Potential and realized economic impacts of NOWITECH innovations

Impello Management AS
Frode Iglebæk

24.05.2017

Impello Management AS

About NOWITECH

- A joint pre-competitive research effort
- Focus on deep offshore wind technology (+30 m)
- Budget (2009-2017) EUR 40 millions
- Co-financed by the Research Council of Norway, industry and research partners
- 25 PhD/post doc grants
- **Key target: innovations reducing cost of energy from offshore wind**
- Vision:
  - large scale deployment
  - internationally leading

Research partners:

- SINTEF Energy (host)
- IFE
- NTNU
- SINTEF Ocean (fmr. MARINTEK)
- SINTEF ICT
- SINTEF MC

Industry partners:

- CD-adapco
- DNV GL
- DONG Energy
- Fedem Technology
- Fugro OCEANOR
- Kongsberg Maritime
- Norsk Automatisering
- Statkraft
- Statoil

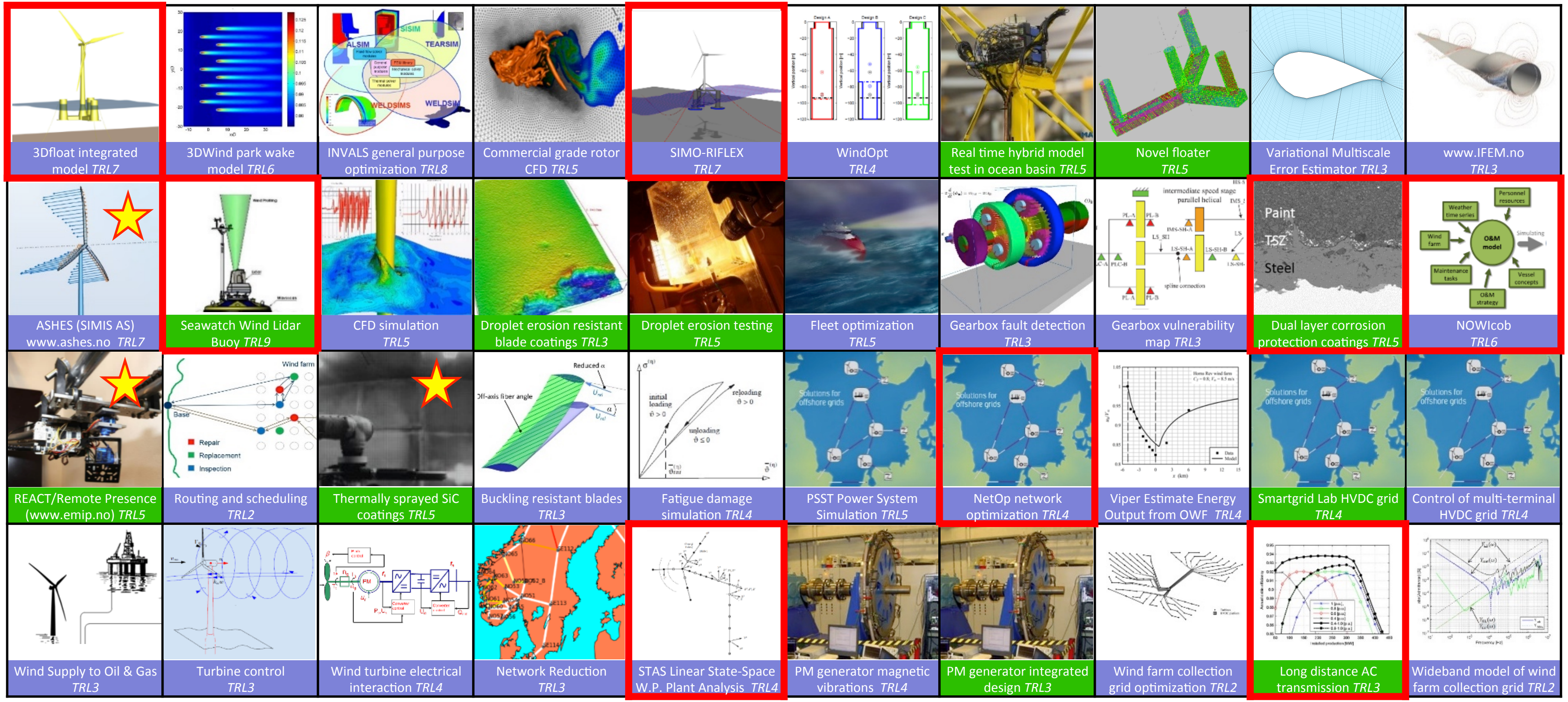
Associated research partners:

- DTU Wind Energy
- Michigan Tech Uni.
- MIT
- NREL
- Fraunhofer IWES
- Uni. Strathclyde
- TU Delft
- Nanyang TU

Associated industry partners:

- Devold AMT AS
- Energy Norway
- Enova
- Innovation Norway
- NCEI
- NORWEA
- NVE
- Wind Cluster Norway

More than 40 innovations from NOWITECH 2009-2017



- 3Dfloat integrated model *TRL7*
- 3DWind park wake model *TRL6*
- INVALS general purpose optimization *TRL8*
- Commercial grade rotor CFD *TRL5*
- SIMO-RIFLEX *TRL7*
- WindOpt *TRL4*
- Real time hybrid model test in ocean basin *TRL5*
- Novel floater *TRL5*
- Variational Multiscale Error Estimator *TRL3*
- www.IFEM.no *TRL3*
- ASHES (SIMIS AS) www.ashes.no *TRL7*
- Seawatch Wind Lidar Buoy *TRL9*
- CFD simulation *TRL5*
- Droplet erosion resistant blade coatings *TRL3*
- Droplet erosion testing *TRL5*
- Fleet optimization *TRL5*
- Gearbox fault detection *TRL3*
- Gearbox vulnerability map *TRL3*
- Dual layer corrosion protection coatings *TRL5*
- NOWIcob *TRL6*
- REACT/Remote Presence (www.emip.no) *TRL5*
- Routing and scheduling *TRL2*
- Thermally sprayed SiC coatings *TRL5*
- Buckling resistant blades *TRL3*
- Fatigue damage simulation *TRL4*
- PSST Power System Simulation *TRL5*
- NetOp network optimization *TRL4*
- Viper Estimate Energy Output from OWF *TRL4*
- Smartgrid Lab HVDC grid *TRL4*
- Control of multi-terminal HVDC grid *TRL4*
- Wind Supply to Oil & Gas *TRL3*
- Turbine control *TRL3*
- Wind turbine electrical interaction *TRL4*
- Network Reduction *TRL3*
- STAS Linear State-Space W.P. Plant Analysis *TRL4*
- PM generator magnetic vibrations *TRL4*
- PM generator integrated design *TRL3*
- Wind farm collection grid optimization *TRL2*
- Long distance AC transmission *TRL3*
- Wideband model of wind farm collection grid *TRL2*

Numerical model | **Technology / process** | **Quantified potential** | ☆ **New business entity (spin-off)**

IMPELLO
Impello Management AS

Commercialized technologies – examples by category

Industrialization in a spin-out company

SIMIS AS - ASHES

- Software for wind turbine simulation
- Based on post.doc work in Nowitech

Seram Coatings AS - THERMASIC

- Method for thermal spraying of silicon carbide (SiC)
- Based on PhD work

EMIP AS – REACT

- Remote presence technology. Inspection and maintenance of offshore turbines
- IP owned by Norsk Automatisering.
- Funded by several RCN and EU projects

Industrialization by established industry

Fugro OCEANOR

- Met/Ocean buoy
- Has contributed to added value and revenues for the company

Internal tool and SW license for clients

NOWIcob - software and methodology

- Simulation tool for optimizing operations and maintenance strategy in offshore wind
- Inhouse tool in SINTEF. Applied in various research and commercial projects
- As members of the research consortium, Statoil, Statkraft and others have been granted free licenses.

Knowhow applied by clients

Statoil/Statkraft - foundation

- Reduced CAPEX by using monopile vs. jacket structure (Dudgeon)

Internal tool and methodology

Optimization of offshore power grids

- Inhouse software tool in SINTEF. Applied in contract research projects
- Estimation of distances for AC transmission
- Several commercial projects carried out

SIMA: SIMO-RIFLEX (add-on functionality)

- Commercial software developed by SINTEF Ocean. Applied in contract research projects
- Extended functionality for offshore wind applications.
- Several commercial projects carried out

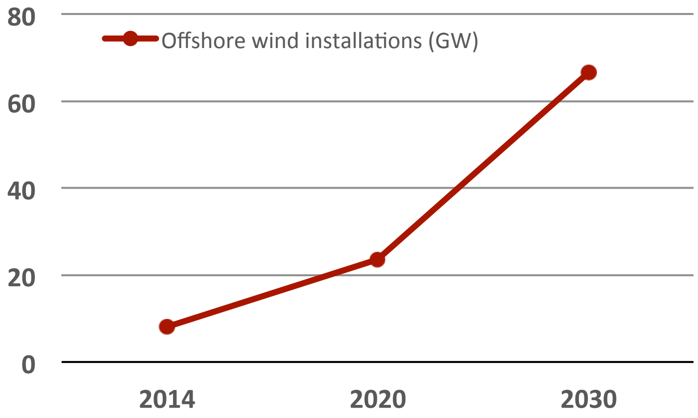
Hybrid testing

- New methodology for testing of offshore wind systems at SINTEF Ocean

IMPELLO
Impello Management AS

Offshore wind installations – WindEurope Central Scenario

- WindEurope's Central Scenario predicts:
  - 66.5 GW of accumulated capacity in 2030
  - 54.0 GW of new capacity added 2017-2030



WindEurope Central scenario	2014	2020	2030
Offshore wind installations (GW)	8,0	23,5	66,5

Cumulative and annual offshore wind installations 2006-2016 (MW)

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Annual MW	93	318	349	614	931	816	1,171	1,606	1,452	3,013	1,558
Cumulative MW	801	1,120	1,469	2,083	3,014	3,830	5,002	6,608	8,060	11,073	12,631

Offshore wind installations (GW) and generation (TWh) in 2030

	Installations (GW)			Generation (TWh)		
	Onshore	Offshore	Total	Onshore	Offshore	Total
Low Scenario	206.3	44.6	250.9	440.2	164.2	604.5
Central Scenario	253.6	66.5	320.1	533.1	244.5	777.7
High Scenario	294.0	98.1	392.1	627.5	360.8	988.3

Sources:

- WindEurope (2017): The European offshore wind industry. Key trends and statistics 2016
- EWEA (2015): Wind energy scenarios for 2030

Assumptions derived from the Central Scenario

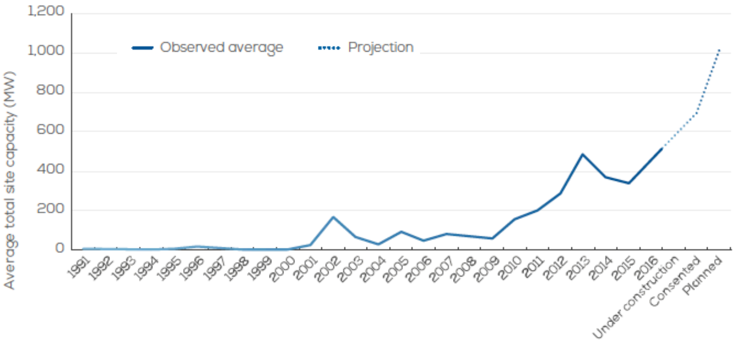
WindEurope Central Scenario - inter/extrapolated	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
New installations (GW) *)		3,0	1,5	2,8	2,8	2,8	2,8	4,3	4,3	4,3	4,3	4,3	4,3	4,3	4,3	4,3	4,3
Accumulated installations (GW)	8,0	11,0	12,5	15,3	18,0	20,8	23,5	27,8	32,1	36,4	40,7	45,0	49,3	53,6	57,9	62,2	66,5
No. of new windfarms/yr **)		8,6	3,0	5,5	5,5	5,5	5,5	8,6	8,6	8,6	8,6	8,6	8,6	8,6	8,6	8,6	8,6
Accumulated no. of windfarms			81	86	92	98	103	112	120	129	137	146	155	163,2	172	180	189
Av. size of windfarm (GW) / yr.	0,38	0,35	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50
INFLATION RATE 2.0 %				*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
Inflation factor (starting 2018)				1,00	1,02	1,04	1,06	1,08	1,10	1,13	1,15	1,17	1,20	1,22	1,24	1,27	1,29

Red figures according to Wind Europe 2030 Central Scenario and key statistics for 2014-2016.
*) **2015/2016**: Actual installations; **2017-2020**: Linear/interpolated added capacity 2.8 GW; **2021-2030**: Linear/interpolated added capacity 4.3 GW
**) Average no. of new wind farms installed per year (start of operation) based on an average size of 0.5 GW per wind farm (fixed for the 2017-2030 period)

Cumulative and annual offshore wind installations 2006-2016 (MW)

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Annual MW	93	318	349	614	931	816	1,171	1,606	1,452	3,013	1,558
Cumulative MW	801	1,120	1,469	2,083	3,014	3,830	5,002	6,608	8,060	11,073	12,631

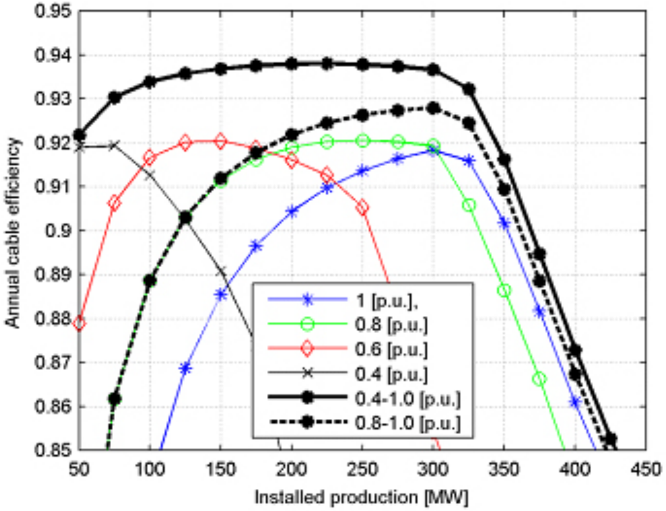
Average size (MW) of offshore wind farm projects



Sources:
- WindEurope (2017): The European offshore wind industry. Key trends and statistics 2016
- EWEA (2015): Wind energy scenarios for 2030

IMPELLO
Impello Management AS

Long distance AC transmission



Quantified potential:

NPV ≈ 200 MEUR

About the innovation

- Control strategy to minimize electrical losses in long HVAC export cable connecting offshore wind farms.
- Losses in long distance AC transmissions can be substantially reduced by continuously adjusting the cable operating voltage according to the instantaneous wind farm power production.
- Estimated loss reduction is 1 percentage point (pp) of produced electricity.

Key assumptions

- The method is applicable for 20 % of all new European wind farms set in operation in the 2020-2030 period.
- Annual savings are calculated for 25 years operation of a total of 90 new farms (approximate number)
- 1 % (pp) reduced electrical loss corresponds to 2 MEUR per year per installed GW offshore wind capacity.
- Additional investment per GW park: 10 MEUR prior to operation.

Long distance AC transmission – NPV estimate

CASHFLOW AND NPV [MEUR]	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	…	2054	NPV MEUR
Investment (3 years prior to operation)	5.5	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	-	-	-		–	
Annual saving (nominal values)	-	-	-	1.1	2.8	4.6	6.3	8.0	9.8	11.5	13.2	15.0	16.7	18.4		1.7	
Net profit/yr (nominal values)	-5.5	-8.6	-8.6	-7.5	-5.8	-4.0	-2.3	-0.6	1.2	2.9	4.6	15.0	16.7	18.4		1.7	113
Net profit/yr (real values)	**-5.5**	**-8.8**	**-8.9**	**-8.0**	**-6.2**	**-4.4**	**-2.6**	**-0.6**	**1.4**	**3.5**	**5.7**	**18.6**	**21.2**	**23.8**		**3.6**	**184**

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Total new installations (GW) – **Central scenario**				2.8	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
Applicable new installations (GW) **(20 %)**				0.6	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Accumulated new applicable installations							0.6	1.4	2.3	3.1	4.0	4.9	5.7	6.6

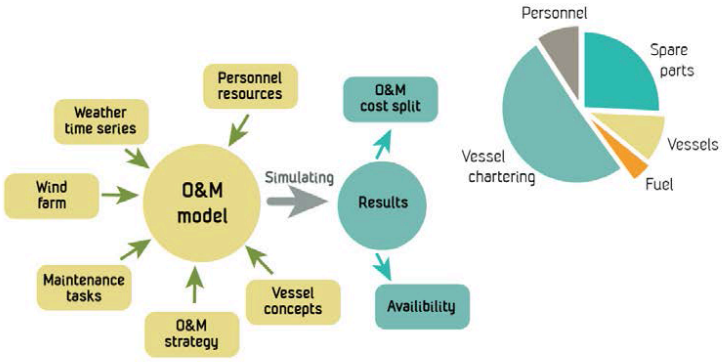
ASSUMPTIONS

Wind farm size	1.2	GW
Investment period	10	yrs
Operation period	25	yrs
Capacity factor	46	%
Full load hours	4030	hrs
Annual electricity production per 1.2 GW farm	4836	GWh
Loss reduction (percent points)	**1.0**	**%**
Loss reduction (GWh) per 1.2 GW farm	48.4	GWh
Market relevance (applicable new installations)	20	%
Inflation rate	2.0	%
Discount rate (cost of capital)	5.0	%
Electricity price	50	EUR/MWh
Annual savings/yr per GW installed	**4.0**	**MEUR**
Additional required investment per GW	**10.0**	**MEUR**

REFERENCES

- **Gustavsen, Bjørn and Olve Mo (2016)** *Variable Transmission Voltage for Loss Minimization in Long Offshore Wind Farm AC Export Cables*, DOI 10.1109/TPWRD.2016.2581879, IEEE Transactions on Power Delivery
- **O. Mo, B. Gustavsen**, EERA Deepwind 2016 presentation, Feb 2016, http://www.sintef.no/globalassets/project/eera-deepwind2016/presentations/b2_olve-mo.pdf

NOWIcob



Schematic of inputs and outputs for the NOWIcob model

Quantified potential:

NPV ≈ 400 MEUR

About the innovation

- NOWIcob is a strategic decision support tool (software) based on a discrete-event simulation model for maintenance activities and logistics throughout the operational phase of offshore wind farms.
- The NOWIcob model can be used as an analysis tool for different aspects of offshore wind farm maintenance and logistics strategies, e.g. for deciding on the optimal strategy for chartering of crew transfer vessels and jack-up vessels to carry out maintenance at a wind farm.

Key assumptions

- The method is applicable for 50-70 % of all new European wind farms set in operation in the 2020-2030 period.
- Investments: Software commercialization 0.7 MEUR
- Additional simulation work 30 kEUR per project/farm
- The technology is assumed valid for 10 years.

NOWIcob applied to vessel strategy optimization – NPV estimate

CASHFLOW AND NPV [MEUR]	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	NPV MEUR
Investment (simulation per project/farm)	-	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	-	
Investment (software commercialization)	0.4	0.4	-	-	-	-	-	-	-	-	-	-	-	
Annual saving (nominal values)	-	-	5.9	15.1	24.3	33.5	42.7	51.9	61.1	70.2	79.4	88.6	97.8	
Net profit/yr (nominal values)	- 0.4	- 0.5	5.6	14.8	24.0	33.2	42.4	51.6	60.8	70.0	79.2	88.4	97.8	354
Net profit (real values)	**- 0.4**	**- 0.5**	**6.0**	**16.0**	**26.5**	**37.4**	**48.7**	**60.5**	**72.7**	**85.3**	**98.5**	**112.1**	**126.6**	**428**

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Total new installations (GW) – **Central scenario**			2.8	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
Applicable new installations (GW) **(60 %)**			1.7	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Accumulated new applicable installations			1.7	4.2	6.8	9.4	12.0	14.6	17.1	19.7	22.3	24.9	27.5

APPLICATIONS

Optimal selection of crew transfer vessel fleet (CTV)

Optimization of charter strategy for jack-up vessels

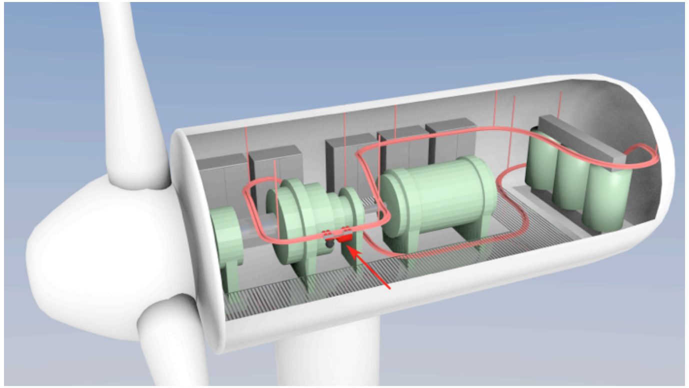
ASSUMPTIONS

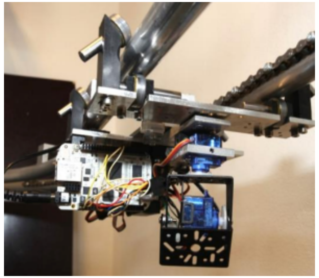
Wind farm size	1.0	GW
Project period (technology is relevant)	10	yrs
Market relevance (applicable new installations)	60	%
Discount rate (cost of capital)	5	%
Annual savings/yr per GW	3.6	MEUR
Investment (simulation cost per project/farm)	25	kEUR
Investment (software commercialization)	0.7	MEUR

REFERENCES

- **Hofmann, M., Sperstad, I. B., Kolstad, M. (2015).** *User guide for the NOWIcob tool (DB.1-2)*, report no. TR A7372, v. 3.0, SINTEF Energy Research, Trondheim.
- **Hofmann, M., Sperstad, I. B., Kolstad, M. (2015).** Technical documentation of the NOWIcob tool (DB.1-2), report no. TR A7374, v. 3.0, SINTEF Energy Research, Trondheim
- **Hofmann, M.; Sperstad, I. B. (2013).** NOWIcob – A tool for reducing the maintenance costs of offshore wind farms. Energy Procedia, vol. 35, 2013, pp. 177–186.
- **Sperstad, I. B.; McAuliffe, F. D.; Kolstad, M.; Sjømark, S. (2016):** Investigating key decision problems to optimise the operation and maintenance strategy of offshore wind farms. Energy Procedia, vol. 94, pp. 261–268.

Remote inspection (EMIP)





Above: Concept illustration of a remote inspection robot inside a simplified and generic nacelle. The nacelle consists of main bearings, gearbox, generator, transformer and cabinets for electronics. The inspection robot is indicated with an arrow. An example rail configuration is also shown.

Left: Lab prototype of rail and camera.

Quantified potential:

NPV ≈ 250 MEUR

About the innovation

- Offshore wind turbines are large, unmanned machines that are deliberately located in areas with strong wind. Access to the turbines is expensive and time consuming.
- A remotely controlled robot can be used to inspect a turbine. The robot is installed inside the wind turbine nacelle and move on a rail.
- NOWIcob simulation results indicate positive effect on the availability and cost of energy for offshore wind turbines.

Key assumptions

- The method is applicable for 50 % of all new European wind farms set in operation in the 2020-2030 period.
- Investments:
  - Commercialization costs: 5 MEUR
  - EMIP equipment and installation: 1 MEUR per GW
- The technology is assumed valid for 10 years.

Remote inspection (EMIP) – NPV estimate

CASHFLOW AND NPV [MEUR]	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	NPV MEUR
Investments (commercialization + EMIP equipm.)	2.0	4.4	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	-	
Annual saving (nominal values)	-	-	3.4	8.8	14.2	19.6	24.9	30.3	35.7	41.1	46.4	51.8	57.2	
Net profit/yr (nominal values)	-2.0	-4.4	1.3	6.7	12.0	17.4	22.8	28.2	33.5	38.9	44.3	49.7	57.2	188
Net profit (real values)	**-2.0**	**-4.6**	**1.4**	**7.2**	**13.3**	**19.6**	**26.2**	**33.0**	**40.1**	**47.4**	**55.1**	**63.0**	**74.0**	**228**

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Total new installations (GW) – **Central scenario**			2.8	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
Applicable new installations (GW) **(50 %)**			1.4	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Accumulated new applicable installations			1.4	3.5	5.7	7.8	10.0	12.1	14.3	16.4	18.6	20.7	22.9

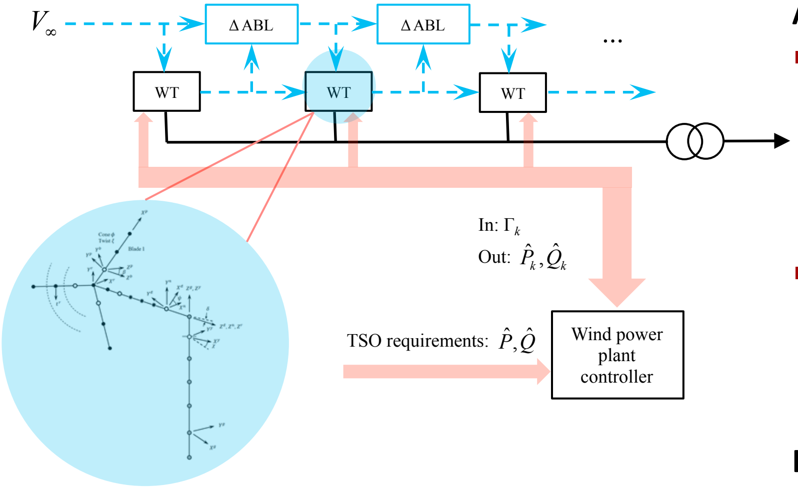
ASSUMPTIONS

Wind farm size	1,0	GW
Project period (technology is relevant)	10	yrs
Market relevance (applicable new installations)	50	%
Discount rate (cost of capital)	5	%
Annual savings/yr per GW	2.5	MEUR
Investment (EMIP equipment/installation per GW)	1.0	MEUR
Investment (commercialization of concept)	5.0	MEUR

REFERENCE

- **Netland et al. (2014).** *Cost-benefit evaluation of remote inspection of offshore wind farms by simulating the operation and maintenance phase.* Energy Procedia, vol. 53, pp. 239-247.
- **Ø. Netland (2014).** *Remote Inspection of Offshore Wind Turbines. A Study of the Benefits, Usability and Feasibility.* Doctoral theses at NTNU, 2014:94

STAS: Optimal Wind Power Plant Control Using the STAS Model



Quantified potential:

NPV ≈ 1100 MEUR

About the innovation

- STAS is a unified state-space model for wind power plant dynamics and control system development. It is used to design wind power plant control algorithms that increase the production and lower the fatigue of wind turbines, while satisfying grid requirements.
- Overall production may be increased by ca. 1 % via optimal power set-points, while under curtailed operation fatigue may be reduced by ca. 30 %.

Key assumptions

- The method is applicable for all new European wind farms set in operation in the 2020-2030 period.
- Annual savings are calculated for 25 years operation of a total of 90 new farms (approximate number)
- 1 % reduced electrical loss corresponds to 2 MEUR per year per installed GW offshore wind capacity.

STAS – NPV estimate

CASHFLOW AND NPV [MEUR]	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	…	2054	NPV MEUR
Investment (3 years prior to operation)	13.8	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	-	-	-		-	
Annual saving (nominal values)	-	-	-	5.4	13.9	22.4	30.8	39.3	47.8	56.3	64.7	73.2	81.7	90.2		8.5	
Net profit/yr (nominal values)	-13.8	-21.5	-21.5	-16.1	-7.6	0.9	9.3	17.8	26.3	34.8	43.2	73.2	81.7	90.2		8.5	726
Net profit/yr (real values)	**-13.8**	**-21.9**	**-22.4**	**-17.1**	**-8.2**	**1.0**	**10.5**	**20.5**	**30.8**	**41.6**	**52.7**	**91.0**	**103.6**	**116.6**		**17.6**	**1 091**
Total new installations (GW) – **Central scenario**				2.8	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3			
Applicable new installations (GW) **(100 %)**				2.8	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3			

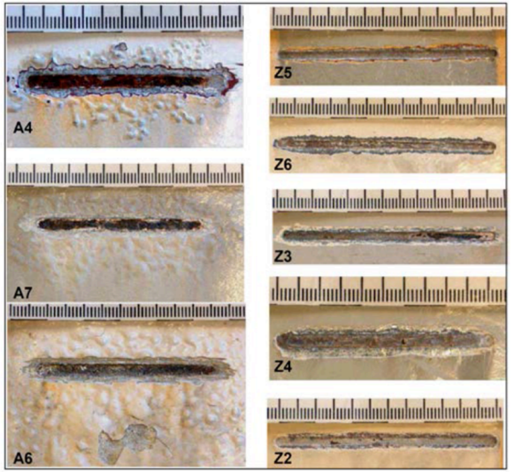
ASSUMPTIONS

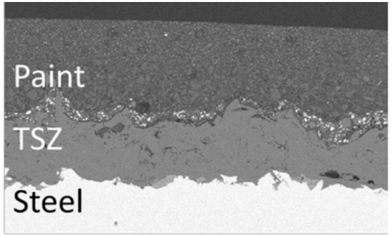
Wind farm size	1.2	GW
Investment period (prior to operation)	3	yrs
Operation period	25	yrs
Capacity factor	45	%
Full load hours	3942	hrs
Annual electricty production per 1.2 GW farm	4730	GWh
Loss reduction (percent points)	**1.0**	**%**
Loss reduction (GWh) per 1.2 GW farm	47.3	GWh
Market relevance (applicable new installations)	100	%
Discount rate (cost of capital)	5.0	%
Electricity price	50	EUR/MWh
Annual savings/yr per GW	**2.0**	**MEUR/yr**
Additional required investment per GW	**5.0**	**MEUR**

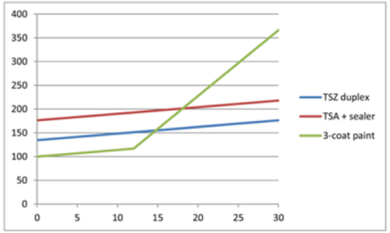
REFERENCES

- **Merz KO (2015).** *A linear state-space model of an offshore wind turbine, implemented in the STAS wind power plant analysis program.* Report TR A7474, SINTEF Energy Research.
- **Merz KO, Pedersen MD (2017).** *Offshore Wind Turbine Controls*. Chapter in Anaya-Lara O, *et al*. (Ed.) *Offshore Wind Energy Technology*. Wiley.

Dual Layer Corrosion Protection Coating







Pictures of some of the costing systems after exposure for five years in corrosive marine atmosphere.
A: Coating systems with thermally sprayed Aluminium.
Z: Coating systems with thermally sprayed zinc.
Right top: Microscope picture of cross section of steel coated with Thermally sprayed zinc and paint.
Right bottom: Lice cycle cost estimate as a function of construction lifetime.

Quantified potential:

NPV ≈ 150 MEUR

About the innovation

- Offshore wind turbine foundations is exposed to highly corrosive environments. The cost of corrosion protection with coatings is the sum of initial application of the coating and following maintenance/repair of the coating.
- Pure organic coatings has the lowest cost in a short term perspective. However, experience has shown that dual layer coatings combining a metallic layer and an organic coatings provide longer lifetime, and hence lower total cost in a long term perspective.
- Standard dual layer coatings utilizes a metallic layer of aluminium or zinc/aluminium. SINTEF has tested dual layer coating with pure thermally sprayed zinc (TSZ).

Key assumptions

- The method is applicable for 50 % of new European wind farms set in operation in the 2020-2030 period.
- SINTEF has estimated total 50 MNOK (5.6 MEUR) in savings over lifetime for 2 MW turbines (1 GW wind parks).
- The technology is assumed valid for 10 years.

Dual Layer Corrosion Protection Coating – NPV estimate

CASHFLOW AND NPV [MEUR]	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	NPV MEUR
Total savings (2016 value adjusted for inflation)	7.8	7.9	8.1	12.9	13.2	13.5	13.7	14.0	14.3	14.6	14.9	15.1	15.5	**165**

Total new installations (GW) – **Central scenario**		2.8	2.8	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
Applicable new installations (GW) **(50 %)**		1.4	1.4	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2

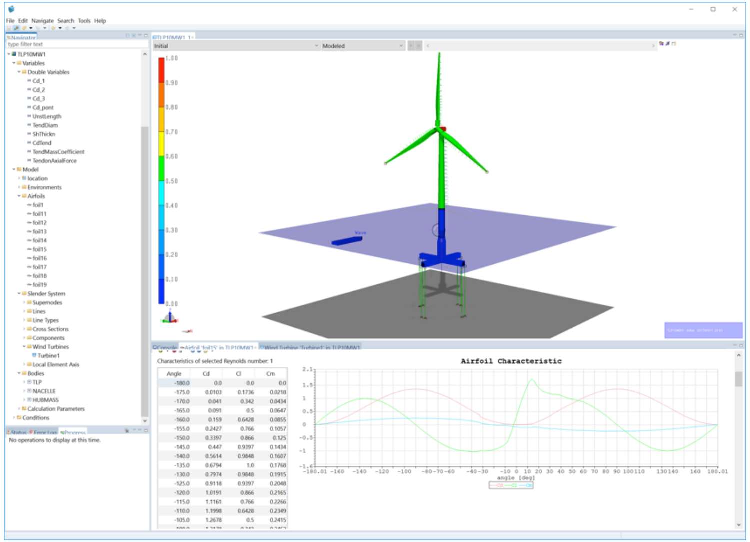
ASSUMPTIONS

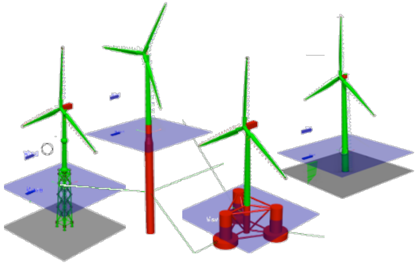
Turbine size	2,0	MW
Wind farm size	1,0	GW
Average no. of turbines per wind farm	500	
Market relevance (applicable new installations)	50	%
Discount rate (cost of capital)	5	%
Total saving per installed GW over lifetime	**5,6**	**MEUR**

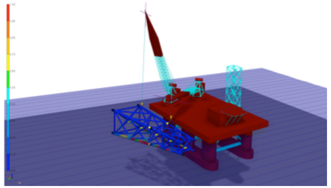
REFERENCES

- **O.Ø. Knudsen, A Bjørgum and LT Døssland (2012).** *Low maintenance coating systems for constructions with long lifetime.* NACE 2012
- **Report, SINTEF F26619.** *New coatings for corrosion protection of offshore wind turbines (D3.3.17)*

SIMA (SIMO/RIFLEX) simulation software



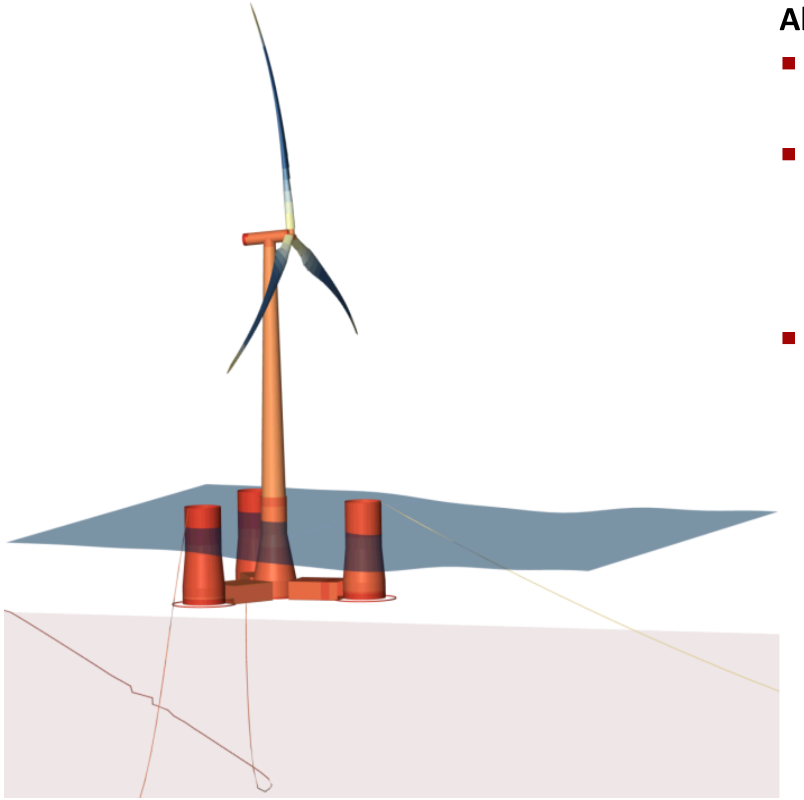




About the innovation

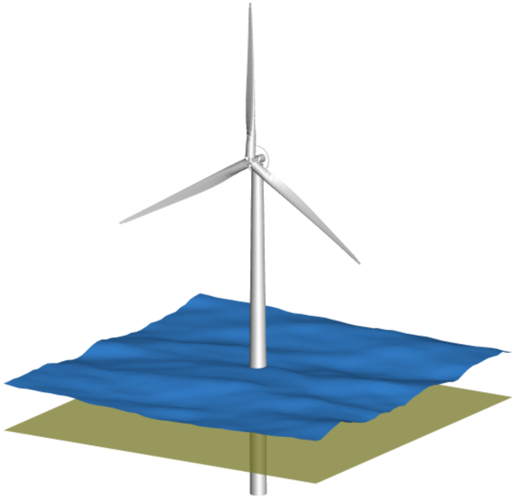
- Improved and validated coupled analysis methods give more accurate load prediction, facilitating optimization and risk reduction.
- SIMA is a Simulation Workbench for marine applications – modeling, simulation and analysis in one single, flexible and powerful tool.
  - Modeling of fixed and floating offshore structures in wind, waves and current.
  - Aerodynamic loads on wind turbine in turbulent 3D wind.
  - Linear and high-order wave kinematics and loads.
  - Nonlinear FE modeling of mooring system, substructure, tower and rotor blades.
  - Internal and arbitrary user-defined wind turbine control system.
  - Arbitrarily shaped substructures.
  - Nonlinear stiffness and damping models for soil.
  - Generic automatic optimization.
  - Marine operations: Complex multi-body analysis.

3Dfloat simulation software



About the innovation

- Improved and validated methods for integrated simulations of structures, wind load and sea loads gives reduced costs and risks.
- 3Dfloat is a software for integrated simulations of wind turbines on land, offshore bottom fixed or floating. It is also used for other structures exposed to sea and/or wind loads.
- It contains state of the art models for:
  - Wind field and wind loads
  - Structural mechanics
  - Waves and sea loads
  - Control systems
  - Moorings and cables
  - Geotechnics



SIMA (SIMO/RIFLEX) and 3Dfloat – NPV estimate

CASHFLOW AND NPV [MEUR]	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	…	NPV MEUR
Investments - 3 years prior to operation	2,8	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	-	-	-		
Annual saving - floater parks (nominal values)	-	-	-	63.1	98.6	98.6	98.6	98.6	98.6	98.6	98.6	98.6	98.6	98.6		
Annual saving - monopile parks (nom. values)	-	-	-	133.4	208.6	208.6	208.6	208.6	208.6	208.6	208.6	208.6	208.6	208.6		
Net profit/yr (nominal values)	-2.8	-4.3	-4.3	192.2	303.0	303.0	303.0	303.0	303.0	303.0	303.0	307.3	307.3	307.3		2 183
Net profit (real values)	**-2.8**	**-4.4**	**-4.5**	**204.0**	**327.9**	**334.5**	**341.2**	**348.0**	**355.0**	**362.1**	**369.3**	**382.1**	**389.7**	**397.5**		**2 551**

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Total new installations (GW) – **Central scen.**				2.8	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
Applicable new installations (GW) **(100 %)**				2.8	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
Accumulated new applicable installations				**2.8**	**7.1**	**11.4**	**15.7**	**20.0**	**24.3**	**28.6**	**32.9**	**37.2**	**41.5**	**45.8**

Key assumptions

- The simulation tools are applicable for all new European wind farms set in operation in the 2020-2030 period.
- This is applicable for both floating and bottom fixed turbines.
- Annual savings are derived from reduced materials use for tower, substructure, mooring and more). This is applicable for both floaters and monopile structures.
- Additional required investments is 1 MEUR/GW park.
- Reduced risk (CAPEX) is not included in the calculations.

ASSUMPTIONS		
Wind farm size	1,0	GW
Project duration (technology obsolete after this)	10	yrs
Market relevance (applicable new installations)	100	%
Materials weight - floater	3 670	tons
Materials weight - monopile	1 370	tons
Reduced materials use (tower, substructure, mooring)	5	%
Unit costs (materials)	5,0	EUR/kg
Materials savings per turbine - floater	918	kEUR
Materials savings per turbine - monopile	343	kEUR
Turbine size	6.0	MW
No. of turbines per wind park (1 GW)	167	turbines
Materials savings per 1 GW - floater park	153	MEUR
Materials savings per 1 GW - monopile park	57	MEUR
Floater park share	15	%
Monopile park share	85	%
Total additional investments per 1 GW park	1.0	MEUR
Discount rate (cost of capital)	5	%

Quantified potential: NPV ≈ 2500 MEUR

SIMA (SIMO/RIFLEX) and 3Dfloat – references

SIMA (SIMO/RIFLEX)

Ormberg, H., and E.E. Bachynski, (2012). Global Analysis of Floating Wind Turbines: Code Development, Model Sensitivity, and Benchmark Study. Proceedings of the 22nd International Offshore (Ocean) and Polar Engineering Conference, Rhodes, Greece, June 2012. 2012-TPC-0734.

Ormberg, H.; Passano, E. & Luxcey, N. (2011). Global Analysis of a Floating Wind Turbine Using an Aero-Hydro-Elastic Model. Part 1: Code Development and Case Study. 30th International Conference on Ocean, Offshore, and Arctic Engineering. OMAE2011-50114.

Luxcey, N.; Ormberg, H. & Passano, E. (2011). Global Analysis of a Floating Wind Turbine Using an Aero-Hydro-Elastic Numerical Model. Part 2: Benchmark Study. 30th International Conference on Ocean, Offshore, and Arctic Engineering, OMAE2011-50088.

Bachynski, E. E., and Ormberg, H., (2015). Hydrodynamic modeling of large-diameter bottom-fixed offshore wind turbines. In: Proceedings of the 34th International Conference on Ocean, Offshore and Arctic Engineering, St. John's, NL, Canada, no. OMAE2015-42028.

Bachynski, E.E. and Ormberg, H., (2015). Comparison of Engineering Models for the Aerodynamic Load Distribution along a Wind Turbine Blade. Proceedings of the 25th International Offshore and Polar Engineering Conference, Kona, Hawaii, USA, June 2015. 2015-TPC-0406.

Ormberg, H., and Bachynski, E.E., (2015). Sensitivity of Estimated Tower Fatigue to Wind Modeling for a Spar Floating Wind Turbine. Proceedings of the 25th International Offshore and Polar Engineering Conference, Kona, Hawaii, USA, June 2015. 2015-TPC-0729.

Berthelsen, P. A.; Bachynski, E. E.; Karimirad, M. & Thys, M., (2016). Real-time Hybrid Model Testing of a Braceless Semi-Submersible Wind Turbine. Part III: Calibration of a Numerical Model. In: Proceedings of the 35th International Conference on Ocean, Offshore and Arctic Engineering, Busan, South Korea, no. OMAE2016-54640.

Graczyk, M and Sandvik P.C. (2012). Study of landing and lift-off operation for wind turbine components on a ship deck, OMAE2012, Rio de Janeiro, Brazil, July 1-6.

Robertson, Amy N., et al. (2016). OC5 Project Phase Ib: Validation of Hydrodynamic Loading on a Fixed, Flexible Cylinder for Offshore Wind Applications. Energy Procedia 94 (2016): 82-101.

3Dfloat

de Vaal, J. B., T. A. Nygaard, and R. Stenbro (2016). *Developing a passive load reduction blade for the DTU 10 MW reference turbine.* Journal of Physics: Conference Series. Vol. 753. No. 4. IOP Publishing, 2016.

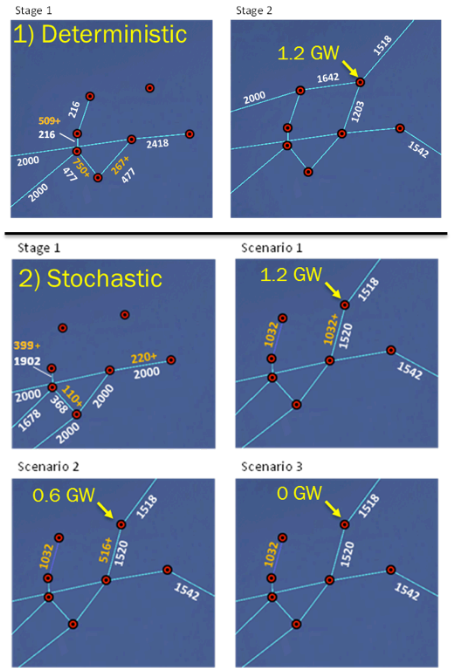
Azcona, José, et al. (2016). *Experimental validation of a dynamic mooring lines code with tension and motion measurements of a submerged chain.* Ocean Engineering (2016).

Robertson, Amy N., et al. (2016). *OC5 Project Phase Ib: Validation of Hydrodynamic Loading on a Fixed, Flexible Cylinder for Offshore Wind Applications.* Energy Procedia 94 (2016): 82-101.

Popko, W., et al. (2012). *Offshore Code Comparison Collaboration Continuation (OC4), Phase I – Results of Coupled Simulation of Offshore Wind Turbine with Jacket Support Structure.* The Proceedings of the Twenty-Second (2012) International Offshore and Polar Engineering Conference, 17–22 June 2012, Rhodes, Greece. Vol. 1, pp. 337-346. International Society of Offshore and Polar Engineers (ISOPE)

IEA Wind (2010). Task 23, Subtask 2 Code Comparison Collaborative (OC3), Final Report, 2010

NetOp/PowerGIM (Network Optimization Tool / Power Grid Investment Module)



Quantified potential:

NPV ≈ 400 MEUR

About the innovation

- NetOp is a tool for optimisation of offshore grid layout for wind farm clusters and HVDC interconnectors. PowerGIM adds functionality to include step-wise investments and uncertain (stochastic) parameters.
- NetOp/PowerGIM is suited to identify economic and robust offshore grid connection alternatives in early stage planning

Key assumptions

- Calculations are done for a case study considering Doggerbank and UK, DE and NO.
- NPV of lifetime costs are computed considering both offshore grid investments and cost of generation required to meet power demand.
- Uncertain stage 2 capacity considered at one sub project (scenario 1 = 1.2 GW, scenario 2 = 0.6 GW, scenario 3 = 0 GW)
- The method is applicable for half of new European offshore wind farms.
- The base case is a grid layout obtained by deterministic optimization, i.e. not taking into account any uncertainty

NetOp/PowerGIM – NPV estimate

CASHFLOW AND NPV [MEUR]	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	NPV MEUR
Investments	–	–	–	–	–	–	–	–	–	–	–	–	–	
Total savings: *11.1 MEUR/GW * appl. GW new installations * inflation*	15,6	15,9	16,2	25,9	26,4	26,9	27,4	28,0	28,5	29,1	29,7	30,3	30,9	
Net profit/yr (nominal values)	15,6	15,9	16,2	25,9	26,4	26,9	27,4	28,0	28,5	29,1	29,7	30,3	30,9	331
Net profit/yr (real values)	**15,9**	**16,5**	**17,2**	**28,0**	**29,1**	**30,3**	**31,5**	**32,8**	**34,1**	**35,5**	**36,9**	**38,4**	**40,0**	**386**

Total new installations (GW) – **Central scenario**	2,8	2,8	2,8	4,3	4,3	4,3	4,3	4,3	4,3	4,3	4,3	4,3	4,3
Applicable new installations (GW) **(50 %)**	1,4	1,4	1,4	1,4	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2

ASSUMPTIONS

Wind farm size	7.2	GW
Time delay between 1st and 2nd stage investments	1	yrs
Operation period	30	yrs
Market relevance (applicable new installations)	50	%
Discount rate (cost of capital)	5.0	%
Expected lifetime cost when not taking into account uncertainty (NetOp) – base case	784.03	GEUR
Expected lifetime cost using method that incorporates uncertainty (PowerGIM)	783.95	GEUR
Saving in lifetime system cost by taking into account uncertainty in grid optimization	**80**	**MEUR**
Total savings in lifetime system cost per GW	**11.1**	**MEUR/GW**

REFERENCES

- **T Trötscher, M Korpås (2011).** *A framework to determine optimal offshore grid structures for wind power integration and power exchange*. Wind Energy 2011, doi: 10.1002/we.461
- **M Kristiansen, HG Svendsen, M Korpås, SE Fleten (2017)**. *Multistage grid investments incorporating uncertainty in offshore wind development*, in: 14th Deep Sea Offshore Wind R&D Conference, EERA DeepWind, Jan 2017
- **HG Svendsen, M Kristiansen, M Korpås (2017)**. *Step-wise stochastic optimisation of transmission grid for offshore wind farm clusters*, To be presented at Offshore Wind Energy 2017, London, June 2017

Dudgeon (Statoil/Statkraft)

The Dudgeon wind farm is expected to produce 1.7 terawatt-hours (TWh) of electricity per year.
Photo: Courtesy of Dudgeon Offshore Wind Farm.

Realized impact > 25 MEUR

Consensus estimate based on dialogue between involved personnel at SINTEF and Statoil/Statkraft.

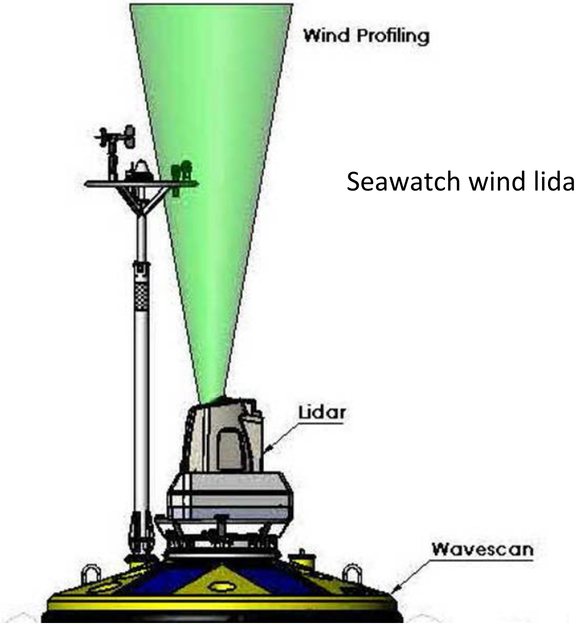
About the innovation

- Selection of monopile rather than jacket foundation for relatively deep water and large turbines
- Importance of non-linear hydrodynamics viewed against the structural responses in an integrated design tool

Realized impact

- Risk and cost reduction through reducing uncertainty
- Extensive hydrodynamic testing by innovative laboratory technique and software development through commercial project
- Complementary development and testing in NOWITECH
  - Short-crested second order irregular wave models,
  - Improved aerodynamic and control options in SIMA
- Improved modeling of both fatigue and extreme loads

Fugro OCEANOR



Seawatch wind lidar buoy

Realized revenues > 10 MEUR

About the innovation

- Seawatch wind lidar buoy is a floating met-ocean buoy with LIDAR for measuring wind speed at different heights above sea level.
- NOWITECH contributed to the start-up of the development.
- The buoy is now offered as a commercial product by Fugro OCEANOR.
- It can drastically reduce the cost of collecting data on current, waves and wind at an offshore site.

Revenue contribution

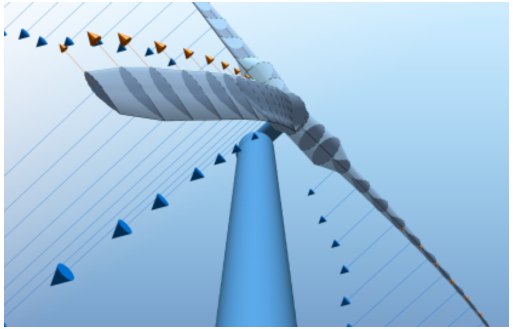
- Since 2012, Fugro's total sales of the Seawatch wind lidar buoy is in the order of 80-100 MNOK (≈ 10 MEUR).

Commercial spin-offs from Nowitech

Seram Coatings AS

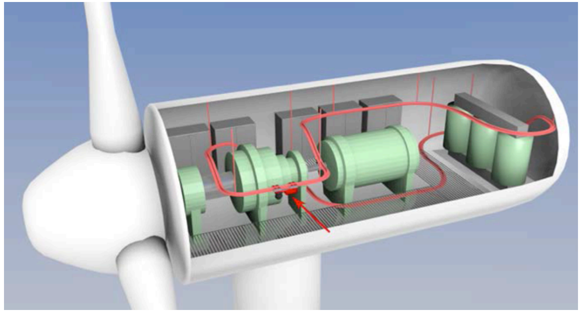
- **Thermasic** – an innovative method for thermal spraying of silicon carbide (SiC).
- Generic technology with a potential large range of future application areas.
- Based on PhD work in Nowitech.
- www.seramcoatings.com

SIMIS AS



- **Ashes** – wind turbine simulation software.
- Integrated simulation of e.g. wind loads, sea waves, gravity, buoyancy, and generator loads.
- Based on post.doc work in Nowitech
- www.simis.io

EMIP AS



- **REACT** – technology for remote inspection and maintenance of offshore turbines.
- IP owned by Norsk Automatisering.
- Funded by several RCN and EU projects.
- Based on PhD work in Nowitech.
- www.emip.no

Potential impact from Nowitech: > 5 billion EUR

- **NOWITECH programme:** 35 MEUR
  - Total project budget for 2009-2017
- **Realized impact**: 35 MEUR (as of 2017)
  - Realized from 5 innovations.
  - In addition, a high potential future value of the new companies.
- ***Exceeds the programme investment!***
- **Potential impact**: >5 billion MEUR
  - Quantified potential for 7 innovations from NOWITECH, and applied for European wind farms according to the Central Scenario (WindEurope).
  - Potential of the other innovations not estimated.

Initial NOWITECH project investment	**MEUR**
320 MNOK (2009-2017)	**35**

Realized impact	**MEUR**
Dudgeon foundations (Statoil/Statkraft)	25
Seawatch buoy (Fugro OCEANOR)	10
Seram Coatings AS	New company
SIMIS AS	New company
EMIP AS (Remote Inspection)	New company
Total (MEUR)	**35**

Potential impact	**NPV**
Long Distance AC Transmission	200
NOWIcob	400
Remote Inspection	250
STAS	1100
Dual Layer Corrosion Protection Coating	150
SIMA (SIMO/RIFLEX) and 3Dfloat	2,500
NetOp/PowerGIM	400
Total (MEUR)	**5,000**

End note: Methodology and assumptions

The potential economic impact of NOWITECH innovations is a theoretic estimate of the economic value for a given technology or concept that is applied for a relevant share of new wind park installations. Market relevance is dependent on e.g. type of park, type of foundation, water depth, distance to shore, etc.

Note that realization of the identified economic potential will require significant investments in further R&D, commercialization and industrialization. These investments are included in the NPV estimates.

The realized impact is a calculation of actual cost savings/ increased revenues up to 2017. The figures are either confirmed by the industry partners, or is a consensus estimate resulting from dialogue between the research and industry partners.

Wind market size figures are based on the Central Scenario for the European offshore wind industry (WindEurope, 2016) for the years 2016, 2020 and 2030. Annual (GW/yr) or accumulated installations (GW) for the years in between 2020/2030 are derived by linear inter/extrapolation.

Potential cost saving/profit for each case study are based on:

- Research papers and scientific studies investigating potential for reducing cost, energy loss, improving energy efficiency, etc. for specific methods, technologies or concepts covered by this report.
- Facts, predictions and/or assumptions by NOWITECH research personnel and industry partners involved in the projects.

Net present value (NPV) of the net cashflow is calculated for either a 10-year period (for technologies assumed to be obsolete/replaced after 10 years), or a 25-year period for installations that are designed for 25 years of operation.

Net cashflow from each case/innovation:
+ Annual savings/increased revenues per year per GW
– Required additional investments per GW
= Net cashflow per year

NPV = Discounted cashflow (rate 5 %) for the time series.

Using other assumptions will give other NPV figures and thus a higher/lower total potential economic impact of NOWITECH.