



WOMBAT Initial Code-to-Code Comparison Results

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Dinwoodie Comparison

Source: Dinwoodie, I., Endrerud, O., Hofmann, M., Martin, R., and Sperstad, I. (2015). "Reference Cases for Verification of Operation and Maintenance Simulation Models for Offshore Wind Farms." *Wind Engineering* **39**(1): 1-14.

Case Description

- Plant capacity: 240 MW
80 x 3-MW Vestas V90 turbines
- Location: North Sea, 50 km from port
- Simulation period: 10 years
- Weather: **FINO 1, 2004-2012** **Dinwoodie et al.**
Alpha Ventus, 2002-2014 **WOMBAT**
- Labor costs: 20 technicians at £80,000/yr
- BOS: not modeled (no cables, substation, etc.)
- O&M models: NOWIcob, Univ. of Stavanger (UiS), ECUME, Strathclyde University

Vessels, Maintenance and Repairs

Vessel type	#	Mobilization time	Mobilization cost	Charter period	Day rate	Max. wave
Crew transfer vessel	3	N/A	N/A	N/A	£1,750	1.5 m
Field support vessel	1	3 weeks	£0	4 weeks	£9,500	1.5 m
Heavy lift vessel	1	2 months	£500,000	4 weeks	£150,000	2 m

Repair type	Time	# Techs	Vessel type	#/turb/yr	Cost
Manual reset	3 h	2	CTV	7.5	£0
Minor repair	7.5 h	2	CTV	3	£1,000
Medium repair	22 h	3	CTV	0.275	£18,500
Major repair	26 h	4	FSV	0.04	£73,500
Major replacement	52 h	5	HLV	0.08	£334,500
Annual service	60 h	3	CTV	1	£18,500

Results – baseline case

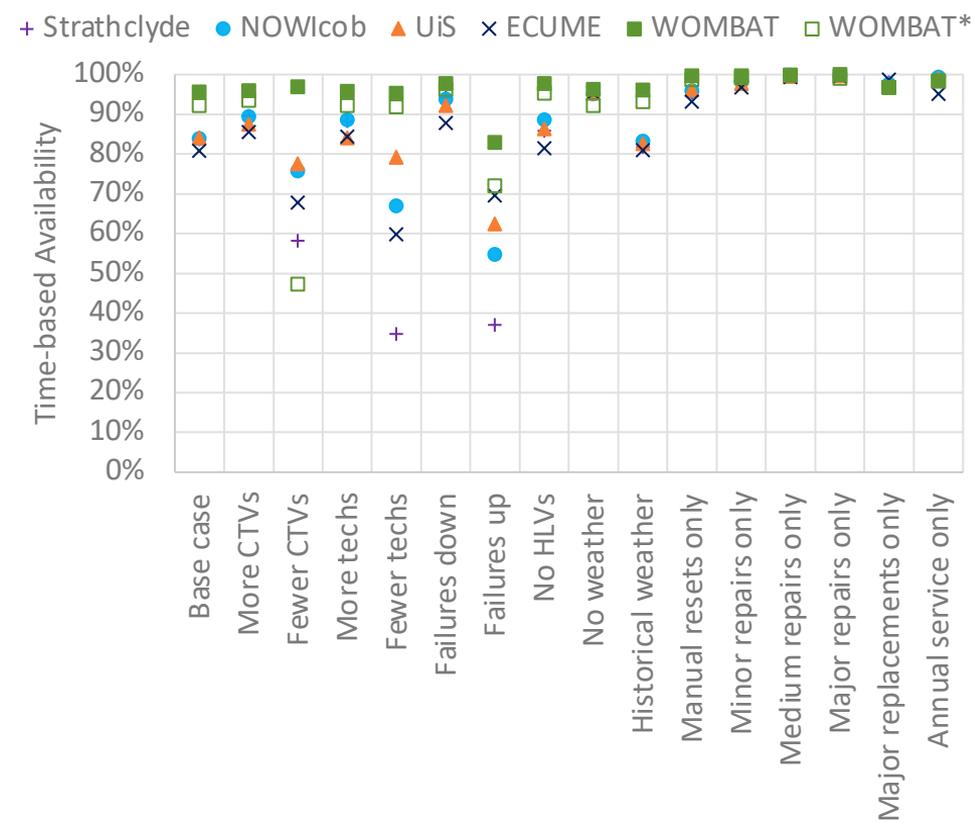
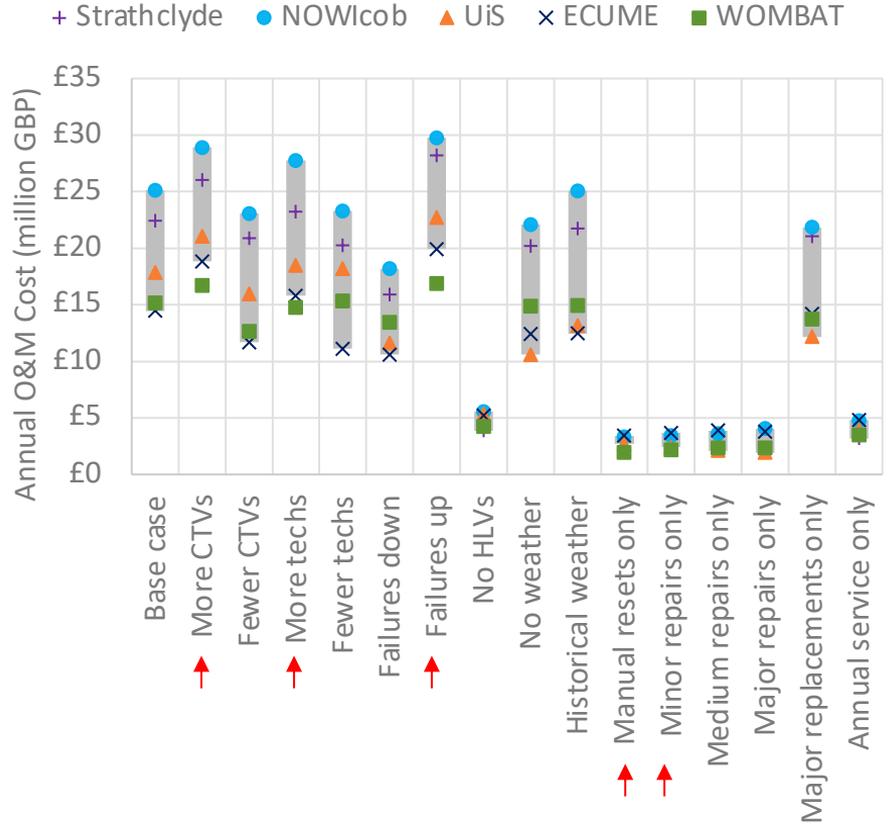
	Strathclyde	NOWIcob	Uis Sim	ECUME	Average	WOMBAT – 1 visit*	WOMBAT – 3 visits*
Availability - time based	83.70%	83.74%	84.40%	80.82%	83.16%	93.89%	95.59%
Availability - energy based	82.11%	82.86%	84.00%	81.70%	82.67%	n/a	n/a
Production loss (million £/yr)	£17.28	£16.63	£15.48	£18.64	£17.01	n/a	n/a
Direct O&M cost (million £/yr)	£22.44	£25.17	£17.93	£14.48	£20.00	£11.67	£15.14
Vessel cost (million £/yr)	£17.84	£19.18	£12.24	£9.30	£14.64	£6.72	£11.43
Repair cost (million £/yr)	£3.00	£4.39	£4.08	£3.58	£3.76	£3.34	£3.71
Technician cost (million £/yr)	£1.60	£1.60	£1.60	£1.60	£1.60	£1.60	£1.60
Standard error: availability	0.22%	0.14%	0.12%	n/a	0.16%	n/a	n/a
Standard error: cost	n/a	£1.34	£2.05	n/a	£1.70	n/a	n/a

*HLV visit schedules:

1 visit: June 1-30, 24-hour work shift

3 visits: May, July, and September (2 weeks each), 7am-7pm work shift

Other cases



Note: Dinwoodie results digitally extracted from plots

*Availability assuming 100% operations reduction for all failures

Results & Analysis

- Availability is significantly higher for WOMBAT, due to allowing turbines to operate between failure and repair (except for major replacements)
- Total direct O&M cost from WOMBAT is within the range of Dinwoodie results for most cases, with the exceptions of “more CTVs”, “more techs”, “failures up”, “manual resets only”, and “minor repairs only”, which are low
- Repair cost (i.e., parts) in WOMBAT is close to Dinwoodie average for the base case, suggesting that repairs are occurring at the same rate
- Total vessel cost is within range of other models, on the low end

IEA Wind Task 26 Comparison

Source: Smart, G., Smith, A., Warner, E., Sperstad, I.B., Prinsen, B., Lacal-Arantequi, R., 2016. *IEA Wind Task 26: Offshore Wind Farm Baseline Documentation* (NREL/TP--6A20-66262). <https://doi.org/10.2172/1259255>

Case Description

- Plant capacity: 400 MW
100 x 4-MW generic turbines (NREL CSM)
- Location: North Sea, 40 km from port
- Simulation period: 20 years
- Weather: Horns Rev 3, 1996-2015
- Labor costs: 30* technicians at €100,000/yr
- BOS: array layout with 6 turbines per string, single export cable, offshore substation with 2 transformers
- O&M models: NOWIcob, ECN O&M Tool

*NOWIcob takes # techs as input, ECN calculates required # techs (between 15-30 throughout year, average ~22)

Vessels, Maintenance and Repairs

Turbine Repairs	Time	Techs	Vessel	#/turb/yr	Cost
Remote reset	2 h	N/A	N/A	7	€0
Manual reset	3 h	2	CTV	5	€238
Minor repair	7.5 h	3	CTV	3	€5,279
Major repair	30 h	4	CTV	0.3	€29,230
Major replacement	42 h	N/A	HLV	0.11	€441,373
Annual service	50 h	3	CTV	1	€4,385

BOS Repairs	Time	Techs	Vessel	#/yr	Cost
Substation inspection	30 h	3	CTV	4	€0
Structure inspection	4 h	2	CTV	100	€0
Small scour repair	8 h	N/A	DSV	2.3	€5,000
Small transformer repair	8 h	3	CTV	0.9	€5,000
Large transformer repair	48 h	4	CTV	0.1	€250,000
Cable replacement	32 h	N/A	CLV	0.04	€350,000

Vessel types

- CTV: crew transfer vessel
- DSV: diving support vessel
- HLV: heavy lift vessel
- CLV: cable laying vessel

Vessel	CTV	DSV	HLV	CLV
#	3	1	1	1
Mob. time	N/A	15 d	60 d	30 d
Mob. cost	N/A	€225k	€500k	€550k
Charter	N/A	4 d	20 d	10 d
Day rate	€3.5k	€75k	€140k	€100k
Max. wave	2 m	2 m	2 m	1 m

Results

	NOW/cob	ECN	WOMBAT - 1 visit	WOMBAT - 2 visits	WOMBAT - 3 visits
Availability (%)					
Time-Based	93.3%	94.9%	72.7%	88.4%	94.5%
Energy-Based	92.6%	94.8%	n/a	n/a	n/a
Costs (million €/yr)					
Total annual costs	25.4	28.4	15.4	21.1	25.1
Technicians	3.0	2.3	3.0	3.0	3.0
Spare parts	7.8	7.9	4.2	6.2	7.1
Vessels	14.5	18.2	8.2	11.8	15.0
- CTV	3.8	1.8	2.6	2.6	2.6
- Jack-up	9.5	15.5	3.6	7.2	10.4
- Diving Support	1.1	0.9	0.5	0.5	0.5
- Cable Laying	0.1	0.1	1.6	1.5	1.6

	NOW/cob	ECN	WOMBAT - 1 visit	WOMBAT - 2 visits	WOMBAT - 3 visits
Downtime (days/turbine/year)					
Total downtime	26	19	70.0	33.9	17.7
Manual resets	7	4	0.5	0.6	0.7
Minor repair	7	4	1.2	1.3	1.4
Major repair	2	1	0.6	0.7	0.7
Major replacement	5	6	65.3	28.9	12.7
Remote reset	1	1	0.1	0.1	0.1
Annual service	3	2	2.1	2.0	1.8
BoS	1	1	0.3	0.3	0.3

Results – 100% Operating Reduction for all Failures

	NOW/cob	ECN	WOMBAT – 1 visit	WOMBAT – 2 visits	WOMBAT – 3 visits
Availability (%)					
Time-Based	93.3%	94.9%	69.5%	88.1%	90.3%
Energy-Based	92.6%	94.8%	n/a	n/a	n/a
Costs (million €/yr)					
Total annual costs	25.4	28.4	15.1	20.6	25.2
Technicians	3.0	2.3	3.0	3.0	3.0
Spare parts	7.8	7.9	4.0	5.9	7.2
Vessels	14.5	18.2	8.2	11.7	15.1
- CTV	3.8	1.8	2.6	2.6	2.6
- Jack-up	9.5	15.5	3.6	7.1	10.5
- Diving Support	1.1	0.9	0.5	0.5	0.5
- Cable Laying	0.1	0.1	1.6	1.6	1.6

	NOW/cob	ECN	WOMBAT – 1 visit	WOMBAT – 2 visits	WOMBAT – 3 visits
Downtime (days/turbine/year)					
Total downtime	26	19	88.7	37.7	30.0
Manual resets	7	4	3.9	6.5	6.9
Minor repair	7	4	2.1	2.8	3.0
Major repair	2	1	0.7	0.8	0.9
Major replacement	5	6	77.5	21.1	13.1
Remote reset	1	1	2.2	2.8	2.8
Annual service	3	2	0.0	0.0	0.0
BoS	1	1	2.3	3.7	3.3

Results & Analysis

- Similar to the Dinwoodie, et al. comparison, 3 jack-up vessel visits brings the combination of costs and availability closely in line with the other O&M models.
- There is more nuance to be understood on the downtime and operation reductions associated with failures