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**AN ENQUIRY INTO THE PHILOSOPHY OF LIGHT-
ENERGY: NIGERIA AS A CASE STUDY**

By

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Abstract

Preview measurements of the inflow by turbine-mounted lidar systems can be used to optimize wind turbine performance by increasing power production and alleviating structural loads¹ Light Detection and Ranging devices (LIDAR) allow preview information about the approaching wind to be used to improve wind turbine control thereby optimizing operational performance of the wind turbine and hence effect increase in energy yield. We employed in this research a theoretical based method to obtain simulation results from lidar scan patterns which indicate a lot of prospects of lidar laser scanners operating in the region of pico and femto seconds regime. This makes the wind energy option in Africa as a whole and Nigeria in particular a welcomed development in renewable energy discussions and the country's energy mix. Again, a generalized philosophy of energy will consider the following aspects: the inquiry into the natural phenomenon of energy; the critique of the functioning of energy in society; and the philosophy of technology within the contexts of energy transitions.

Keywords: wind energy, Lidar-assisted control, wind turbine optimization, remote sensing, preview wind measurements, lidar scan patterns.

Introduction:

There has been a steady rise in energy production worldwide since 2004, with substantial actively installed capacity in Africa.

In fact, it was noted that wind energy is the “fastest growing installed alternative-energy production”, with at least 20% of United States energy expected to be supplied by offshore and onshore wind farms by 2030² The problem that light detecting and ranging devices hope to address in the design-models and in systems that has begun to implement its feedforward system is that in such systems, information concerning the behavior of an approaching wind is provided ahead of time by a fast-scanning laser. This remote sensor device enables an automatic shift in the direction of the turbine blades to effect minimum impact and maximum energy generation respectively.

The erratic behaviour of the approaching wind in front of the turbine and the feedback method of collecting data for optimization by the traditional models has its attendant problems. The primary challenge that the feedback system presents is that the damage done to the turbine by the wind would have been completed before the signal information is received, processed and acted upon by the system units (a sort of crying when the head is already off!). This looks like a damage control mechanism that will not help technological advancements in wind energy generation and design improvements. Thus, as Eric Smiley, Holger Fürst, Florian Haizmann and David Schlipf, in the article “Optimizing Lidars for Wind Turbine Control Applications—Results from the IEA Wind Task 32 Workshop” *Remote Sens.* **2018**, *10*, 863 noted clearly, this approach has proved to be ineffective in addressing the problem of control and design in the wind energy development³

From the foregoing discussions therefore, this thesis set out to contribute to the discussions on lidar systems as a remote sensor and feedforward mechanism in wind turbines designs. Our main approach was to simulate the factors that will provide a prospect for increasing the present nanosecond lidar scanners to those of pico and femto seconds regime. We further established, the correlation between wind turbines and lidar systems hence providing invaluable insights into overcoming the barriers

preventing the widespread use of Lidars for wind turbine control strategies, and maximizing the effectiveness of Lidars for control applications.

From a theoretical perspective, the optimization of lidar scan patterns by minimizing the error between the measurements and the rotor effective wind speed of interest is discussed. Frequency domain methods for directly calculating measurement error using a stochastic wind field model are reviewed and applied to the optimization of several continuous wave and pulsed Doppler lidar scan patterns based on commercially-available systems. An overview of the design process for a lidar-assisted pitch controller for rotor speed regulation highlights design choices that can impact the usefulness of lidar measurements beyond scan pattern optimization. Finally, using measurements from an optimized scan pattern, it is shown that the rotor speed regulation achieved after optimizing the lidar-assisted control scenario via time domain simulations matches the performance predicted by the theoretical frequency domain model.

The significance of this research follows the main purpose of the International Energy Agency (IEA) wind task workshop-32 that was held in Boston, MA, USA in July 2016. This agrees completely with the analysis of Eric Smiley et al cited above who argued that: The workshop, ‘optimizing Lidar designs for wind energy applications’ was held to identify Lidar system properties that are desirable for wind turbine control applications and help foster the widespread application of Lidar-assisted control (LAC).

PULSED LASERS IN LIDAR APPLICATIONS:

By way of a simplified definition of terms, elementary physics defines wind as the flow of atmospheric gases on a very large scale. Wind flow are generally caused by uneven heating of the atmosphere by the sun, the irregularities of the earth’s surface, and the rotation of the earth. However, wind flow patterns are modified by the earth’s terrain features, bodies of water, and

surrounding vegetation.

A wind turbine is used to harness the kinetic energy of the vast amounts of wind, and transform it into electricity. This can be expressed in a physical equation as seen by the equation [1] below. First, we need to recall that wind is an air mass moving from an area of high pressure to an area of low pressure. This movement of air implies a kinetic form of energy which for a given air of mass m , moving at a velocity v , can be expressed as:

$$(1). \quad E_k = \frac{1}{2} mv^2$$

Considering a certain cross-sectional area, A , through which the air passes at velocity v , the volume V , flowing in a certain time unit t , the so-called volume flow, is given by:

$$\begin{aligned} \frac{dv}{dt} &= v \frac{dA}{dt} & (2) \text{ And the mass flow with air density } \rho \text{ is} \\ m' &= \rho vA & (3) \end{aligned}$$

This mass flow can now be substituted into the formula for kinetic energy of the moving air to give the amount of energy passing through the cross-sectional area A , per unit time. This energy is physically identical to the power P expressed as:

$$P = \frac{1}{2} \rho v^3 A \quad (4)$$

Therefore, the amount of energy in the wind is controlled by the density, surface area and velocity of the moving air. The equation [4] above shows that identifying an area of high wind velocity is the most crucial part of picking out an area to situate a wind turbine in a wind farm.

In reality however, the equation for kinetic energy of wind does not represent the amount of energy that a wind turbine is able to harness. Wind turbines like other physical machines are not 100% efficient; and are unable to convert all of the kinetic energy into wind. If a wind turbine was 100% efficient, then wind speeds would drop to 0 km/h after passing through the turbine.

The German scientist, Albert Betz, published a work in 1926 that showed that it is only possible to extract 16/27 or 59% of the energy from an approaching wind by the wind turbine. This is called Betz's law⁴ Therefore, the theoretical energy model for a wind turbine is given by the expression:

$$P = \frac{16}{27} - \frac{1}{2} \rho v^3 A \quad (5)$$

The lidar operation is based on the scientific theory of fluid mechanics and some elements of aerodynamics. Modern wind turbines catch the wind by turning them into or away from air flows. Wind moves the propeller mounted on a rotor and the movement turns a high-speed shaft coupled to an electric or induction generator.

The majority of wind turbines consist of three blades mounted to a tower made from tubular steel. There are less common varieties with two blades, or with concrete or steel lattice towers. At 100ft or more above the ground, the tower allows the turbine to take advantage of faster speeds found at higher altitudes.

Wind Modelling:

Wind can be mathematically described by a set of three-dimensional wind speed vectors at each point in time and space. For aero-elastic simulations, the wind speed vectors are usually only generated at the rotor plane to calculate the aerodynamic forces and moments. Thus, understanding the nature of a wind field over the full space in front of the turbine is necessary to simulate lidar systems, (see figure 1).

The inertial coordinate systems were used in this thesis to describe the wind models for the lidar simulations and a reduced model for wind field reconstruction.

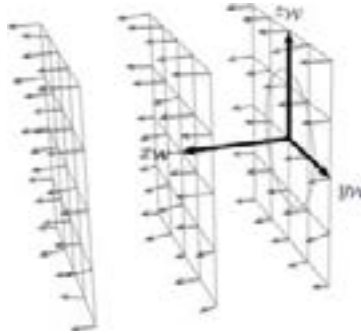


Figure 1: Snapshot of the time variant vector field as a general description of wind.

Wind and Inertial Coordinate System

The wind coordinate system is denoted in this work by the subscript W . It is used to describe the wind flow and is aligned

with the mean wind direction regarding the inertial coordinate system, which is denoted here by the subscript I . The direction is defined by the horizontal inflow angle α_h (azimuth or rotation around the z_I -axis) and the vertical inflow angle α_v (elevation or rotation around the rotated y_I -axis), (see figure 2). Although all six DOFs could be used in principle, a rotation of around the x_I is not considered in this work but might be useful for very complex terrain.

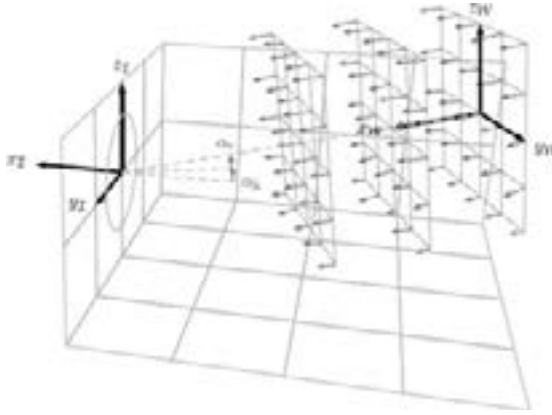


Figure 2: Orientation of the wind coordinate system (subscript W) in the inertial coordinate system (subscript I). Rotation order is defined as azimuth $\rightarrow$ elevation ($\alpha_h \rightarrow \alpha_v$).

LIDAR and Lidar Modelling systems

Generally, Lidar (Light Detection and Ranging) is a remote sensing technology similar to radar (Radio Detection and Ranging) or sonar (SOUND Navigation And Ranging). In the case of lidar, a light pulse is emitted into the atmosphere. Light from the beam is scattered in all directions from molecules and particulates in the atmosphere. A portion of the light is scattered back towards the lidar system. This light is collected by a telescope and focused upon a photo-detector that measures the amount of backscattered light as a function of distance. The lidar system uses light in the form of a pulsed laser for powerful

data collection that provides 3-D information for an area of interest. Among many things, it is useful for such tasks as surface mapping, vegetation mapping, transportation, corridor mapping, transmission route mapping, and 3-D building mapping.

According to Arthur Cracknell, over the last decades, lidar has largely contributed to our knowledge of our atmosphere. The interactions of the emitted light with the molecules and aerosols allow the observation of atmospheric parameters such as temperature, pressure, wind, humidity, and concentration of gases (ozone, methane, nitrous oxide, etc.)⁵. Lidar originated in the early 1960's, shortly after the invention of the laser. Its first applications came in meteorology where it was used to measure clouds⁶. Since then, lidar has been used not only in meteorology, but also in a wide range of other applications, such as laser range finders, altimeters, and satellite trackers.⁷ The essential concept of lidar was originated by E. H. Synge in 1930, who envisaged the use of powerful search lights to probe the atmosphere. Indeed, lidar has since been used extensively for atmospheric research and meteorology. Lidar instruments fitted to aircraft and satellites carry out surveying and mapping – a recent example being the U.S. Geological Survey Experimental Advance Airborne Research Lidar. NASA has identified lidar as a key technology for enabling autonomous precision safe landing of future robotic and crewed lunar-landing vehicles.

Lidar Operating Principle

The operating principle of lidar is based on the assumption that wind speed has the same value as the small particles in the air, called aerosols. Pollen, droplets, smoke, and particles of dust form these particles. Lidar technology relies on detecting backscattered light from moving aerosols in the atmosphere, when illuminated by laser radiation with coherent detection (best for measuring Doppler shifts, or changes

in phase of the reflected light). Coherent systems generally use optical heterodyne detection⁸. This is more sensitive than

direct detection and allows them to operate at much lower power, but requires more complex trans-receivers. By measuring the Doppler frequency shift of the backscattered light, the wind speed can be determined remotely. The basic concept can be illustrated as in figure 3.

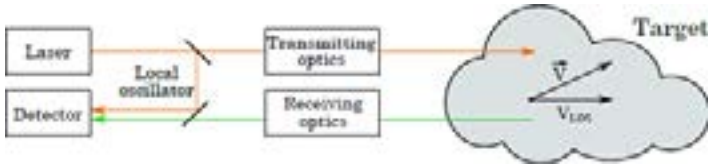


Figure 3: Generic Doppler lidar concept where $\mathbf{V}$ is the mean velocity of the target, and V_{los} is projected radial wind speed.

Lidar Equation

In the simplest form, the detected lidar signal can be written as

$$P(r) = KG(r)\beta(r)T(r) \quad (6)$$

where P is the power received from a distance r , K summarizes the performance of the lidar system and is called the lidar system constant, $G(r)$ describes the range- dependent measurement geometry. The term $\beta(r)$ is the back scattered coefficient at distance r . It stands for the ability of the atmosphere to scatter light back into the direction from which it comes. $T(r)$ is the transmission term and describes how much light gets lost on the way from the lidar to the distance r and back.

RESULTS FROM SIMULATIONS

Lidar Measurement Coherence

The quality of a wind speed measurement as influenced by evolution can be judged by the coherence between the estimate of the u component of the line-of-sight lidar system measurement

and the true u component that reaches the rotor plane. Referring to figure 4, the up-wind point at which the lidar is focused is called point j , while the point where the evolved wind meets the rotor plane is called point i . Points i and j have the same transverse coordinates in the yz plane but are separated longitudinally by the preview distance D .

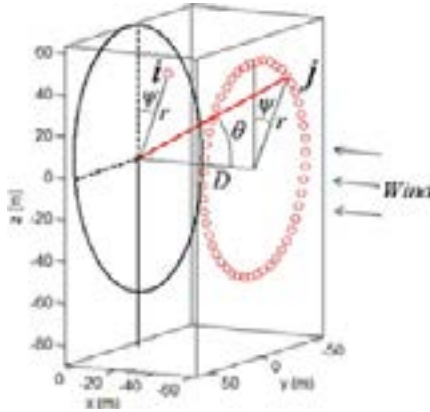


Figure 4: Coordinate system and measurement variables used. The lidar is assumed to be mounted in the wind hub at $(x_h, y_h, z_h) = (0, 0, 0)$.

Components of Measurement Coherence

There are several factors that may cause a decrease in measurement coherence. In addition to wind evolution, error sources that are characteristics of lidar measurements in non-evolving wind fields, such as range weighting and directional bias, will cause a loss of coherence. Figures 5 and 6 compare the components of coherence for three different measurement geometries by showing the measurement coherence that was calculated using the appropriate physical equations with various combination of the error sources included. Figure 5 uses the spectral properties of the TurbSim wind field with exponential wind evolution, while figure 6 uses characteristics of the large eddy simulation (LES) wind field. The decay parameter used with the exponential model is $\alpha = 0.45$. Coherence plots for both wind fields are provided to compare and contrast the simple wind evolution model and the model that is derived from the

LES results. In both figures, each scenario involves a lidar that is located at the hub, measuring wind at a radial distance of $r = 47.25\text{m}$ at an azimuth angle of $\psi = 90^\circ$, but with different preview distances ($D = 24, 58$, and 130m). The curves in figure 5 and 6 do not include the effects of uv or uw correlation in order to highlight the other sources of coherence loss. Although the exact measurement curves differ for the two wind field models, the following trends apply to both scenarios.

When $D = 24\text{m}$, the measurement angle is large, longitudinal coherence (dashed) is relatively high, and the effects of range weighting are insignificant due to the short focal distance. Here, directional bias dominates the overall coherence, with wind evolution causing some degradation at higher frequencies.

When $D = 130\text{m}$, the measurement angle is low, longitudinal coherence is low, due to wind evolution, and range weighting is significant due to the long focal distance. Wind evolution, is the dominant component of measurement coherence, with range weighting adding a further loss of coherence.

For the $D = 58\text{m}$ scenario, all three sources of coherence loss are significant. Directional bias and wind evolution, both have very strong impacts, with range weighting causing an additional loss of coherence.

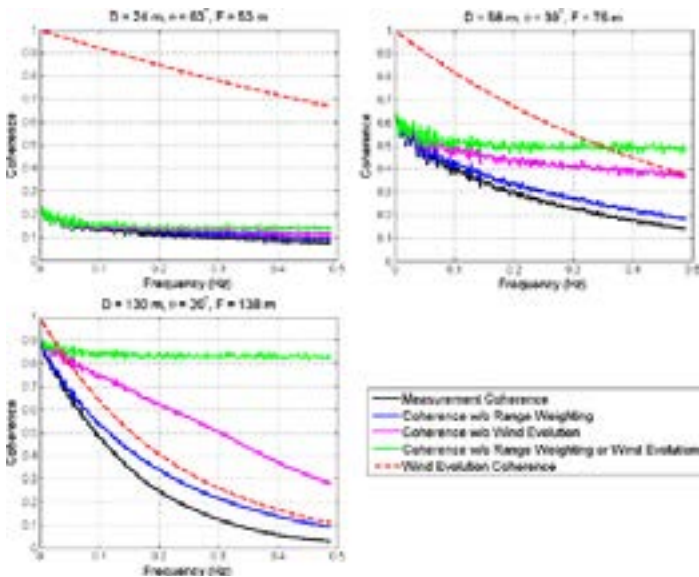


Figure 5: A comparison of the components of measurement of coherence for a scanning LIDAR scenario, with scan radius $r = 47.25\text{m}$ using the Great Plains-Low Level Jet wind field and exponential coherence with $a = 0.45$

Figures 5 and 6 above reveal that the (green) coherence curves from directional bias alone are relatively constant over all frequencies and increase as the measurement angle decreases. Although not shown in figure 5 or 6, when the effects of uv and uw coherence (present in the Great Plains-Low Level Jet wind field) are included, measurement coherence, due to directional bias, changes because of the non-zero correlation between the u and v as well as u and w components. By comparing the green and magenta curves, it can be seen that range weighting adds a significant coherence loss when wind evolution is not included, especially for larger preview distances. However, by comparing the blue and black curves, it is clear that with wind evolution included, range weighting never dominates the overall coherence loss.

Lidar Measurements of Evolving Wind Fields

Two metrics are used to reveal the measurement quality for different scan geometries. The first metric is the “coherence bandwidth,” defined here as the bandwidth where the measurement coherence remains above 0.5. A higher coherence bandwidth yields a better measurement, because more of the measured turbulence spectrum can be used in a wind preview-based controller. The second metric is the integral of measurement coherence, or the area under the coherence curve. The integration is only performed for a bandwidth of about 0.5 hertz (Hz), based on the Nyquist frequency of the LES wind field. A larger area under the coherence curve will yield a better measurement. Results based on the two metrics are similar, but both are provided here for comparison:

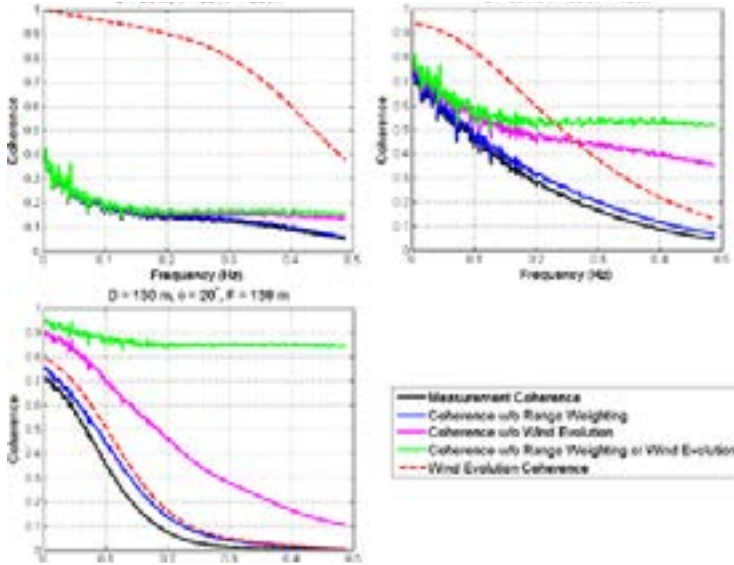


Figure 6: A comparison of the components of measurement of coherence for a scanning LIDAR scenario, with $r = 47.25$ m using the stable Large Eddy Simulation (LES) wind field and evolution model

The following results compare measurement quality for different scan geometries and reveal the optimal preview distances in terms of maximising the coherence bandwidth or coherence integration. For the exponential wind evolution model, the decay parameter α is varied to show the impact that wind evolution intensity has on optimal preview distance. For the LES-based model, the results reveal what typical preview distances might be in a stable wind field with physics-based wind evolution, but a wind field that is less productive from a wind energy perspective.

Separate results are provided for four different lidar azimuth angles ($\psi = 0^\circ, 90^\circ, 180^\circ, -90^\circ$) because the wind spectra and transverse coherences vary with height and direction. In addition, for the TurbSim generated wind field, the uv and uw correlations will have different impacts on measurement coherence (depending

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on azimuth angle).

The chosen scan geometries are based on the National Renewable Energy Laboratory (NREL) 5-megawatt (MW) turbine model. Scan radii of 15.75m, 31.5m, 47.25m, and 63m are investigated, which corresponds to 25%, 50%, 75%, and 100% blade span. For the Great Plains-Low Level Jet scenario, the lidar is located at a height of 90m, but for the LES wind field, the lidar is located at a height of 100m, which is the center of that wind field.

CONCLUSIONS FROM RESULTS OF SIMULATIONS

From the foregoing discussions, lidar simulation results show that for a circular scan pattern, a scan radius close to 70% rotor radius provides the strongest measurement correlation. Small scan radii, such as $r = 0.1R$ produce lower correlations because the measured winds are representative of a smaller portion of the rotor plane. For preview distances roughly equivalent to the rotor radius, the coherence drops as the preview distance increases due to wind evolution. However, preview distance must roughly double before coherence drops by more than 0.1. When knowledge of the wind speed and direction at heights other than hub height is used to determine the scan geometry, measurement coherence can be increased, but at most by 0.1 for $r = 0.7R$ and $24\text{m} < D < 130\text{m}$.

The modified scan pattern (temporal attenuation) improves measurement quality more for longer preview distances. The general scan pattern optimization results show that: (i) as the number of beams increases, the measurement accuracy increases as well and (ii) additional measurement ranges afforded by pulsed lidars improve measurement.

Coherence bandwidth is maximized using shorter preview distances which prevent the coherence at higher frequencies from decaying too much from wind evolution. Measuring the wind farther away than the optimal preview distances causes

wind evolution to become more severe, increasing measurement error as well. The extra preview time provided by longer preview distances are useful when attempting to detect extreme wind events and take necessary action to protect the turbine. However, using coherence bandwidth as a metric, it was revealed that, for a given scan radius, the optimal preview distance is not very sensitive to the amount of wind evolution. Optimal preview distances based on the coherence bandwidth for lidar measurements in the unstable Great plains wind field, are roughly 60m for a scan radius of $r = 31.5\text{m}$, 80m for $r = 47.25\text{m}$, and 120m for $r = 63\text{m}$ for decay parameters less than one. These approximate optimal preview distances are formed by averaging over all four azimuth angles.

Measuring the wind at multiple range gates with pulsed lidar offers the advantage of being able to track wind speeds as they travel towards the turbine as well as allowing measurements at different preview distances to be combined to improve the simultaneous estimation of wind shear and direction. Thus, from controls perspective, a preview measurement at 47.25m or 75% rotor radius for the 5 MW model is the most useful due to maximum power capture near this blade span. The results reveal that the bandwidth of coherent measurements at $r = 47.25\text{m}$ is roughly 0.11Hz based on $\gamma^2 = 0.5$ bandwidth definition.

When comparing results based on coherence bandwidth for different decay parameters, it can be seen that unless the intensity of evolution is very strong, the optimal preview distances are almost the same with wind evolution or without ($a = 0$). Using the integral of coherence as a metric, the optimal preview distances vary considerably as the decay parameter changes.

WIND ENERGY MIX IN NIGERIA

According to the Reglobal analysis, four key modern renewable energy technologies with highest deployment potentials for Africa are modern biomass for cooking; hydropower; wind; and solar power¹⁰. The power sector presents significant opportunity

to be transformed through the increased deployment of renewable energy technologies.

The nature journal of science news.org reports suggest that renewable energy sources such as wind and solar power will make up less than 10% of Africa's total electrical power generation by 2030, (Nature Energy Journal 25/01/ 2021).

This is a very abysmal rate compared to many first world and developing countries. This means that Africa and Nigeria in particular with her teeming population of over 200 million inhabitants needs to wake up from her slumber and begin to deploy wind energy as much as it is currently harping on solar energy as an option for renewable energy. The current scourge of epileptic electricity supplies in Nigeria makes any theoretical model discussions that have capacity to improve the current energy mix a necessity whose time is now.

It is important to note too that wind turbine developments are long term and capital intensive; hence, the Nigerian government through the appropriate ministry must show commitment to the development of wind energy technology in a medium- and long-term mode. The only existing wind farm in the country as at January 2021 is at Lambar Rimi, Katsina state. Continuing on the Lambar Rimi wind farm project, the Reglobal analysis had the caption, "Nigeria to complete 10 MW wind project in Katsina". (March 12, 2021) |



Figure 7: A typical wind farm with wind turbines (courtesy Reglobal analysis as in nature journal of science)

The government of Nigeria, continued the analysis, plans to commission a wind power project with a capacity of 10 MW which is located in the Lambar Rimi area of Katsina State. Katsina wind farm was set to be commissioned in March 2021. The project includes 37 GEVMP wind turbine generators with capacities of 275kW, step-up transformers for each turbine 315KVA/33KV/400V, SCADA system, installation of 2 7.5MVA transformer and accessories. The project began in 2005 under the governor of the state at the time, Umaru Musa Yar'Adua. It was then taken over by the Federal Government in 2007. It initially had a completion period of 24 months; however, the project has been met with several delays. The project commissioning was scheduled for 2012 but it never happened. This project received millions of naira in annual budgetary allocations from the government with no expenditure details.

The above picture leaves one with no doubt that at the moment, Nigeria's implementation of the wind energy is nothing to write home about. This narrative makes it even more expedient for scientists and engineers in the field of wind energy generation to wake up to the challenge before them, viz, moving from theoretical conceptions and frameworks to the field and provide clear road map for the current energy crisis in Nigeria. The government on her part must show commitment to the blue print by partnering with several international and local organizations in turning around the matter under discussion which is providing of electricity to the people.

THE PHILOSOPHY OF LIGHT-ENERGY

The philosophical conceptions of light energy in general and wind energy in particular raises once again the question of the ancient Ionian philosophers, that is, *ex qua materia constituti mundi* which means, of what material is the universe made of? The cosmologies and cosmogonies that arose from these ultimate questions became as it were less profound than the question itself. Thus, light energy with solar energy as a natural example,

metamorphoses into different forms such as wind, solar radiation, etc. Wind energy is a veritable and very safe and promising part of the discussions on renewable energy and safe environment. But again, as we stated in the discussion of the energy mix in Nigeria, the 10MW Lambar Rimi wind farm is still operating at about 25% of its capacity since the entire project is conceived to generate 36MW for a nation of over 200million inhabitants!

Thus, a philosophy of energy will raise a lot of fundamental questions: what constitutes authentic existence in Nigeria with the political will and its attendant religio-ethnic drama as experienced currently in the nation? What constitutes the ultimate solution to the current energy crisis in Nigeria that has further worsened the already deteriorated economic inflation? How can authentic existence be achieved amidst the current unethical standards of politics and civil operations in Nigeria? the rising spate of insecurity, the quest for regional self-determination, the morality of banditry and kidnapping that has now become the order of the day, the whole issue of the value of human life with due regard for human dignity and freedom of choices, and several other existential questions that relate energy and the functionality of the society.

Statistics show that over 60% of the Nigerian populace are living in conditions below the authentic existence conceived by many of the 20th century existentialist philosophers. Poverty as experienced in Nigeria is fast blurring the idea of authentic existence, the frugal comfort that light (electricity) and energy provide as well as what self-actualization implies. The declining economic fortune that these debacles spell also questions the whole issue of the equitable distribution of the world resources, the current migration issues of the young talented Nigerians fleeing to Europe and America for a better life and the future of the Nigerian Nation in a medium term and long-term mode.

Robert-Jan Geerts (2014) et al in their article *Towards a Philosophy of Energy* as contained in *Scientiae Studia Journal* had a detailed analysis of the criteria that a good philosophy of energy

should meet. According to them, “transition to a sustainable energy regime is one of the key global societal challenges for the coming decades. Many technological innovations are in the pipeline, but an uncritical appraisal of anything and everything called green innovation lacks methods for testing both the necessity and the sufficiency of these developments”¹¹.

Continuing this analysis, they argued that the task of the philosophy of energy is to explore and clarify the space in which the so-called energy transition is taking place. This will sketch the fundamentals of such a philosophy and suggests how it might be built upon the work of twentieth century critics of the functioning of energy in society, including Mumford, Bataille, and Heidegger; through the example of flux and potentiality - two apparently opposing conceptions of energy - they proposed that a philosophy of energy allows for a broader perspective on specific problems in energy transition, and illuminates implicit and problematic assumptions behind these problems.¹²

Talking about philosophies of energy, we note that there are at least three lines of thought to be found dealing to a greater or lesser extent with aspects of energy:

- (1) the inquiry into the natural phenomenon of energy;
- (2) the critique of the functioning of energy in society;
- (3) the philosophy of technology.

All three lines of thought contribute the essential ingredients to a fully-fledged philosophy of energy: the first two can be seen as attempts to develop philosophies of energy in their own right, whereas the third guides us towards a more fruitful level of analysis for issues relating to the current energy transition. Some brief elucidation of these philosophies of energy may suffice here:

1. Inquiry into the natural phenomenon of energy

Inquiry into the natural phenomenon of energy stretches back

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to Heraclitus (c.535 c.475 AD) and Aristotle (384-322 AD). Whereas the former allegedly argued that everything changes, the latter noticed that this was not exactly true: although change happens, a lot of things also stay the same. The energy historian R. Bruce Lindsay suggests that, from Aristotle onwards, an unbroken line of inquiry into the concept of energy can be drawn all the way to Albert Einstein, with as common denominator based on the assumption that “the root of the concept is the notion of invariance or constancy in the midst of change” (Lindsay, 1971, p. 383). The domain of these inquiries steadily expanded from mechanical questions on the functioning of levers and pulleys through to thermodynamic phenomena such as combustion, electromagnetism, and the discovery of mass-energy equivalence in the early twentieth century.

We do not need to reiterate this history in any detail here; what is important here involves realizing the exceptional breadth of phenomena that are fruitfully connected with the concept of energy. Over time, these insights have led to increasingly complex technologies for converting one kind of energy into another. windmills convert the linear movement of air into a rotating movement, steam engines convert chemical energy into a rotating movement via heat and pressure, solar panels convert the energy in sunlight into electricity, and, in our homes, our appliances convert electricity back into movement, light, heat, and sound. Arguably, all our activities are understandable simply in terms of converting one kind of energy into another.

There is a specific understanding of energy underpinning all these developments: a quantitative, abstract concept of “the ability to do work” that mutually interconnects a broad range of physical phenomena. This is the first philosophy of energy that we encounter, and most present-day natural scientists subscribe to some similar form of understanding energy. Although the unification of physical phenomena via the concept of energy has been exceptionally successful, conflicting conceptions of energy

do exist. These conceptions are also the result of inquiry into the natural phenomenon of energy, but, rather than relating to the scientific, quantitative paradigm, they appeal to qualitative approaches.

The scientific understanding of energy has enabled society to plug into ever increasing amounts of energy in various forms, but it fails to say much about the *effects* of these developments on society.

As changes in energy practices became increasingly visible and influential in industrial societies, in the late nineteenth century, an interest in energy emerged in the area that can broadly be described as social critique. In the twentieth century, this was picked up by a few great thinkers, and here we do find some ideas on how society relates to energy, and how this relationship developed throughout history. Thinkers like Lewis Mumford, Georges Bataille, and Martin Heidegger fall into this category.

2. Critique of energy in society

In his ground breaking book *Technics and civilization*, Lewis Mumford (2010 [1934]) places energy usage squarely in the middle of his analysis of society. From his perspective, there are four steps in the functioning of energy in society: conversion, production, consumption, and creation.

Some philosophical questions on the issue of energy at the service of the society and human existence in general comes to mind: Is there a maximum creation-to-conversion ratio? Are there different levels of energy consumption at which we attain the same quality of life, by organizing society differently?

However, before plunging into such questions, we take a step back and move onto the work of Georges Bataille, who contests the instrumental conception of energy proposed by Mumford. In *The accursed share*, Bataille (1991 [1949]) suggests that our energy practices are not instrumental to satisfying our needs, but rather it is the other way around; satisfying our needs is a way

of dealing with the excessive emission of energy by the sun. Our growing energy production and consumption simply represent an extension of this natural tendency of life to look for ever increasing accumulation and niches to fill, and to burn off the excess when accumulation is not possible.

Meanwhile, spokespersons for green technology appeal neither to paths of ruthless fossil fuel exploitation nor to sober frugality. Instead, they tend to sketch Bataillean visions of abundance: “the Earth receives more energy from the Sun each hour than humans use in a year”, implying that we simply need to better harness this energy and thereby avoid any such thing as an energy crisis. Another question to be raised could be: Why exactly would our lives become better should we command an even greater amount of energy?

Both Mumford and Bataille develop critiques against the energy practices of their day agreeing on how energy is not guided towards its proper purpose while disagreeing sharply on just what would constitute that proper usage.

One other twentieth-century thinker needs addressing in this context. Bataille appeals to our existence as individuals with access to a certain amount of energy. This represents a rather specific perspective on just what forms the human existence, with a similar perspective playing a key role in the writing of Martin Heidegger, for whom human existence changed radically with the advent of modern technology. Heidegger argues that, in modern times, the only way of understanding the world and ourselves is as a “standing-reserve” that is ready to be put to use. Stored energy proves the purest form of this standing-reserve.

Heidegger reaches this insight in his essay “*The question concerning technology*” (1977 [1954]), in which he searches for the essence of technology. This essence can be found, he holds, in the way that, that which is comes into being. In ancient Greece, the process of coming into being was called *poiesis*, a bringing-forth. This concept served both for that which emerged of its own accord (like a flower) and whatever had a specific

creator (a poem, or a tool). Bringing-forth thus represented a particular form of “unconcealing” that which was previously concealed, one in which Aristotle’s four causes have play. The general process of shifting from concealed to unconcealed was called revealing, from *aletheia*, *veritas* in Latin, and now usually translated as truth.

What is modern technology? It too is a revealing. Only when we allow our attention to rest on this fundamental characteristic does that which is new in modern technology show itself to us. The tendency of modern technology to store and extract energy on demand features here as a crucial moment in history. It is the central characteristic of a new way of revealing.

The very way the world presents itself to us has been changed by this new way of revealing, which Heidegger proceeds to call *enframing* [*Ge-stell*]. But how does humanity relate to this enframing? Because modern technology remains a human invention, one might assume we control it or can at least remain outside of its scope, but this does not prove the case. Although we might have put it in place, we have no control over the way of revealing.

The inquiry into the natural phenomenon of energy and the critique of energy in society both point to the universal applicability of the concept.

A philosophy of energy might help tackle issues in energy transition via conceptual analysis, critical reflection on argumentation, and raising the level of abstraction, while also broadening the playing field by drawing from a range of sources. It also problematizes the concept of energy neutrality as the ultimate target for energy transition by emphasizing the importance of temporality in our energy systems.

The fact that energy is understood as something storable proves essential here. Energy is here patiently waiting; this represents what we propose calling *potentiality*, *something static* that can be put to use at the flick of a switch

Heidegger notes how this is a new phenomenon; it is the merit of modern technology to have access to energy in the form of potentiality: “but does this not hold true for the old windmill as well? No. Its sails do indeed turn in the wind; they are left entirely to the wind’s blowing. But the windmill does not unlock energy from the air currents in order to store it”¹³.

Energy as conveyed in the example of the traditional windmill, will be more amenable to the philosophical concept of flux. The crucial difference between flux and potentiality therefore revolves around whether or not humanity *controls* it.

CONCLUSION

In conclusion then, a generalized philosophy of energy will be able to deal with developments in what is known broadly as the energy transition. A philosophy of energy would be able to explore and clarify the space in which the so-called energy transition is taking place. The philosophy of energy would help in tackling issues inherent in energy transition through conceptual analysis, critical reflection on argumentation, and raising the level of abstraction, whilst simultaneously broadening the playing field by drawing on a range of sources.

‘Energy transition’ is not simply a technological and economic problem but also an epistemological, cultural, anthropological and even metaphysical one. What will be the consequences of our necessary departure from ‘petro-modernity’, that is, from the mode of living that came with fossil fuels to modern times that shape our current age of the Anthropocene? The framework of the philosophy of light-energy in general and wind energy in particular will be able to raise ultimate questions on authentic existence and frugal comfort that electricity and energy need raises in the Nigerian context.

Endnotes

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