PO.240

Cost of Energy for Wind Turbines With Different Drive Train Types

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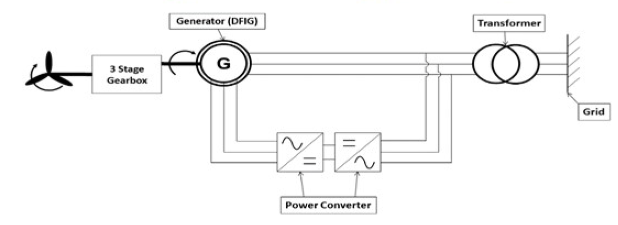
Introduction and Drivetrains

Introduction

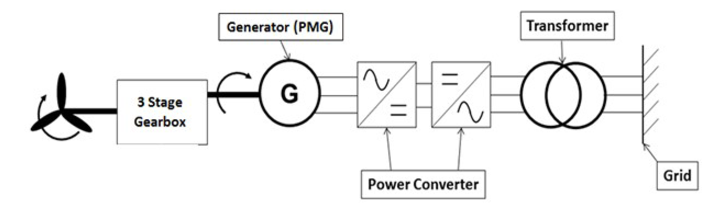
- How do you choose between different competing wind turbine models when planning an offshore wind farm?
- Many turbine types available
- Drive train biggest differentiator
- This work shows how the drive train choice effects the CoE of offshore wind farms
- 3 hypothetical Sites located at different distances from shore
- Each site has one of four different drive train types

4 Drive Train Types Analysed

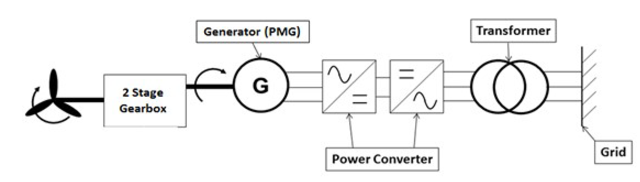
Turbine Type 1: 3 Stage, DFIG, PRC



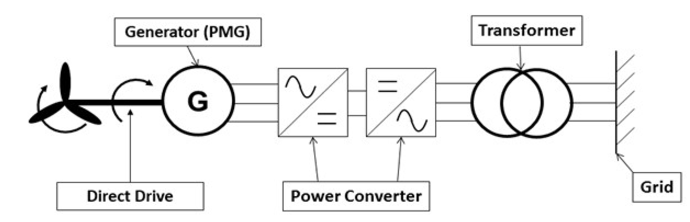
Turbine Type 2: 3 Stage, PMG, FRC



Turbine Type 3: 2 Stage, PMG, FRC



Turbine Type 4: DD, PMG, FRC



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Method, CoE Equation, Models and Hypothetical Sites

Method

1. Obtain or create required models
2. Secure empirical data
3. Adjust empirical data. REMM, Cost, Power Curve
4. Combine all models and input data to work out CoE for 4 drive train types
5. Compare results and draw conclusions

2. CoE Equation & Input Models Used:

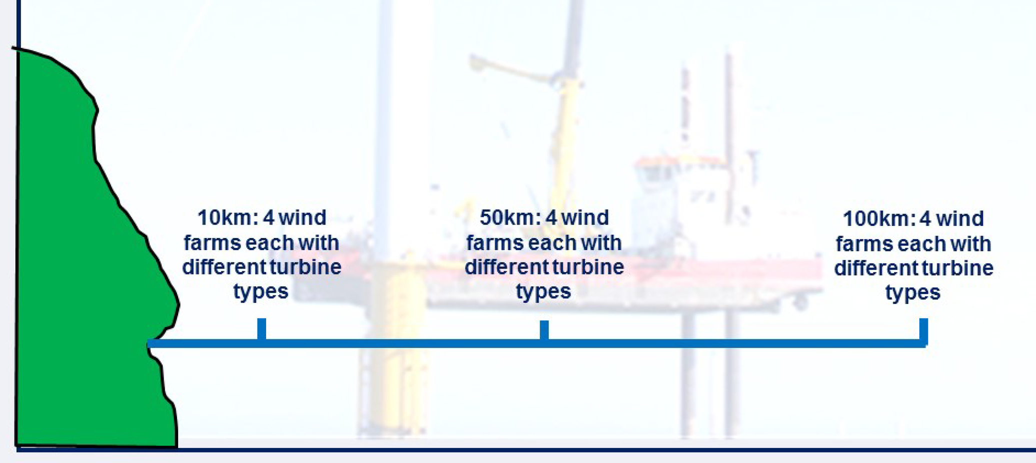
$$\frac{(\text{Initial Capital Costs} \times \text{Fixed Charge Rates}) + (\text{O\&M Costs})}{\text{Energy Production}}$$

- **Initial Capital costs:** Turbine costs, BoS (Port, foundation, electrical infrastructure etc.) Other Capital Costs (contingency, decommissioning etc.)
- **O&M costs** include the staff costs, repair costs and transport costs.

Model and Output	Description	Input and source of input
O&M Cost Model. Output: O&M costs for each drive train type at each site	The O&M cost model used in this work was the AM02 model created at the university of Strathclyde [1]	Empirical failure rates, repair times, no. of technicians required for repair, repair costs and so on, from a population of ~350 offshore modern multi MW turbines from between 5-10 offshore wind farms throughout Europe.
Energy Production Model. Output: Energy produced by each turbine type at each site.	The energy production model used in this work was the AM02 model created at the University of Strathclyde [1]	Empirical power curves from wind turbines with different drive train types, wind and wave data from a north sea site
BoP Model Output: BoS costs for each turbine type at each site	The balance of plant model from which results were obtained was created by NREL [2]	Costs of: ports, staging, substructure, foundation, electrical infrastructure, assembly, installation, development, engineering, management and commissioning. Model populated by Garrad Hassan
Other outputs:	Wind Turbine Costs for different turbine types. Component cost for different wind turbine types.	Provided by a leading wind turbine manufacturer who was the PhD industrial partner to the author

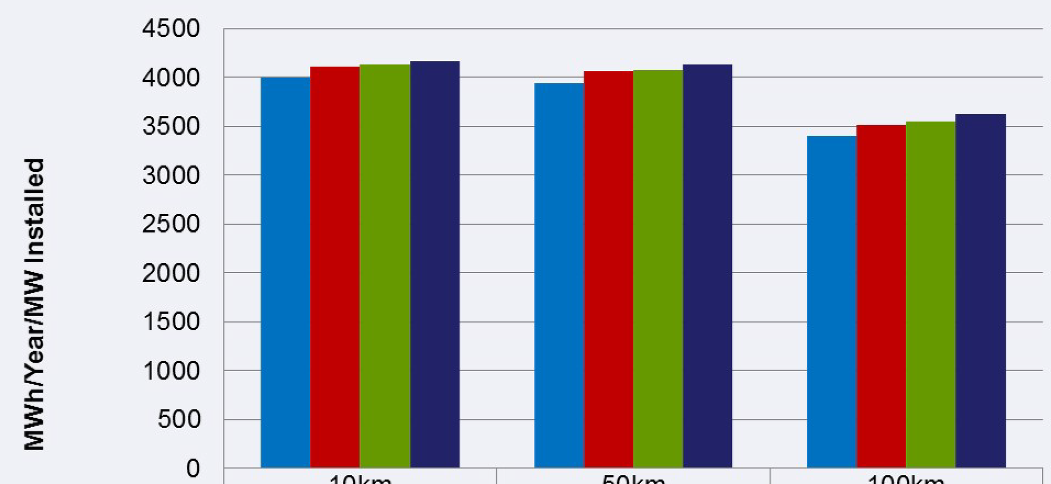
3. Hypothetical Sites:

- 12 Wind Farms
- 4 at 10km, 4 at 50km, 4 at 100km
- 100 modern MW offshore wind turbines of the same rated power
- Each of the 4 at 10km will have one of the 4 turbine types described earlier
- FINO climate and sea state data used
- FINO representative of a North Sea Site



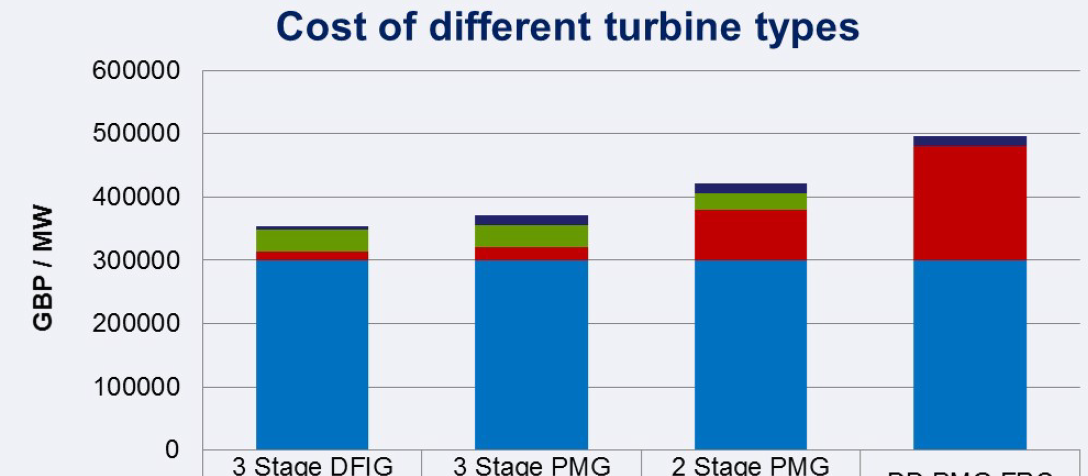
Results and Conclusions

Energy production for each drive train type at each site



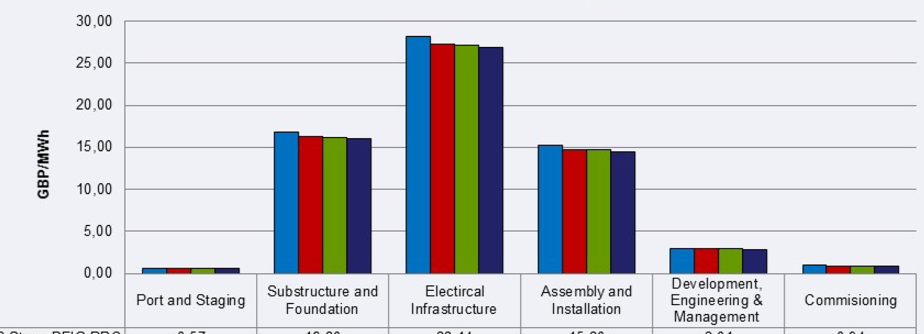
	10km	50km	100km
3 Stage DFIG PRC	4002	3940	3400
3 Stage PMG FRC	4110	4060	3520
2 Stage PMG FRC	4130	4080	3550
DD PMG FRC	4170	4130	3630

Cost of different turbine types



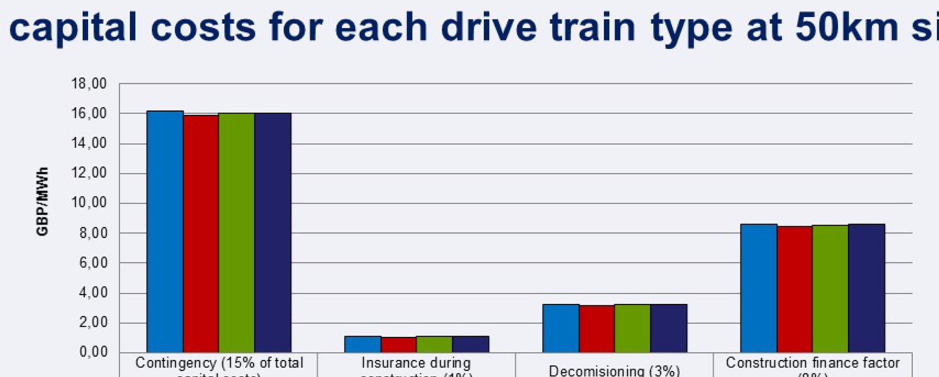
	3 Stage DFIG PRC	3 Stage PMG FRC	2 Stage PMG FRC	DD PMG FRC
Converter	6000	15500	15500	15500
Gearbox	35000	36000	25000	0
Generator	13500	20000	80000	180000
Rest of Turbine	300000	300000	300000	300000

BoP costs for each drive train type at 50km site



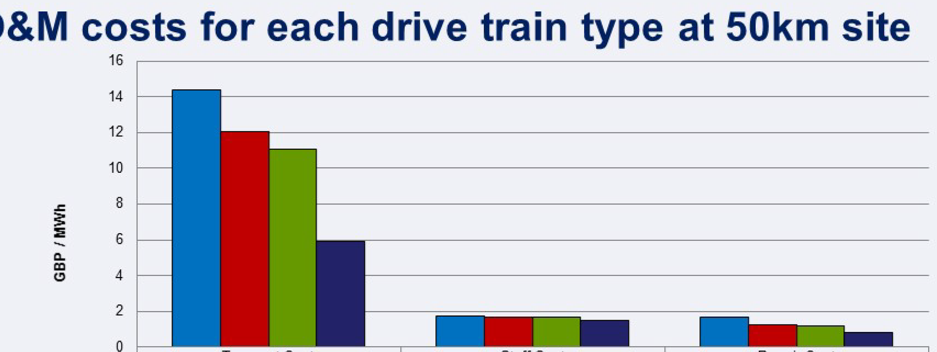
	Port and Staging	Substructure and Foundation	Electircal Infrastructure	Assembly and Installation	Development, Engineering & Management	Commisioning
3 Stage DFIG PRC	0,57	16,80	28,14	15,20	3,01	0,94
3 Stage PMG FRC	0,55	16,30	27,31	14,75	2,92	0,91
2 Stage PMG FRC	0,55	16,22	27,17	14,68	2,90	0,90
DD PMG FRC	0,54	16,02	26,84	14,50	2,87	0,89

Other capital costs for each drive train type at 50km site



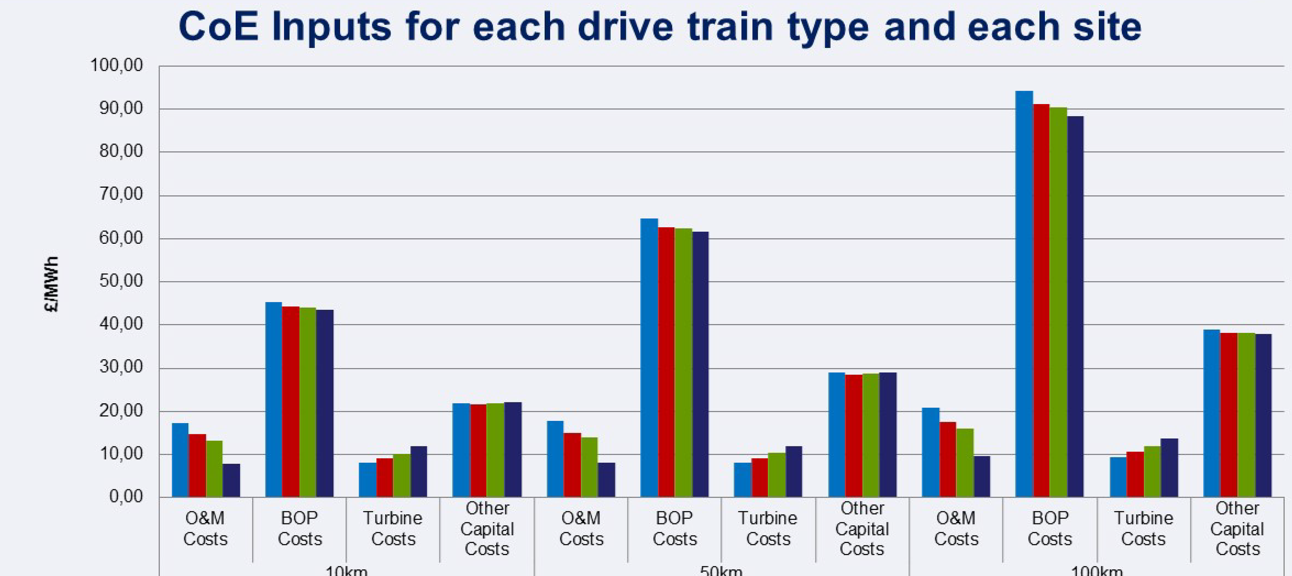
	Contingency (15% of total capital costs)	Insurance during construction (1%)	Decomisioning (3%)	Construction finance factor (8%)
3 Stage DFIG PRC	16,17	1,08	3,23	8,62
3 Stage PMG FRC	15,88	1,06	3,18	8,47
2 Stage PMG FRC	15,99	1,07	3,20	8,53
DD PMG FRC	16,06	1,07	3,21	8,56

O&M costs for each drive train type at 50km site



	Tansport Cost	Staff Cost	Repair Cost
3 Stage DFIG PRC	14,37	1,74	1,65
3 Stage PMG FRC	12,05	1,65	1,26
2 Stage PMG FRC	11,06	1,65	1,15
DD PMG FRC	5,88	1,5	0,80

CoE Inputs for each drive train type and each site



	10km				50km				100km			
	O&M Costs	BOP Costs	Turbine Costs	Other Capital Costs	O&M Costs	BOP Costs	Turbine Costs	Other Capital Costs	O&M Costs	BOP Costs	Turbine Costs	Other Capital Costs
3 Stage DFIG PRC	17,27	45,40	8,01	21,90	17,76	64,65	8,13	29,10	20,92	94,31	9,43	38,97
3 Stage PMG FRC	14,64	44,21	9,03	21,66	14,96	62,73	9,14	28,58	17,60	91,10	10,54	38,03
2 Stage PMG FRC	13,27	43,99	10,23	21,89	13,86	62,43	10,35	28,78	15,93	90,33	11,90	38,10
DD PMG FRC	7,94	43,57	11,87	22,15	8,18	61,67	11,98	28,90	9,62	88,34	13,63	37,80

Final CoE Result

	10km	50km	100km
3 Stage DFIG PRC	92,58	119,64	163,63
3 Stage PMG FRC	89,53	115,41	157,27
2 Stage PMG FRC	89,38	115,42	156,25
DD PMG FRC	85,52	110,74	149,38

References

[1]. Promotional Material from Vestas and Siemens

[2]. Dalgic Y, Dinwoodie I, Lazakis I, McMillan D, Revie M. Optimum CTV fleet selection for offshore wind farm O&M activities. ESREL 2014, Wroclaw, Poland

[3]. Saur G, Maples B, Meadows B, Hand M, Musial W, Elkington C. Offshore Wind Plant Balance-of-Station Cost Drivers and Sensitivities NREL

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