Executive Summary
Offshore Energy Hubs - Super Power of the Future

Hosted by DTU Wind and Energy Systems in cooperation with the Danish Energy Agency and IEA Wind TCP
2nd December 2022

Offshore energy hubs are a hot topic in the energy sector. Governments and investors alike have high expectations for offshore energy hubs as a super power concentration of the energy transition.

The world's first energy islands will be constructed in Danish waters, exploiting the immense wind resources in the North and the Baltic Seas.[1] Parallel to governmental initiatives, investors have developed visions for making energy hubs such as The Hydrogen Island by Copenhagen Infrastructure Partners or The IJver Island, a multifunctional artificial island by a Dutch consortium**.** They will serve as offshore hubs that can create optimal conditions for the establishment, operation, and innovation with respect to offshore wind and provide better and cost-effective connections between the offshore wind farms and the energy systems in the region. As such the energy hubs will enable large-scale sector coupling in the region and will function as green power plants at sea.

The offshore energy hubs build on dedicated strategic research on large scale wind energy in the energy system, the power system transformation, new policy measures and planning. Wind energy research has since the 1970ies benefitted from the thriving international cooperation in the IEA Wind Energy Systems Technology Collaboration Programme (Wind TCP), which brings together leading researchers to avoid overlap and fill research gaps with the overall mission to develop clean energy technologies.

On 2nd December 2022, more than 200 participants signed up for a webinar hosted by DTU Wind and Energy Systems, the Danish Energy Agency and the IEA Wind TCP to discuss offshore energy hubs and answer two questions:

- What can specific Tasks of the IEA Wind TCP and others provide to the further development of offshore energy hubs?
- Can the offshore energy hubs be further researched in a specific Task or do we need a separate Task to cover all important aspects related to offshore energy hubs to accelerate the green energy transition?

Birte Holst Jørgensen, DTU Wind and Energy Systems and Danish Alternate Member of the IEA Wind TCP, welcomed the participants and gave a short introduction to the webinar.

[1] Denmark's Energy Islands | Energistyrelsen (ens.dk)

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Karina Remler, Danish Energy Agency and Member of the IEA Wind TCP, welcomed the participants and presented the Danish Energy Development and Demonstration Funding Programme (EUDP). The programme was founded in 2007 and allocates annually ~ DKK 500 million to energy development and demonstration projects, whose project partners co-finance with a similar amount. EUDP also finances feasibility studies, technology partnerships and Danish participation in international collaboration programmes such as IEA TCPs, Mission Innovation and the EU Strategic Energy Technology Plan. Examples related to offshore energy hubs include the North Sea Energy Hub Feasibility Study and the recent development project Offshore Energy Hubs. Karina's presentation is available here.

Carl-Christian Munk-Nielsen, Technical Director, Danish Energy Agency, explained the rationale for the Danish energy islands as the start of a new era of offshore wind development. It has strong political support at national as well as EU level. The Esbjerg Declaration signed in May 2022 by Belgium, Denmark, Germany and the Netherlands aims at jointly developing 150 GW offshore wind in their North Sea territories. The Marienborg Declaration signed in august 2022 by eight Baltic Sea countries agrees to increase offshore wind capacity sevenfold by 2030. Denmark is already well connected to neighbouring countries and has further agreed to new interconnections relevant to the energy islands in the North Sea and Baltic Sea. The Danish Energy Agency is leading the planning of the energy islands, which is one of Denmark's largest construction projects ever. The Energy Island Bornholm will accommodate 3 GW offshore wind with onshore facilities on the island of Bornholm and connections to Zealand and Germany. The North Sea Energy Island will combine on-island transmission with a platform-based system located around the island. The technical design is both flexible and scalable, starting with 3 GW offshore wind by 2030 and reaching 10 GW by 2040. There will be a tender for the construction of the energy island after which a public-private Energy Island Company will be established. As the energy islands are considered critical infrastructure, there will be a thorough investment screening. The innovation options will not be included in the selection criteria but will be organized at the discretion of the company. Carl-Christian's presentation is available here.

Jacob Østergaard, Professor, DTU Wind and Energy Systems, gave his take on the unique research challenges related to the energy islands. The islands will be the first of its kind, involving the design of an extreme power system with unprecedented characteristics. The 100% inverter-based separation to other systems will result in an extremely low short circuit power and the system will have no or very limited inertia. This will require new solutions for ensuring a stable operation of the grid. Research challenges to be solved thus include: stability, fault management, optimal grid topology, multi-vendor HVDC, grid-forming converters, optimal power-to-x integration and market design. The system impact of the offshore energy hubs is huge and has just recently been researched in e.g. Frequency dynamics of the Northern European AC/DC power system and North Sea Energy Islands: Impact on National Markets and Grids. Challenges are also related to where to place the electrolysers to convert power to fuels. A recent study found out that offshore placement was more affordable compared to onshore and in-turbine placement. The European MultiDC consortium has researched inter alia zero inertia offshore grids and analysed the required electric system topology on the energy island so that it can integrate up to 10 GW of wind per island while eliminating blackout risk. The presentation concluded with the Baltic Energy Island where Bornholm will operate as a first test island for energy hub technologies.
Jacob's presentation is available here.

The panel discussion was moderated by Nicolaos Cutululis, Professor, DTU Wind and Energy Systems

Stephan Barth, Chairman of the IEA Wind TCP, found that offshore energy hubs are a fascinating topic which requires to think out of the box and not limit us to known solutions and technologies. Security is obviously a key concern, and the question is if such infrastructures need more or less protection than e.g. nuclear power plants. There are also other concerns such as environmental, social, and other issues. What will happen to birds with such massive offshore energy built out? Can the enormous societal investments be justified in terms of jobs, export possibilities etc. Finally, can energy islands be a blueprint for other areas of the world or is it a solution that only works in European waters. This is indeed a question to be explored and discussed as part of IEA activities, not just within the Wind TCP Wind but also other TCPs.

Hannele Holttinen, Operating Agent of Task 25 (Integration of high amounts of wind energy), congratulated the Danish organizers to introduce this new topic on offshore energy hubs, which has only briefly been discussed at the Wind TCP. It seemed to be of interest for other countries and parts of the world.

Eric Lantz, Operating Agent of Task 53 (Wind Economics) gave a short insight into the current collaboration on technology development, the impacts of specific innovations, the financing and uncertainty, covering both costs and values. Collaboration also touches upon offshore energy transmission and hydrogen production, all of which are relevant to the energy islands. The topic is relevant for countries looking at 100% clean energy futures, not just having 100% clean electricity but the whole energy system supplied directly or indirectly by green electrons.

Gregor Giebel, Operating Agent of Task 51 (Forecasting) has been in forecasting of wind resources for quite some years but today it has changed to forecasting for weather-driven energy systems, covering wind, solar and hydro with time scales from the minute scale to seasonal forecasts. The task is closely related to other tasks such as LIDAR, Airborne wind, Hybrids and also other TCPs such as Photo Voltaic Power Systems, Hydrogen, Biomass and others. Forecast for energy islands will be used for both system stability as well as for the local and regional power markets. Some of the challenges are related to the large local aggregation of power where the forecast errors on the hour scale cannot be smoothed out by the geographical distribution of wind. The sub-hourly variations would probably vanish though due to the large areas. Wind measurements at the front could be advected to yield better hour scale predictions. We need details of the technologies and how to smoothen out the residual electricity transmission to the shore.

Andreas Hauer, Operating Agent of Task 35, TCP Energy Storage (Sector coupling) highlighted the importance of collaborating with other TCPs as energy storage is always connected to something between the energy source and the final consumer. In the renewable energy system, it is not just about electricity but also thermal heating and cooling and the mobility sector. By using storage technologies, it is possible to convert electricity to heat which is much cheaper to store than electricity. And some transport modes are difficult to electrify but may benefit from synthetic fuels produced from green electrons.

Extracts from discussion:

- The topic »Offshore energy hubs« is **broader than wind energy**. It has close connections to hydrogen as an energy carrier option, other energy storage technologies and ocean energy technologies. They will facilitate operation and maintenance and act as hosts for unmanned drones, automatic vessels and research or inspection vessels.

- The offshore energy hubs will consist of **different technologies with different maturity levels** even on the electricity part. On top of that comes power-to-x and together storage technologies. The economics of such complex system is critical. Somehow it is necessary to decide who should the winners be before actually building the system. It is basically a research challenge to do experiments, to test these technologies and collect the empirical data. The value does not necessarily have to be static, meaning that modelling the values of the energy systems of today will give one answer but modelling the energy system of the future will give another answer. Approximations are needed. This will not be an easy task but through some of these cross technology collaborations, we may be better at analysing different scenarios or sensitivities over time and even decades.

- The **energy storage** capacity of the energy island must be further explored. As of today, there is no market demand for storage from the artificial islands. The fluctuating power production will need storage/balancing support, but the ambition is also to produce hydrogen for the industrial and transport markets. Thorough analysis is needed to decide whether to convert the power to hydrogen offshore or onshore. A recent study made by the North Sea Wind Power Hub indicates that in some cases offshore hydrogen production may be the best option instead of transporting the power to shore for the hydrogen conversion. The discussion on molecules versus electrons is still ongoing and extends beyond the energy sector.

- Although the wind technology development has been driven by **cost reductions (LCoE)**, the question is whether this will also be the case in the decades to come. Other priorities and values may also drive the technology development such as security, sustainability, etc. But with storage technologies in the equation, LCoE may be highly relevant again. Close cooperation with the Storage TCP may bring new knowledge to the table.

- **Speed of development** matters: the business case for many of those technologies may be good enough to forego extensive optimisation in favour of a quicker process. The optimisation challenge is huge. Combining the energy systems coupling to the power system, and including the timeline of the projects as an additional optimisation variable would increase the challenge even further. The offshore energy hubs bring immense challenges, but also great opportunities related to the speed of development of the technology, e.g., grid forming converters, and stability of what basically will be a (extreme) version of a system that is fully based on power electronics (low/zero inertia, low short-circuit power, etc).

- **Collaboration** is key to create the best solutions to complex challenges. The Wind TCP cooperates across tasks and also cooperates with other TCPs (e.g., Ocean Energy). It is important not to get stuck in formalities but rather find a pragmatic way to cooperate, irrespective of different organisational set-ups and fee structure. First step is to start working

on the topics and the technology challenges and questions, which obviously are not confined to one technology. It is important to build on the momentum and interest in this new topic and invite member countries (and TCPs) to participate in drafting the research topic(-s) for offshore energy hubs. In the meanwhile, the TCP leadership should think about how to facilitate the more formal side of such collaboration, which will be needed to generate the necessary national funding for the research communities to join the collaborative research.

Concluding remarks

The organizers will follow-up on the strong interest in this emerging area characterized by various complexities and spanning different domains. The ambition is to propose a dedicated Task to the IEA Wind TCP to address the challenges and also opportunities of such offshore energy hubs. International cooperation is key to accelerate the development of such offshore energy hubs so that they can be the superpower of the future.

A follow-up virtual workshop will be organized in week 11 or 12 (by invitation only) to draft the research topic, work packages, work plan and budget. Interested academic and industry stakeholders are welcome to express their interest to Nicolaos Cutululis (niac@dtu.dk) or Birte Holst Jørgensen (bhjq@dtu.dk).