INTERNATIONAL ENERGY AGENCY

Implementing Agreement for Co-operation in the Research, Development and Deployment of Wind Turbine Systems
Task 11

Topical Expert Meeting #100 on

Aviation System Cohabitation

IEA Wind Task 11

December 8 & 9, 2020

Online meeting

Photo by M. Ducret, Planair SA

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Executive Summary of TEM#100

Introduction

Numerous countries are facing cohabitation issues between civil and military aviation and wind turbines due to possible interferences. Two main interference types are observed: wind turbines could be physical obstacles to aircrafts, and may also cause electromagnetic wave interferences (e.g., reflection, diffraction, scattering) to communication, surveillance, and navaid systems.

Conflicts with aviation arise in a large number of cases, and finding manners of tackling and solving them is paramount. It is often observed that specific policies are made for each and every country, and that knowledge of international practices is often missing. Wind Europe has recently reached out to create a task force dedicated to aviation safety and wind energy plants conflicts in order to define and harmonize good practices across Europe. In Switzerland for example, given its small territory, those issues have been addressed for years and experiences have evolved into good practice. On the other hand, Sweden is actively looking for appropriate solutions over their territory.

A set of recommended policies for different contexts, based on worldwide experience and good practices, would be a precious tool for the wind energy sector and for policy makers. It was the primary goal of the IEA Wind Topical Expert Meeting number 100 (referred to as TEM#100) to bring together governments, aviation authorities and developers from across the world to identify the needs, share experiences and highlight best practices that could be generalized, thus shortening planning processes and unlocking new wind power potential.

Meeting Overview

TEM#100 on Aviation System Cohabitation was organized by Planair SA, the Swedish Energy Agency and the Physikalisch-Technische Bundesanstalt on December 8th & 9th, 2020, as an online meeting. Over both days, a total of 32 participants from 8 different countries coming from national energy boards, defense departments, civil aviation authorities, air navigation service providers, private company, wind turbine manufacturers & operators, research institutes and other interested parties joined the discussion. The organizers were also pleased to be able to benefit from the expertise of Asian member countries although they were not available to join the meeting.

A good balance between presentations and discussion sessions was chosen for the two days. The focus of day 1 was set on introducing the IEA Wind TCP & Task 11 as well as the general topic of cohabitation before diving into two presentation sessions on lighting and RADAR systems. A 40-minutes breakout session allowed the participants to actively share their experience and problems with each other in two smaller groups, and interest was high from all parties to agree on best practices. Day 2 was dedicated to VOR systems and to further discussion, going into the details for selected outcomes of day 1. The key takeaways from both breakout groups were summarized during a plenary synthesis.

From the discussion notes, the organizing team will identify still open questions as well as best practices for solving conflicts between wind turbines and aviation systems, with the aim to establish a short factsheet highlighting the best practices and guidelines towards an optimal process for solving cohabitation issues. Harmonizing international practices regarding flight safety would avoid a multiplication of systems, ultimately lowering the wind turbine cost, while reducing park impacts on life and surrounding organisms.

Main Results

Several navigation and radar systems are in use to ensure flight safety and perform military tasks. Wind turbines are large objects in the landscape and are affecting the function of navigation and radar systems in a similar way as other large objects like chimneys and buildings. Consequently, requirements from navigation and radar systems and uncertainty in the assessment and consenting process are impacting the deployment of wind power and in some countries quite severely. In Germany for instance, around 5 GW are prevented from being built, which represents 10% of the installed capacity. In Sweden, 30% of the land area is affected, impacting both new installation and repowering.

It is important to acknowledge that today's situation between aviation and wind power is resulting in a non-satisfactory assessment and consenting process both for new installation and repowering of wind power in many countries. It is foreseen, as the deployment of wind power increases, that the issue will worsen. There is therefore an urgent need to develop solutions and adopt new practices.

The IEA Wind TEM#100 provided a precious overview of existing navigation and radar systems as well as of the challenges and benefits linked with the use of these systems. Furthermore, the meeting allowed the participants to discuss the barriers preventing harmonious cohabitation of these systems with wind turbines, as well as highlight best practices in their respective country in terms of dialogue or planning. Future developments that could allow for efficient, innovative solutions were also listed.

While this section focuses on best practices and future developments only for the sake of conciseness, a full summary of the systems and practices addressed during the meeting is available in APPENDIX FOUR – Meeting Summary. Abbreviations are listed in APPENDIX FIVE – List of Abbreviations.

Aviation systems

Through the different presentations given during TEM#100, an overview of the impacted navigation and radar systems and flight operation regulations was obtained. The discussions allowed to complete the picture and better define certain aspects of the following systems:

- Communications: radio digital link, microwave link
- Navigation: VHF omnidirectional radio-range (VOR), distance measuring equipment (DME), non-directional (radio) beacon (NDB)
- Surveillance: Radars
- Flight procedures and protective areas: minimum sector altitude (MSA), stop area, low flight area (LFA)
- Obstruction lighting

Best and recommended practices for conflict mitigation

The following selected mitigation solutions, proposed during TEM#100, were identified as best practices by the participants.

Management mitigations – Foster collaboration and dialogue

- Set up a **management board between the main stakeholders** – defense, wind industry, air traffic control and national administration – to address conflicts of interest and develop mitigations;
  - Applied in the UK since 2019 with the Joint Air Defence and Offshore Wind Programme Board (Sector Deal Commitment)
  - Applied in the US for radar interference (Wind Turbine-Radar Interference Mitigation Working Group);
- Establish a clear political statement that the best possible cooperation of all stakeholders is desired and necessary in order to solve this national task.
- Assign **one single authority** that manages the assessment and consenting processes at the national level;
  - Applied in Switzerland with the Guichet Unique;
- Have a **time-limited consenting/permitting process**;
  - Partly applied in Switzerland, where the assessment has a maximal duration of 60 days;
  - The DIRECTIVE (EU) 2018/2001 of the European Parliament stipulates that the permit-granting process shall not exceed two years for power plants, including all relevant procedures of competent authorities.

Operational and procedural mitigation

- Foster **early engagement and assessment** during initial planning process, yielding more flexibility before wind turbine locations become settled and centralized;
  - Increasingly applied in Switzerland;
- Predefine all issues to be solved as a catalogue which developers can simply follow;
  - Part of the process in Switzerland;
- Implement **streamlined processes**, but prefer **case by case/dynamic assessment** instead of exclusion zones/static assessment as there might be no one-fits-all-solution. There is a need to shape the solution in each case in order to avoid costly fixed safe-to-operate margins (confident solution).
  - Applied in Switzerland, for example for MSA and Stop areas with no pre-defined circular areas;
- Operationally amend activity routes and paths by working with appropriate stakeholders to consider changes to airspace, coupled with technical mitigation;
  - Applied in the UK with e.g., changes to helicopter main routes aligned with offshore wind farms in the Aeronautical Information Publication (AIP);
- Establish and maintain a data base where all existing wind turbines are collected and stored with detailed information;
  - Applied in the US, and in Sweden.

Technical mitigations

- Assess radio/microwave link case-by-case rather than using exclusion zones based on Fresnel ellipsoids only;
    - Applied in Switzerland, with dynamic zones that reduce significantly the impacted area
- Use a predictive model/simulation that is validated by measurements;
    - Applied in Germany, Switzerland and France for bearing angle errors of VOR
- Carry out drone-based measurements and full-wave simulations to validate a certified model, used later-on to predict impact of WT on aviation systems (VOR, Radars, …);
    - Applied in Germany (WERAN project), where on-site and drone-based measurements are available on VOR, Radars (military surveillance, airport surveillance, weather radar), NDBs, ILS.
- Solutions for radars:
    - Maximise wind farm tolerance with current radar capabilities available;
    - Include clutter mapping in assessment;
    - Use cell or sector blanking;
        - Applied in the UK in combination with TMZ for offshore, or with infill/gap-filler radar integration for onshore;
        - Approved by skyguide (Swiss ANSP) for currently planned projects;
    - Create Non-Auto Initiation Zone or inhibition zone avoiding the creation of new trace corresponding to an aircraft route on the air traffic operator's display;
        - Applied in the UK, where it may require radar hardware and/or software upgrade;
    - Rearrange wind turbines location in radar cells;
        - Applied in the US and in Switzerland;
    - Use infill radars – Involves a main radar and an infill radar: the infill radar captures unwanted clutter of its area of interest and cuts it out from the main radar coverage picture;
        - Applied in the UK and in the US;
    - Use gap-filler radars – Involves a main radar and a gap-filler radar: a gap-filler radar is installed and configured to scan the area hid by the unwanted clutter in the main radar coverage picture;
        - Applied in the UK and in the US
    - Use wind farm radars – A radar installed at the wind farm can mitigate the impact of the farm on existing radars and could actually result in improved surveillance quality;
    - Relocate existing radar installations in accordance with wind farm development;
- Obstruction lighting:
    - Use night vision goggles (NVGs) and infrared lighting could lead to a reduction of visible lighting, thus increasing local resident acceptance;
        - Increasingly applied in Switzerland;
    - Operate lighting on aviation demand with a passive receiver;
        - Applied in Germany (e.g., www.passiv-radar.de).

Mitigation solutions under development

- Use an appropriate configuration of antennas on aircraft to capture VOR-information for future flight inspection and model validation (radial/other axes/routes/orbit flights);
  - Under development in Germany
- Apply new method of Doppler cross-bearing to identify reflectors and obtain pre-load of VORs;
  - Under development in Germany
- Operate wind turbines to remove radar and radio-link interference, coupled with an optimization program in order to reduce wind turbines downtime;
  - Under development in Switzerland, first phase planned in 2021
    - Blade pitch control – Excluding certain angles of the blade pitch results in a significant reduction of the echo from a wind turbine;
    - Collect telemetry data of wind turbines with a timestamp of under 1 second;
- Replace legacy radars with the next generation of new complex clutter-managing radar;
  - Under development in the UK;
- Make MSA publicly accessible, and develop a tool to explain how a WT does affect it and to increase visibility in approach plans.
  - Future need identified, not under development yet to our knowledge

This selection of methods, already applied in some countries, provides a powerful toolbox for solving cohabitation issues of terrestrial navigation & radar and wind turbines. A wider adoption of these best practices would unlock new wind power potential and contribute to speeding up the authorization processes.

Summary of Presentations

The information in this section provides an overview and selected highlights of each of the presentations during TEM#100. Discussion results are summarized in the next chapter.

All meeting material from TEM#100 is available on the IEA Wind website, on the TEM#100 website (meeting documents). Access for download can be requested from the Task 11 Operating Agent.

Day 1: December 8, 2020

Introduction session

Nicolas El Hayek from Planair SA (Task 11 Operating Agent) welcomed all participants and presented the meeting goals and format before sending the participant to ice-breaker breakout groups. He then provided a short overview of the IEA Wind TCP and of Task 11, presenting the organization's goals and the Task's activities such as Topical Expert Meetings and Recommended Practices. In particular, the participants were made aware of IEA Wind's mission and of how they can benefit from an international collaboration effort. A more detailed presentation about the IEA Wind TCP is available online in the meeting documents.

Matthieu Ducret from Planair SA provided explanations on the root causes of aviation conflicts and gave an overview of solution as an introduction to the upcoming expert's presentations. As an expert of the topic, he mentioned his findings in 2018, confirmed by Swiss Air Force and Federal office of Meteorology ones in 2020, these findings lead to an interesting mitigation concept based on programming blade angles that must be avoided because they generate high interference peaks on radio frequency equipment. Matthieu Ducret also emphasizes that current best practices are based on dynamic assessments. Later, prior to the break-out sessions, he provided an in-sight of the pre-conference survey results with best and failed practices.

Reto Pauli from Swiss Air Force & Swiss MAA presented how assessments are currently performed and further development in Switzerland. He described an assessment example of a wind farm close to a military airbase in central Switzerland. The assessment didn't rely on static protective areas and was dynamic: the analysis is done from an operational need point of view, it takes care of routes for approaches and departures (gradient), instrument landing system vs. precision approach radar, surveillance capabilities and actual lines of sight, possible technical mitigation solution, etc. As M. Ducret, he emphasized again on blades angles with 1° increment, sufficient to reduce unwanted echoes from wind turbines. Programming this on wind turbines is a high-potential solution and has to be developed.

Pierre-Jean Rigole from Swedish Energy Agency, highlighted that Sweden has the ambitious goal of being climate neutral by 2045. This implies decarbonizing the industry and transport sectors, where electrification is perceived as a key solution. This electrification will boost the demand for electricity in Sweden and wind power is expected to be one of main pillar (up to 50%) of the electricity production by 2040. Although Sweden is a large country with a low population density and excellent wind resources, wind power is experiencing a severe conflict with other interest's claims: Nature, culture and recreation, infrastructure, defense (mainly related to aviation) and reindeer pasture. In total, there is only 2% of land area free of conflict.

Aviation both civil and military is setting requirements for high objects, i.e. wind turbines, in 30% of the total land area of Sweden having a significant impact on the potential for wind power deployment. Cohabitation issues are due to: Low flight areas for air force training; minimum safety altitude (MSA) areas around airport, stop area for high object around air force bases. Another issue in Sweden affecting the permitting process is requirement on obstruction lighting for wind turbines since it impacts people living close to turbines. Sweden is applying the rule of high intensity lights for turbines taller than 150 m, despite the recommendation from International Civil Aviation Organization of only medium-intensity obstruction light is requested for wind turbines up to 315 m in total height.

Ulrika Gustafsson from the Swedish Armed Forces closed the introduction session with a presentation on conflicts between Swedish Armed Forces (SAF) and wind turbines. Conflict areas are stop areas and MSA around air bases, there are also four designated areas for low altitude training (just above the tree level). In these areas wind turbines can be an obstacle for the exercises, as enough free air space is needed to conduct exercises on low altitudes. SAF receives around 200-400 remittances regarding wind turbines every year. These remittances are analyzed regarding how the proposed project would affect national defense interests. Approximately 80 % of the proposed position are not in conflict with the defense interests.

Session 1 – Lighting of Wind Turbines

Ali Binisi from Scandinavian Avionics gave an presentation of Pondetect´s Transponder-based Aircraft Detection Lighting System (ADLS) that makes nights darker without risking flight safety. The ADLS uses the signal that a transponder in an aircraft transmits to control the obstacle lights in the wind farm. In the event of errors, which the system categorizes as serious, a Failsafe mode is activated. Due to the non-transponder requirement on certain aircraft in Sweden, the transponder-based system need to establish a Transponder Mandatory Zone, TMZ, around the current wind farm. TMZ is defined in EU regulations, for example in Germany, Netherlands and Finland.

Matthieu Ducret from Planair and Reto Pauli from Swiss MAA dived into the topic of lighting. They described current solutions deployed worldwide, their pros and cons, as for instance: transponder-based lighting activation isn't appreciated by air forces although supports public acceptance, and practices and development with infrared in Switzerland where other detectors aren't efficient for in a hilly landscape.

Session 2 – RADAR Systems

Dujon Goncalves-Collins from Vattenfall gave an overview of how the UK offshore wind industry is working with aviation and defence stakeholders. There exists a cultural alignment that recognizes value of wind and jointly develop concepts on co-location and co-existence; Collaboration is key to resolve issues in timely manner, reduce risks and provide business and investment certainties, across all stakeholders. A collegiate approach across government departments and between industries allows for viable and mutually beneficial innovation to be developed. He explained that communication is key to understanding each other's requirements; commence as early as possible, across and with all stakeholders. Favour a Programme Management approach that develops, agrees and executes to time-lines, milestones, roles and responsibilities, technical and operational requirements, costs, risks and resources. In UK, OWIC with MOD have shown that once we do communicate and work with the 'right' staff and each other that we can make progress; including senior executive management that are accountable and responsible, underpinned by government policies, targets and ministerial oversight.

Jason Biddle from MIT Lincoln Lab summarized MIT Lincoln Laboratory research focused on two areas: 1) wind farm layout/spacing effects on radar performance, and 2) radar upgrade mitigations for air traffic control and air surveillance radar systems in the United States. The research found the distance between the wind farm and radar, the density of wind turbines, the number of wind turbines occupying each radar resolution cell, and the number of radar resolution cells that do not contain wind turbines all affect radar performance to varying degrees. The research also demonstrated the viability of a multi-elevation beam nulling (TANC) and increased range resolution mitigation techniques.

Bryan Miller from BEM Int'l, LLC presented the results of the Travis air force base pilot mitigation project, which investigated the use of one or several infill radars to reduce interference from wind turbines on the base's radar systems. Radar performance was evaluated for several flight paths over the wind resource area, which led to successfully validating the mitigation concept. He provided an overview of the next steps of the project, which aims at defining a concept of operations and demonstrating infill radars as a mitigation technology to wind turbine clutter.

Day 2: December 9, 2020

Recap from day 1

Thorsten Schrader from Physikalisch-Technische Bundesanstalt (PTB) briefly reminded the main takeaways from the previous day, before giving an overview of the day's agenda.

Henrik Sjöström from OX2 discussed that Sweden faces significant possibilities working toward a 100% renewable electricity production by 2040 and zero CO2 emission by 2045. Today aviation and military combined cover more than 30% of Swedish territory which if utilized for wind power project would strongly strengthen the Total defense. Countries such as Denmark have already established methods to enable these interests to join forces and together form a strong coalition. For example, obstruction light control systems have been implemented, but also requirements from the defense where the developers shall finance any additional radar needed to maintain the capability. This results in a conditional YES.

Daniel Mortensen from Ørsted presented an overview of coexistence history between defence and offshore wind, putting in perspective the approaches of both parties. He provided insight into several concepts under consideration for conflict solving such as the installation of offshore or onshore-placed 2D or 3D infill radars, or the replacement of radar head with more recent wind farm tolerant radar. He also presented successful test results for the 2D offshore infill radar solution, and plans to test the remaining considered mitigation solutions.

Jochen Bredemeyer from FCS Flight Calibration Services GmbH presented a dedicated Radar receiver for L/S/C band signals mounted on a drone (UAS), which is used as a valuable tool to perform on-site measurements of signals-in-space. That device was developed within the research project "WERAN plus". Some results from flights above wind turbines show the complexity in how reflections change the Radar signal on the forward-scatter path. That gives a good indication on the 2D Radar performance degradation that may arise when the target is close to a wind farm. It can be assumed that changes in horizontal and vertical antenna patterns on-site due to near-by effects may also have a distinct influence on the performance. He showed some antenna pattern measurements ranging from low tilt to high elevation angles (50°). These were gained from drone flights within the control zone of an operational ATC Radar in S band.

Session 3 – VOR Systems

Thorsten Schrader, from Physikalisch-Technische Bundesanstalt (PTB) opened session 3 with an overview of the WERAN and WERAN plus projects. One focus of the WERAN project was the development of drone-based measurement capabilities of the signal-in-space of conventional (CVOR) and Doppler VORs (DVOR) as well as radars (including airport surveillance, precipitation, wind profiling, and military radars). The second focus was full-wave simulation of wind turbine (WT) and DVOR interaction using a mainframe computer. The studies showed good agreement of the bearing error of DVOR caused by WT by both real-world measurements and numerical simulation. For the first time, the measurements clearly showed the influence that can be associated with wind turbines. On this basis, a simple and practical tool for the prediction of the DVOR bearing angle error caused by WTs was developed in the ongoing WERAN plus project. It has been in operational use at the German Air Navigation and Service Provider since June 2020. Along the validation process of the prognosis tool, the influence of HV lines on the bearing angle error could be shown. First results of the bearing error of CVORs caused by WTs were shown, including on-site measurements, full wave simulation and prediction by the new CVOR prognosis tool.

Karsten Schubert from Jade University of Applied Sciences Wilhelmshaven Oldenburg Elsfleth presented a methodology for scatter object localisation and characterisation using radio signal of D-VOR transmitters. This methodology is based on airborne measurements deploying a research touring motor glider equipped with VHF-measurement hardware. This hardware logs information on time, position, speed and heading by means of an IMU and a GNSS receiver. Furthermore, it captures the VOR radio signal using a software defined radio receiver. Carrying out post processing, the captured IQ baseband data allows cross bearing of reflecting objects. This post processing includes ultra-narrow band pass filtering and cross correlation. Additional calculations allow scatter object mapping. The bearing accuracy of a VOR transmitter for aeronautic navigation depends especially on scattering and reflecting objects in the environment. Maximum bearing error is regulated in ICAO rules and monitored by national authorities. In approval procedures for wind turbines, these authorities often expect a negative impact on aviation safety from reflection caused by wind turbines. Due to insufficient knowledge, the safety distance between wind turbines and a VOR transmitter is very conservatively chosen (i.e. rather large) resulting in many cases in a denied approval. The presented methodology provides new knowledge for rating of wind turbines in approval procedures. Using this method, bearing error due to additional wind turbines can be determined. The given talk showed some examples, classified near Bremen VOR, of different detected scatter objects like chimneys, large industry buildings, pylons and wind turbines. Some of those objects reflect 5 to 50 times stronger than wind turbines in the same area.

Robert Geise from TU Braunschweig closed session 3 with a presentation that dealt with measurement results in a miniaturized environment with VORs and wind turbines in a lot of parameter variations (e.g. blade orientation, pitch, rotational speed and distance to VOR). Results have been validated with inspection flights at DVOR Hehlingen and VOR Magdeburg. A particular focus was also on the superposition of error contributions of several wind turbines and the influence of the signal strength. The major conclusion is that the influence of WTs is currently overestimated. The requested takeaway is that stakeholders should substantially read and review what already has been published. Corresponding links were provided.

Final session

Nicolas El Hayek from Planair SA (Task 11 operating agent) thanked warmly all participants and the meeting organisers, and highlighted the next steps after TEM#100. He encouraged all meeting participants to contribute to the elaboration of the best practices factsheet and to initiate dialogue at a national level.

Breakout Session Notes

The breakout discussions that took place on each day saw the participants split into two smaller groups after the presentations to discuss in-depth the different technical solutions as well as operational and procedural mitigations. The goal of these discussions was to identify open questions and agree on best practices for mitigation of conflicts between wind turbines and aviation systems.

The outcomes of each discussion group were presented in plenum during a short synthesis. The following section provides a consolidated summary of all notes.

Consolidated Summary

During the process to obtain building permits for new wind turbines, civil aviation or airports often are not very responsive to applicants. Processes still lack a clear, transparent way which government agencies or other official bureaus need to be contacted and when. The evaluation processes are neither standardized, nor streamlined; therefore, assessments can be quite different from project to project. Applicants experience great uncertainty about timelines and documents to be submitted. In most countries, government agencies do not work together in a coordinated manner, in which one agency would act as a central contact point. It they do, it takes forever to get their answer back.

Their decision is sometimes based on a database where all existing wind turbines are collected and stored with detailed information. This is regarded as extremely helpful as it serves all government agencies (https://eerscmap.usgs.gov/uswtdb/).

Some countries such as Switzerland have implemented fast and efficient processes, one central office coordinates all questions and assessments needed and are guiding each individual process. In 2018 a regulation was adopted by the Ministry of Energy that led to greatly improved cooperation among government agencies. The regulation included single points of contact (SPOC) and also limited the processing time, which is by law limited to 60 days. Thereby all federal interests are considered in a very streamlined process. All projects are equally treated, at an early stage of the planning phase, which is preferable because it gives more flexibility to make changes. The Federal Department of Energy generally tries to come up and find a solution, even pre-assessments on individual projects are possible.

From a technical standpoint, many mitigation solutions exist for radar systems and wind turbines, but there is not one simple solution which works everywhere; tailored solutions are necessary case-by-case. Like in Denmark and the UK, adapted radar systems could be a solution. Despite these coexistence problems, many projects are working properly. In the UK, a wider approach is aimed for. It may not be possible to eliminate the impact of WT on specific radars easily, but a systems approach helps at least in parts.

The way forward is not only to consider what is needed for today, but also for tomorrow in order to allow WT coexist with radars in the future. Different measures need to be combined. This issue requires to think ahead in the next 20-25 years because of large innovation cycles of radar and surveillance systems, given defense/civil aviation requirements and long-term wind turbine deployment.

Besides in-fill radars, specific radar/s, a multi-systems approach should be considered. Siting of radars may be one key important task to optimize radar performance and safeguarding tracking of routes. However, space between wind turbines and their siting takes in many factors, optimizing their siting for radar processing viability can be very difficult due to many other factors.

We need mutual accommodation to find the best possible and economical solution. In the final analysis, this even requires solutions that seem almost impossible today. This includes investments in additional parts to combine technical systems. Radar operators may not want to depend on wind park operators, but it may be the way forward i.e., when windfarms become part of a radar system using infill radars installed on wind turbine towers.

The US has installed a Wind Turbine Radar Interference Mitigation Working Group including all U.S. government stakeholders with radar assets. The link to the working group and the review process can be found here: https://windexchange.energy.gov/projects/radar-interference-working-group.

High intensity light (> 100 candelas) is costly. Adaptive lighting is a good solution (i.e., lighting by detection as seen in earlier presentations). It is accepted in the UK but not in Denmark. Vestas and other manufacturers propose this kind of solution. An open approach may be important to approach the authorities and to reach a permit for the selected solution.

In Switzerland (onshore), the lighting is only allowed up to medium intensity. Too strong lights may cause problems for aviation, for instance for infrared lighting as high intensity and proximity halo effects occur in NVGs.

Although VORs are being replaced by GNSS based systems, they will be maintained as back-up systems for air navigation in the future. In general, VOR can be subdivided into two systems, the old conventional CVOR, and the modern Doppler DVOR. CVOR are by far more affected by nearby wind turbines. With increasing distance, the disturbance drops and at 10 km the influence is very small and almost negligible. The WERAN and WERAN plus projects are generally well received. The scientific outcome is considered to be at the forefront. The certified model approach based on full-wave simulation and on-site measurements is transparent and helps for new or repowering applications. The results show how to quantify and to include terrain effects, HV lines, etc. Existing assessment tools have been revised based on the results and are still the topic of ongoing research.

Germany has installed more than 30.000 wind turbines and it operates around 60 VOR. The assessment in Germany about the influence of wind turbines is not in line with ICAO. The larger protective area up to 15 km radius is applied both to CVOR and DVOR. This procedure differs from other countries, which are much more permissive.

UK is operating DVORs only. No evidence could be reported so far, that onshore wind turbine applications had to be turned down due to DVOR restrictions. As long as developers keep distance to aerodromes, no reasons exist to build hurdles to wind farms. Communication with NATS (National Air Traffic Services) helped to mitigate, even moving the equipment would be taken upon oneself. Wind developers will talk to airfields in an early stage of their application.

VOR are being phased out in Switzerland (down from 12 to 3) and in other countries, i.e., Canada will reduce the VOR from 110 to 50, many will be decommissioned the next years. GPS sometimes does not reliably work, because truck drivers are jamming the signal. Having a back-up in place is fundamental in these cases, especially with DME (distance measuring equipment). It is based on response time and less affected by wind turbines. Therefore, the radius of the protection zone around DME can be reduced to 3 km, which is much less than 15 km on VOR.

No problems due to VOR have been brought up by the participants from Sweden.

The European program encourages the ANSPs to primarily use satellite-based air navigation systems, but the transition takes long time. Although maintenance costs fall sharply due to decommissioned VORs, rearranging the whole air space is costly. Back-up equipment on the ground such as VOR will be maintained for safety and redundancy reasons, protection zones around DME will prevail.

VOR will be used in the US for long-term in remote areas and for military purposes, but GNSS is expected to become the major means of air navigation.

Conclusions & Next Steps

Given the inspiring presentations and following discussions that took place during TEM#100, the organizing committee is happy to observe that this online meeting was fruitful. The resulting factsheet is expected to be a good base to guide the dialogue between stakeholders in order to reach a smooth cohabitation between aviation, both civil and military, and wind power.

Several navigation and radar systems are in use to ensure flight safety and perform military tasks. Wind turbines are large objects in the landscape and are affecting aviation in a similar way as other large objects in the landscape like chimneys and buildings. Consequently, requirements from aviation systems and uncertainty in the consenting/permitting process are impacting the deployment of wind power, and in some countries quite severely.

Wind power is foreseen to be in many countries the backbone of the electricity production and will be part of the landscape in a green society. In this new landscape, aviation and wind power will have to cohabitate to create a **safe-to-fly and defendable green world**.

Building on the findings and observations from TEM#100, the organizing committee will put together a factsheet of best practices. Several participants have expressed their desire to participate to the elaboration or review process, showing that such a document is indeed needed. Its structure will be organized around the following axes:

- Existing aviation systems and practices for flight safety
- Management mitigations – Foster collaboration and dialogue
- Operational and procedural mitigations
- Technical mitigations
- Future needs and developments

The organizing committee will seek coordination with the IEA Wind secretariat and Communications sub-committee of the IEA Wind TCP in order to publish a factsheet as a reference document for policy makers and national authorities by mid-2021.

APPENDIX ONE – TEM#100 Introductory Note

INTRODUCTORY NOTE

IEA WIND TASK 11 TOPICAL EXPERT MEETING #100

ON

AVIATION SYSTEM COHABITATION

Matthieu Ducret – Planair SA, Suisse Eole
Pierre-Jean Rigole, Maria Stenkvist – Swedish Energy Agency
Thorsten Schrader – Physikalisch-Technische Bundesanstalt

BACKGROUND

Countries are facing cohabitation issues with civil and military aviation systems and wind turbines due to possible interferences. Two interference types are addressed: wind turbines could be physical obstacles to aircrafts, and may also cause electromagnetic-wave interferences (reflexion, diffraction, scattering, …) to Communication, Surveillance and Navaid systems.

Many countries are facing issues with aviation, and finding manners of tackling and solving conflicts is paramount. It is often observed that specific policies are made for each and every country, and knowledge of international practices is often missing. Wind Europe has recently reached out to create a task force dedicated to aviation safety and wind energy plants conflicts in order to define and harmonise good practices across Europe. In Switzerland for example, given its small territory, those issues have been addressed for years and experiences have evolved into good practice. A set of recommended policies for different contexts, based on worldwide experience and good practices, would be a precious tool for the wind energy sector and for policy makers.


Photography: Matthieu Ducret

OBJECTIVES

The proposed TEM intends to gather good practices from the member countries in order to establish a list of policies as a decisional help for worldwide authorities.

The presentations will cover:

1. Best practices preventing legal monopolies and lobbies (out of wind energy domain)
2. Solutions and evolution strategy for obstacles
3. Solutions and evolution strategy for radio wave system

The participants will be expected to exchange information and ideas to include best practices granting the best possible cohabitation between aviation and wind energy plants.

TENTATIVE PROGRAM

The proposed TEM will be hosted online on December 8-10, 2020. A mixed format between interactive presentations and small group discussions is planned, with a total of 4 hours each day.

TEM#100 was originally to be collocated with the EMWT 2020, but the latter was cancelled. The meeting now takes place in the week following the Wind Energy Hamburg fair.

The final agenda will be shaped in the course of registrations; the foreseen program is as follows:

Prior to TEM#100: pre-meeting survey

To maximize the benefit of the meeting, we would like to ask invitees to kindly participate in a pre-meeting questionnaire. Your responses and feedback will help inform the meeting agenda and will be summarized during the TEM's opening presentation. Further, your responses will provide quantitative data that will be incorporated into the final TEM report.

Note that the survey is anonymous, and we will not know who provided which answers. Finally, note also that even if you do not intend to attend the meeting in person, we invite you to participate in this questionnaire so that your expert opinion can be included. Thank you very much for your time!

Day 1: December 8th, 2020 – setting the context & glossary

- Introduction by host
- Example situations of conflicts between wind turbines and aviation
- Technical aspects: state-of-the art and agreement on definitions
- Short breakout sessions

Day 2: December 9th, 2020 – experience sharing

- Recap of day 1
- Case descriptions: country & participants presentations
    - Proposed and implemented solutions
    - Dialogue and collaboration models
    - National aviation procedures and policies evolution
- Discussion and break-out sessions

Day 3: December 10th, 2020 – agreement on best practices

- Recap of day 2
- Further case descriptions
- Agreement on best practices: document draft
- Wrap-up and next steps

INTENDED PARTICIPATION

Participation is expected from the following parties:

- Wind farm operators;
- Civil aviation authorities;
- National defence departments;
- National and regional energy boards;
- European and national wind associations;
- Other interested and relevant parties.

SPECIFIC OUTCOMES

We see a strong interest of bringing the different stakeholder to discuss together and identify best practices.

The outcome of this meeting will be a report summarising:

- Presentations from the participants;
- Recommendation and summaries for all areas discussed.

A factsheet summarising best practices and guidelines for policy makers as well as project developers will be another key outcome of this meeting.

APPENDIX TWO – Meeting agenda

IEA Wind TEM#100 on Aviation System Cohabitation

Online meeting, 8-9 December 2020

Meeting Agenda

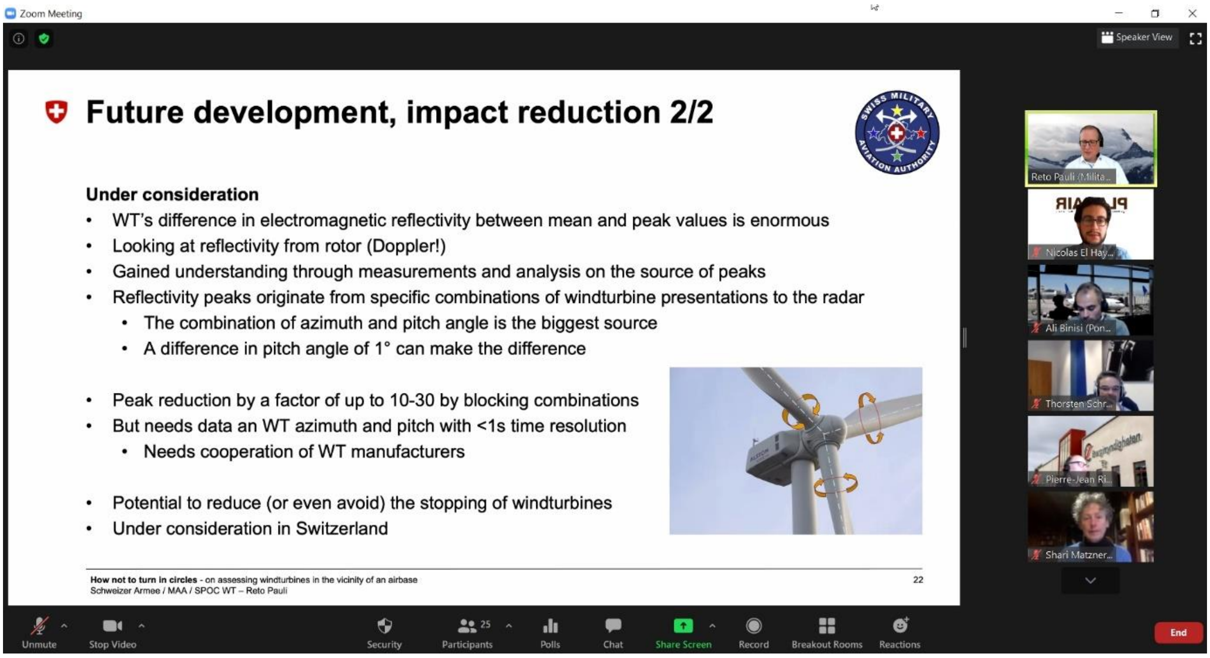
Time	Topic	Presenter
Tuesday, 8 December 2020		
Introduction Session		
13:25 CET	Check-in	All
13:30	Welcome and meeting overview	N. El Hayek, *IEA Wind Task 11*
	Speed-Dating - online meeting ice-breaker *3 min. break-outs with 3 randomly chosen participants*	
	IEA Wind TCP and Task 11	N. El Hayek, *IEA Wind Task 11*
13:45	Introduction to the topic: exclusion vs. case-by-case	M. Ducret, *Planair SA*
14:00	A RADAR case study – case-by-case analysis *Q&A*	R. Pauli, *Swiss Air Force & Swiss MAA*
14:20	Example conflict situations between wind turbines and aviation – A Swedish case study *Q&A*	M. Stenkvist & P.-J. Rigole, *Swedish Energy Agency* U. Gustafsson, *Swedish Defence*
Session 1: Lighting of Wind Turbines		
14:45	Transponder-based system for the control of obstacle lights of wind farms	A. Binisi, *Scandinavian Avionics*
15:00	Lighting: current practices & developments *Q&A*	M. Ducret, *Planair* R. Pauli, *Swiss MAA*
15:15	Break (15 minutes)	
Session 2: RADAR Systems		
15:30	The Offshore Wind Industry Working with Aviation and Defence Stakeholders	D. Goncalves, *Vattenfall*
15:50	Wind Turbine Radar Interference Mitigation Efforts in the United States	Jason Biddle, *MIT Lincoln Lab* Bryan Miller, *BEM Int'l, LLC*
Discussion session		
16:30	Trends and worthwhile discussions based on pre-meeting questionnaire	M. Ducret, *Planair SA*
16:35	Moderated Break-out session: Identification of open issues and needed solutions • Open questions & needed solutions • Main roadblocks and priority topics	Chairs: 1. M. Ducret 2. P.J. Rigole Note takers: 1. M. Stenkvist 2. T. Schrader
17:15	Plenary with overview of results of break-out groups *Short discussion / Q&A*	N. El Hayek, *IEA Wind Task 11*
17:30	Group picture & Close of the day	

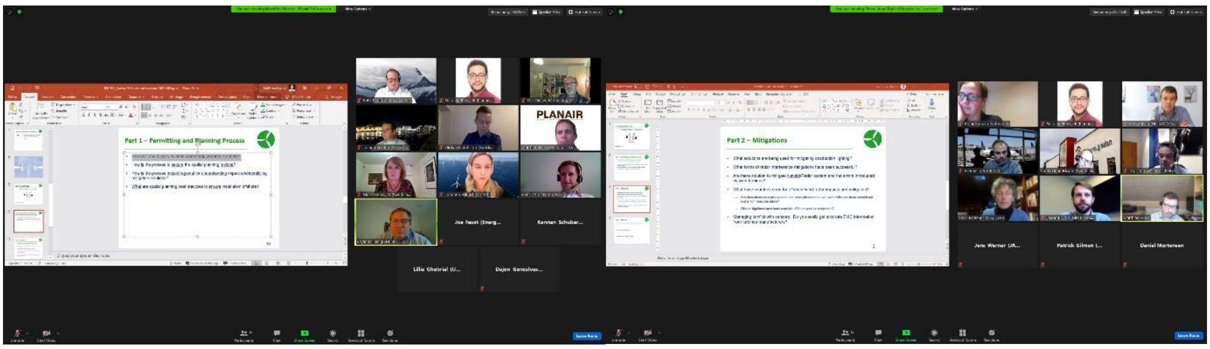
Time	Topic	Presenter
Wednesday, 9 December 2020		
13:25 CET	Check-in	All
13:30	Welcome and Recap of Day 1 Definitions: what have you learnt?	T. Schrader, *Physikalisch-Technische Bundesanstalt PTB*
13:40	Identified issues, past and current experiences	H. Sjöström, *OX2* D. Mortensen, *Ørsted*
14:10	Investigations on operational Radars using Octocopters - antenna measurements and obstacle reflectivity	Jochen Bredemeyer, *FCS Flight Calibration Services GmbH*
Session 3: VOR Systems		
14:35	WERAN and WERANPLUS projects (Part 1) *Q&A*	T. Schrader, *PTB*
14:55	WERAN and WERANPLUS projects (Part 2)	T. Schrader, *PTB*
15:15	Break (25 minutes)	All
15:40	Localisation and characterisation of large reflecting objects (wind turbines, towers, buildings) in the vicinity of D-VORs by airborne VHF passive RADAR techniques	K. Schubert, *Jade Hochschule Wilhelmshaven Oldenburg Elsfleth*
16:00	Results of the min-VOR project and a short summary on related report activities in Germany	R. Geise, *TU Braunschweig*
Discussion session		
16:20	Moderated Break-out sessions • Lessons learnt • Still open issues • Way forward	Chairs: 1. M. Ducret 2. P.J. Rigole Note takers: 1. M. Stenkvist 2. T. Schrader
17:00	Plenary with overview of results of break-out groups *Short discussion / Q&A*	N. El Hayek, *IEA Wind Task 11*
17:20	Discussion and consensus among all participants • Timeline and next steps • Interactive poll	N. El Hayek, *IEA Wind Task 11*
17:30	Event close	N. El Hayek, *IEA Wind Task 11*

APPENDIX THREE – Meeting Participants

A total of 34 participants were registered to TEM#100, coming from 8 countries across the globe. The detailed list of participants is available on the [TEM#100 website (meeting documents)].

A deck of introductory slides to 19 of the participants was put together, highlighting their background and research interest. This precious document is also available for download on the TEM#100 website.





APPENDIX FOUR – Meeting Summary

Aviation systems

Through the different presentations given during TEM#100, an overview of the impacted navigation and radar systems and flight operation regulations was obtained. The discussions allowed to complete the picture and better define certain aspects, highlighting the following systems:

- Communications
    - Radio digital link / Microwave link and broadcasting of alarms, video and audio services.
- Navigation
    - Satellite and ground-based systems.
    - VOR – VHF Omnidirectional Radio Range is the ICAO standard short and medium range navigation aid that is installed at airports and en-route locations. There are two types of VOR aids: CVOR (Conventional VOR) and DVOR (Doppler VOR). Although these are being more and more replaced by GPS-based systems, they are still needed for redundancy and military purposes.
    - DME – Distance Measurement Equipment is a radio navigation technology that measures the slant range (distance) between an aircraft and a ground station.
    - NDB – Non-Directional Beacon is a radio transmitter at a known location, used as an aviation or marine navigational aid.
- Surveillance
    - Radars – These are airport surveillance radars, air defense radars, precision approach radars, military surveillance radars, and weather radars.
- Flight procedures and protective areas
    - MSA – Minimum Sector Altitude is the lowest altitude which may be used which will provide a minimum clearance of 300 m (1 000 ft). This minimum clearance is subject to change according to the area types, above all objects located in the area contained within a sector of a circle of 46 km (25 NM) radius.
    - Stop area – An exclusion zone for high objects around an airport.
    - LFA – Low Flight Area are for training military aircraft to fly at low altitude. Some countries have large military reservations for such training to take place without affecting the civilian population.
- Obstruction lighting
    - All structures exceeding a certain height above ground level must be appropriately marked with tower, nacelle and blades lights. Requirements are set by the country regulating authorities. The International Civil Aviation Organization, ICAO, recommends medium-intensity obstruction lighting for wind turbines up to 315 m total height (ICAO Annex 14, for taller wind turbines additional marking and lighting may be required by an aeronautical study).

Common practices for conflict mitigation

The aviation systems mentioned above currently all experience, or have experienced to some extent, conflicts with existing wind turbines or cause delays to wind turbine permitting processes. Additionally, some mitigation solutions can have a non-negligible impact on a wind park's annual energy production (AEP) or on the acceptance by the local population.

The following list of practices for mitigation has been established based on the talks and discussions that took place during TEM#100, and can be classified in three high-level categories.

Management mitigations – Foster collaboration and dialogue

- Set up a **management board between the main stakeholders** – defense, wind industry, air traffic control and national administration – to address conflicts of interest and develop mitigations;
- Establish a clear political statement that the best possible cooperation of all stakeholders is desired and necessary in order to solve this national task.
- Assign **one single authority** that manages the assessment and consenting processes at the national level;
- Have a **time-limited consenting/permitting process**.

Operational and procedural mitigation

- Foster **early engagement and assessment** during initial planning process, yielding more flexibility before wind turbine locations become settled and centralized;
- Predefine all issues to be solved as a catalogue which developers can simply follow;
- Implement **streamlined processes**, but prefer **case by case/dynamic assessment** instead of exclusion zones/static assessment as there might be no one-fits-all-solution. There is a need to shape the solution in each case in order to avoid costly fixed safe-to-operate margins (confident solution).
- Operationally amend activity routes and paths by working with appropriate stakeholders to consider changes to airspace, coupled with technical mitigation;
- Establish and maintain a data base where all existing wind turbines are collected and stored with detailed information;
- Procedurally safeguard vital radars and areas;
- Use transponder mandatory zones (TMZ) within agreed airspace volume around the wind farm;
- Turn off wind turbines to reduce interference;
- Harmonize lighting for offshore and onshore (all countries specific cases must be taken into account).

Technical mitigations and tools

- Assess radio/microwave link case-by-case rather than using exclusion zones based on Fresnel ellipsoids only;
- Use a predictive model/simulation that is validated by measurements;
- Carry out drone-based measurements and full-wave simulations to validate a certified model, used later-on to predict impact of wind turbines on aviation systems (VOR, Radars, …);
- Use an appropriate configuration of antennas on aircraft to capture VOR-information for future flight inspection and model validation (radial/other axes/routes/orbit flights);

- Apply new method of Doppler cross-bearing to identify reflectors and obtain pre-load of VORs;
- Reduce number of VOR installations and upgrade conventional VOR to more modern Doppler VOR systems;
- Solutions for radars:
  - Maximise wind farm tolerance with current radar capabilities available;
  - Include clutter mapping in assessment;
  - Use Range Azimuth Gating;
  - Use cell or sector blanking;
  - Create Non-Auto Initiation Zone or inhibition zone avoiding the creation of new trace corresponding to an aircraft route on the air traffic operator's display – this may require radar hardware and/or software upgrade;
  - Rearrange wind turbines location in radar cells;
  - Upgrade radar (more processing units for more NAIZ, …);
  - Replace legacy radars with the next generation of new complex clutter-managing radar;
  - Use infill radars – Involves a main radar and an infill radar: the infill radar captures unwanted clutter of its area of interest and cuts it out from the main radar coverage picture;
  - Use gap-filler radars – Involves a main radar and a gap-filler radar: a gap-filler radar is installed and configured to scan the area hid by the unwanted clutter in the main radar coverage picture;
  - Use wind farm radars – A radar installed at the wind farm can mitigate the impact of the farm on existing radars and could actually result in improved surveillance quality;
  - Relocate existing radar installations in accordance with wind farm development.
- Operate wind turbines to reduce interference, coupled with an optimization program in order to minimize wind turbines downtime, as for example:
  - Blade pitch control – Excluding certain angles of the blade pitch results in a significant reduction of the echo from a wind turbine;
  - Shut down of wind turbine operation by air traffic control (wind turbines without motion will become part of the ground clutter map and blanked out);
  - Collect telemetry data of wind turbines with a timestamp of under 1 second;
- Stealth wind turbines:
  - Wind turbine design and manufacture changes in order to reduce interference;
- Obstruction lighting:
  - Use night vision goggles (NVGs) and infrared lighting could lead to a reduction of visible lighting, thus increasing local resident acceptance;
  - Operate lighting on aviation demand:
    - Manually switch on demand by wind farm operator;
    - Transponder based;
    - Radar based;
    - Passive receiver based.

APPENDIX FIVE – List of Abbreviations

ADLS	Aircraft Detection Lighting System
AIP	Aeronautical Information Publication
ANSP	Air Navigation Service Provider
ATC	Air Traffic Control
ATM	Air Traffic Management
CVOR	Conventional VOR
DME	Distance Measuring Equipment
DVOR	Doppler VOR
GNSS	Global Navigation Satellite System
HV	High Voltage (Lines)
ICAO	International Civil Aviation Organisation
IEA	International Energy Agency
ILS	Instrument Landing System
IMU	Inertial Measurement Unit
LFA	Low Flight Area
MAA	Military Aviation Authority
MSA	Minimum Sector Altitude
NATS	National Air Traffic Services (UK)
NAVAID	Navigational Aid
NDB	Non-Directional (radio) Beacon
NVG	Night Vision Goggles
OWIC	The Offshore Wind Industry Council (UK)
RADAR	Radio Detection And Ranging
TANC	Turbine Adaptive Nulling Concept
TMZ	Transponder Mandatory Zone
VHF	Very High Frequency
VOR	VHF Omnidirectional radio-Range
WT	Wind Turbine

APPENDIX SIX – IEA Agreement

International Energy Agency Agreement

Implement Agreement for Co-operation in the Research, Development and Deployment of Wind Turbine Systems (IEA Wind)

The IEA international collaboration on energy technology and RD&D is organized under the legal structure of Implementing Agreements, in which Governments, or their delegated agents, participate as Contracting Parties and undertake Tasks identified in specific Annexes.

The IEA's Wind Implementing Agreement began in 1977 and is now called the Implementing Agreement for Co-operation in the Research, Development, and Deployment of Wind Energy Systems (IEA Wind). At present, 26 contracting parties from 22 countries, the European Commission, and Wind Europe, participate in IEA Wind. Austria, Belgium, Canada, CWEA, Denmark, the European Commission, Finland, France, Germany, Greece, Ireland, Italy (two contracting parties), Japan, Republic of Korea, Mexico, Netherlands, Norway (two contracting parties), Portugal, Spain, Sweden, Switzerland, United Kingdom, the United States and WindEurope are now members.

The development and maturing of wind energy technology over the past 30 years has been facilitated through vigorous national programs of research, development, demonstration, and financial incentives. In this process, IEA Wind has played a role by providing a flexible framework for cost-effective joint research projects and information exchange.

The mission of the IEA Wind Agreement continues to be to encourage and support the technological development and global deployment of wind energy technology. To do this, the contracting parties exchange information on their continuing and planned activities and participate in IEA Wind Tasks regarding cooperative research, development, and demonstration of wind systems.

Task 11 of the IEA Wind Agreement, Base Technology Information Exchange, has the objective to promote and disseminate knowledge through cooperative activities and information exchange on R&D topics of common interest to the Task members. These cooperative activities have been part of the Wind Implementing Agreement since 1978.

Task 11 is an important instrument of IEA Wind. It can react flexibly on new technical and scientific developments and information needs. It brings the latest knowledge to wind energy players in the member countries and collects information and recommendations for the work of the IEA Wind Agreement. Task 11 is also an important catalyst for starting new tasks within IEA Wind.

IEA Wind TASK 11: BASE TECHNOLOGY INFORMATION EXCHANGE

The objective of this Task is to promote disseminating knowledge through cooperative activities and information exchange on R&D topics of common interest. Four meetings on different topics are arranged every year, gathering active researchers and experts. These cooperative activities have been part of the Agreement since 1978.

Three Subtasks

The task includes three subtasks.

The objective of the first subtask is to develop recommended practices (RP) in collaboration with the other IEA Tasks.

The objective of the second subtask is to conduct Topical Expert Meetings (TEM) in research areas identified by the IEA R&D Wind Executive Committee. The Executive Committee designates topics in research areas of current interest, which requires an exchange of information. So far, TEMs are arranged four times a year. Additional self-sustained TEMs allowing shorter reaction times, broader audience and augmented visibility can be proposed by member countries or organisations.

The objective of the third subtask is to provide room for exchanges within the wind energy expert community. This is done through the IEA Wind platform with online communities.

Documentation

Since these activities were initiated in 1978, more than 90 volumes of proceedings have been published. In the series of Recommended Practices, 20 documents were published and six of these have revised editions.

All documents produced under Task 11 and published by the Operating Agent are available to citizens of member countries participating in this Task. Some documents are publicly available one year after first publication.

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COUNTRIES PRESENTLY PARTICIPATING IN TASK 11 (2020)	
COUNTRY	**INSTITUTION**
Belgium	Government of Belgium
Canada	Natural Resources Canada
Denmark	Danish Energy Authority
Finland	Business Finland
France	IFP Energies Nouvelles
Germany	Federal Ministry for Economic Affairs and Energy (BMWi)
Ireland	Sustainable Energy Authority of Ireland (SEI)
Italy	Ricerca sul sistema energetico (RSE S.p.A.)
Japan	New Energy and Industrial Technology Development Organization (NEDO)
Mexico	Instituto de Investigaciones Electricas (IIE)
Netherlands	Ministry of Economic Affairs
Norway	The Norwegian Water Resources and Energy Directorate (NVE)
Republic of China	Chinese Wind Energy Association (CWEA)
Republic of Korea	Korea Institute of Energy Technology Evaluation and Planning (KETEP)
Spain	Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas (CIEMAT)
Sweden	Energimyndigheten - Swedish Energy Agency
Switzerland	Swiss Federal Office of Energy (SFOE)
United Kingdom	Offshore Renewable Energy CATAPULT
United States	The U.S Department of Energy (DOE)