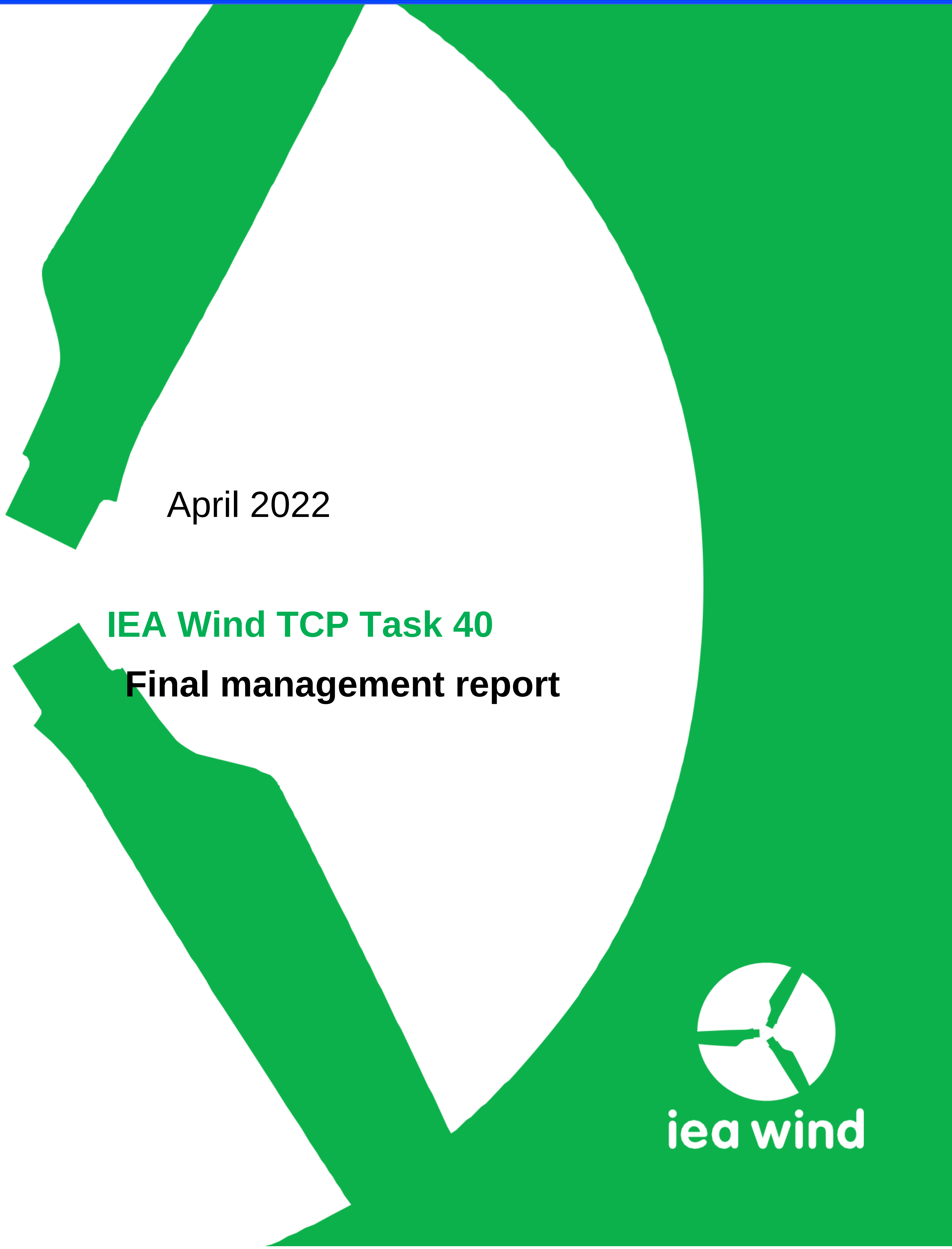
Technology Collaboration Programme
by iea



April 2022

IEA Wind TCP Task 40

Final management report

iea wind

CONTENTS

1. Purpose…………………………………………………………………………………2
2. Responsible Party……………………………………………………………………...2
3. Review of the cooperative activities………………………………………………….2
4. Accomplishments………………………………………………………………………3
5. Degree to which objectives were achieved…………………………………………4
6. Effectiveness of national participation………………………………………………7
7. Participation……………………………………………………………………………7
8. Conclusions/Recommendations……………………………………………………..8
9. Information and Dissemination activities……………………………………………8
10. Unresolved technical issues…………………………………………………………9
11. Lessons learnt…………………………………………………………………………9
12. List of participating experts…………………………………………………………10
Appendix

1. Purpose

Task 40 is to coordinate international research and investigate the benefits of downwind turbine technologies toward the reduction of levelized cost of electricity (LCOE) and proliferation of onshore and offshore wind plants. The task is designed to capitalize on past experiences as well as recently developed computational capabilities. Key research aspects are dynamic response, loads, controls, and impact on LCOE compared with upwind turbine. The Task include an objective, harmonized approach to assessing the LCOE of downwind turbines based on select baseline turbine models and methods accepted by the participants.

2. Responsible Party

Operating Agent: Shigeo Yoshida, Kyushu University / Saga University (Japan)

Co-Operating Agent: Masataka Owada, Wind Energy Institute of Tokyo (Japan)

3. Review of the cooperative activities

Four people agreed to conduct the forum “Downwind Turbine Technologies” in September of 2015, and the kick-off meeting of the forum was held online in May 2016 with 27 participants from 7 countries. After the meeting NREL advised IEA Wind TCP to continue the forum, we also proposed the effort to the Japanese IEA Wind TCP Steering Committee. After getting approval by the Japanese Steering Committee, we proposed a TEM for downwind turbine technologies to IEA Wind TCP. TEM#86 “Downwind Turbine Technologies” was held in Tokyo in November 2016. We decided to propose the task of downwind turbine technologies for IEA Wind TCP ExCo#79 at Helsinki in June 2017. After getting approval, we held the kick-off meeting in Tokyo in November 2017. Then, we started Task 40 in March 2018. During the course of the task, we held 3 plenary meetings (PMs) and 3 workshops (WSs) which are shown in Table 1. After the second plenary meeting all meetings were held online due to the COVID-19 pandemic.

Table 1 Cooperative events

			-4	-3	-2	-1	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	31	32	33	34	35	36	36
					2018												2019												2020												37		
Activities		Organizer	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
1	ExCo meetings		🟩						🟩					🟩					🟩						🟩								🟩					🟩					
2	Kick-off meeting	WEIT		🟦																																							
3	Plenary Meeting	WEIT																			🟦												🟦										🟦
4	Workshop	KU															🟦									🟦												🟦					

Task 40 contains 4 work packages (WPs) and 11 sub-work packages and assigned leaders and sub-leaders for each WP and Sub-WP as shown Table 2.

Table 2 Work packages and assignment

No	WP	Leader	Sub-WP		Sub-Leader	Participans
WP0	Management and coordination	WEIT	WP0-1	Technical management	KU	BWC
			WP0-2	Administrative management	WEIT	BWC
WP1	Model development and verification	KU	WP1-1	2MW baseline turbine model	UTokyo	Hitachi
			WP1-2	Tower shadow	KU	F.IWES, Hitachi
			WP1-3	Nacelle-Rotor interaction	KU	KU
			WP1-4	Stability & control	Hitachi	Utokyo/Hitachi F.IWES
			WP1-5	Complex terrain	AIST	Hitachi
WP2	Design and LCOE assessment	NREL	WP2-1	Blade optimization for downwind turbines	NREL	Hitachi
			WP2-2	Scalability benefits for downwind turbines	NREL	Hitachi, X1Wind
WP3	Recommended practice	KU	WP3-1	Standards evaluation for downwind turbines	KU	All
			WP3-2	Recommended Practices for Downwind Turbines	KU	All

4. Accomplishments

Each Sub-WP teams collaborated to accomplish each goal. Each party presented at workshops and plenary meetings as shown in Table 3 and observers also presented their research efforts.

Table 3 Presentations from participating parties

No	Sub-WP		Participants	WS#1	PM#1	WS#2	PM#2	WS#3	PM#3
WP0	WP0-1	Technical management	KU		X	X	X	X	X
	WP0-2	Administrative management	WEIT	X	X	X	X	X	X
WP1	WP1-1	2MW baseline turbine model	UTokyo	X		X			X
			Hitachi		X	X	X		
			KU				X		
	WP1-2	Tower shadow	KU	X	X	X	X	X	X
			F.IWES	X	X	X		X	X
			CENER	X					
			X1Wind		X			X	
	WP1-3	Nacelle-Rotor interaction	KU				X		
	WP1-4	Stability & control	Hitachi	X			X		
			KU		X				
			X1Wind	X					X
			ETHZ	X					
	WP1-5	Complex terrain	AIST	X					
			Hitachi	X					
			CENER	X	X				
WP2	WP2-1	Blade optimization for downwind turbines	NREL		X	X	X	X	X
			Hitachi			X			
			CENER	X					
	WP2-2	Scalability benefits for downwind turbines	NREL	X	X		X	X	X
			Hitachi					X	
WP3	WP3-1	Standards Evaluation for Downwind Turbines	KU			X			
	WP3-2	Recommended practices for downwind turbines	KU			X			
			CENER		X				

Accomplishments are shown in Table 5 corresponding to work package and papers are listed in Appendix.

Table 5 Accomplishments for all work packages

No	WP	Sub-WP		Accomplishments	papers etc.
WP0	Management and coordination	WP0-1	Technical management	1) Technical report 2) Managed by Gantt Chart	1
		WP0-2	Administrative management	1) Management report 2) Kick-off meeting, 3 plenary meetings, 3 workshops	1
WP1	Model development and verification	WP1-1	2MW baseline turbine model	1) 2MW baseline downwind turbine model (FAST & Bladed)	1
		WP1-2	Tower shadow	1) CFD and FSI for downwind turbines with tubular and truss towers 2) Load equivalnt model and dynamic stall model for blade aerodynamic loads 3) Average and dynamic models for tower aerodynamic loads 4) System engineering model	3
		WP1-3	Nacelle-Rotor interaction	1) Water tunnel tank test and performance of rotor 2)BEM model for typical nacelle shape	1
		WP1-4	Stability & Control	1) Aeroelastic simulation conditions for passive yaw idling 2) Yawing characteristics of single point moored floating downwind turbine	2
		WP1-5	Complex terrain	1) Wind characteristics in complex terrain 2) Wind inclination effects on power curve	2
WP2	Design and LCOE assessment	WP2-1	Blade optimization for downwind turbines	1) Optimized 10MW downwind turbine blade	8
		WP2-2	Scalability benefits for downwind turbines	1) LCOE of 10MW downwind and upwind turbines at Class 3 2) LCOE of 10MW downwind and upwind turbines at Class 1 3) Aeroelastic scaling law 4) Morphing effects of downwind turbine	1
WP3	Recommended practice	WP3-1	Standards evaluation for downwind turbines	1) System engineering model including tower shadow model 2) Nacelle blockage model for BEM. 3) Yaw system model for passive yaw control for BEM. 4) New DLC; long-term wind direction change in 1~50-year storm.	0
		WP3-2	Recommended practices for downwind turbines		

5. Degree to which objectives were achieved

Achievement of objectives from WP0 to WP3 are described the in the following section.

WP0 contains the technical and administrative management and coordination activities of the Operating Agent (OA). The following 3 items were achieved during task period.

1. The communication of essential information between the participants on the achievement of the technical objectives.
2. The activities which are required to inform the IEA Wind Executive Committee.
3. Development of the dedicated project web site for the coordination of the project.

WP1 sets up the foundation for comparisons between upwind and downwind turbines.

1. The 2 MW downwind turbine model was developed that is suitable for comparing data from recent operating experience on the 2 MW downwind turbines. This model made for Bladed and FAST. These downwind turbines have experienced a wide range of operating conditions including typhoons. For the load cases for model verification, calculations

were performed using the standard downwind model of Bladed besides upwind turbines.

2. This baseline turbine model can be used for comparison and verification of tower shadow models, nacelle-rotor interaction effects, noise, and control of downwind turbines such as different approaches to yaw control through extreme conditions.

   - Tower shadow: This downwind turbine model was used as input for CFD calculation of tower shadow. Load of tower is smaller by effect of elasticity of blades and the effect of tower shadow varies by turbulence or wind share. An equivalent load model of the tower shadow will be considered for these effects.

   - Nacelle-rotor interaction effects: ETH Zurich carried out a water tunnel tank test. The performance of the rotor was shown to be increased by water speed and increases load to the nacelle.

   - Noise: We had the presentation about measurement of noise form turbines in Japan and talked with Task 39 OA, but did not make project about noise research.

   - Control: Evaluation of wind loads by a passive yaw control at the extreme wind speed condition and its verification by measurements.

3. The dynamic behavior of downwind turbines in different operating environments and applications will dictate design loads; for example, during design driving events such as typhoons, and high turbulence in complex terrain.

   - The dynamic behavior during typhoons: The evaluation method for passive yaw control in parked condition at extreme wind speed was proposed and validated by actual measurement.

   - The dynamic behavior in complex terrain: The wind conditions in the mountainous area were measured using a Doppler Lidar, and the downwind turbine performance in the up-flow wind was evaluated.

4. Participants in this work package will explore different design approaches beginning with the baseline turbine and progressing to more innovative designs.

   - Innovative designs by long frequency wind direction change during storm stand-by or tower shadow model in dynamic stall and load change of tower
   - Optimization of the nacelle shape by Nacelle-rotor interaction effects
   - Optimization of the turbine performance by up flow in complex terrain

5. Participants could propose alternative baseline turbines or use the baseline turbine to validate models and scale to larger designs, showing the impact of scaling on different technical innovations.

   - Developed system engineering model including tower shadow model for larger downwind turbines.

6. The baseline turbine is expected to provide a common set of economic assumptions to

the LCOE model as well.

- Evaluated of LCOE for 2 MW, 5 MW, 10 MW

WP2 represents one of the most important aspects of this task that will compare various LCOE benefits of downwind turbines on a relative basis and in a transparent way. Quantifying the technical and economic benefits will provide a measure of the value of the different innovations made possible with downwind turbines.

1. Areas for these assessments included blade optimization and the potential for enabling the deployment of larger turbine sizes.

   -Blades and towers of 10 MW turbines were optimized to compare the performance of DWTs to UWTs at Class IA.

   -The optimized DWTs achieved better LCOE than the UWTs with conventional prebend (6 m) due to its lighter and flexible blades.
2. The core LCOE models developed in IEA Wind Task 37 on System Engineering could be used as the starting point for this work package.

   - The downwind turbines showed advantage in cost at the sacrifice of AEP because the lighter blades also decreased the thrust force and RNA mass.
3. This work package will reveal the benefits and technical challenges facing downwind turbines with specific attention to dynamic loads. Downwind turbines are also believed to offer advantages in emerging markets that have particularly challenging requirements. This WP will focus on highlighting the benefits in these anticipated markets.

   -The tower mass of the downwind turbines was comparable to that of the UWTs because the center of gravity of RNA was near the tower axis in 10 MW turbines.

   -The upwind turbines required significantly large prebend of 11 m to obtain comparable LCOE to the downwind turbines.

WP3 explores deficiencies in existing international and national standards and regulations and the need for a recommended practice on downwind turbine technologies. Since downwind turbines have not been certified regularly it is possible that international standards have hidden deficiencies that would require interpretations of the existing IEC standards. It is also possible that some countries have prejudicial regulations based on outdated or lack of experience.

1. This work package will assess such impediments, if any, and provide guidelines, recommended practices or clarification sheets to standards committees (IEC TC88), regulators and conformity assessment organizations (IECRE).
2. Recommended practices developed under IEA Wind Tasks often serve as pre-

normative guidelines in advance of formal standards to promote best practices available for wind turbine technology and deployment and to inform national regulators. This WP seeks to fill this purpose for downwind turbine technologies such models as the rotor-tower aerodynamic interaction (tower shadow effect), and the rotor-nacelle aerodynamic interactions (nacelle blockage), the passive yaw idling model and conditions, the glavo-aeroelastic scaling for elastic blades of downwind turbines, and system engineering model for downwind turbines, etc.

6. Effectiveness of national participation

When we were making the work plan, we selected 9 countries which were doing research, development and production. We recruited research organizations, companies and budgeting organizations for each country and organized a global network that coordinates research and verification effort. 4 countries and 16 organizations participated in Task 40. Each organization had research experience and development data, participant researchers had a deep understanding of downwind turbine technologies. During some tasks the project team was organized based on special expertise.

7. Participation

Responsible parties are 4 countries, 5 contracting parties and 16 participating parties as shown in Table 6.

Table 6 Participation

No.	Country	Contracting Party	Participating Party		Remarks
1	Germany	BMWK	F.IWES	Fraunhofer Institute for Wind Energy and Energy System Technology	
2			TUM	Technische Universität München	
3	Japan	NEDO	AIST	National Institute of Advanced Industrial Science and Technology	
4			ClassNK	Nippon Kaiji Kyokai	
5			Hitachi	Hitachi, Ltd.	
6			KU	Kyushu University	
7			UTokyo	The University of Tokyo	
8			RCCM	Research Center of Computational Mechanics, Inc	
9			WEIT	Wind Energy Institute of Tokyo, Inc.	
10	Spain	CENER	CENER	Centro Nacional de Energías Renovables	1 year (First year)
11		X1Wind	X1Wind		
12	USA	NREL	NREL	The National Renewable Energy Laboratory	
13			BWC	Boulder Wind Consulting	
14			UTD	The University of Texas at Dallas	
15			UVA	University of Virginia	
16			Otherlab		
17	Swizerland	-	ETHZ	Swiss Federal Institute of Technology Zurich	Obserber (1 year)
18	Denmark	-	Suzlon		Obserber (1 year)

8. Conclusions/Recommendations

Almost research items which are defined in the work packages of Task 40 are done by Task 40 experts.

WP0: OAs managed and coordinated Task 40 by IEA Wind ExCo members and secretaries.

WP1: Experts developed 2MW downwind turbine model and verified downwind turbine model.

WP2: Experts optimized blades such as 10 MW downwind turbine and evaluate LCOE of 10 MW downwind turbine and compared with LCOE of upwind turbine. Some analysis showed that LCOE of 10 MW downwind turbine is better than LCOE of 10 MW upwind turbine, however other analysis showed that upwind turbines offer slightly lower LCOE.

WP3: The main results in WP2 and WP3, such models as the rotor-tower aerodynamic interaction (tower shadow effect), and the rotor-nacelle aerodynamic interactions (nacelle blockage), the passive yaw idling model and conditions, the glavo-aeroelastic scaling for elastic blades of downwind turbines, and system engineering model for downwind turbines, are summarized and included in the technical report as the engineering recommendations for downwind turbines.

9. Information and Dissemination activities

USA:

NREL is leading two downwind turbine research projects. One is the Big Adaptive Rotor (BAR) which is a 6-year research program that is analyzing 5 MW onshore downwind turbines.

The another is Segmented Ultralight Morphing Rotor (SUMR) which is over 25 MW downwind turbine research project.

Spain:

X1Wind is under development of downwind floating offshore wind and made collaboration in Task 40 participants.

Japan:

There were several chances to disseminate in Japan such as Japanese IEA Wind seminar, Japan Wind Energy Association symposium, Ashikaga University symposium once a year.

And the output of Task 40 research was published some papers.

10. Unresolved technical issues

1) Effects of turbulence and wind turbine control of the tower shadow effect models.
2) Influences of self-excitation and flutter on the downwind turbine system engineering model, with flexible blades.
3) Manufacturing and transportation costs of pre-bending blades.
4) System impacts of downwind turbines on floating platforms.
5) Farm level AEP impacts from downwind turbines and tilt control of wakes.

11. Lessons learned

1) IEA Wind TCP is good platform to organize the certain global research projects. Regarding downwind turbine technologies, we could build up Task 40 successfully by strong supports of IEA Wind TCP.
2) Decision of participating in certain task as country is difficult because there are some conditions such as industry participation, research organization, target research project and budget.
3) Organizing good network is very effective to proceed research projects.
4) Experimental data is very sensitive to disclose even in task inside.

12. List of participating experts

Participating experts from the beginning to end of task are listed in Table 7 (see back page).

Table 7 Task 40 Participating experts

Country	No	Organization	Name
Germany	1	F.IWES	Bernhard Stoevesandt
Germany	2	F.IWES	Bastian Dose
Germany	3	F.IWES	Hamid Rahimi
Germany	4	F.IWES	Elia Daniele
Germany	5	F.IWES	Leo Höning
Germany	6	F.IWES	Johannes Theron
Germany	7	TUM	Bortolotti Pietro
Germany	8	TUM	Carlo L. Bottasso
Germany	9	TUM	Helena Canet
Germany	10	TUM	Carlo Sucameli
Germany	11	TUM	Thorsten Lutz
Spain	12	CENER	Xabier Munduate
Spain	13	CENER	Mikel Iribas Latour
Spain	14	CENER	Antonio Ugarte
Spain	15	CENER	Beatriz Mendez
Spain	16	X1Wind	Alex Raventos
Spain	17	X1Wind	Carlos Casanovas
Spain	18	X1Wind	Rocio Torres
USA	19	NREL	Rick Damiani
USA	20	NREL	Fabian Wendt
USA	21	NREL	Tyler Stehly
USA	22	NREL	Nick Johnson
USA	23	NREL	Pietro Bortolotti
USA	24	LBNL	Ryan Wiser
USA	25	BWC	Sandy Butteerfield
USA	26	University of Virginia	Eric Loth
USA	27	the University of Massachusetts	James Manwell
USA	28	NextEra	Dan Brake
USA	29	Otherlab	Sam Kanner
USA	30	Otherlab	James Reeves
USA	31	the University of Texas at Dallas	Prof. Todd Griffith
Japan	32	AIST	Tetsuya Kogaki
Japan	33	AIST	Shigemitsu Aoki
Japan	34	ClassNK	Tomoya Iwashita
Japan	35	HITACHI	Mitsuru Saeki
Japan	36	HITACHI	Mamoru Kimura
Japan	37	HITACHI	Nobuhiro Kusuno
Japan	38	HITACHI	Yasushi Shigenaga
Japan	39	HITACHI	Masaya Kozakai
Japan	40	HITACHI	Soichiro kiyoki
Japan	41	HITACHI	Nobuo Namura
Japan	42	HITACHI	Yasuo Osone
Japan	43	HITACHI	Kunihiko Tomiyasu
Japan	44	HITACHI	Yusuke Otake
Japan	45	HITACHI	Takumi Tadano
Japan	46	HITACHI	Shinya Ohara
Japan	47	HITACHI	Shigehisa Funabashi
Japan	48	KU	Shigeo Yoshida
Japan	49	Utokyo	Atsushi Yamaguchi
Japan	50	Utokyo	Jay Prakash Goit
Japan	51	WEIT	Yoshitaka Totsuka
Japan	52	WEIT	Masataka Owada
Japan	53	RCCM	Noriki Iwanaga

Appendix

Task 40 papers list

WP1-1

1. Dose B., Rahimi H., Stoevesandt B., Peinke J., Fluid-structure coupled investigations of the NREL 5 MW wind turbine for two downwind configurations. Renewable Energy, 2020, 146, 1113-1123.

WP1-2

2. Simpson J, E Loth E., Field Tests and Simulations of Tower Shadow Effect for a Downwind Turbine, AIAA Scitech 2021 Forum, 1718

3. Noyes C., Qin C., Loth E., Tower shadow induced blade loads for an extreme ‐ scale downwind turbine, Wind Energy 23 (3), 2020, 458-470

4. Yoshida S., Dynamic Stall Model for Tower Shadow Effects on Downwind Turbines and Its Scale Effects, energies, 10.3390/en13195237, 1-19, Energies 2020, 13, 5237, 2020.

WP1-3

5. Anderson B, Branlard E., Vijayakumar G., Johnson N., Investigation of the nacelle blockage effect for a downwind turbine, Journal of Physics: Conference Series. Vol. 1618. No. 6. IOP Publishing, 2020.

WP1-4

6. Kiyoki S., Ishihara T., Saeki M., Tobinaga I., Evaluation of wind loads by a passive yaw control at the extreme wind speed condition and its verification by measurement, GRE2018, Yokohama, Japan, 2018.

7. Urban A.M., Volta L., Lio W.H., Torres R., Preliminary assessment of yaw alignment on a single point moored downwind floating platform, J.Physics: Conference Series, 2021.

WP1-5

8. Kogaki T., Sakurai K., Shimada S., Kawabata H., Otake Y., Kondo K., Fujita E., Field Measurements of Wind Characteristics Using LiDAR on a Wind Farm with Downwind Turbines Installed in a Complex Terrain Region, energies 2020 13(19) 5135.

9. Otake Y., Kondo K., Fuijita E., Kogaki T., Sakurai K., Evaluation of up-flow wind effects on downwind turbine installed in mountainous area, J. Wind Energy, JWEA, 2021 45(2) 23-30.

WP2-1

10. Pao L.Y., Zalkind D.S., Griffith D.T., Chetan M., Selig M.S., Ananda G.K., Bay C.J. Control co-design of 13 MW downwind two-bladed rotors to achieve 25% reduction in levelized cost of wind energy, Annual Reviews in Control, 2021.

11. Kaminski M., Noyes C., Loth E., Damiani R., Hughes S., Bay C., Chetan M., Gravo‐aeroelastic scaling of a 13‐MW downwind rotor for 20% scale blades, Wind Energy 24 (3), 229-245

12. Kaminski M., Loth E., Zalkind D., Pao L., Selig M., Johnson, N., Servo-aero-gravo-elastic (SAGE) scaling and its application to a 13-MW downwind turbine, Journal of Renewable and Sustainable Energy 12(6), 063301, 2020.

13. Qin C., Loth E., Zalkind D.S., Pao L.Y., Yao, S., Griffith D.T., Selig M.S., Downwind coning concept rotor for a 25 MW offshore wind turbine, Renewable Energy 156, 2020, 314-327.

14. Yao S., Griffith D.T., Chetan M., Bay C.J., Damiani R., Kaminski M., Loth E., A gravo-aeroelastically scaled wind turbine rotor at field-prototype scale with strict structural requirements, Renewable Energy 156, 2020, 535-547.

15. Kaminski M., Loth E., Griffith D.T., Qin C., Ground testing of a 1% gravo-aeroelastically scaled additively-manufactured wind turbine blade with bio-inspired structural design, Renewable Energy 148, 2020, 639-650.

16. Noyes C., Qin C., Loth E., Analytic analysis of load alignment for coning extreme‐scale rotors, Wind Energy 23 (2), 2019, 357-369.

17. Noyes C., Loth E., Martin D., Johnson, K., Ananda G., Selig M., Extreme-scale load-aligning rotor: To hinge or not to hinge?, Applied Energy 257, 2020, 113985

WP2-2

18. Namura N,, Shinozaki Y., "Design Optimization of 10MW Downwind Turbines with

Flexible Blades and Comparison with Upwind Turbines," Journal of Physics: Conference Series, Vol. 1618, No. 4, 042021, 2020.

19. Bortolotti P., Ivanov H., Johnson N., Barter G., Veers P., Namura N., Challenges, opportunities, and a research roadmap for downwind wind turbines, Wind Energy, 2021. https://doi.org/10.1002/we.2676.