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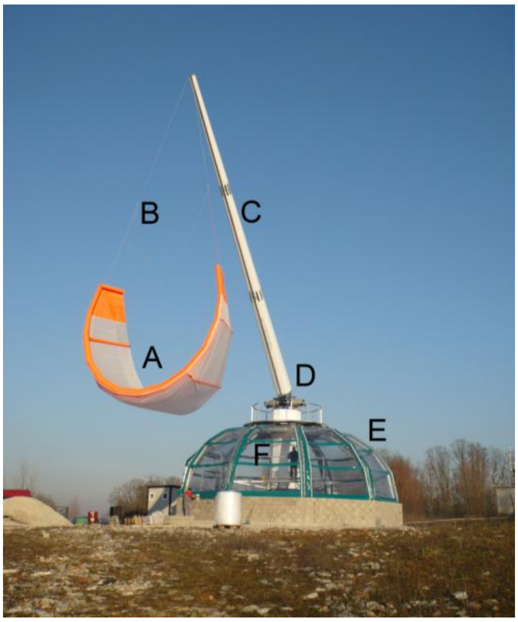
High Altitude Wind Generation

High-altitude wind - the benefits of its energy exploitation



P48-2014-95-DOCUMENT

Version	<1.0>
Created	<10/12/2014>
Author	<M. Ippolito, E. Saraceno, A.Papini>
Doc Name	<High_Altitude_Wind_EN >
Last Revision	12 December 2014
Access	<P>

HIGH-ALTITUDE WIND - THE BENEFITS OF ITS ENERGY EXPLOITATION

Massimo Ippolito, Eugenio Saraceno, Andrea Papini (KiteGen®)

(English version of the article appeared on “L’Energia Elettrica”, March-April 2014, n.2 Vol.9)

High-altitude wind is a concentrated, powerful and steady resource. Its potential has long been known, but only thanks to recent developments in the field of engineering and mechatronics, is its exploitation now possible. At worldwide level, the Italian Company owner of the technology (granted patents), is KiteGen®. The purpose of this article is to explain with clarity and scientific impartiality the physical, technological and economic reasons motivating KiteGen®’s investments and business decisions.

1. Tropospheric wind: the physical-economic reasons behind this choice

Due to its characteristics of abundance, geographic availability and high territorial density, high-altitude wind is a very interesting resource.

Wind is solar energy transformed into mechanical energy by the largest “solar panel” at our disposal: the Earth's atmosphere. A panel that can be defined photokinetic rather than photovoltaic, always ready for use and serviced by nature, free of charge.

High-altitude wind, or rather, the steady currents of geostrophic air, represent the largest energy reservoir from renewable sources on the planet and is constantly fed by the solar radiation from which it is derived.

Considering that the wind speed increases significantly with altitude and that its power increases with the cube of wind speed, if the wind speed doubles its specific power will increase by 8 times. The tropospheric wind is also a fluid in laminar flow: as it moves away from the boundary layer and from the roughness of the Earth’s surface, that inhibit and affect its motion, it gradually increases in speed, persistence and steadiness.

In order to clarify the importance of the wind resource, it is essential to mention the article published in the September 2012 edition of Nature Climate Change. The article confirms the quantification of extractable power, without appreciable changes in the tropospheric wind, in numbers close to 1800 TW, over one hundred (100) times - in terms of energy flow - the current need of the entire humanity (estimated at about 16 - 18TW)[1]. The value of one hundred (100) gives an idea of the potential of tropospheric wind not only as generic data of the atmosphere’s physical phenomenon, but as a clear indication of the availability and local concentration of the resource, with an immediate impact on the economic and feasibility assessments (e.g. wind farms).

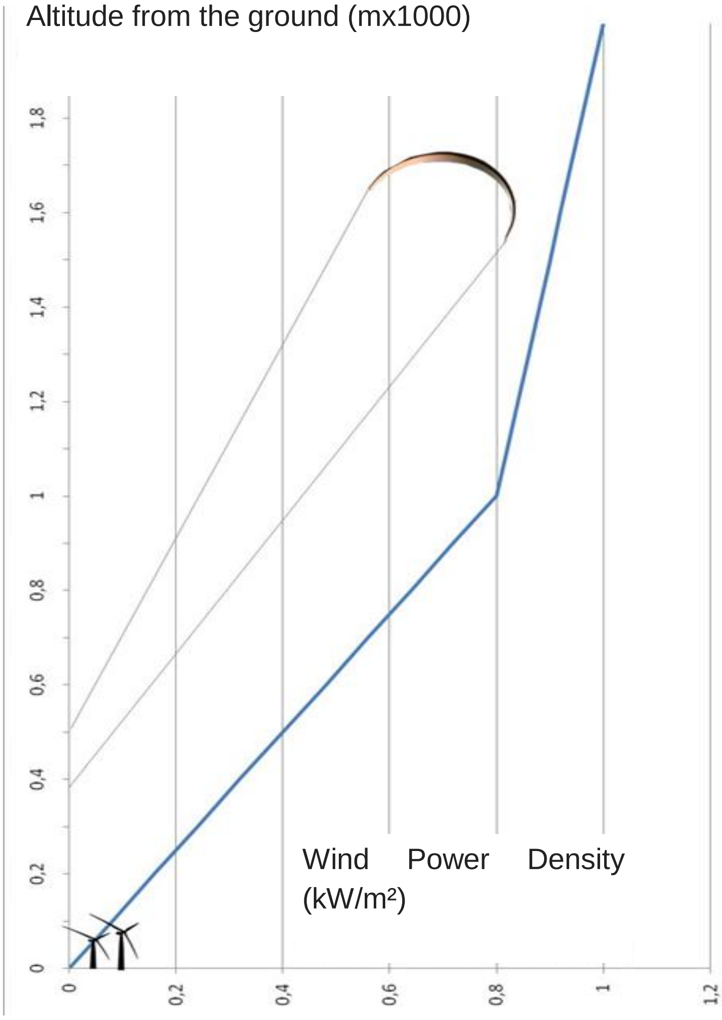


Figure 1: Data from KNMI De Bilt (Olanda) Weather Report Station/ average data 1961–1980 (Source: TU Delft University)

Already at a few hundred meters from the ground level, tropospheric wind has a wind front with an average power density in terms of W/m² well above the power density present on the ground (see Figure 1: Wind Power Density).

For this reason, in the incessant altitude race to which they are subject, the most impressive turbines arrive to ”sweep” the wind at an altitude of 120-150 meters, a height in which traditional wind towers have already exceeded their affordability limit. The increase in height, in fact, implies an exponential increase of the turbine masses and foundations in order to withstand the occasional extreme forces exerted by the wind on the structure during its life cycle, thus dispelling both in economic and in energy cost terms, the advantage in size.

The KiteGen® generators, designed to operate at high altitude with wings, and with Stem and Carousel equipment on the ground, may be subject to an increment in design dimensioning without any negative impact on the economy of the plants.

Scalability and territorial energy density are other relevant strengths of tropospheric wind energy (See Figure 2: Territorial Energy Density). The KiteGen® generators can collect energy from huge wind fronts in areas with few structural limitations. The project’s strategy is that flight control will be able to manoeuvre many wings contemporarily and, in the near future, the creation and management of proper wind farms constituted of many machines in foreseen.

Finally, tropospheric wind exploitation can count on a reservoir available on the majority of the planet surface, which is not limited by the topography of the area and which is, in fact, a source of energy available even in places usually unsuitable for wind turbines.

In order to qualify the availability and the production potential of the tropospheric wind resource, it is sufficient to consult the specific atlases produced by recent scientific papers[2]. As an example, let us consider a country not thoroughly endowed of the wind conditions usually required to allow traditional wind turbines reach their best performances: Italy. From the high altitude wind data instead, it can be inferred that Italy enjoys a promising position with regards to winds: in fact, Italy appreciates a flow of total power the order of magnitude of which is around 100 TW. Assuming we manage to extract a continuous minimum of 0.1 % (100 GW), the obtainable power corresponds to over 800 TWh per year, equivalent to a net production of endogenous wealth estimated at € 80 billion per year (a figure similar to the current Italian energy bill). The result is an unambiguous invitation towards conversion addressed to a society based largely on electrical power, with its relative virtuous industrial fallouts.

A few dozen large wind machines (KiteGen Carousel® or KiteGen Stem Farms®) distributed from North to South, would perform their task without intermittence problems and at a significantly lower cost than that of thermoelectric power, including electronuclear power programmes.

2. Scalability, mechanical principles of operation, maximum altitude

The technological reasons proving the thesis that the exploitation of tropospheric winds can meet the national energy needs and, subsequently, the world's, are linked to the easy scalability of the concept without the stringent requirements of machine over sizing.

• Scalability

In order to study in depth the prerogative of scalability, extending the assessments to other technologies, we will make a few comparisons between wind turbines and airfoil systems. The attempt to enlarge a wind turbine presents strict economic feasibility limits inflicted by the structure, summarized as follows: doubling the size of the wind tower would, on the one hand, cause the production of energy to quadruple but, on the other, it would also imply a 10-fold increase in terms of materials and costs, in order to withstand the load.

KiteGen Stem® follows a different law of scalability. In fact, by doubling the linear dimensions of its wing, the wing surface, the lift and the tension of the cables will increase by a factor of four (accordingly, to be four times more resistant, the cable will have a double diameter and a drag about 2 times higher).

Whenever the linear dimensions are doubled, without any pretence of precision, it ensues that the ratio efficiency/aerodynamics (lift to drag) is likely to increase by a factor of 2 (if the kite-ropes system has an aerodynamic efficiency of 5, by doubling its linear dimensions an aerodynamic efficiency of 10 would occur).

The doubling of the aerodynamic efficiency leads to a quadruple increase in productivity.

• Project Requirements

The structure of a wind turbine is designed to withstand extreme events based on a statistical evaluation of the maximum winds faced by structure during its lifecycle. The KiteGen® is designed, instead, to operate at its nominal power since, during extreme wind events, it can rely upon tuning or operational interruption strategies to ensure safety.

• High Altitudes

With regards to the possibility of reaching significantly high altitudes (in the order of kilometres), the calculation models developed by KiteGen® confirm the continuous increase in power in spite of the weight and aerodynamic drag of the ropes.

The maximum technically profitable achievable altitude is 9 km, due to the trade-off between air density and wind speed.

In tropospheric wind energy, the ability to vary the operational altitude, in order to better adapt to the needs of the network, provides the opportunity to modulate the supply, thus mitigating both intermittency problems and storage needs.

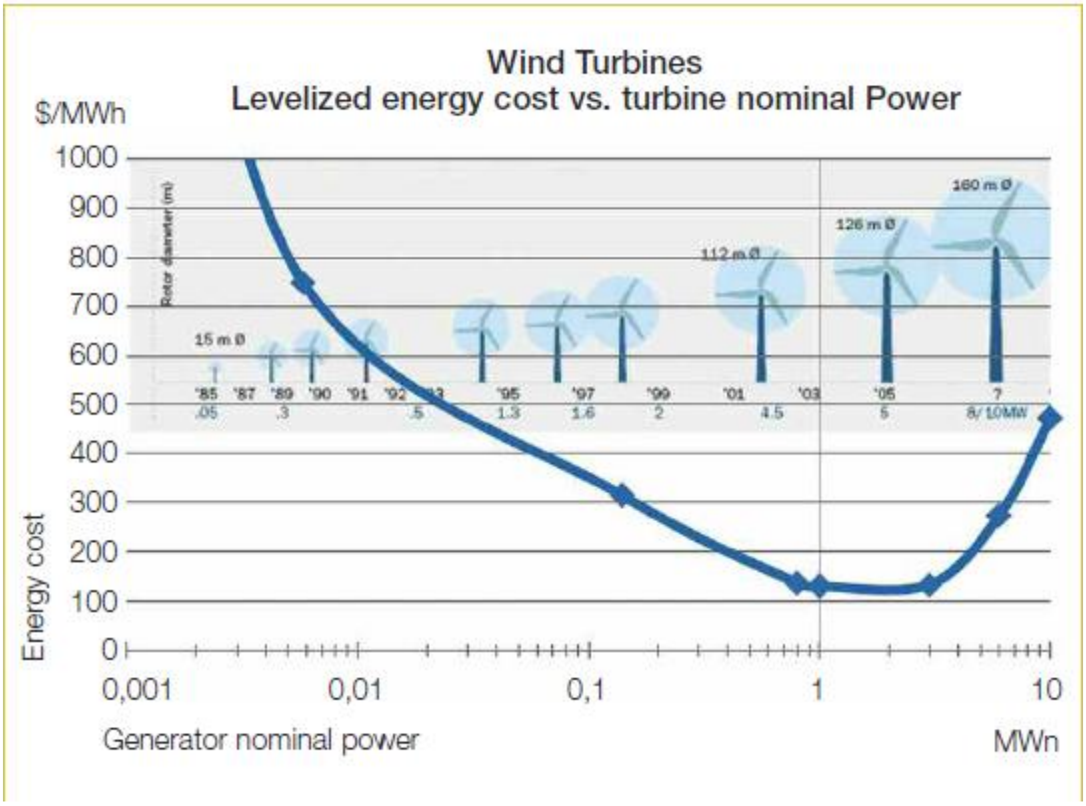


Figure 2: LEC and nominal power of traditional wind turbines
(Source: elaboration on data KiteGen Research, 2013)

3. Intermittency of Renewables

An excellent, as always, analysis by Domenico Coiante[3] evaluates renewable sources and establishes the need for both daily and seasonal accumulation.

The operation of the KiteGen® Stem, unlike the Carousel, introduces a minutes' pulse due to the yo-yo production cycle; this is solved by an accumulation through supercapacitors that ensures the quality of the supply.

The grid operators[4] are planning to introduce accumulation nodes by means of electrochemical batteries in specific network topologies, where it is feared that disturbances due to the massive input of energy in a non-programmable and intermittent form are more likely to occur, but the overall KiteGen® system offers a completely new solution to these problems. The novelty lies in the fact that it is the same steady state of high-altitude winds to create an accumulation, in fact, the energy in the stationary atmospheric motion is huge (about 250000TWh[1]) and continually renewed by the sun. Since this flow is never interrupted, but varies in intensity and latitude, the availability of a given power P is close to 100 %, if we consider two drawing points at suitable distances. This allows a choice between the configuration with a power generator of size P plus an adequately sized accumulator, and the configuration with two aptly spaced P sized high-altitude power generators. The choice of the configuration should be driven by purely economic criteria, considering on the one hand the costs of the storage system (under an LCA complete assessment), and on the other the costs sustained in order to double the generator and to modify the network constraints. One must also, however, consider the benefits of being able to have at one's disposal, and for a good part of the year, a power greater than P and, furthermore, the possibility to employ the excess power in interruptible energy-consuming processes such as seawater desalination, the production of hydrogen as a raw material for the chemical industry (fertilizers, fuels), the processing of ferrous and non-ferrous minerals, or for high temperature thermal storage.

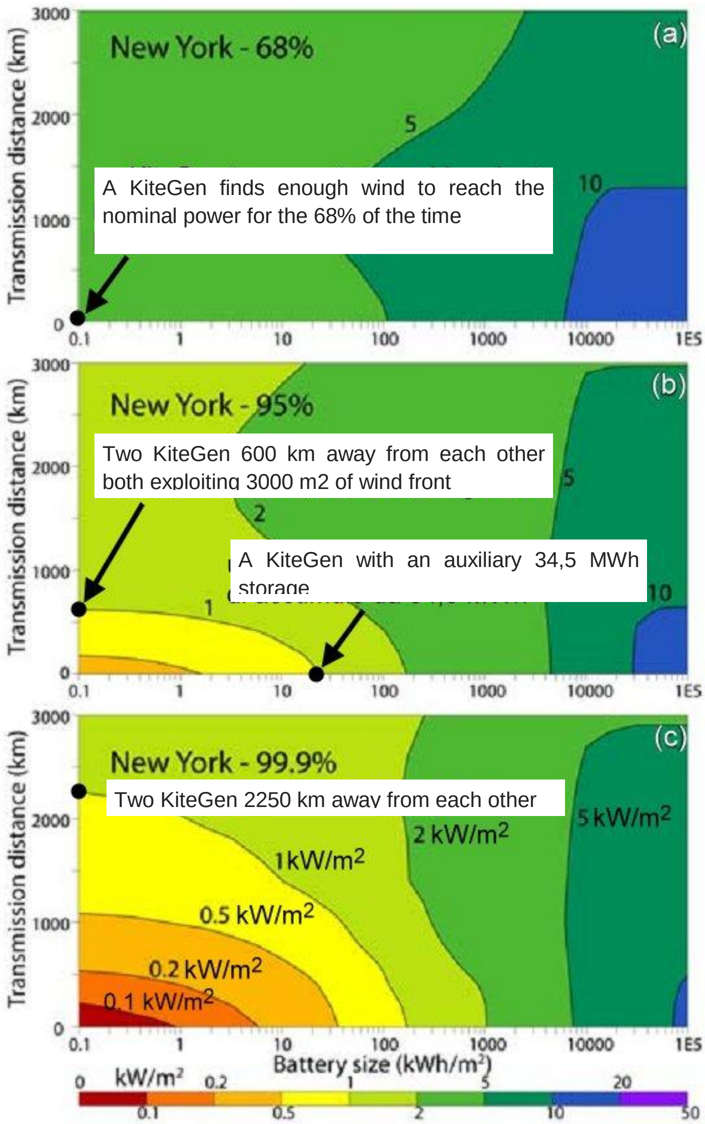
On a specific landsite (using an example given in the document mentioned under note [2], the New York area), the KiteGen® generator can reach and harvest energy from this flow, with the probability of finding it sufficiently powerful to produce energy at the nominal power for 68% of the time, an equivalent of about 6,000 hours a year (since the wind flow generally does not fade but will change latitude erratically and cyclically).

So what is the evidence that the graph expresses to indicate a 95% or even a 99.9% probability of availability of tropospheric wind?

The answer is relatively simple: the area in question requires at least two generators positioned at a sufficient distance to have at least one engaged by the wind flow.

The two generators would therefore have to be considered as a single system that will continuously produce a quantity of power at least equal to the contribution of only one of the two generators.

[1] The atmosphere's mass is about 5E+18 kg, the average wind (compensated for the mass) at an average altitude is about 20 m/s. The kinetic energy is therefore 1/2*400*5E+18=1E+21J=270.000 TWh



What can be deduced from these reflections?

1) The redundancy would occasionally cause an excessive potential production, but the KiteGen® systems are quickly and easily adaptable by means of a central coordination, and provide a precise adaptation to the demand curve. Therefore, in the absence of grid constraints, the operator would be free to define that, in presence of a certain P power request, the sum of the powers produced by the two generators be always equal to P.

2) Unlike wind turbines, the economic balance of this hypothetical double system will be able to take on the redundancy of the generators since it will be able to count on a 95% annual availability of the nominal power of a single generator and, additionally, on power unnecessary to the network but hypothetically usable externally at no further cost (e.g. with short lines dedicated to neighbouring industrial sites)

3) In the event of a sufficient spatial distribution of KiteGen Stem® or KiteGen Carousel® generators, these speculations would be overcome, as the redundancy effect would be inherently achieved.

4) The supply intermittency that plagues conventional wind and photovoltaic generators can be successfully overcome with tropospheric wind generators, as in such a scenario it would no longer be necessary to ascribe the baseload exclusivity to thermoelectric energy.
5) Considerations made with reference to the area of New York are valid for the majority of the world as well, since the orographic deceleration influence on winds fades with the altitude.

4. The KiteGen Stem® and KiteGen Carousel® Configurations

The KiteGen® system is based on the conversion of the kinetic energy of the wind into electrical energy by using a tropospheric alternator. For this purpose, Kite Gen Research has developed two different configurations: KiteGen Stem® and KiteGen Carousel®.

In conventional wind turbines, the part of the rotor that collects the greatest amount of energy is constituted by the ends of the blades (in red, in Figure 5), because they intercept a greater front wind in a more efficient way.

The essence of the KiteGen® concept is therefore not comparable to a wind tower. KiteGen®, in fact, employs only the truly necessary components: the ends of the blades and the generator, which is conveniently installed on the ground. The resulting structure, including the ground foundations, is much lighter.

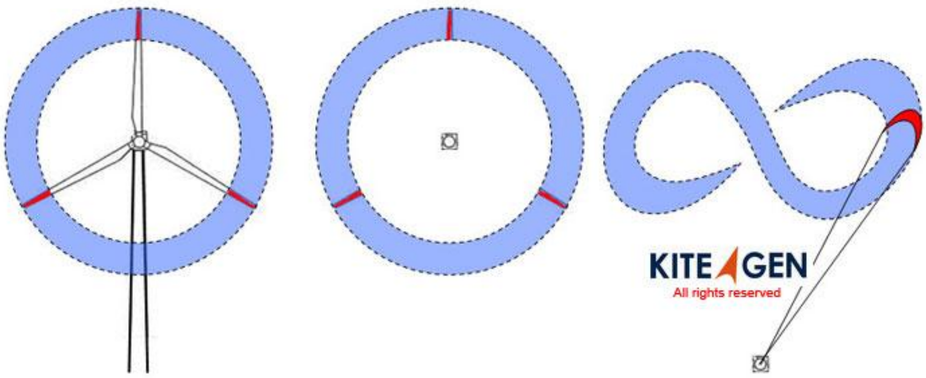


Figure 3: The KiteGen® Concept

The operational altitude and flight mode of the wings are also variable, depending on the existing wind conditions, in order to optimize in a continuous way the extraction of energy from the wind.

The control of the kite (or wing) is obtained mainly by differentially manoeuvring the cables that protrude from the two storage reels through the motor-alternators which control the pre-load pulleys.

An innovative software is the heart of the system which, without human intervention, and based on data received by the generator from a network of sensors positioned both on the edge of the wing and on the ground structure, acts on the relative length of the cables. In this manner, the flight trajectories can be controlled and usually directed towards the maximum production of energy, in accordance with the operating specifications of the machine.

KiteGen® is, from this point of view, a sophisticated application of mechatronics, made possible by the recent advances in the field of sensors and by the increased computation capabilities developed by computer systems.

KiteGen Stem®

This is a mono-wing generator with a nominal power of 3 MW; its diameter on the ground is equal to 12 meters, and its weight is 6 tons per nominal MW. Its production cycle can be broken down into two phases:

- The first stage of **generation**: the flight of the wing generates a lift (traction) on the cables that set off the rotation of the drums and alternators;
- Second phase of **recovery**: the wing is set in a position in which it loses lift ("side-slip" procedure); the alternators behave as engines which assist in and accelerate the rewinding sequence of the cables up to the altitude in which the asset of wing flight is restored and the generation cycle resumes.

The amount of energy consumed in the recovery phase is an infinitesimal fraction of that produced during the generation and it is spent largely in the strategic decision to speed up the recovery of the kite, profitably anticipating the production phase.

The kite, like the wing of an airplane, develops a lift (i.e. the component of the aerodynamic force in the direction of the cables) which, by means of special cables, origins the rotation of the drums around which the cables are bound. By means of an alternator, it transforms the mechanical energy of the wind into electricity.

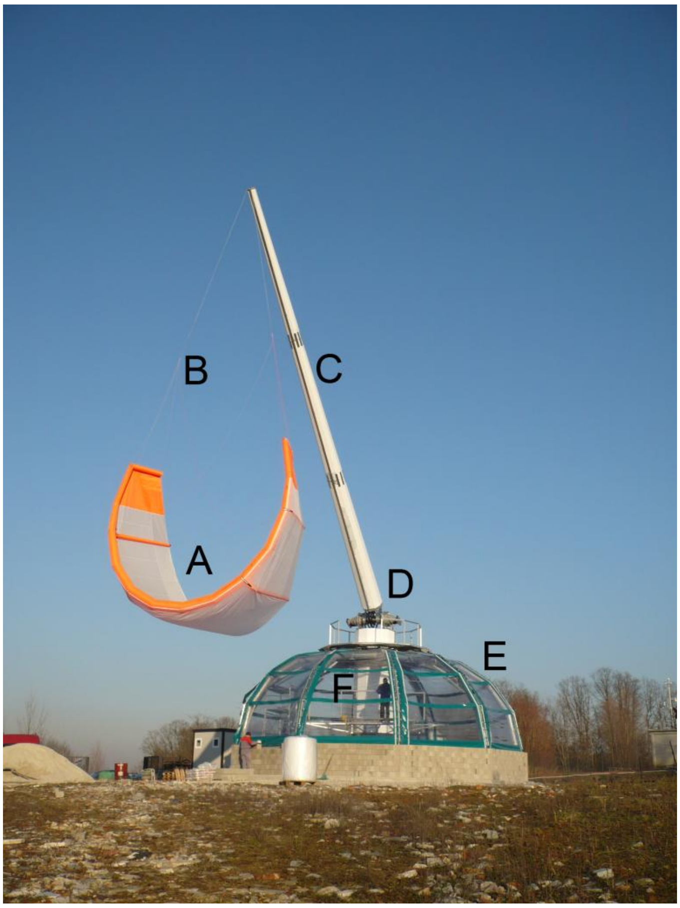


Figure 4: KiteGen® STEM Generator at Sommariva Perno (CN): A: Wing (Kite); B: Cables; C: Stem; D: Stem Lift and Rotation System; E: "Igloo"; F: Machine Room (Motor-Alternators, Drums, Electric Control).

The KiteGen Stem® generator is essentially a robot designed to control a tethered wing in order to maximize energy production and optimally manage the loads on the structure. The latter is formed by a base which has a shape similar to an “igloo” and the “Stem”, an “arm” of at least twenty meters from which the cables protrude. The structure has been designed to interact with the forces of the wind (natural and therefore unpredictable) through a network of sensors that detects in real time the shock loads and supplies the control system with the necessary information to act on the wing flight and on the position of the arm, in the case where the measured forces exceed the foreseen thresholds of security. The entire structure has been designed to withstand loads with an adequate safety factor.

The flight control sensors include two wing-mounted electronic systems (developed by the KiteGen® team), each of which includes radio transmitters, accelerometers, gyroscope, magnetometer, GPS, barometer, temperature and apparent wind speed detectors, all redundant and powered by a system that integrates micro-turbines and batteries. The circuit boards transmit information via radio to earth, communicating position, speed, direction, acceleration and other parameters. The control system is able to process this information and to make assumptions about the trajectories of the wing in the immediate future, choosing the optimal manoeuvres the results of which are, in turn, re-interpreted and used to improve the control model: a continuous self- learning loop that takes place dozens of times per second, aimed at adapting the machine to the characteristics of the site and to gain continuous and progressive performance improvements.

KiteGen Carousel®

Figure 5: KiteGen Carousel® Concept Drawing

This is a technological solution involving a ring path that puts in cooperation a number of KiteGen Stem® generators, therefore considered as a “single module” of the carousel configuration. In this configuration, the force transmitted by the cables is maintained constant, while the length of the same varies in order to control the wings and choose the ideal trajectory. The Kites pull the rotor structure, fitted with linear alternators, along a circular path placed at ground level, the diameter of which is of a few kilometres.

The software works on the differential of the length of the cables, ensuring that the flight paths of each wing is controlled, synchronized with the others, and functional towards the maximization of the production of energy.

While the wings flying at high altitude, the entire structure is hauled along a circular path, and energy is generated by the relative rotor-stator motion.

When fully operational, the flight of the entire set of wings is manoeuvred in such a way as to rotate the “Carousel” at the desired speed, allowing the operation of the alternators.

Figure 9 shows the front of the wind intercepted by a generator of the “Carousel” type with a diameter of 800 m; the same amount is reached with about 150 large wind towers. Note that the wind turbines need to be adequately spaced in order to avoid interfering with each other, with a consequent total yield decrease. They would therefore have to occupy a total ground area of over 40 km². In this specific case, the central KiteGen would occupy about 5 km², including a safety boundary area.

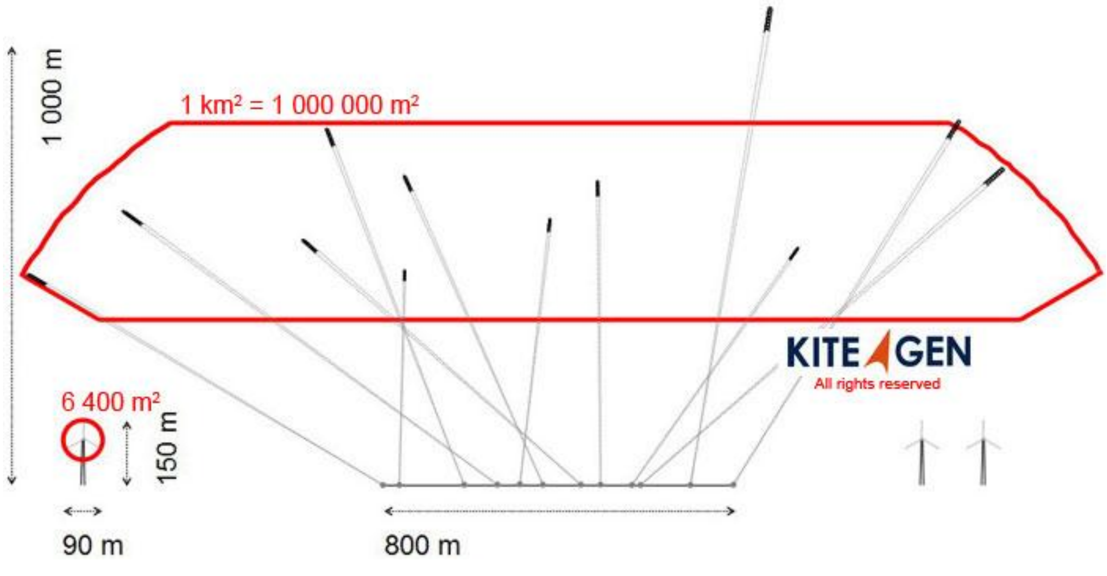


Figure 6: Space used by a 800m Diameter KiteGen® Carousel

The maximum reachable size of a Carousel is object of research, but it appears, from initial estimates, that it will be able to exceed 1,000 MW (1 GW) without significant structural risks, with a diameter of about 1,600 m.

Although not compatible with the current electrical system, the theoretical limits of this configuration are exceptional and can be imagined as a 25 km diameter ring, very similar to a railway viaduct, with wings that fly at an altitude of 10 km in a controlled formation, generating an output that exceeds 60 GW with a LEC estimated at less than 10 €/MWh.

As for the Stem, the Carousel layout is protected by international patents (granted) and its implementation will follow the industrialization of the of the single-wing type Stem generators, as it fully inherits its key technologies.

5. The Global Competitive Scenario

The number of organizations engaged in high-altitude wind energy projects, also as consequence of the KiteGen®'s dissemination activities, is undergoing a very strong increase.

To date, we can number over 45 universities and companies interested in high altitude wind energy exploitation. Many initiatives are clearly inspired by the concepts and contents of KiteGen®, and often denote an attempt to skirt them. In KiteGen®'s vision, this shows the absolute supremacy of the concepts discovered and formalized.

On the other hand, having priority over the most important concepts of high-altitude wind energy places a heavy responsibility on KiteGen because the patents have sterilized the investments of possible competitors, thus precluding the right of exploitation, as it is exclusively KiteGen's, and furthermore denied the world the main method to quickly find the solution to the global economic crisis.

Below is a brief overview of research projects with international relevance:

Delft University of Technology

The ASSET Institute of the Delft University of Technology, was the first partner of KiteGen in 2003 in the presentation of a European project to DG Energy. The original concept of Delft, named Laddermill, today has been set aside to follow the "pumping kite groundgen" KiteGen approach and now is working on a prototype with a kite of 25 m² and a 20 kW generator. The kite is connected to earth via a single cable and is controlled by a system of actuators positioned immediately below the kite.

NASA

In full agreement with what claimed by KiteGen Research, David North, NASA Team engineer, in an editorial[5] reported by phis.org, stated the following:

"Most turbine towers are approximately 80 to 100 meters high, which is 'pathetically low compared to the boundary layer of the Earth.' The boundary layer is where the friction from the Earth's surface maintains a relatively slow and turbulent wind. The weak point of wind power begins below 2000 feet (600 m). At that altitude, in order to use wind to produce energy, you would have to build a turbine tower higher than the Empire State Building. Or you could fly a kite."

The NASA Team, at the Langley Research Centre - Virginia, is experimenting on a high-altitude wind power pilot project and, from an extra- business point of view, is working to support the newly born field with a contribution focused on two aspects: autonomous flight control and aerodynamics. The NASA Centre is presently hosting a validation phase of the KiteGen® patents' technology: in particular of the double-cable control system and of the camcorder as an autopilot sensor device. The U.S. space agency has currently developed a 10 kW demonstrator which is sufficient to implement the logical and control validation. Other developments are intended for use in space: in particular on Mars, where there is a lot of wind6 and the energy supply through solar panels causes payload and productivity inefficiencies.

The following image is explanatory of the number and location of public and private organizations involved in the new sector.

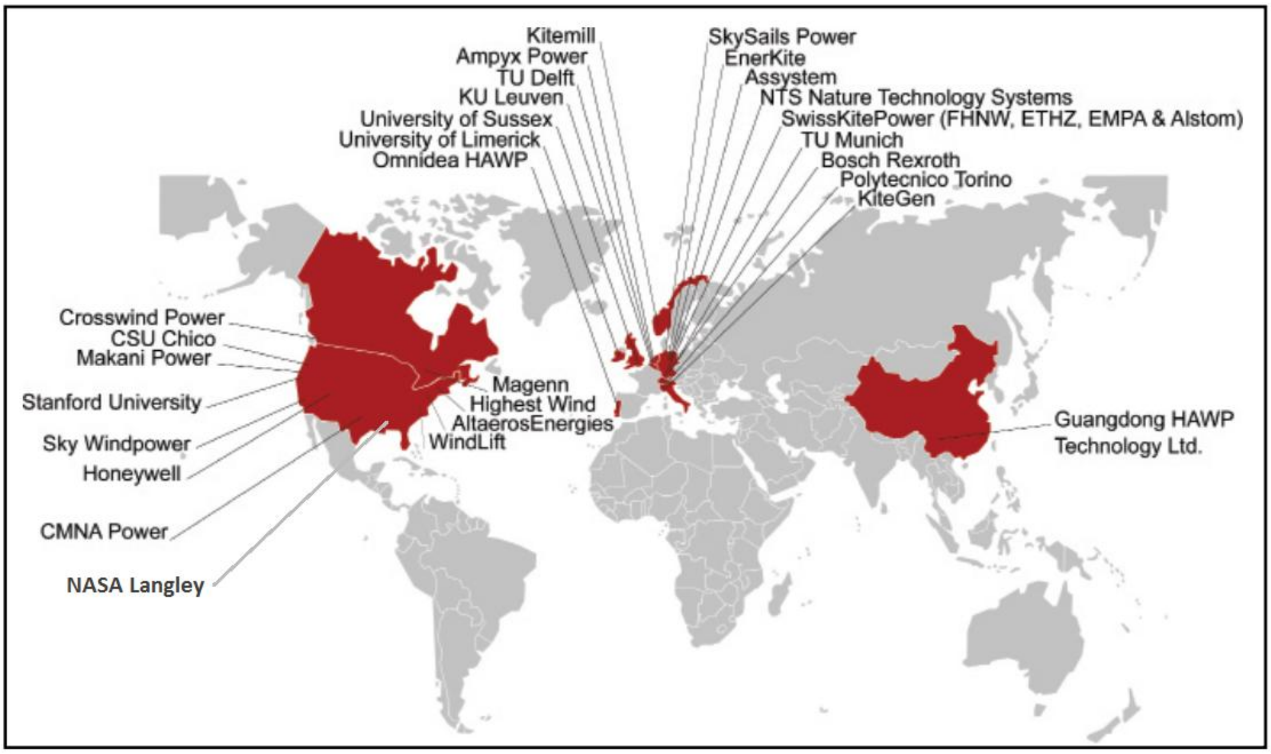


Figure 7: High Altitude Global Scenario of the wind sector. Reprocessing data to:
http://windsystemsmag.com/media/pdfs/Articles/2012_July/0712_Kite.pdf

6. Economic projections KiteGen FARM ® - LCOE (Levelized Cost of Energy)

If one considers the current economic situation and the situation of energy sources: oil becoming more and more expensive and with an adverse impact on the environment, coal being considered one of the sources with the highest negative impact on CO2 emissions, nuclear industry in great difficulty and renewable sources still limited by problems regarding economic sustainability and network dispatching, high-altitude wind power represents a great opportunity to overcome the severe combination of energy, environmental and economic crises.

Though KiteGen® is a “new” technology, having obtained confirmation of its ”grant” of the first patents only in 2009, it has already achieved and tested the production of energy through a small-scale prototype called KSU1 (100 kW range) and is completing a pre-series industrial 3 MW machine of the “Stem” type, including a control system capable of orchestrating a number of machines which can range from just a few to a few hundreds (each of which requires at most one hectare of dedicated space). It is, therefore, in such a stage of development as to be able to estimate the cost of production by making some assumptions on the process of technological evolution, which necessarily characterizes each technology in its initial phase (see Fig. 8).

A feature of great interest in the “ground-gen” concept is also given by the ability to maintain a high level of optimization of the fundamental segments of sails and cables, subject to a deterioration proportional to the energy production.

New, more efficient solutions may in fact be implemented from existing installations, without modifying the plant and during routine maintenance procedures, when the equipment’s periodic replacement of is due.

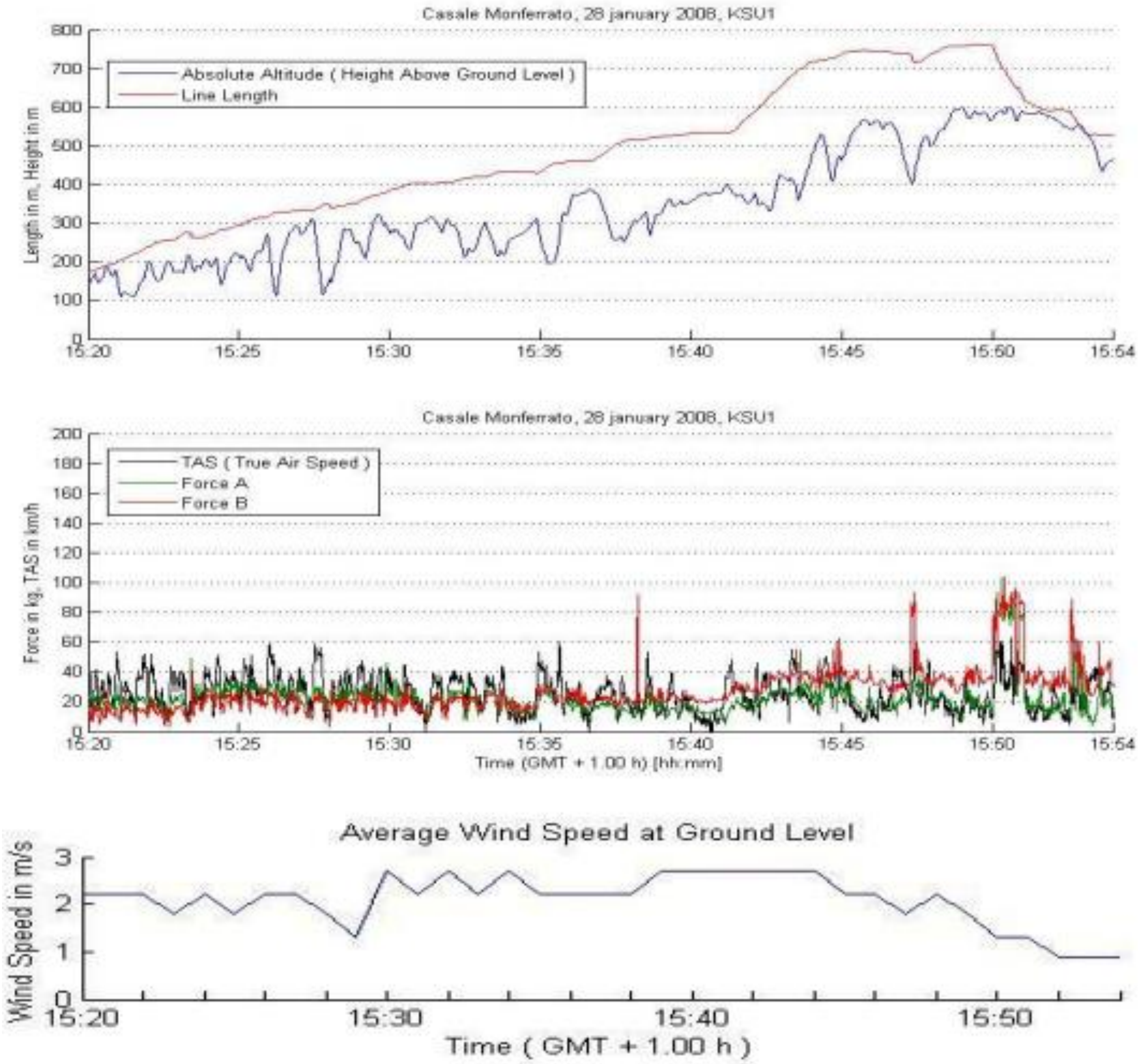


Figure 8: Findings from tests prototype KSU1 (Source KiteGen Research[7])

These aspects are of great importance for the analysis of the two economic items illustrated below, in the case of a 150 MW farm connected to the AT network through a single connection point:

1) Cost of production €/MWh (IEA methodology)
2) Levelized Cost Of Energy (LCOE) (NREL methodology)

The calculation of the **cost of production** for a 3 MW KiteGen Stem® generator was carried out according to the simplified IEA methodology (no fuel expense, cost of refurbishment at greenfield equal to the value of the salvaged dismantled plant components) based on the following facts, compatible with the Italian reality:

- The industrial cost of the Stem (3 MW) installation on the basis of scale economies due to the cumulative number of installed machines and the learning curve: from € 10 million to € 1.65 million
- Ground diameter of each machine: 12 m
- Nominal power of the farm: 150 MW
- Number of machines (KiteGen Stem®) per FARM (150 MW): 50
- Annual average productivity assumption for the first version of the system MWh/MW: 600
- Optimized annual average productivity assumption MWh/MW: 3400
- Annual O&M Cost: 5% for the first 5 years, then 4%
- Cost of replacement of consumable parts (cables, sails): from 2 to 1.8 €/MWh
- Insurance costs: 3%
- Interest rate: 6%
- Level of taxation: 40%
- Installation site with average winds of 8 m/s at an operational altitude (see CESI Research now RSE[8]).

Below we illustrate a few considerations that led to the choice of parameters for this scenario.

The research and development phase on the KiteGen® concept is complete and only a few problems of mere engineering nature, concerning optimization and debugging, still need to be addressed which, with the resources already available on the project, will soon be solved.

At the state of the art, the system can be divided into: area of components which do not require innovation but only development, engineering and scale economics, and the area of components which present innovative elements. Within the first group we can mention:

- The sensors and electronics with a very large integration scale, essential for the accurate testing of flight conditions, have already been developed and miniaturized in light circuit boards, which are suitable to be carried in flight. They will have to be mass produced, ensuing economic advantages and enhanced reliability.
- The first version of the machine control and sail piloting software is already available and has been tested both on the field, using the reduced scale prototype up to an altitude of 800 m a.g.l., and on a MW (Stem) or GW (Carousel) class scale using fluid dynamic simulators. However, like all software, it will benefit from the steady increase in computing performances and the simultaneous reduction of prices that has been affecting the hardware industry for decades making available, in the short-term, more powerful fluid dynamic engines and more sophisticated control algorithms, which can strongly contribute to the optimization of the performance of energy production.
- The electrical and mechanical components are largely available on the market or from specialized suppliers able to realize them according to CAD drawings. The technological complexity of the KiteGen® Stem, from the point of view of these components, is typical of industrial robotics. Possible optimizations concern further cost reductions.

The second area of "innovations" includes:

- Specific high-efficiency and low-weight wings, able to withstand loads in the order of about one hundred kN. The possible choices concerning the geometry and the composite materials for these components have generated an elaborate decision matrix that, due to the lack of available and documented experience, will inevitably have to be revised and extended several times in order to achieve increasingly high performances.

- Special high-productivity pulleys, capable of transmitting the greatest possible fraction of mechanical energy to the alternators avoiding frictions and dispersions, which are unacceptable from an energetic point of view and for the high temperatures reached by the cables. The design of such devices allows to "guide" the cables, avoiding the chafing caused by the load difference between the entry and exit points of the cable. A normal pulley would dissipate 5% of the energy; the goal of the new project is 1%. The maximum power that can be dissipated by the pulleys determines the maximum power manageable by the machine. Halving the friction, at an equal dissipation percentage, will allow the management of twice the power, with major productivity benefits.

A few favourable side-effects were also considered that contributed to the choice of the scenario parameters, concerning in particular the estimate of the operation and maintenance costs, and the ease of finding sites with the desired anemological features:

- Materials in special polymers (carbon fibers, glass, Dyneema® and Vectran®) are available on the market and in constant evolution. These give the cables a resistance higher than steel, with a much lower weight, and allow the sails to offer performances and guarantee a reliability typical of wings, but without the constraints of stiffness and weightiness.
- Sites with average wind speeds compatible with a power generation in the order of MW even at lower altitudes are widespread from tropical to northern latitudes as, per Italy, the CESI Research (now RSE[2]) study confirms. Therefore, in sites with good features, even a system with an annual average wind availability of less than 50% could easily operate for the number of hours set as the target of the early technological learning plan equivalent to 3400.

We therefore deem possible a scenario of accelerated technological learning on the basis of the following considerations:

- A programme of technological learning aimed at improving the performance of the sails and cables can gradually reduce their production costs and improve their availability and reliability, making them more competitive on the electricity markets even in the absence of public grants.
- If the learning process is considered according to Pareto's principle, the greatest improvement would occur in the early years of development; therefore, the rapid achievement of 50% of the theoretical maximum expected performance is not to be considered ambitious. A second slower learning phase will lead to the maturity of the product and to its best performances

Table A shows the analysis of the costs of MWh according to the main drivers upon which the technological learning will proceed: scale economies, increased performance in terms of annual production (GWh/MW) and maintenance/replacement cost reduction of the main technological components of the system (cables, wings, servo driver, electronics, software, mechanics, sensors). The analysis reveals that if a first immature version of the system, with a limited number of machines, were to fly on average only one day a week, staying in upkeep for the rest of the time, can already sustain itself economically thanks to forms of incentive such as: green certificates, feed-in rates or exchange carbon credits. This sustainability is also clear if seen as an annual productivity derived by primary energy saving, calculated using the thermoelectric coefficient of 1,800 thermal kcal per electric kWh. The last column shows the performances envisaged upon the reaching of the KiteGen Stem technology maturity.

[2] See Note 12

Number of 3 MW Cumulative Installations	1	2	5	20	200	2000	20000	200000	2000000
Industrial plant cost 3MW €	10,000,000	7,500,000	2,857,143	1,650,000	1,650,000	1,650,000	1,650,000	1,650,000	1,650,000
Annual Production in MWh/MW	600	1,000	1,400	1,800	2,200	2,600	3,000	3,400	6,800
Annual productivity in terms of primary energy savings Wh/MW	1,258	2,096	2,935	3,774	4,612	5,451	6,289	7,128	13,627
% of Interest Rate	6%	6%	6%	6%	6%	6%	6%	6%	6%
Number of years amortization period	25	25	25	25	25	25	25	25	25
Tax %	40%	40%	40%	40%	40%	40%	40%	40%	40%
% Depreciation of plant cost	30%	40%	50%	60%	70%	80%	90%	90%	90%
Number of years depreciation duration	9	9	9	9	9	9	9	9	9
% Annuity plant depreciation factor cost	15%	14%	13%	12%	11%	10%	10%	10%	10%
% Annual insurance fixed plant cost	3%	3%	3%	3%	3%	3%	3%	3%	3%
% Cost of plant operation and maintenance	5%	5%	5%	5%	5%	4%	4%	4%	4%
€/MWh spare parts variable cost	2,00	2,00	1,90	1,90	1,80	1,80	1,8	1,8	1,8
Annuity quota (% annual rate of plant cost)	7.82%	7.82%	7.82%	7.82%	7.82%	7.82%	7.82%	7.82%	7.82%
Depreciation quota	0.23%	0.25%	0.26%	0.27%	0.28%	0.29%	0.30%	0.33%	0.33%
Cost €/MWh (IEA Methodology)	**1169.10**	**527.13**	**144.78**	**66.07**	**54.30**	**44.11**	**38.46**	**34.14**	**17.97**

Table A. Production cost analysis on the basis of assumptions made and the learning curve (IEA Methodology 1991[9]).

A different point of view of this issue is given by the calculation of the **Levelized Cost of Energy (LCOE)** that does not consider levies and was carried out according to the simplified NREL methodology (no charge for fuel) based on assumptions compatible with the international situation, in which the operator can select the sources of funding and the most favourable fiscal areas.

Cumulative installations	1	2	5	20	200	2000	20000	200000	2000000
- Industrial plant cost €/MW	3,300,000	2,500,000	952,381	550,000	550,000	550,000	550,000	550,000	550,000
- Annual production in MWh/MW	600	1,000	1,400	1,800	2,200	2,600	3,000	3,400	6,800
- Annual productivity in terms of primary saved energy MWh/MW	1,258	2,096	2,935	3,774	4,612	5,451	6,289	7,128	13,627
- Interest rate	5%	5%	5%	5%	5%	5%	5%	5%	5%
- Duration of amortization in years	25	25	25	25	25	25	25	25	25
- Cost of operation, maintenance, Investment insurance in %	7%	7%	7%	7%	7%	7%	7%	7%	7%
- Variable spare parts cost €/MWh	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
- Annuity quota (annual rate plant cost in %)	7.10%	7.10%	7.10%	7.10%	7.10%	7.10%	7.10%	7.10%	7.10%
LEC €/MWh (NREL methodology)	**777.24**	**354.38**	**97.89**	**45.07**	**37.24**	**31.82**	**27.84**	**24.80**	**13.40**

Table B. LCOE analysis on the basis of assumptions made and the technology learning curve (NREL Methodology[10]).

This analysis was at the basis of a proposal for the use of the European decarbonisation funds recently granted to the Italian institutions, which suggested that the current grants to intensively energy-consuming production facilities could be replaced by initiatives for the development of KiteGen Farms®, dedicated to the self-production of electricity.

The analysis states that if, in the scenario of technological learning previously detailed in Table A, instead of subsidizing energy-productions with a simple discount on the bill, which requires programming (and defending at a European level) new subsidies at the end of each incentive period, the European funds had been used for the development and optimization of high-altitude wind power technology, the cost per MWh could progressively and permanently be defined, without further need for subsidies, at levels considered acceptable by the large, energy-consuming, multinational metallurgical companies. These values are well below those of the market and are around 25€/MWh.

Cost is, therefore, one of the elements that contribute in making the KiteGen® a technology of maximum interest, even in the short- and medium-term energy scenarios. We believe that the analysis illustrated above, regarding the dispatching issues of the energy produced by KiteGen®, highlight that the development of KiteGen® installations present problems which are much more manageable than those that would be expected in a scenario of photovoltaic and wind penetration, in percentages which are critical for the management of the network itself.

Another strategic aspect is the large distribution throughout the planet of areas crossed by high-altitude winds with the appropriate production characteristics, which are also widespread in Italy, as shown in the aforementioned study. Aside from the obvious advantage of having an abundant domestic source of energy available on almost all the national territory, there is also the possibility of using areas of low landscape value. A further benefit is the near freedom to place the production plants in such a manner as to weigh as little as possible on the transfer restrictions existent between the various electrical regions

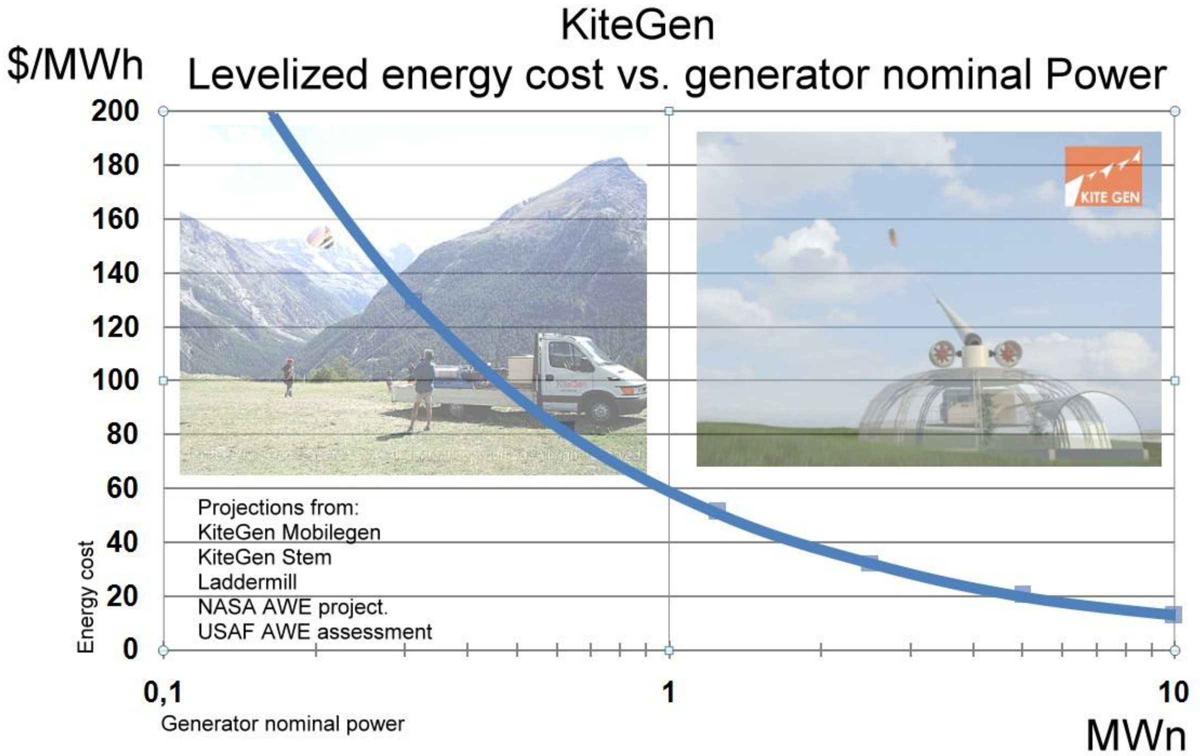


Figure 9: MWh Cost and nominal power of the generator
(source: data elaboration[11] Kite Gen Research 2013)

7. Concluding remarks

High-altitude, or tropospheric, wind is increasingly being recognized and correctly classified. The data on this natural resource are indisputable, we are faced with the most noble, abundant and available resource that our planet has donated to us. In the troposphere, the largest energy source ever discovered flows incessantly; furthermore, it is also renewable and can be easily converted from kinetic energy of air masses into usable and marketable energy.

If adequately exploited, it would be a source of endogenous wealth and would originate a new economic paradigm available to the entire planet, with potential repercussions able to restore the freedom of self-determination, otherwise compromised, of economies in crisis and of the future generations. This is due to a predictably very low LEC reachable at the end of the learning curve.

A technological risk analysis allows to state that this source doubtlessly exists and is easily accessible by a specific technology. KiteGen® has proven since 2006 that the technology is easy to implement even on an artisanal level and with personal investments, obviously very limited when compared to the importance of the topic.

KiteGen® has thereafter almost autonomously completed the research on the concept and the protection of the intellectual property and has started the production on an industrial scale, initially continuing to rely on a support based on the participation to public tenders focused on renewable energy and technological innovation. Due to the particular Italian situation, the total grant of 78 million Euros, conquered and assigned for a number of specific tenders, has never been granted.

KiteGen® has finally chosen to proffer the technology to the market by obtaining from the Saudi Arabian Basic Industries Corporation (SABIC) a suitable agreement for the development and deployment of the technology, regulated by territorial exclusivity and a strict growth programme.

8. Bibliography and Web Resources

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[1] Nature Climate Change, September 2012 . http://www.nature.com/nclimate/journal/vaop/ncurrent/full/nclimate1683.html

[2] Archer C.L., Caldeira K.: Global Assessment of High-Altitude Wind Power. Energies, Vol. 2, n 2, 2009, p. 307-319: http://www.mdpi.com/1996-1073/2/2/307

[3] Coiante D.: Energie rinnovabili. Salvare l'ambiente accumulando energia. www.imille.org. 2012. http://www.imille.org/2012/06/energie-rinnovabilisalvarelambiente-accumulando-energia/

[4] See http://appalti.dgmarket.com/tenders/np-notice.do?noticeId=10097061).

[5] Silberg R.: Electricity in the air. Pphys.org, Jul 03, 2012. http://phys.org/news/2012-07-electricityair.html

[6] http://www.lpi.usra.edu/publications/slidesets/winds/

[7] See http://www.inrim.it/events/lib/Maneia_2009.pdf

[8] CESI Research – Evaluation of the Kite Wind Generator Systems: http://kitegen.com/pdf/P%2021%202012%2020CESI%20RICERCA%20Valutazioni%20sui%20sistemi%20Kite%20Wind%20Generator%20-%202009.pdf

[9] IEA 1991: Guidelines for the economic analisys of Renewable Energy Applications. OECD/IEA, Paris.

[10] LCOE Analysis NREL: http://www.nrel.gov/analysis/tech_lcoe_documentation.html

[11] Elaboration of the authors on energy cost projections available at:Kitegen (http://kitegen.com), Laddermill (http://en.wikipedia.org/wiki/Laddermill), NASA AWE Project (http://climate.nasa.gov/energy_innovations/727) and USAFAWE assessment (http://www.afit.edu/EN/docs/ANT/11%20Theses/ThesisCahoon.pdf?PA=88ABW-2011-1636_14Jan13)