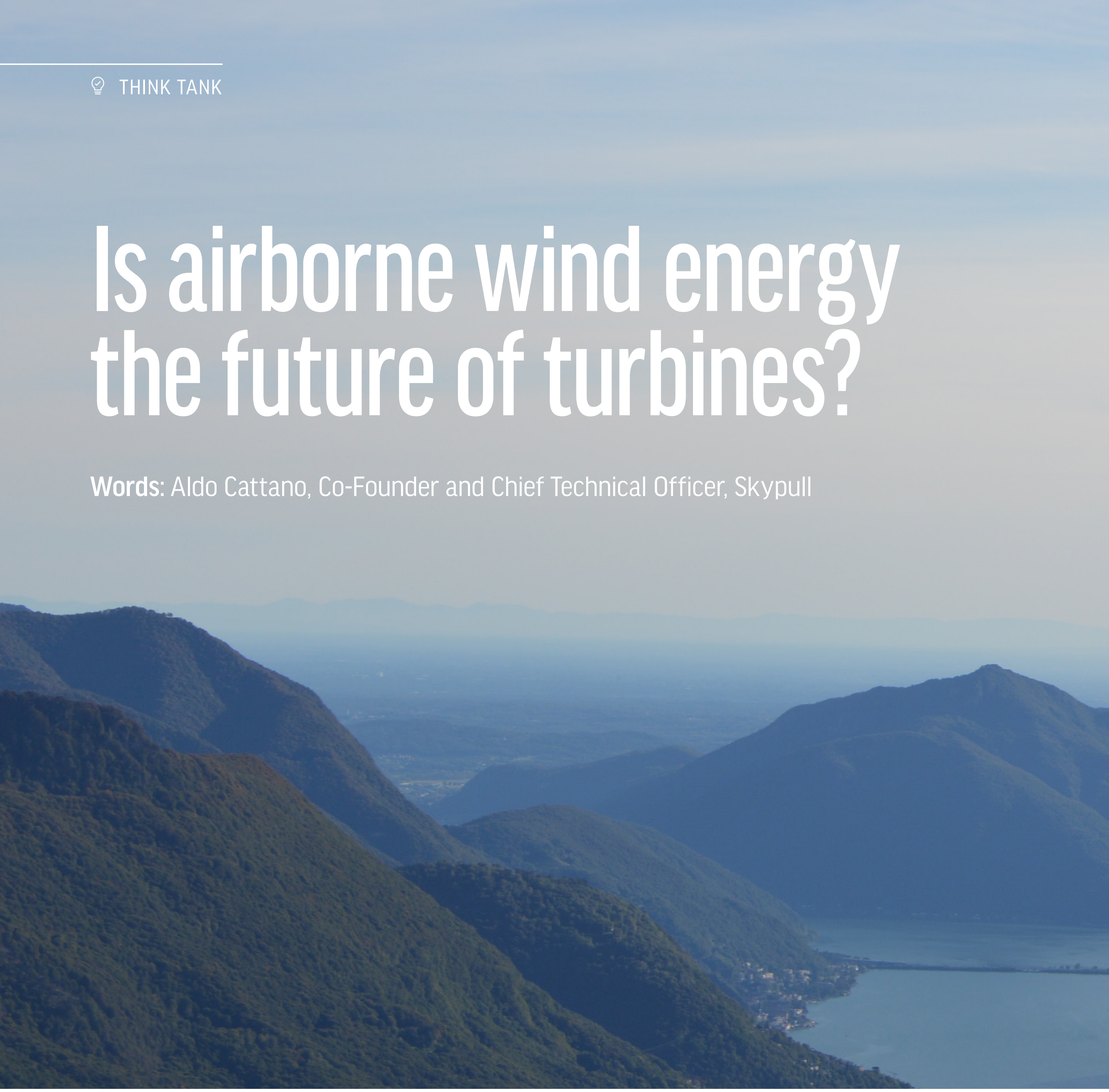


Is airborne wind energy the future of turbines?

Words: Aldo Cattano, Co-Founder and Chief Technical Officer, Skypull

Airborne Wind Energy has many potential advantages that could see it play a crucial role in the long-term transition to renewable energy. However, such a new innovation requires some clever thinking and financial backing to really get it off the ground. Cost-effectiveness is one barrier to its success so far, so how can this be overcome to enable the technical progress to shine through?

Airborne Wind Energy (AWE) is an early-stage wind power technology, employing innovative wind turbine systems based on flying devices such as kites, aerostats and planes. These are connected to the ground by a tether to reach and exploit the more consistent and stronger high-altitude winds for generating electricity.

The aim of AWE is to provide a wind generator that is not restricted by bulky blades and unmovable towers that characterise conventional wind turbines. Instead, power generation occurs either 'on-board' the flying device or on 'the ground'.

In the first case, on-board wind turbines are combined with a conducting tether. In the second case, the pulling power of the flying device unwinds the tether from a drum on the ground, which drives the generator and requires the tether to be reeled back. The use of a lightweight tether instead of a fixed tower significantly reduces material consumption and installation costs. It also allows for a continuous adjustment and optimization of the wind harvesting altitude of the flying device, thus increasing its power production capacity.

In 2019, the International Renewable Energy Agency (IRENA) acknowledged that the emerging AWE technology could be a ‘potential game-changer’ for reaching the long-term energy transition and full decarbonisation of energy systems.

In the last decade, the AWE domain has increased rapidly. Today around 100 AWE players, ranging from academic institutions to start-ups and public companies, are active worldwide, proposing several concepts and layouts.

Hundreds of patents have been filed and more than $700m have been spent roughly, involving players such as Google, EoN, ABB, Sabic, Alstom, NASA, Fraunhofer etc., investing into and supporting the AWE sector. However, only a few of them have reached a prototype phase and none have yet succeeded in delivering an effective, efficient, reliable and resilient system. The question inevitably arises: what is the missing link?

AWE is extremely challenging from a technical point of view. The solutions involve using an autonomous flying device, which continuously adjusts to changing wind intensity and direction to increase energy yields. Additionally, the flying device has to be coordinated precisely, with a tethered system combined to a ground station. Such highly sophisticated and intertwined mechanisms require the optimisation of the aerodynamic performances of the flying device, the development of autonomous operations, as well as ensuring the deployment of the system and overall reliability. The first successful AWE system with such characteristics may lead to a quantum leap and a radical change to global energy scenarios.

The winding road towards commercially viable AWE systems

Currently, the AWE sector is experiencing market barriers, similar to those experienced in the past by solar PV and onshore wind power. Despite strong technical progress, AWE solutions are not yet cost-competitive. Two recent examples in the AWE sector are the shutdown of Makani Power in 2020 and the bankruptcy of Ampyx Power in May 2022. In both cases, the proposed solutions failed to reach the commercialisation phase, as the second round investment request was too high and no investor was willing to further finance the project.

Looking back at the market evolution of solar photovoltaic technology, it took around 30 years, and many public subsidies, for this technology to become cost-competitive and reach market maturity.

The same can be said for conventional wind turbines. For instance, Vestas, the world's leading wind energy company, took 20 years before moving from a 50 kW to a 1 MW nominal power wind turbine.

Successful technology advancements in the AWE sector ultimately require time and money. A closer look at the two cited case studies, Makani and Ampyx Power, give a clearer picture of where the main obstacles lie.

For over a decade, more than $500 million flowed into Makani Power, attracting large investors such as Google X and Royal Dutch Shell, thanks to its promising AWE solution. However, the proposed Makani kite-energy system had some important conceptual drawbacks for future commercialisation.

This included the choice to generate electricity via wind turbines mounted on top of the main flying device. In this way, the propellers used to produce power were the same as those used for take-off and landing. The power produced by the on-board generators was meant to be transferred to the ground station and back, via a heavy tether. As such, this kind of a system does not include on-board batteries for motors to control the flight of the device in case the tether detaches or breaks, as this would further burden the kite-system which already has to fly the mass of the generators, see Lloyd,1980.

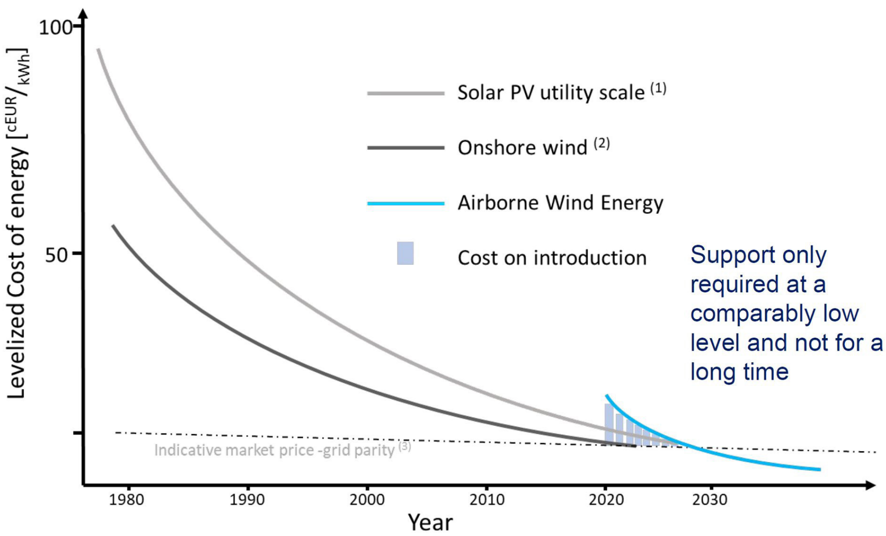
Consequently, the Makani kite-system would only be able to glide for a short time period before falling to the ground. This heavily impacted the potential deployment of this technology, making it suitable only for uninhabited places, such as deserts or offshore.

As a result, the sizing methodology immediately moved to a new business model, targeting mammoth projects involving MW wind farm installations. Consequently, Makani Power quickly moved from a first demonstration project of 20 kW to one that was 30 times bigger, at 600 kW. This required a very heavy and bulky tether, which subsequently posed problems and slowed down the unwinding and winding process of the tether. This presumably was a contributing factor in Makani's last landing, in the sea, before the project was abandoned.

Considering that conventional wind turbines can be installed in populated areas, AWE solutions must also be able to do so. Last, but not least: Makani designed a flying device similar to a standard aeroplane, featuring wings, a fuselage and tail. However, the fuselage represents elements that are, above all, functional to the transport of people and pilots and the tail is needed for flight stability when you are not connected via a tether.

The technology solution proposed by Ampyx Power, the largest AWE project in Europe, also had its drawbacks. Compared to Makani's on-board generation approach, Ampyx Power used ground generation as a principle: a tethered glider-aircraft, attached to a ground-based generator, flies following a crosswind pattern. As the tether unwinds under high tension, and rewinds under near-zero tension, the ground station produces electricity. Launching and landing of the glider-aircraft occurs automatically from a platform using a catapult (Kruijff & Ruiterkamp, 2018).

Considering that even in the military domain, the take-off phase of combat aeroplanes from aircraft carriers can be difficult, developing the launching and landing system



for the proposed AWE solution became a considerably challenging part of the project. In fact, a combination of conventional technologies was used and adapted.

While the initial idea was to use a standard glider as the main flying device, as the project advanced and scaled up, changes occurred and over the last two years the flying device was turned into a motorized glider. In addition, having to provide a commercially deployable system, proposing a conventional field landing solution on a 130 x 100m runway field for the glider-aircraft was not possible and a conceptual trade-off had to be found. This added complexity to the project and resulted in higher construction cycle costs. Ultimately, Ampyx Power was unable to find second round investors to support the proposed innovation.

Future energy scenarios: challenging times ahead

As the demand for renewable energy innovation grows, the financial resources to support emerging energy transition technologies should be found. In the field of taxi drone start-ups, a lot of companies received NYSE funding. But do we really need taxi drones to survive? Is it really so important to arrive in a short time to a place that is 100km away from where we live? Sustainable, clean energy systems, on the other hand, are pivotal to future society.

Europe is facing an on-going energy crisis caused by a combination of external and internal factors, including the volatility of the current energy mix, the interruptions of oil and gas supplies amid the Russia-Ukraine war, extreme weather conditions, etc. According to analysis published by Bloomberg (2022), households in Europe are set to pay an average of 54% more for energy compared to 2020.

Europe is responding with the REPowerEU Strategy (EC, 2022) and is implementing measures to reduce fossil fuel use. However, current renewable energy solutions come with limitations (EUROSTAT, 2022). Hydropower represents 33% of renewable electricity generated in EU in 2020, but requires considerable land for water reservoirs. Photovoltaic systems (14%) use toxic chemicals (CdS; GaAs), while wind turbine (36%) output is limited due to low-speed winds (6 m/s) that are available close to the ground (<120 m).

To gain energy independence and achieve EU climate goals, society needs a new approach to renewables, e.g. harvesting wind power at high altitudes, which has 4.5x greater power generating potential (Marvel et al., 2013) than is possible at 100m.

Skypull: thinking outside of the box

As an aerospace engineer, I moved from designing ultralight aeroplanes to conventional wind turbines, ranging from mini wind turbines up to 50 kW installations. All the engineers I met had a tendency to derive the same aerofoil shape of aeroplanes for the design of wind turbine blades. This is a mistake, as when designing a flying device aimed at generating power, the one unavoidable feature you actually need is a wing.

If the flying device is not an aeroplane, both the tail and the fuselage become redundant. The tether, combined with the use of bridles, can provide flying stability to a wing. For instance, a paraglider flies safely, even though the device doesn't have a tail. This is because there is a load present beneath the wing, in the form of the pilot, connected through bridles, which stabilizes the flight.

Considering that the tail, on average, corresponds to approximately 11% of the bulk of an aeroplane, and the fuselage adds another 15%, Skypull opted to remove these features from the proposed AWE system and to combine an aeroplane and a paraglider into the design. The flying device is inevitably lighter than its Makani and Ampyx Power counterparts. Above all, our core concept is to reach innovative solutions by abandoning conventional aircraft design.

Skypull's proposed AWE technology harvests wind energy at an average height of 400m by means of a rigid-wing drone that acts as a kite. The flying device is designed as an autonomous vertical take-off and landing multi-copter drone, with the ability to recharge the on-board batteries during flight to ensure continuous 24x7 operation.

Skypull is a low cost, lightweight system that will be able to produce electricity at a LCoE of €38/MWh or less, up to 45% cheaper compared to conventional onshore wind turbines. The system requires only 10% of the infrastructural material needed to build a standard wind turbine, resulting in a lower CO_2 footprint too. Power production will, however, double compared to conventional turbines.

Compared to its many competitors in the AWE sector, where systems range from soft sails, to fixed-wing kites on launchers to VTOL drones etc., Skypull's technology stands out for several reasons. Firstly, it uses drone technology for take-off, landing and flight control of the flying device, because it has proven safe, cost effective and has already reached the mass production stage. In production, Skypull concentrates on pultrusion, similar to extrusion with metals, guaranteeing large volumes, low cost and high-fidelity products.

In addition, the box wing design is lighter, with the same aerodynamic efficiency. Installation is possible where needed, even in residential areas, using less ground than other renewable resources and with a low impact on the environment.

Conclusion

In the AWE sector, industry is aiming for both small-scale off-grid solutions and large-scale onshore and offshore installations.

Simplicity is a very important element in AWE design: the simpler a device the longer its operating life and the more reliable it will be. If operational costs are too high, they would offset the advantages gained by the use of less material in the first place.

A successful development path is the core for reaching commercial availability. How to get to a scaled MW system with grid parity LCoE? Firstly, we need to produce and sell small scale systems in niche markets where LCoE is not a priority. Then sales and a continuously growing record of operative hours will ultimately support further innovation, until the proposed AWE solution gets to a competitive volume. Economy of scale will be reached in the end.

https://www.skypull.technology/

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