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Professor: Alberto De Marco
Supervisor: Enrico Di Martino

- Financial Modeling to support decisions in offshore wind projects -

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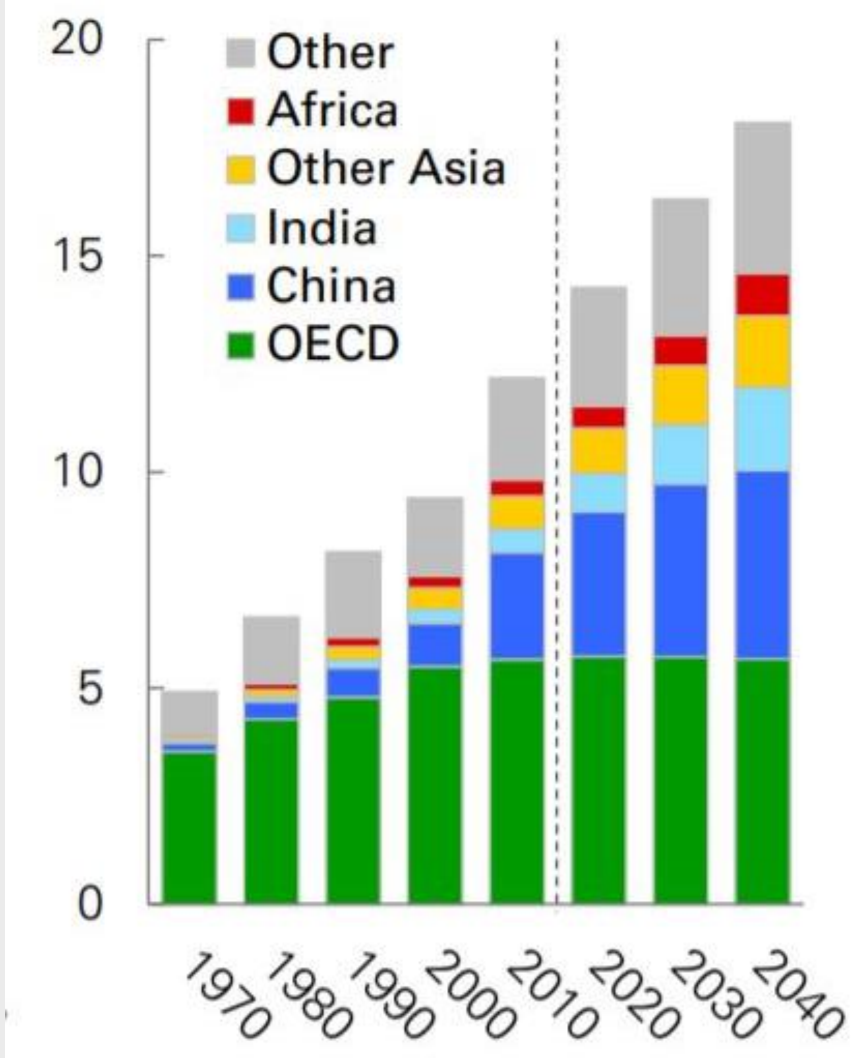
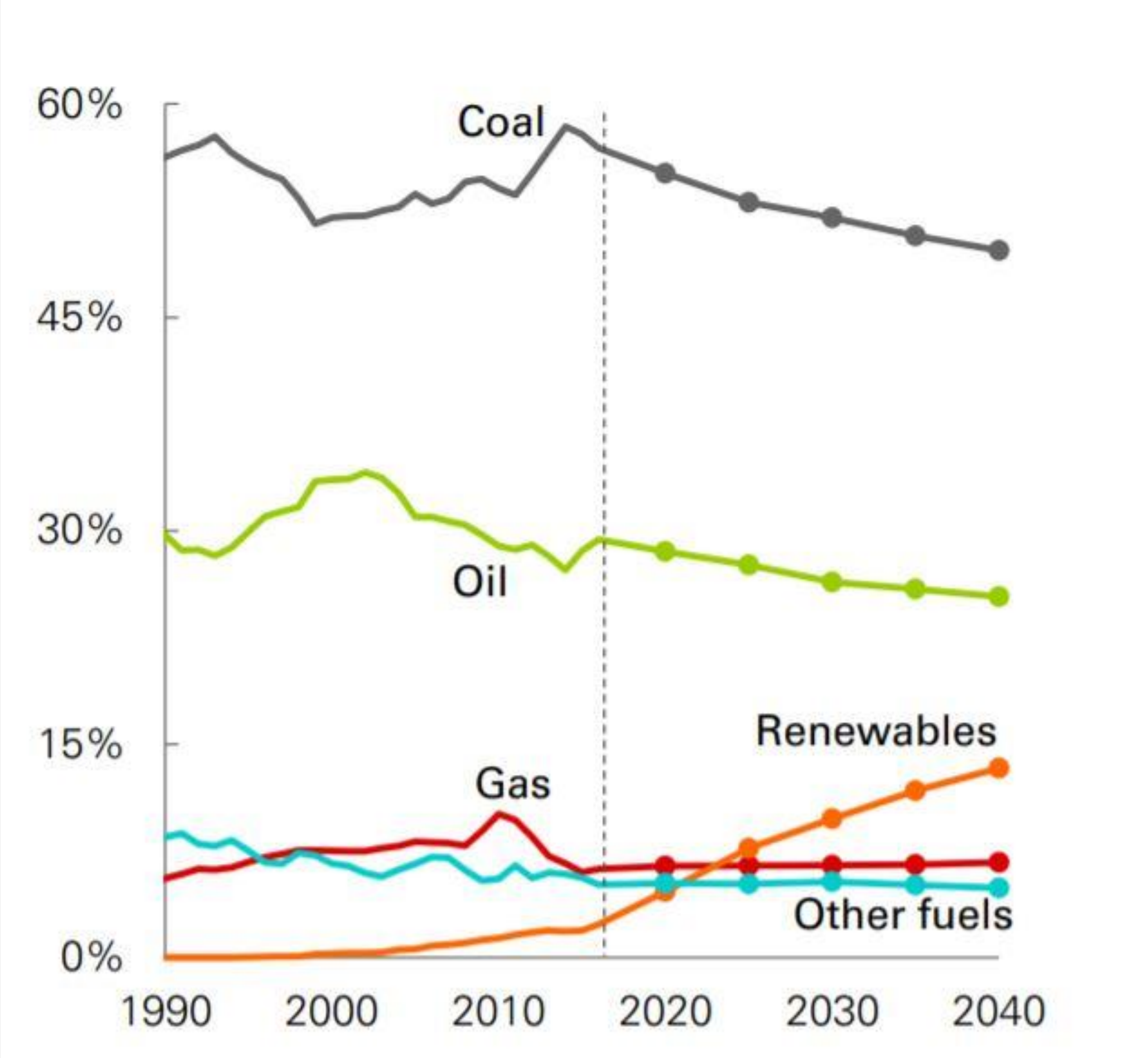
Energy Outlook (BP - 2018) (1/1)

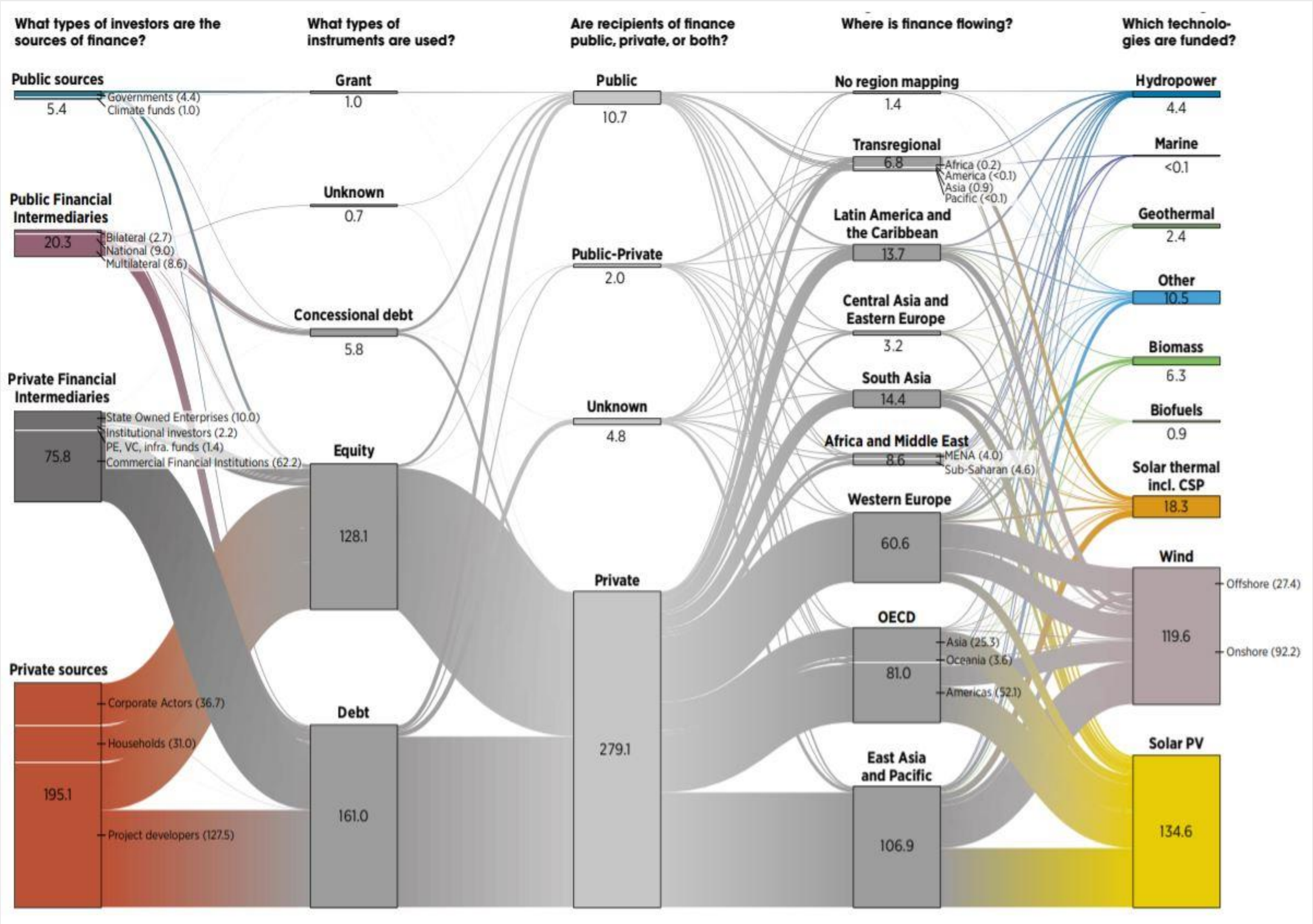
Energy consumption by regions and shares of primary energy





Investments trends in renewable energy (1/2)

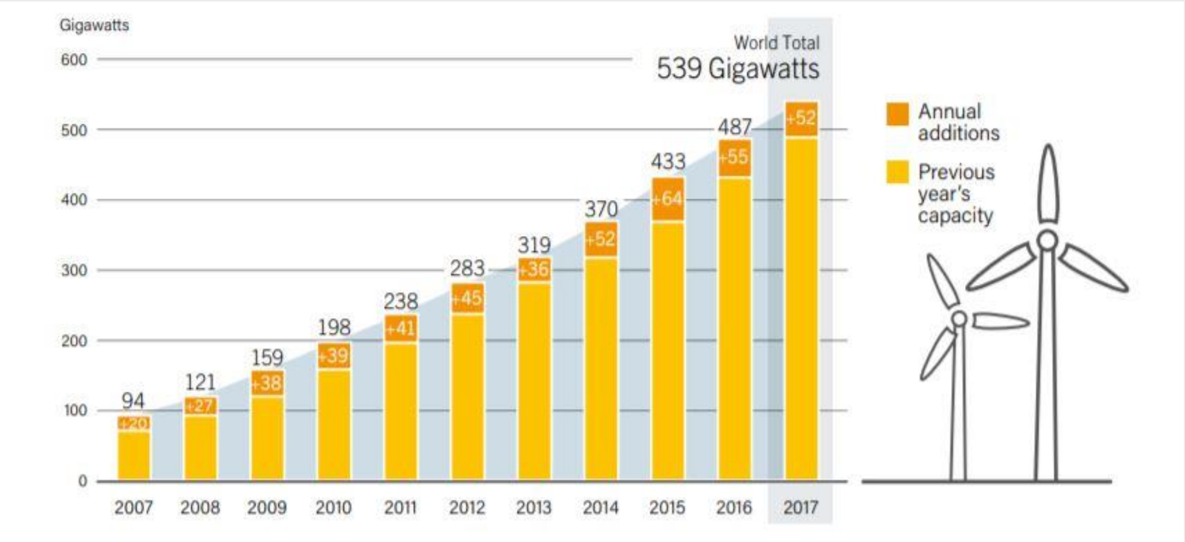
Global landscape of renewable energy finance



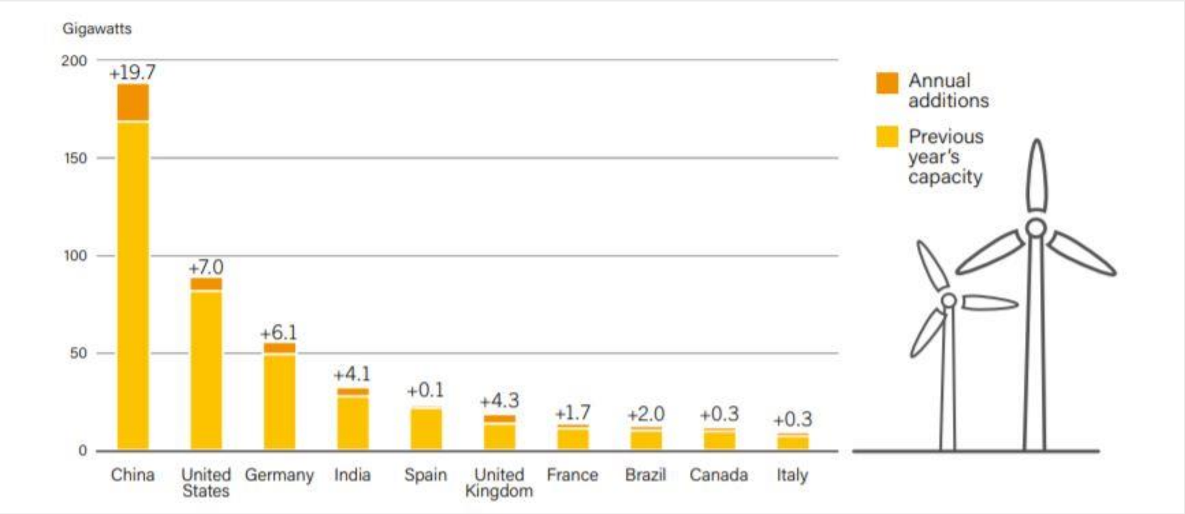
- The bulk of renewable energy investment in 2017 was financed mainly from private sources (about 90%)
- The most used finance instrument was debt 54%, equity accounted for about 43%
- Overall, private renewable energy investment stayed predominantly (93%) within the country of origin
- Investment in solar and wind (onshore and offshore) accounted for, on average, 90% of total private finance between in 2017

Investments trends in renewable energy (2/2)

Wind(Both onshore and offshore) as a growing market



→ In 2017 more than 52 GW of wind power were added globally reaching around 539 GW of total capacity installed



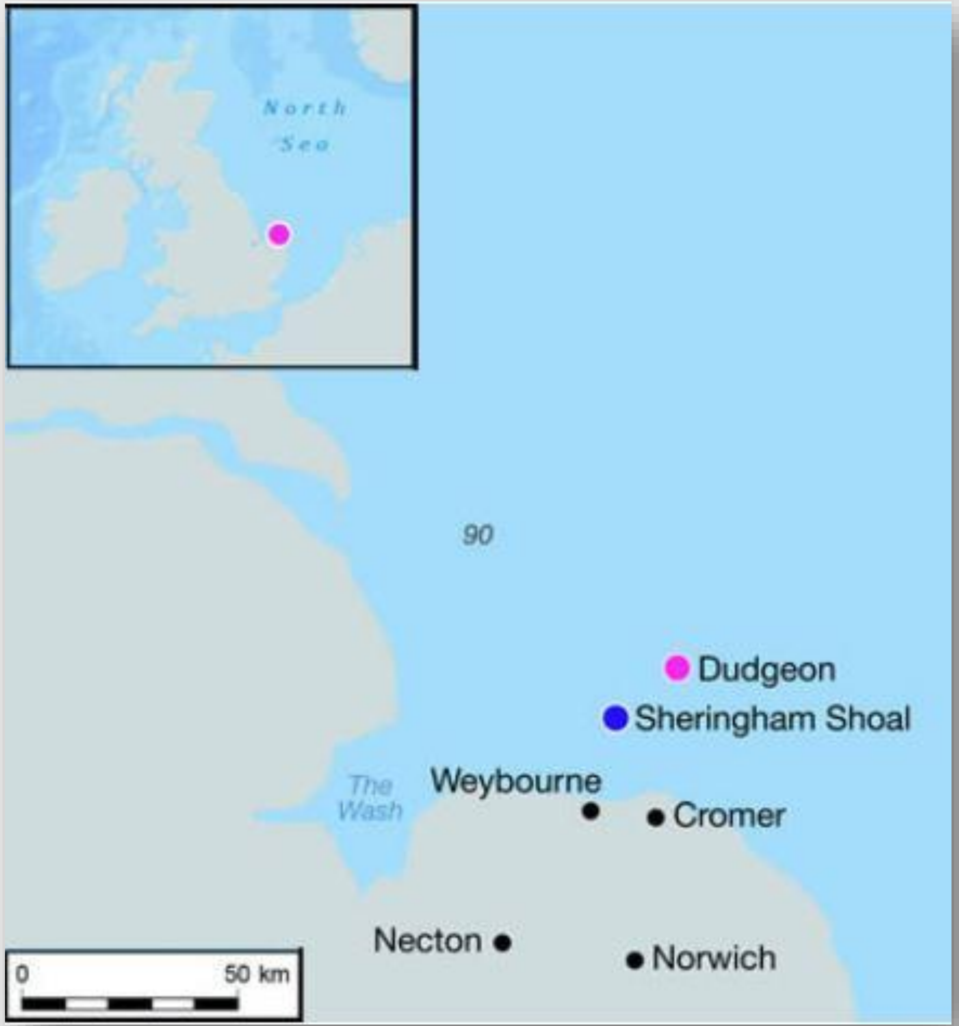
→ In 2017, for the ninth consecutive year Asia was the biggest market representing about 50% of added capacity, second was Europe with about 30%, the rest was 14% for North America and almost 6% for Latin America and Caribbean.

Case Study (1/1)

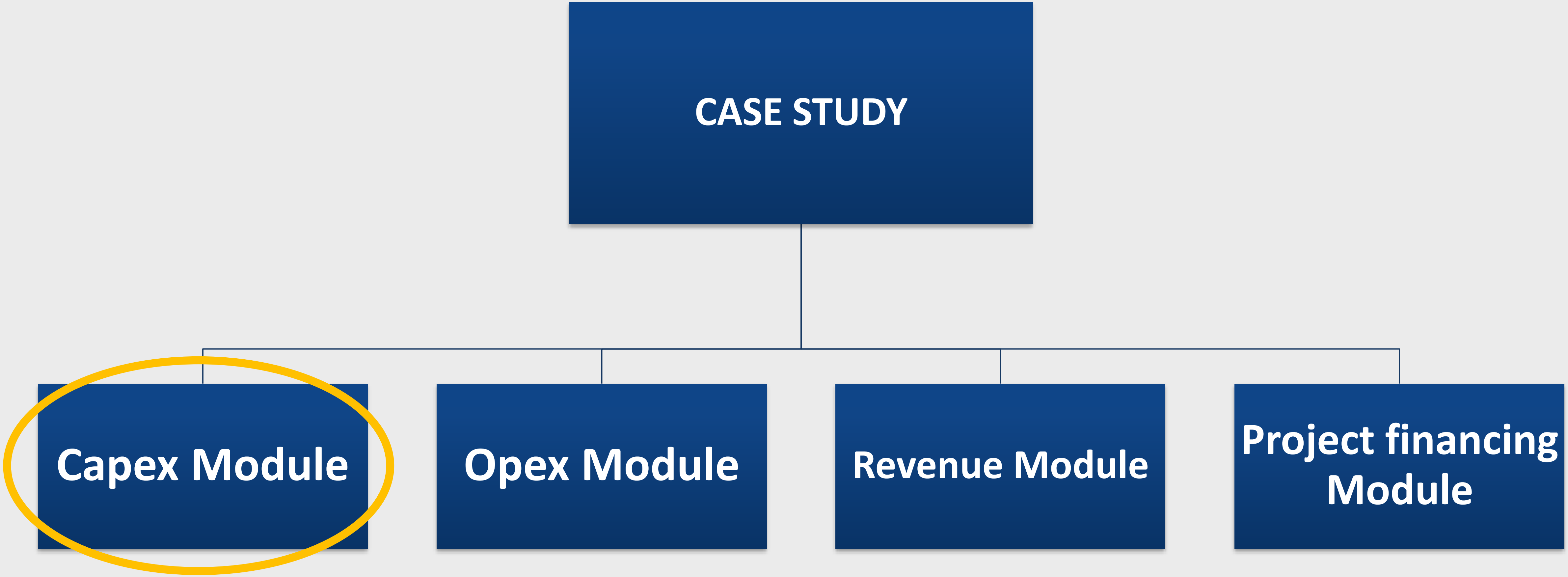
Description

- ➢ Location: North Sea (UK)
- ➢ Construction period: 5 Years
- ➢ Operational Life: 25 Years

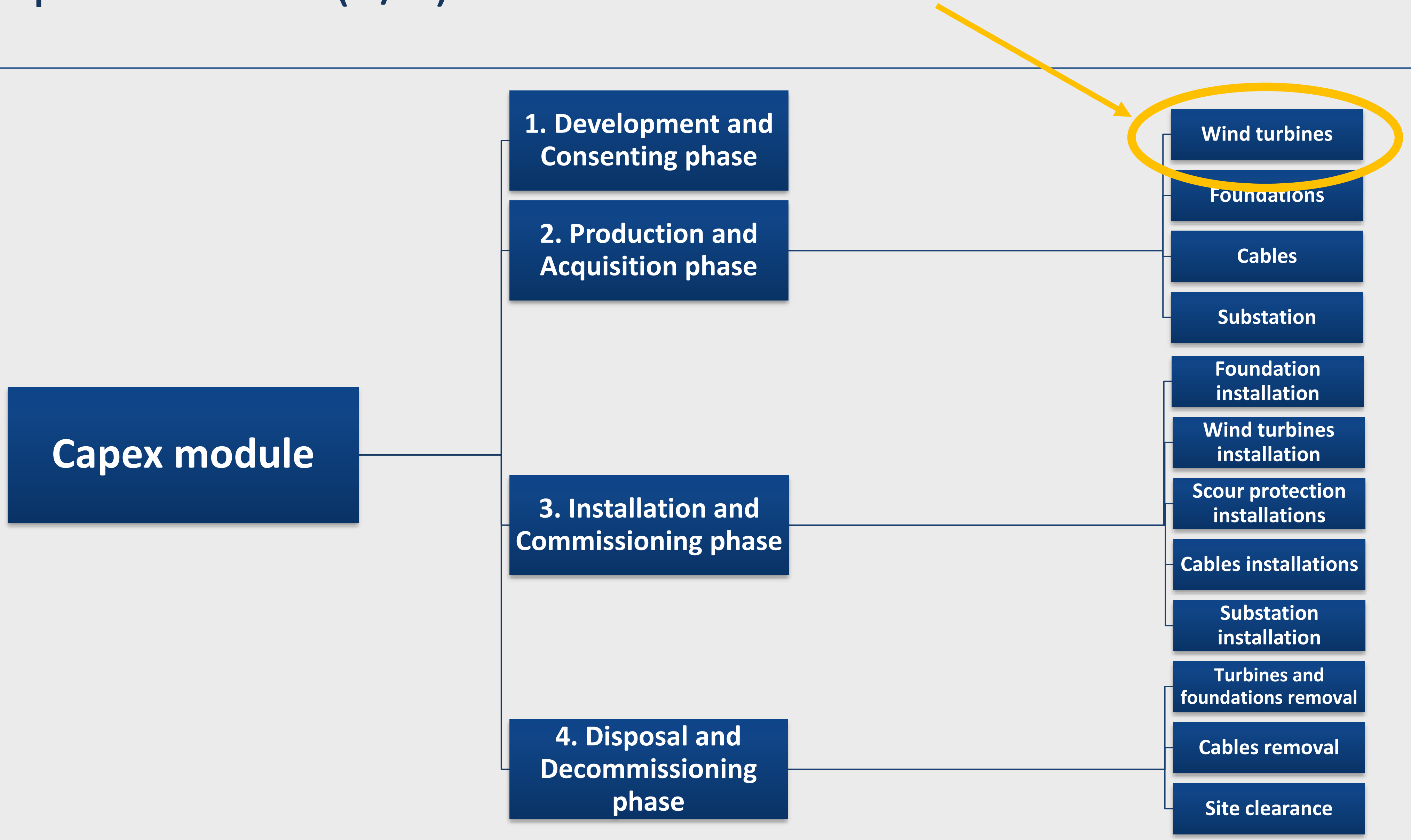
The wind farm is situated at 40 km distance from the port and is composed by **67 wind turbines**, each one generating a power of **6MW**. Therefore, the total wind farm capacity is **402 MW**. The wind farm is composed by **one substation** that will collect all the energy generated by all the turbines and will transfer it **to shore thank you to seabed cables**. An onshore substation has the responsibility to transfer the energy to the grid.



Phases of the Project



Capex Module (1/4)



Capex Module (2/4)

Wind turbines acquisition

The wind turbines are one of the most expensive component of an offshore wind project. Their cost is usually expressed as a function of the capacity. In [23] a parametric expression is used to estimate the wind turbine cost:

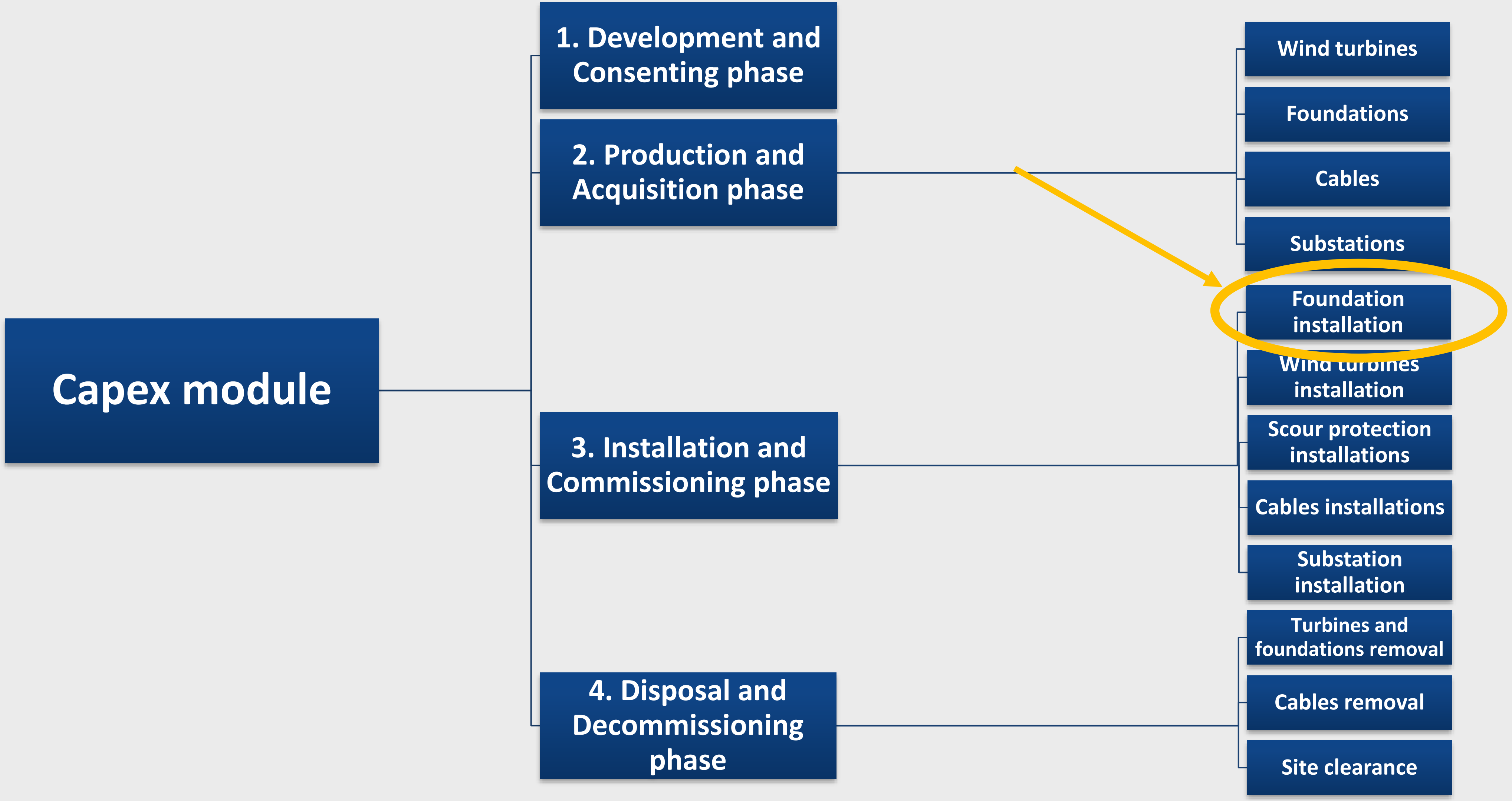
$$C_{wind\ turbines} = 3 * 10^6 * \ln(P_{wt}) - 662400$$

Where P_{wt} is the capacity of a single wind turbine that is assumed to be 6 MW

The cost for a single wind turbine accounts for about **£4,712 Million/turbine**

Capex module (3/4)

Capex module



Capex Module (4/4)

Foundation installation

$$T_{foundation\ installation} = \underbrace{2 * N_f * T_{port} + 2 * n_{wt} * T_{site}}_{\text{Time to jack up/down the vessel at the port and at the installation site}} + \underbrace{n_{wt} * T_{load}}_{\text{Monopile foundation loading time at the port}} + \underbrace{T_{port\ to\ farm}}_{\text{Travel time from port to farm}} + \underbrace{T_{betturb}}_{\text{Travel time between turbines}} + \underbrace{n_{wt} * T_f}_{\text{Installation time of the foundations}}$$

Where: N_f is the number of voyages, T_{port} is the time of jacking at the port, n_{wt} is the number of turbines, T_{site} is the time of jacking at the farm, T_{load} is the monopile foundation loading time, $T_{port\ to\ farm}$ is the travel time from port to farm, $T_{betturb}$ is the travel time between turbines and T_f is the installation time

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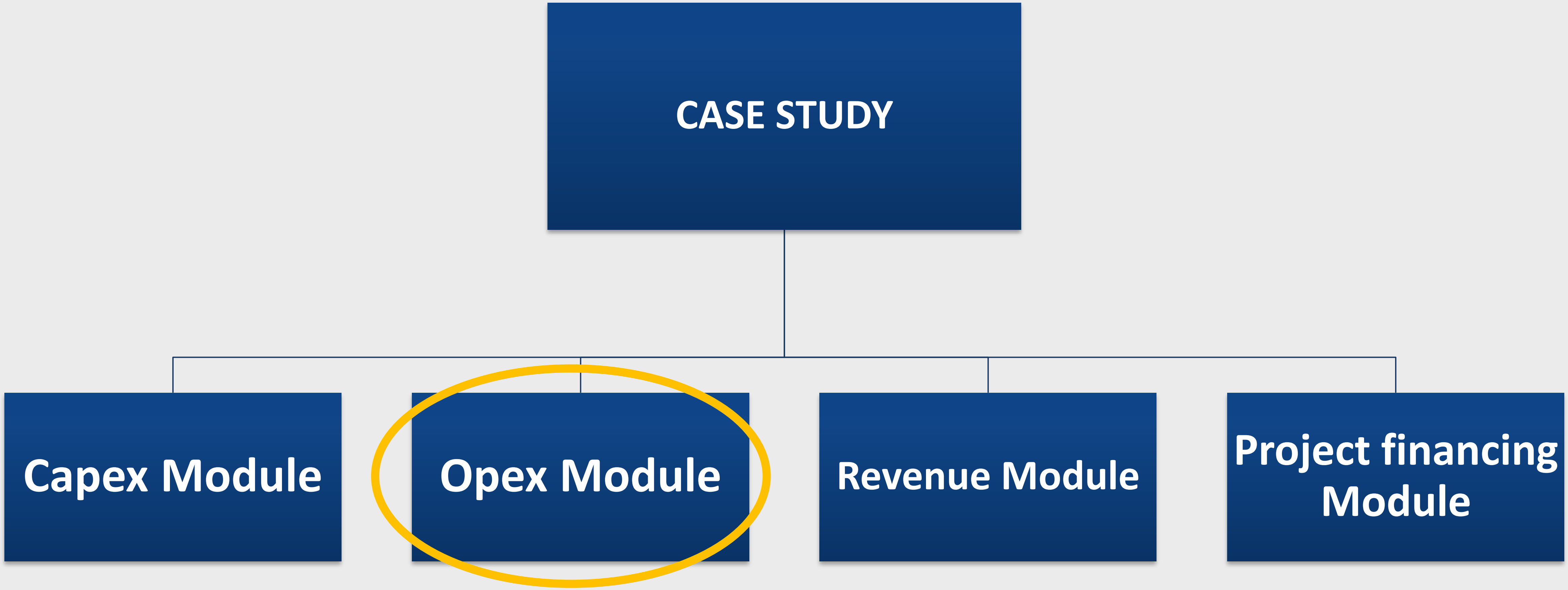
Installation of foundations assumptions		
Item	**Unit**	**Value**
Required installation days per MW installed	Days/MW	**0,3**
Total days to rent the foundation vessel	Days	**134**
Effective personnel time to install all the foundations	Days	**134**
Number of workers for the installation of foundations	Unit	**30**
Numbers of voyages	Unit	**22**
Time of jacking at the port	h	**2**
Time of jacking at farm site	h	**1**
Total time to travel between turbines	h	**3**
Monopile foundation loading time	h/turbine	**4**
Monopile installation in the subsea	h/turbine	**5**
Total travel time from port to farm	h	**447**
Jack up vessel capacity of foundations	Units/trip	**3**
Jacking up speed	m/h	**30**
Water depth at wind farm site	m	**40**
Vessel speed	Km/h	**4**
Mean distance between consecutive turbines	m	**250**
ADJweather	Unit	**0,8**
Voyage time	h	**10**
Distance from port to offshore farm	km	**40**

Phases of the Project



Opex module (1/1)

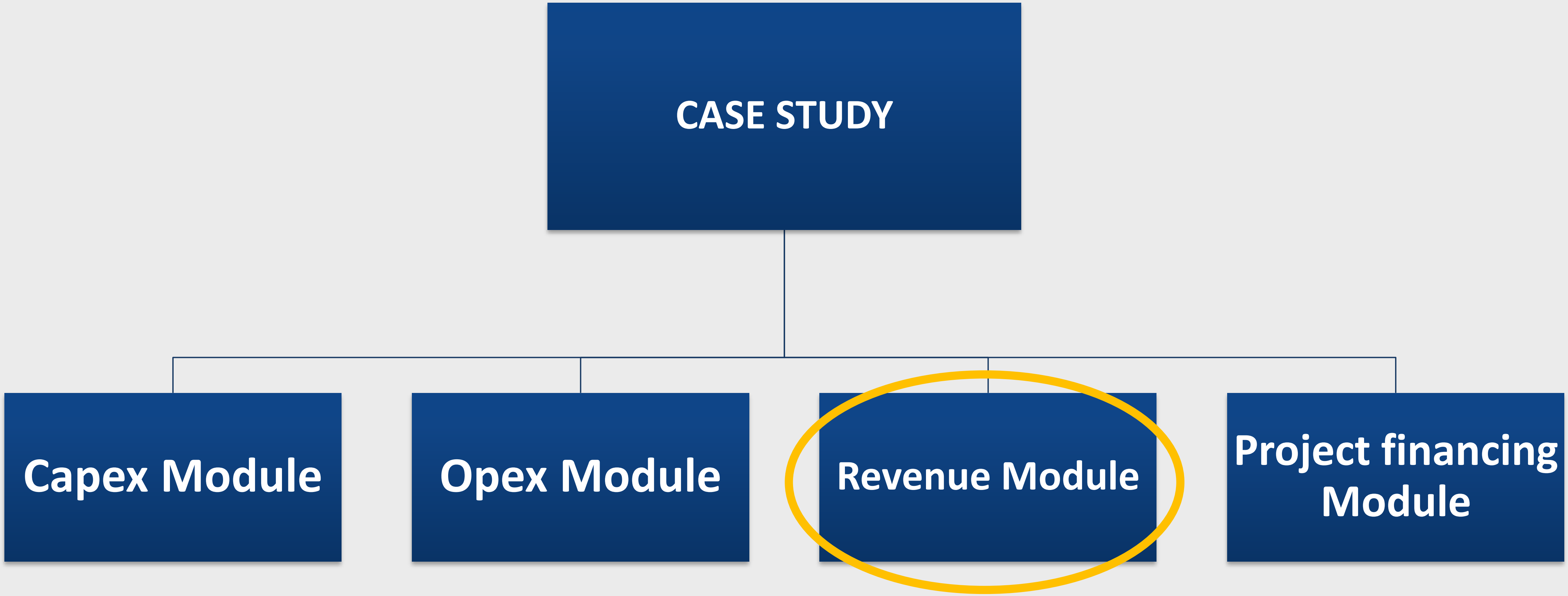
Calculation of operational costs

Operational cost represents a consistence cost driver when evaluating the profitability of an offshore wind farm. Under this category are listed all the costs that are related with the monitoring, scheduled and unscheduled maintenance etc.

Source	Estimate Opex (£/MWh)
KPMG	21.26
Levitt AC- Pricing offshore wind power	24
IRENA	25.76
IEA	17.1
Market Report - Aaron Smith	35.5

To evaluate all these sources equally an operational cost of **£24.722/MWh is assumed**.

Phases of the Project



Revenue model (1/1)

Phases for an Offshore project

The revenue is generated by multiplying the total energy produced of the offshore wind farm with the price of electricity. It is assumed that all the energy produced is sold

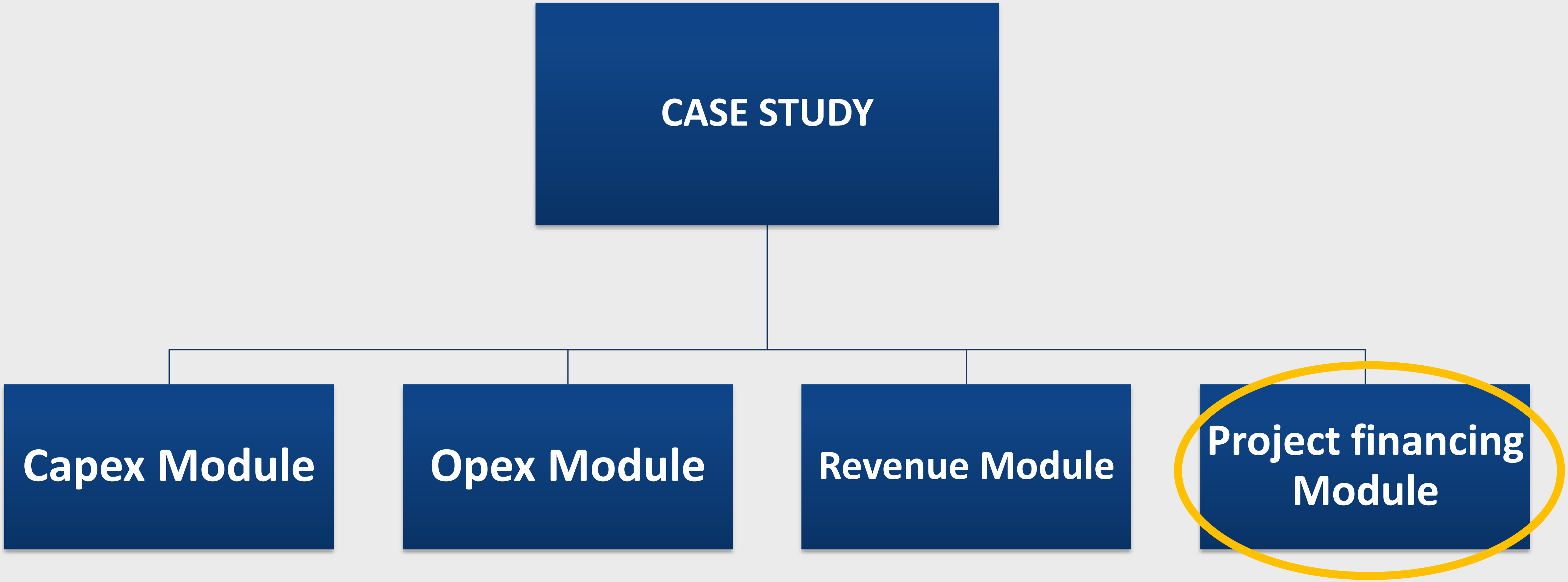
$$\text{Total energy produced per year(MWh)} = \text{Installed capacity(MW)} * 8760\text{(numbers of hours per year)} * \text{capacity factor}$$

Since the **project is placed in UK the policy instruments supporting the renewable industry is valid**. The contract for difference (CfD) scheme is effective in United Kingdom for companies generating energy from renewable sources. **The purpose of the CfD is to incentivize investments in new-low carbon electricity generation in the UK by providing stability and predictability to future revenue streams.**

For the case study, the strike price adopted amounts to **£143/MWh**, that corresponds to the average strike price for offshore wind farm during 2018.

$$Total\ Revenue\ per\ year = Total\ energy\ produced\ per\ year\ * Strike\ price$$

Phases of the Project



Project financing module (1/2)

Cost of capital

The weighted average cost of capital(WACC) is a calculation of a firm's cost of capital in which each category of capital is proportionally weighted and it can be expressed as:

$$Cost\ of\ equity = r_f + \beta * (E(r_m) - r_f)$$

$$WACC = \frac{E}{E+D} * Cost\ of\ Equity + \frac{D}{E+D} * \text{Cost of Debt}$$

$$Cost\ of\ debt = interest\ rate * (1 - corporate\ tax\ rate)$$

WACC Calculation	
Leverage D/(D+E)	40%
Tax Rate	19%
Interest rate	3.25%
Rf(Risk free rate)	1.7%
β (Beta)	1.1
Market risk premium	4.5%
Cost of equity	6.685%
Cost of debt	3%
WACC	5.31%

	Nordex	Vestas	Siemens Gamesa
Levered Beta	1.25	1.29	1.38
Gearing (Debt/Equity)	0.79	1.08	1.33
Unlevered Beta	0.78	0.71	0.68

$$\beta_u = \frac{\beta_l}{1 + \frac{D}{E} * (1 - t)}$$

$$\beta_l = \beta_u * (1 + (1 - T) * \frac{D}{E})$$

Project financing Module (2/2)

Capital allowances

In UK is available the tax depreciation through capital allowances regime, according to which the 18% of qualifying expenditure on equipment is reduced. The effect of depreciation is estimated by **dividing the equipment cost of the wind farm, $C_{equipment}$, over the total life span of the asset and deducting 18% of this annual cost from the tax payment**. Therefore, the net tax T_{net} can be calculated by deducting the depreciation credit D_{Credit} from the yearly tax payment, $T_{payment}$ as shown below:

$$D_{Credit} = \frac{C_{equipment}}{n} * d_{rate}(18\%)$$

$$T_{payment} = T_c * Pgr$$

$$T_{net} = T_{Payment} - d_{credit}$$

Where Pgr is the Gross profit

Results (1/2)

Deterministic scenario + Sensitivity analysis on Capex and Opex

On the baseline scenario the NPV of the investment was calculated to be **467.4 M£** and an **IRR=8,36%.** The Breakeven time is reached between year 19 and year 20.

Capex

Opex	1.050.000.000	1.100.000.000	1.163.043.305	1.200.000.000	1.250.000.000	1.300.000.000	1.400.000.000	1.500.000.000	1.600.000.000	1.615.000.000
20	652.026.201	600.536.550	535.614.993	497.557.247	446.067.595	394.577.944	291.598.641	188.619.338	85.640.035	70.193.140
21	637.581.961	586.092.309	521.170.753	483.113.006	431.623.355	380.133.703	277.154.400	174.175.097	71.195.794	55.748.899
22	623.137.720	571.648.069	506.726.512	468.668.766	417.179.114	365.689.463	262.710.160	159.730.857	56.751.554	41.304.658
23	608.693.479	557.203.828	492.282.271	454.224.525	402.734.873	351.245.222	248.265.919	145.286.616	42.307.313	26.860.418
24,7	583.820.497	532.330.845	**467.409.289**	429.351.542	377.861.891	326.372.239	223.392.936	120.413.634	17.434.331	1.987.435
26	565.360.757	513.871.106	448.949.549	410.891.803	359.402.151	307.912.500	204.933.197	101.953.894	-1.025.409	-16.472.304
27	550.916.517	499.426.865	434.505.309	396.447.562	344.957.911	293.468.259	190.488.956	87.509.653	-15.469.650	-30.916.545
28	536.472.276	484.982.624	420.061.068	382.003.321	330.513.670	279.024.018	176.044.716	73.065.413	-29.913.890	-45.360.786

Capex

Opex	1.050.000.000	1.100.000.000	1.163.043.305	1.200.000.000	1.250.000.000	1.300.000.000	1.400.000.000	1.500.000.000	1.600.000.000	1.615.000.000
20	9,84%	9,34%	8,77%	8,45%	8,04%	7,66%	6,96%	6,32%	5,75%	5,67%
21	9,75%	9,26%	8,68%	8,37%	7,96%	7,58%	6,88%	6,25%	5,68%	5,60%
22	9,66%	9,17%	8,60%	8,28%	7,88%	7,50%	6,80%	6,17%	5,60%	5,52%
23	9,57%	9,08%	8,51%	8,20%	7,80%	7,42%	6,72%	6,10%	5,53%	5,45%
24,7	9,41%	8,93%	**8,36%**	8,05%	7,65%	7,28%	6,59%	5,96%	5,40%	5,32%
26	9,29%	8,81%	8,25%	7,94%	7,54%	7,17%	6,48%	5,87%	5,31%	5,23%
27	9,20%	8,72%	8,16%	7,85%	7,46%	7,09%	6,40%	5,79%	5,23%	5,15%
28	9,11%	8,63%	8,07%	7,77%	7,37%	7,00%	6,32%	5,71%	5,15%	5,08%

Results (2/2)

Sensitivity analysis (Capacity Factor, Delay time and Debt Ratio)

Debt ratio (%)	20	30	40	50	60	70	80
WACC (%)	6%	5,65%	5,31%	4,96%	4,62%	4,28%	3,93%
NPV (M£)	518.7	494.8	467.4	436.1	400.7	360.8	316.1
IRR (%)	9,78%	9,07%	8,36%	7,65%	6,95%	6,25%	5,55%

Delay time (Year)	1	2	3	4	5
NPV (M£)	348.8	242.4	145.2	55.7	- 27.2
IRR (%)	7,63%	6,96%	6,32%	5,71%	5,11%

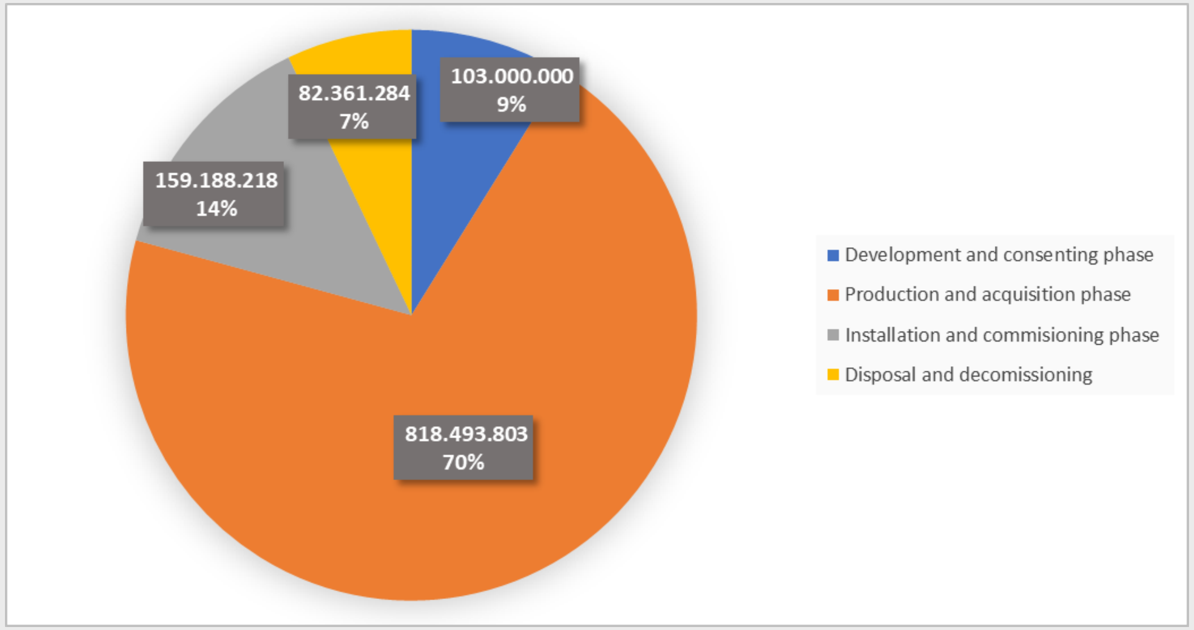
Net capacity factor (%)	NPV (£)	IRR (%)
0,45	363.340.340	7,73%
0,46	398.029.990	7,94%
0,47	432.719.639	8,15%
0,48	467.409.289	8,36%
0,49	502.098.938	8,57%
0,5	536.788.588	8,77%
0,51	571.478.238	8,98%
0,52	606.167.887	9,18%
0,53	640.857.537	9,38%
0,54	675.547.186	9,57%

Conclusion

- **Paris Agreement**: To meet this important agreement a massive introduction of renewable source to produce energy must be made, and offshore wind can have a determinant role in it
- **It is Profitable:** IRR of 8.36%. “Classic” renewable energy projects such as onshore wind and solar have an IRR in the range of 9-11%. This is due to higher capex cost that offshore wind projects required → Possible reduction due to economies of scale
- **Risk intrinsic**: Risks are intrinsic in the development of the project and they can be found at different levels and at different steps of the development
- **Environmental impact**: The effect on the environmental are way less negative compared with the conventional fossil fuels, wind turbines during their lifetime do not pollute the atmosphere with greenhouse gases and do not create any problems for future generations with radioactive waste
- **Stochastic source of energy**: Due to its nature, wind is not constant. There is the need to integrate wind and solar with other renewable and not renewable energy sources to stabilize the grid

Thank you for your attention!

Backup



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9%
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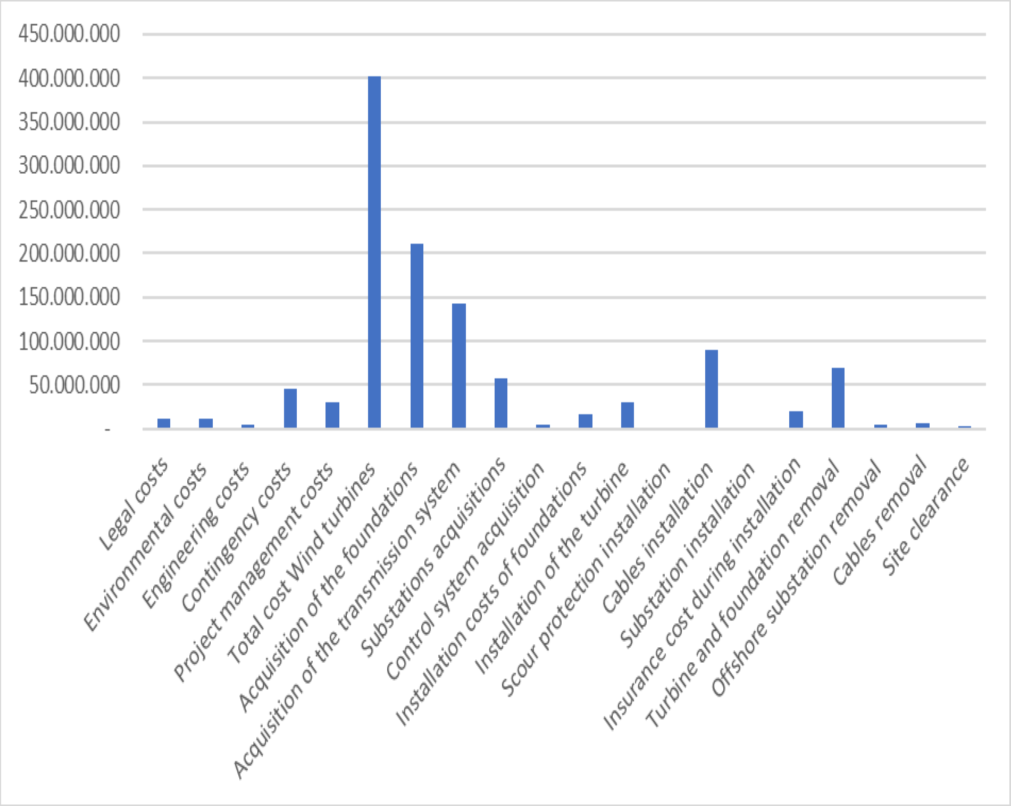
70%
Development and consenting phase
Production and acquisition phase
Installation and commisioning phase
Disposal and decomissioning



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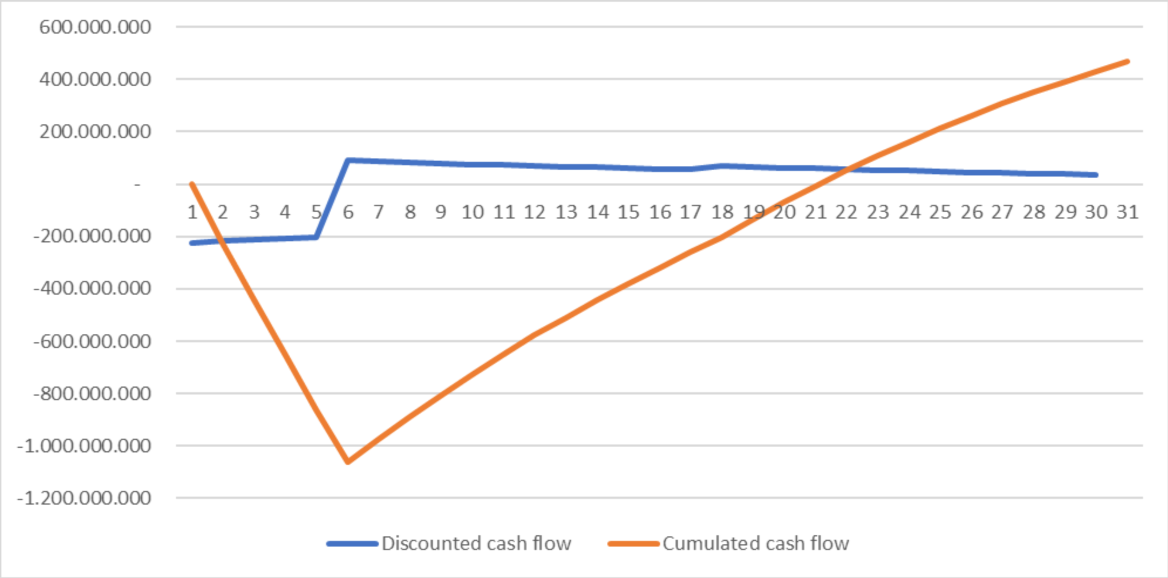
Legal costs
Environmental costs
Engineering costs
Contingency costs
Project management costs
Total cost Wind turbines
Acquisition of the foundations
Acquisition of the transmission system
Substations acquisitions
Control system acquisition
Installation costs of foundations
Installation of the turbine
Scour protection installation
Cables installation
Substation installation
Insurance cost during installation
Turbine and foundation removal
Offshore substation removal
Cables removal
Site clearance

Backup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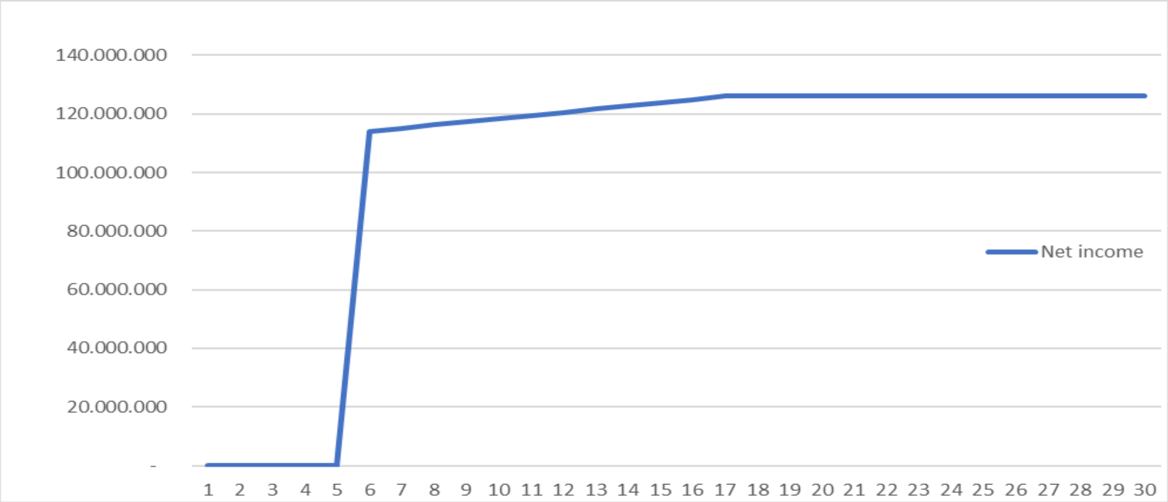
Discounted cash flow
Cumulated cash flow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-
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Net income

Backup

Production and acquisition phase – Foundations

$$C_{foundation} = 320000 * P_{wt} * \left(1 + 0.02 * (WD - 8)\right) * (1 + 8 * 10^{-7}(h * \left((d/2)^2 - 100000)\right)\right)$$

This equation links the cost of the foundations with the turbine geometry (hub height(h), the rotor diameter(d)) and the water depth(WD))

Backup
Production and acquisition phase – Cables

- Array cables: Cables that allow the interconnection of all the turbines at the wind farm site. These cables obtained energy from each wind turbine and transfer it to the offshore substation. Usually Mean voltage (MV) submarine cables are used as array cables. In order to estimate the length of the array cables an equation from [25] is used that use as input parameters the number of the wind turbines(n_{wt}) and the rotor diameter(d):

$$L1 = 1.125 * n_{wt} + 1055 * d - 122640$$

- Offshore cables: Offshore cables are usually high-voltage alternating current (HVAC) or high-voltage direct current (HVDC). The offshore cables have the responsibility to transfer energy from the offshore substation to the onshore one. The distance from the offshore substation and the onshore one is assumed to be equal to the distance from the substation to the port (40 Km). The connection occurs thank you to three subsea export cables.
- Onshore cables: Provide the transfer of the energy from the onshore substation to the grid connection. It is assumed a distance of 20km from the onshore substation to the grid connection. As for the offshore cables, three export cables are assumed

Cables information		
Item	**Unit**	**Value**
Array cables length	Meters	**85.665**
Offshore export cable length (x3)	Meters	**120.000**
Onshore export cable length (x3)	Meters	**60.000**
Cost per meter for array cable	£/Meter	**190**
Cost per meter for Offshore cable	£/Meter	**780**
Cost per meter for Onshore cable	£/Meter	**260**

Backup

Production and acquisition phase – Substation

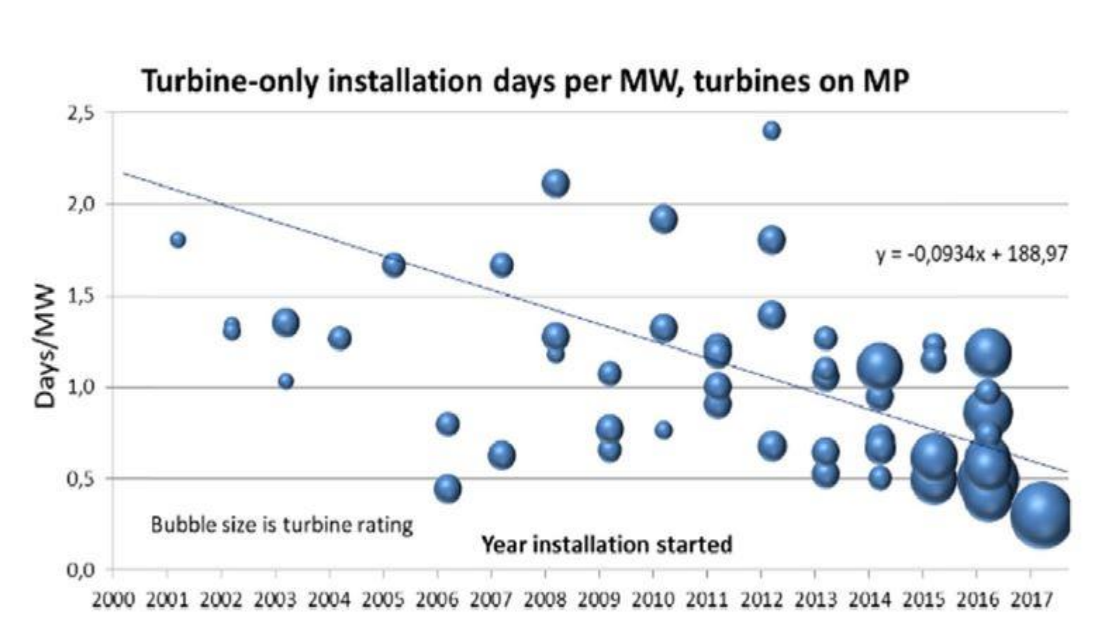
$$CoS = 539 * P^{0.678}$$

Where CoS stands for cost of the offshore substation in K£, P the wind power capacity in MW. This equation suggests us that the cost of acquisition for the offshore substation is approximately 31.5 Million.

As a precautionary measure, considering figure 18 that shows the cost of the offshore substation for many different projects a cost of 38 Million is adopted. The onshore substation was assumed to cost half of the cost of the offshore one.

Backup

Installation and commissioning phase – wind turbines



Turbines are installed after the foundations have been placed. According to [29], the installation time per megawatt for the wind turbines have decreased enormously in the last years reaching on average **0,62 days/MW in 2017**.

Backup

Installation and commissioning phase – Scour protection

The total time required per trip is the sum of the loading time plus the dumping time and the travel time. Considering the capacity of the rock-dumping vessel and the ton of rocks required for each turbine a total of almost 17 trips is required. Considering 12 working hours per day and a weather adjuster of 0,85, 59 days are required for the scour protection installation. The installation cost of scour protection was then estimated considering the vessel day rate.

Scour protection installation information		
Item	**Unit**	**Value**
Total effective days for scour protection installation	Days	**59**
Total time	h	**597**
Total time required per trip	h	**36**
Tonnage of scour protection per unit	Ton/turbine	**8.000**
Rock-dumping vessel capacity	Ton	**32.000**
Number of trips required for the scour protection	Unit	**17**
Loading time per trip	h	**10**
Dumping time per trip	h	**24**
Travel time	h	**2**
Distance from port to offshore farm	km	**40**
Speed of the vessel	km/h	**24**
ADJ weather	Unit	**0,85**

Backup

Installation and commissioning phase – Substation

$$T_{substation} = (n_{subst} * R_{subst} * D_{pile}) + T_{reposit} + T_{subst jacket}$$

Installation of offshore substation information		
Item	**Unit**	**Value**
Total effective installation days for the substation	Days	**10,1**
Total installation time for substation	h	**55**
Total time for transport the offshore substation	h	**5**
Speed of the substation vessel	km/h	**15**
Number of piles per substation foundation	Unit	**4**
Rate of piling the piles of the substructure	h/m	**0,1**
Depth of pile under the soil	m	**40**
Reposition time of the vessel	h	**12**
Installation time of the substation’s jacket	h	**25**
ADJ weather	Unit	**0,5**

Backup

Disposal and decommissioning

Turbine and foundation removal – INPUTS		
Remove time per turbine with a self-propelled jack up vessel	h/turbine	**20**
Complete turbines (including foundations) capacity of a Jack up vessel	Turbines/trip	**4**
Number of jacks up vessels for the removal of the wind turbines	Unit	**3**
Number of workboats employed for the decommissioning of the turbines	Unit	**2**
Number of technicians per workboat	Unit	**8**
Offloading time of turbines/monopiles	h/item	**8**
Time to cut the foundation	h/foundation	**8**
Time to lift the item and place on the deck	h/item	**13**
Turbine and foundation removal – OUTPUTS		
Total duration of each trip which equals the sum of the travel time to and from site, the removal time of turbines and monopile, the loading time and the intra-field movement time of the jack up vessel	h	**312**
Total time per trip (adjusted to weather and working hours)	Days	**30,6**
Total effective days for turbines and monopiles removal divided by the number of vessels	Days	**171**
Total cost of hiring technicians and workboats during the decommissioning of the wind turbines	£	**1.933.278**
Cost for removing all wind turbines with monopiles	£	**69.167.647**

Offshore substation removal – outputs		
Total time for the removal of the substation (Assumption Removal of the substation = 4 turbines completed removal)	days	**30,6**
Total cost for the removal of the substation	£	**4.129.412**

Cables removal		
Rate of removal of inner-array cables	m/day	**800**
Rate of removal of export cables	m/day	**1200**
Days required	days	**322**
Cost of cables removal	£	**6.441.625**

Backup

Disposal and decommissioning – Site clearance

$$Area = -51.5 + 0.41 * d + 0.65 * N \quad (In\ km)$$

Where d is the rotor diameter and N is the number of turbines

Site clearance		
Area	km^2	**44**
Total cost for site clearance	£	**2.622.600**