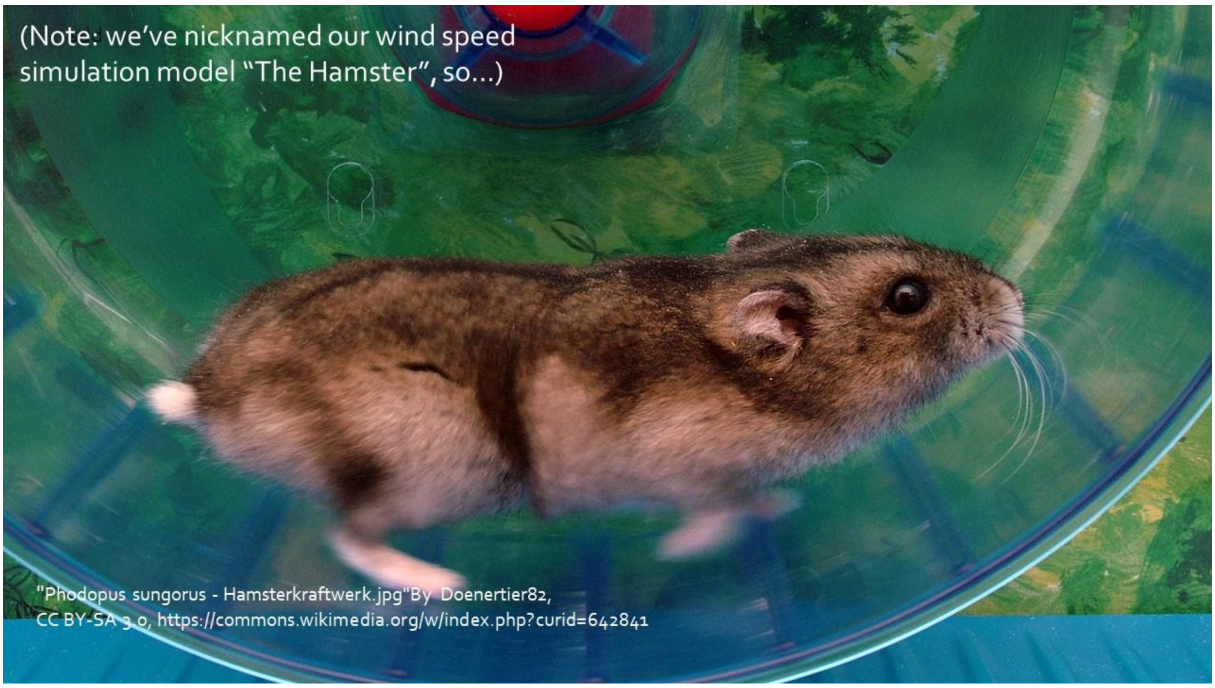

From United Kingdom
in collaboration with
Ken Kasriel
Average wind speed at 150m (m/s)
< 7 m/s
7 m/s to 8 m/s
8 m/s to 9 m/s
> 9 m/s
km
0 100 200
km
0 100 200

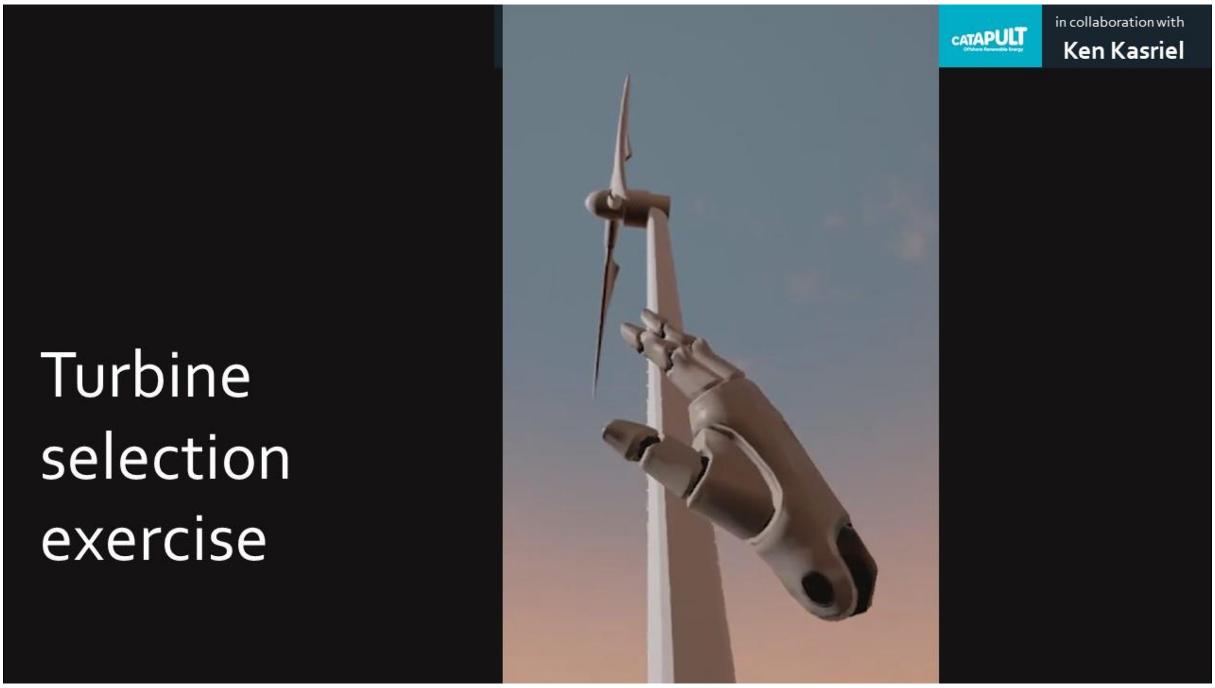

Northern Japan
もったいない
in collaboration with
Ken Kasriel
Mottainai "conveys a sense of regret over waste; the exclamation "mottainai!" can translate as "What a waste!"
By mahlervv, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=47107625

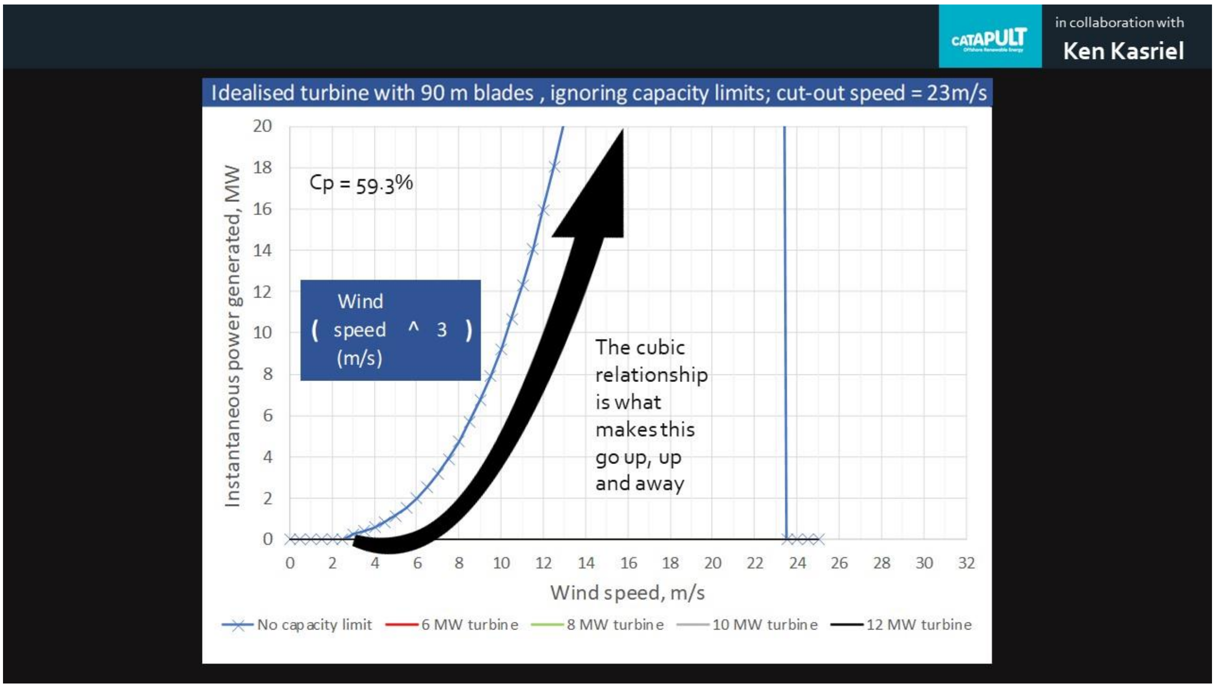


https://ore-catapult-school.thinkific.com/ ore.catapult.org.uk


Turbine -->
Large Turbine C (10 MW)
Mean wind speed -->
9.25
Turbine power curve and Annual wind speed distribution
KW
Hours per year
Windspeed bins (m/s) (bin start values are displayed)
Assumed mean windspeed: 9.25 m/s (21 mph)
# of hours per year when wind blows at a given speed (total =8766) (right axis)
Chosen turbine generation (KW) at different windspeeds (left axis)
Gross, single turbine Annual Eletricity Production
KWh
46,374,236
Wind speed (m/s)
Capacity factor: 52.9%
Powers 12.5 K typical UK homes for a year
Annual Electricity Production (KWh) (left axis)
Cumulative Annual Electrcity Production (KWh) (right axis)


(Note: we've nicknamed our wind speed simulation model "The Hamster", so...)
"Phodopus sungorus - Hamsterkraftwerk.jpg"By Doenertier82, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=642841





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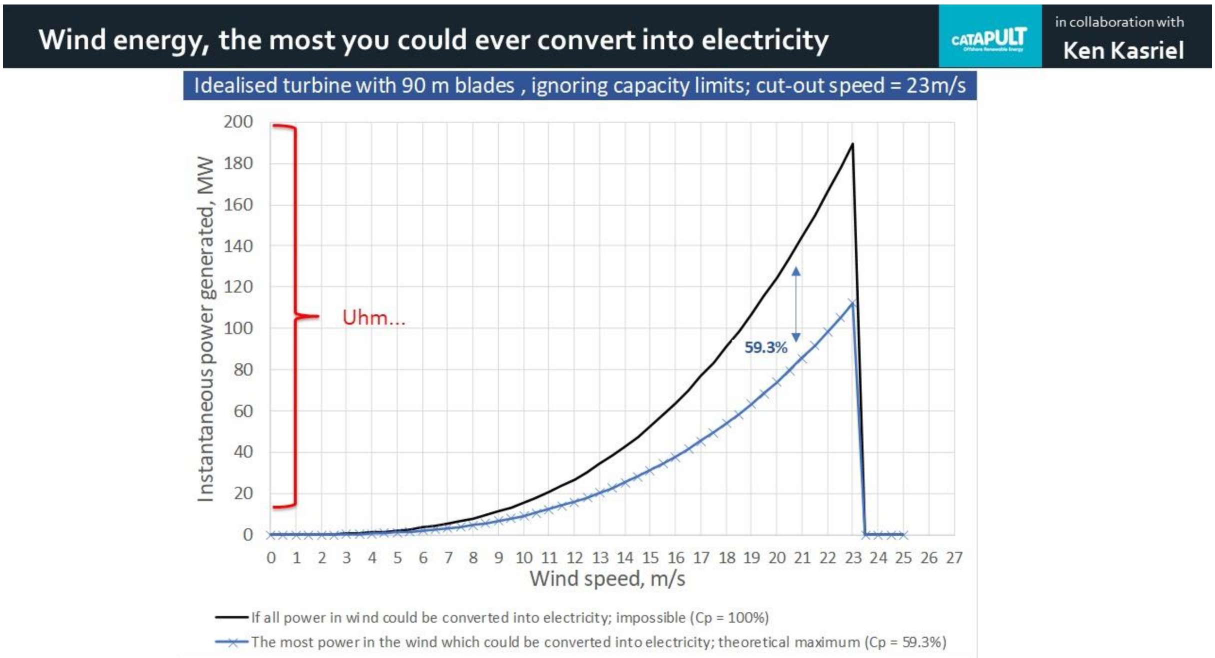

Wind energy, the most you could ever convert into electricity
CATAPULT
in collaboration with
Ken Kasriel
Idealised turbine with 90 m blades , ignoring capacity limits; cut-out speed = 23m/s
Instantaneous power generated, MW
Uhm...
59.3%
Wind speed, m/s
If all power in wind could be converted into electricity; impossible (Cp = 100%)
The most power in the wind which could be converted into electricity; theoretical maximum (Cp = 59.3%)


Circumference:
1 revolution is
537 m
Diameter
including
hub :
171 m

Wind energy equation: density

in collaboration with
Ken Kasriel

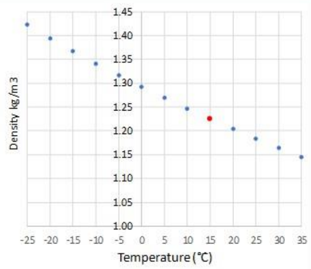
Equation for instantaneous electricity from wind (ignoring capacity limits)

Blue font = hard=coded values
m = meter W = Watts

(	0.5	x	Air density (kg / m3)	x	Swept area (m2)	x	(	Wind speed (m/s)	^	3	)	x	Coeffcient of Power (Cp)	)	=	Power (W)	=	Power (KW)	=	**Power (MW)**
(	0.5	x	1.225	x	25,447	x	(	10.0	^	3	)	x	59.26%	)	=	9,236,283	=	9,236	=	**9.2**

1.225 is the reference standard. It assumes being at sea level in at 15 degrees Celsius.

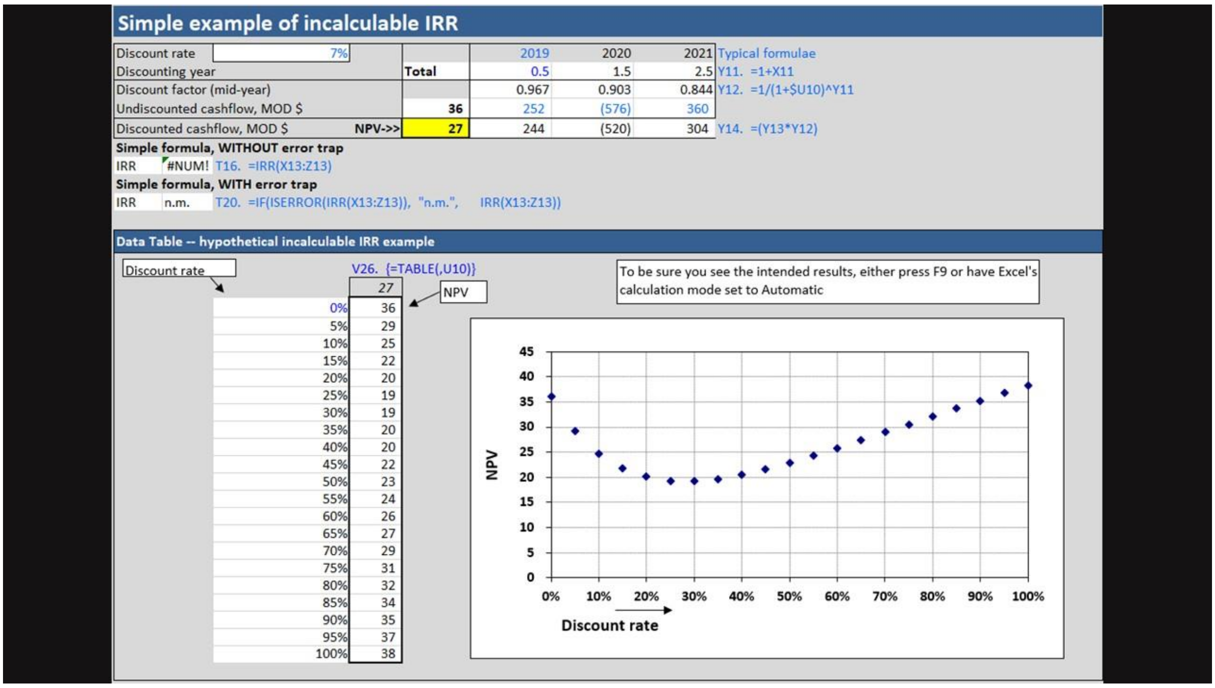
Temp. (°C)	Density (kg / m3)
35	1.15
30	1.16
25	1.18
20	1.20
15	1.23
10	1.25
5	1.27
0	1.29
-5	1.32
-10	1.34
-15	1.37
-20	1.39
-25	1.42



https://en.wikipedia.org/wiki/Density_of_air

From Unit 3


in collaboration with
Ken Kasriel
Discount rate
7%
<-- These sync safely with their duplicates on the other tab -->
Assume cashflows all received
2 Jul
When the discount rate is 7%, a dollar received or spent on these dates is worth X% of $1
120.0%
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
96.7%
68.9%
49.1%
35.0%
25.0%
17.8%
12.7%
9.1%
84.4%
for Year 3, at our case studies' Base Case discount rate assumption of 7%
2 Jul of Yr 1
2 Jul of Yr 6
2 Jul of Yr 11
2 Jul of Yr 16
2 Jul of Yr 21
2 Jul of Yr 26
2 Jul of Yr 31
2 Jul of Yr 36



Simple example of incalculable IRR

		Total	2019	2020	2021	Typical formulae
Discount rate	7%					
Discounting year			0.5	1.5	2.5	Y11. =1+X11
Discount factor (mid-year)			0.967	0.903	0.844	Y12. =1/(1+$U10)^Y11
Undiscounted cashflow, MOD $		36	252	(576)	360	
Discounted cashflow, MOD $	NPV->>	27	244	(520)	304	Y14. =(Y13*Y12)

Simple formula, WITHOUT error trap
IRR #NUM! T16. =IRR(X13:Z13)
Simple formula, WITH error trap
IRR n.m. T20. =IF(ISERROR(IRR(X13:Z13)), "n.m.", IRR(X13:Z13))

Data Table -- hypothetical incalculable IRR example

To be sure you see the intended results, either press F9 or have Excel's calculation mode set to Automatic

V26. {=TABLE(,U10)}

Discount rate	NPV: 27
0%	36
5%	29
10%	25
15%	22
20%	20
25%	19
30%	19
35%	20
40%	20
45%	22
50%	23
55%	24
60%	26
65%	27
70%	29
75%	31
80%	32
85%	34
90%	35
95%	37
100%	38

Exercises

I. Analysis

Many assume the following are always true:

1) Undiscounted total project Net Cashflow ("NCF") is always higher than Discounted total project NCF (i.e. NPV).
2) The higher the discount rate is, the lower NPV will be.
3) The longer a project is delayed, the lower NPV will be.

We certainly saw these things happen in the lecture.

But *always*?

1) Please press the button, in row 14 of the "Model tab", to Reset the model assumptions to the base case (though they should already be set this way when you receive this. Still, to be sure.)

2) Make row 19 of the Model tab the top-most visible row. Place your cursor in cell A30, and then in Excel's menu bar, go to View, and click Split. This should divide the screen into top and bottom parts.

From Unit 4

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Multi-option case study: Near or far? Shallow or deep? Now or later?

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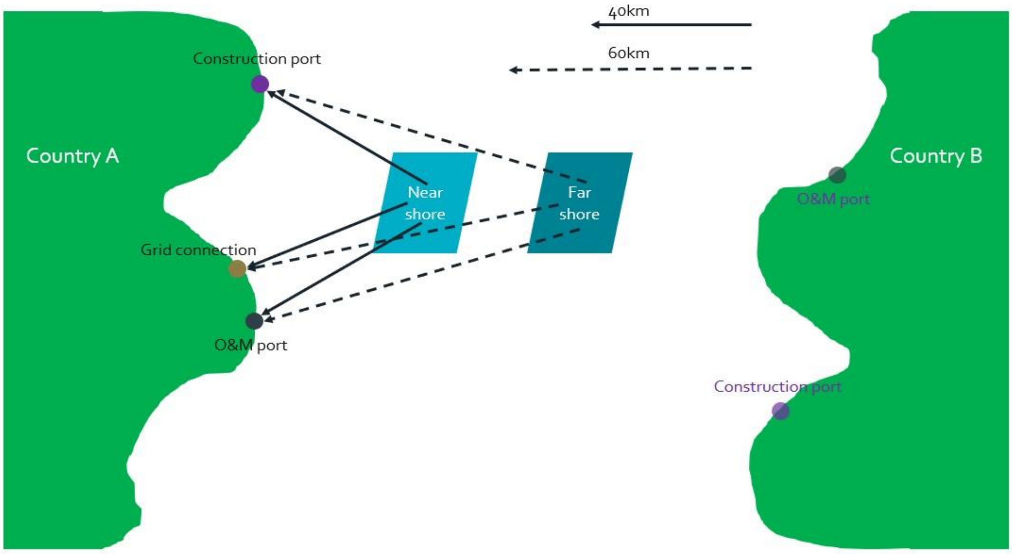

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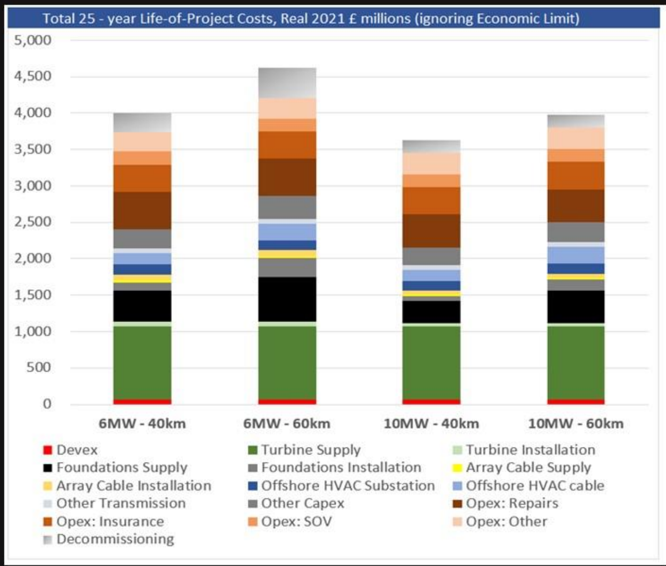
Case study cost assumptions (early 2020s tech)



Monopile vs jacket mass

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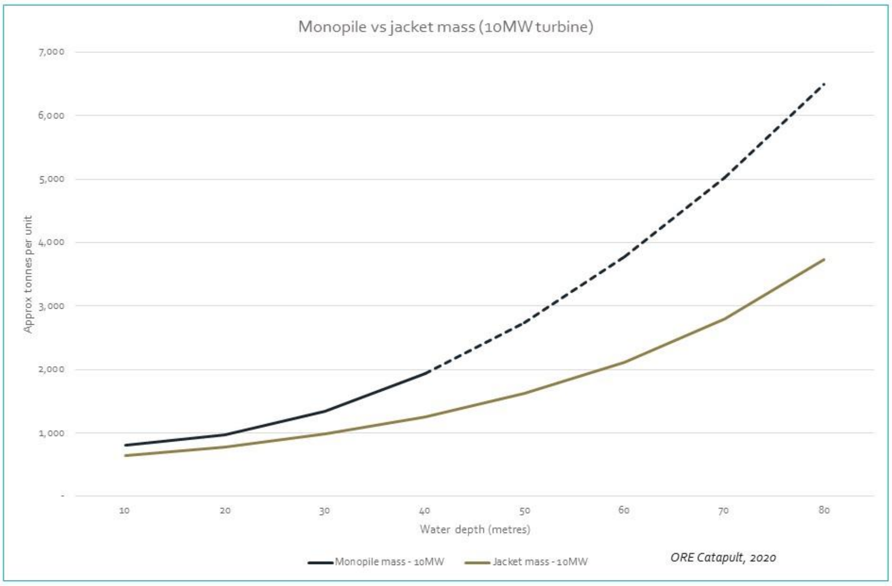
Ken Kasriel



36

Case study site parameters – distance to grid connection

in collaboration with
Ken Kasriel

Key technology, cost and value elements driven by distance to grid connection point

Site parameter	Unit	Near (40km)	Far (60km)
Distance to cable landfall	km	40	60
Offshore export cable length	km	Lower (positive)	Higher (negative)
Installation time	hours	Lower (positive)	Higher (negative)

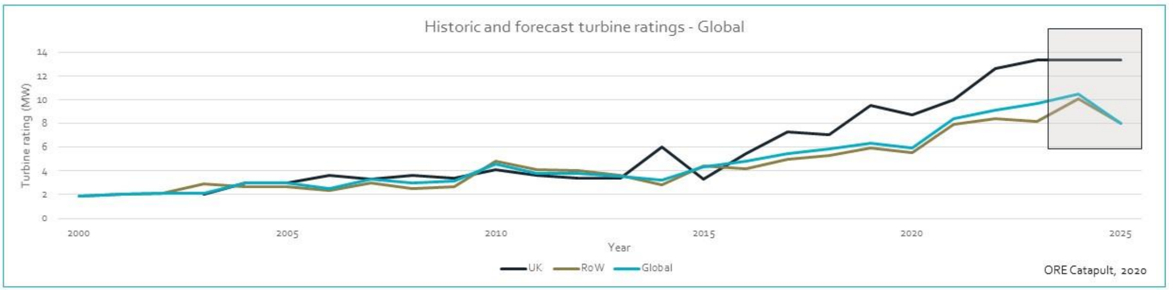
Site parameter	Unit	Near (40km)	Far (60km)
Onshore cable distance	km	10	10
Onshore export cable length	km	Neutral	Neutral
Installation time	hours	Neutral	Neutral

Transmission distance and windfarm size will determine choice of HVAC or HVDC technology.
Our case study sites all use HVAC connections [this point is treated in more detail in a separate lecture]

Case studies description

in collaboration with
Ken Kasriel

Average rating of offshore turbines installed by year



Points to note

- Our case study project has FID January 2022
- Implies project fully commissioned ~2025-2026
- If case study were UK project, expect ~12MW turbines

Case study uses 10MW turbines due to

- Making case study as globally generic as possible (not all markets as advanced as UK)
- ~10MW turbines being installed over the next 5 years – soon have empirical data

Final note

- 6MW turbine scenarios included to illustrate economies of small vs large turbines
- Unlikely to see 6MW being installed offshore in future except where countries develop own new technology

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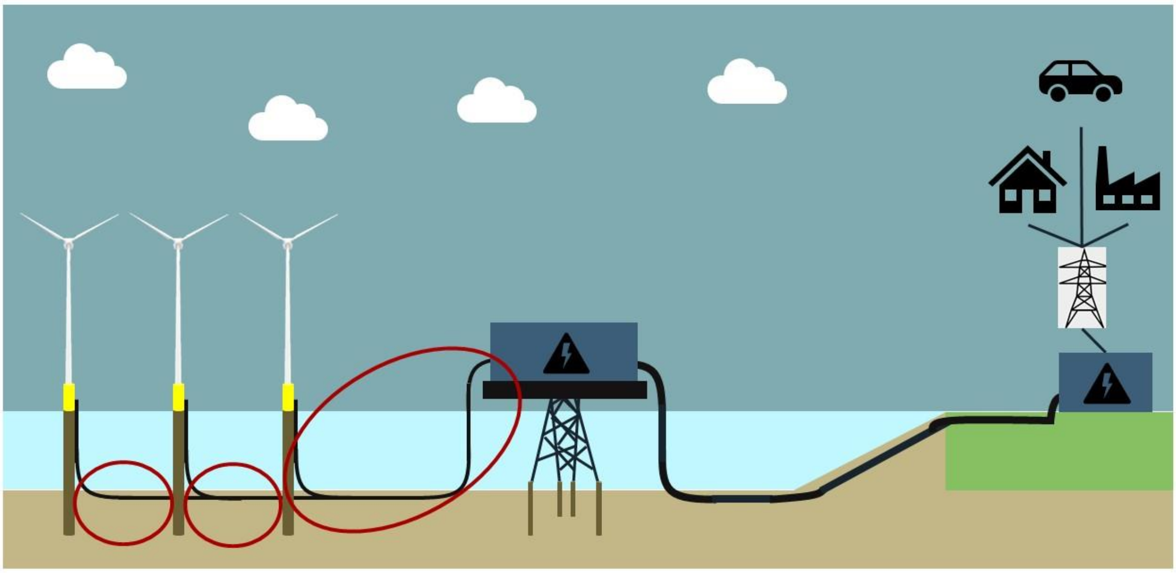
Offshore wind assets – array cables

in collaboration with Ken Kasriel



Transmission technology tradeoffs

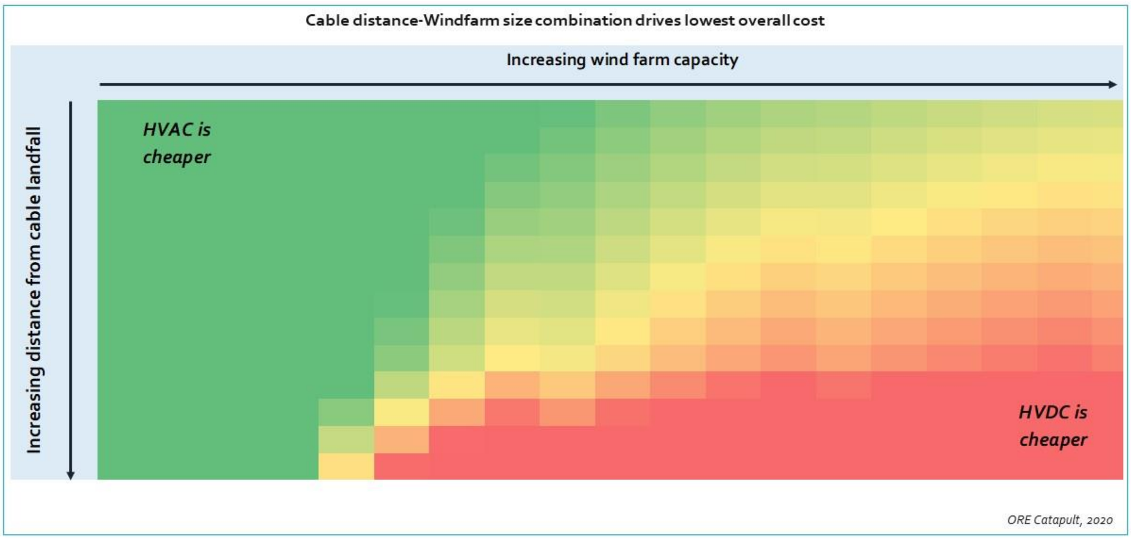
in collaboration with Ken Kasriel

Lowering transmission losses means extra revenue....

... but extra costs too

Offshore export cables HVAC and HVDC

in collaboration with
Ken Kasriel




Cars

Salt aerosols: rust never sleeps

CATAPULT in collaboration with Ken Kasriel

"Corrosion on exposed metal, including a bolt and nut," https://en.wikipedia.org/wiki/Corrosion#/media/File:Rust_Bolt.JPG By Thester11 - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=5202538

From Unit 5

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Case studies description

CATAPULT in collaboration with Ken Kasriel

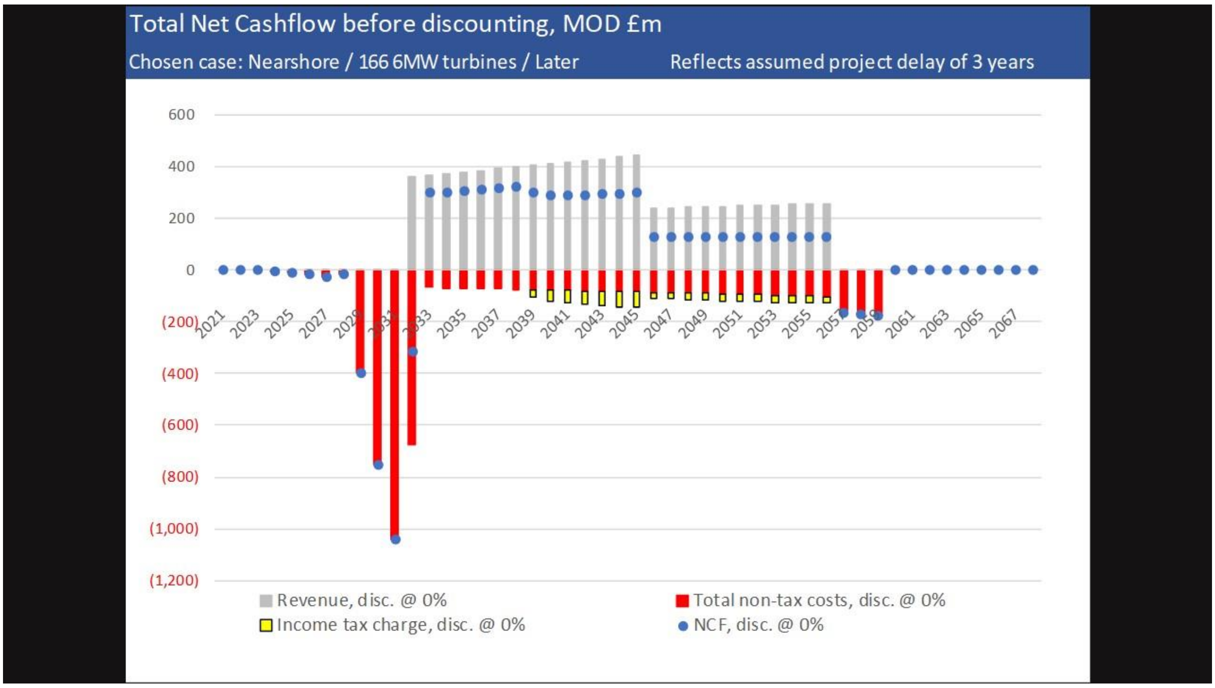
Development Cases

Index #	Name	Comment
1	Nearshore / 166 6MW turbines / Later	<--- Delay and uncertainty: You will only know if you may proceed once the court has ruled
2	Nearshore / 100 10MW turbines / Later	
3	Farshore / 166 6MW turbines / Now	<--- You're free to start immediately
4	Farshore / 100 10MW turbines / Now	
5	Farshore / 166 6MW turbines / Later	<--- Perhaps there is some value in waiting to see the court's outcome, even though you may start now ?
6	Farshore / 100 10MW turbines / Later	
7	*Nearshore / 166 6MW turbines / Now (notional)	<--- Notional because this won't happen; this is what residents are contesting. Perhaps of academic interest.
8	* Nearshore / 100 10MW turbines / Now (notional)	

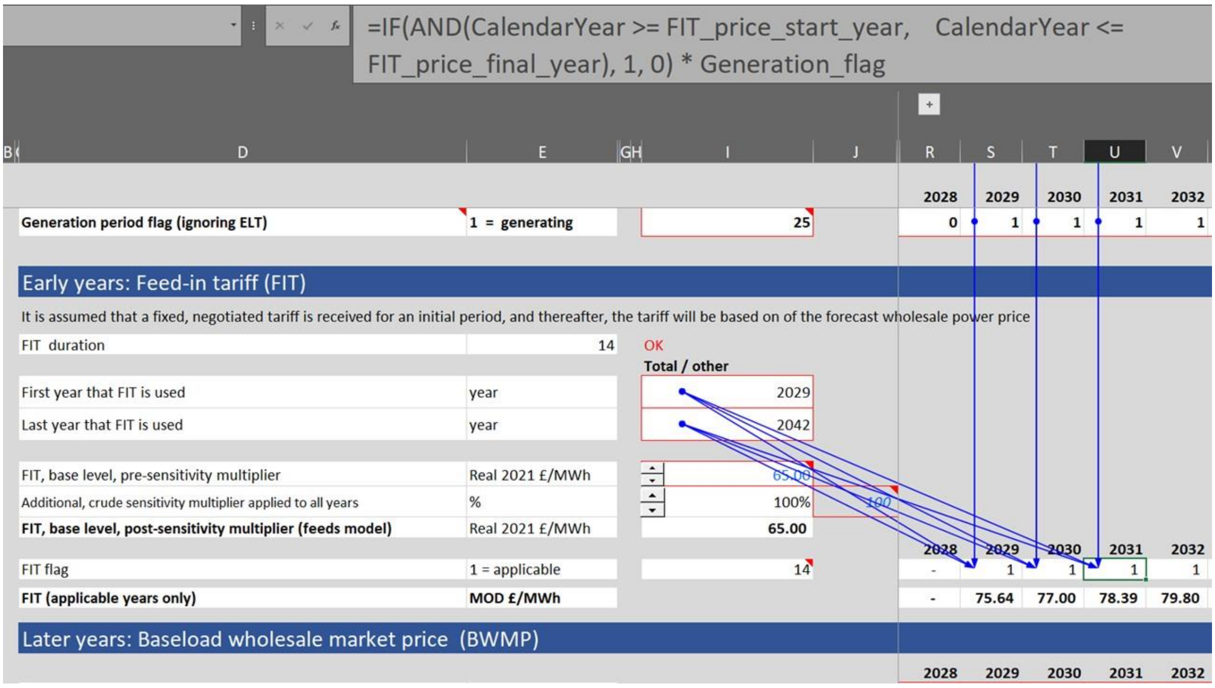
Can we..?	40km (Nearshore)	60km (Farshore)
Now	No, can't proceed now due to local objections ⑦ ⑧	Yes, no objections to farshore project ③ 166 smaller turbines ④ 100 larger turbines
Later	Maybe, only if we win in court ① 166 smaller turbines ② 100 larger turbines	Win or lose in court, can do this, but unsure when we'll know! ⑤ 166 smaller turbines ⑥ 100 larger turbines

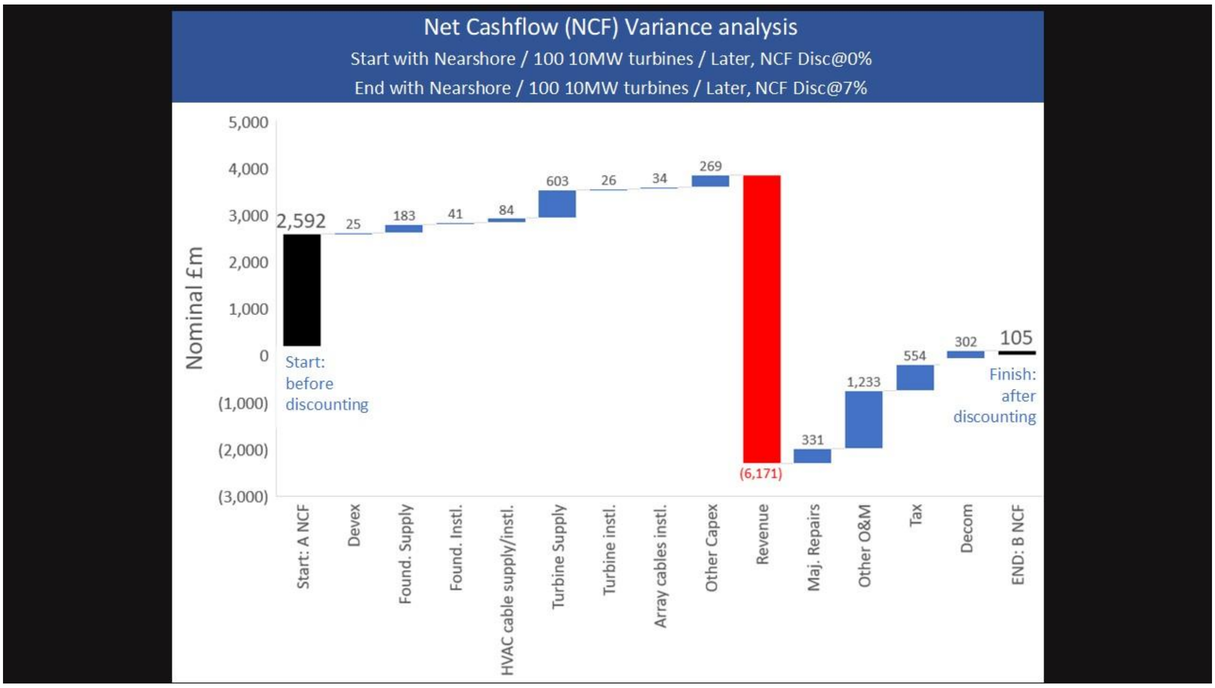
Discount rate	7.00%
FIT Duration	14 OK
FIT, base level, pre-sensitivity multiplier Real £/MWh	65.00
Years delay applied to the "Later" cases:	3

Power losses other than erosion	As expressed by engineer	Converted for product formula
Wake losses	9.0%	91.0%
Turbine downtime	2.8%	97.2%
Icing	0.0%	100.0%
Electrical losses	2.0%	98.0%
Other losses	1.0%	99.0%
Net AEP before erosion, as a % of Gross		86%



https://ore-catapult-school.thinkific.com/ ore.catapult.org.uk


=IF(AND(CalendarYear >= FIT_price_start_year, CalendarYear <= FIT_price_final_year), 1, 0) * Generation_flag
Generation period flag (ignoring ELT)
1 = generating
25
2028 2029 2030 2031 2032
0 1 1 1 1
Early years: Feed-in tariff (FIT)
It is assumed that a fixed, negotiated tariff is received for an initial period, and thereafter, the tariff will be based on of the forecast wholesale power price
FIT duration 14
OK
Total / other
First year that FIT is used year 2029
Last year that FIT is used year 2042
FIT, base level, pre-sensitivity multiplier Real 2021 £/MWh 65.00
Additional, crude sensitivity multiplier applied to all years % 100%
FIT, base level, post-sensitivity multiplier (feeds model) Real 2021 £/MWh 65.00
FIT flag 1 = applicable 14
- 1 1 1 1
FIT (applicable years only) MOD £/MWh
- 75.64 77.00 78.39 79.80
Later years: Baseload wholesale market price (BWMP)
2028 2029 2030 2031 2032


Net Cashflow (NCF) Variance analysis
Start with Nearshore / 100 10MW turbines / Later, NCF Disc@0%
End with Nearshore / 100 10MW turbines / Later, NCF Disc@7%
Nominal £m
5,000
4,000
3,000
2,000
1,000
0
(1,000)
(2,000)
(3,000)
2,592
25
183
41
84
603
26
34
269
(6,171)
331
1,233
554
302
105
Start: before discounting
Finish: after discounting
Start: A NCF
Devex
Found. Supply
Found. Instl.
HVAC cable supply/instl.
Turbine Supply
Turbine instl.
Array cables instl.
Other Capex
Revenue
Maj. Repairs
Other O&M
Tax
Decom
END: B NCF

Classification of costs for Tax purposes	MOD £m	
Chosen case: Farshore / 166 6MW turbines / Now		
Costs which are expensed for tax purposes		
		Total / other
Devex	MOD £m	73
Construction Insurance (classed as capex)	MOD £m	45
Project Management (classed as capex)	MOD £m	100
Total O&M	MOD £m	1,973
Decommissioning	MOD £m	770
Total costs expensible for tax purposes	MOD £m	2,961
Costs which are depreciated for tax purposes		
		Total / other
All other capex not named above	MOD £m	3,025
Total costs depreciable for tax purposes, when incurred	MOD £m	3,025
Checksums	0 = ok	0

Use Goal Seek to try to calculate LCOE

SPECIAL: Levelised tariff for LCOE Goal Seek	Real 2021 £/MWh	**52.56**
SPECIAL: Levelised tariff for LCOE Goal Seek	**MOD £/MWh**	
For GoalSeek use: NPV from below, £MOD M"		(0.0)

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