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Hydrogen fuelling sustainability of energy systems, regional integration and development: the Sahara Wind Project

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Abstract : With a 96% energy dependency from fossil fuel imports absorbing most of Morocco's export revenues, developing new sustainable energy consumption alternatives is of critical importance. Morocco's location on the main routes of migrant populations from Sub-Saharan Africa and being itself an exporter of immigrants, together constitute a significant security threat to both the region and NATO countries. The situation is fairly similar in Mauritania, whose scarce population is distributed over a vast territory in which access to electricity is difficult to grant through conventional grid infrastructures. Initially encouraged to provide employment in the relatively poor North Sea regions of Germany, the wind energy industry has emerged in the last 10 years, as a major business providing most competitive prices of electricity even when operated under marginal European wind conditions. The trade winds that blow along the Atlantic coast from Morocco to Senegal represent the largest and most productive wind potential available on earth. Because of the erratic nature of winds however, wind energy cannot be integrated locally on any significant scale unless far ranging, more advanced energy technologies are considered. Wind-electrolysis for the production of hydrogen offers great possibilities in absorbing large quantities of cheap generated wind electricity to maximize renewable energy uptake in the weak grids infrastructures of the region. This project is initiated by Sahara Wind Inc. a company from the private sector to serve as the foundation of an ambitious program supporting a vision highlighting possibilities for tackling energy scarcity and sustainable development objectives on a regional basis. This combination is likely to take advantage of the significant breakthroughs expected to happen in the near future regarding hydrogen technologies particularly through its association with large sources of renewable energies.

Key words: trade winds, renewable, wind energy, wind-electrolysis, electricity, grid stability, alternating current, high voltage direct current HVDC, European Union, electricity markets, infrastructure, applied research centers, carbon free, hydrogen, integration, pilot/demonstration project, Tarfaya, Morocco, Mauritania.

1. Wind Power, a vast renewable energy source

Close to the African coast, the junction of the Sahara desert with the Atlantic Ocean creates a zone of global energy exchange were the climate is dominated by steady winds: the Trade winds. Local thermal winds coming inland from the Sahara’s hot surfaces are actually superimposed upon the global trade wind system generated over the Atlantic and this creates one of the largest and steadiest wind systems available on earth. The higher latitude of such large wind resource (barely distant of 1800 kilometers south of the European continent) makes it rather compelling to envision the development of a clean, sustainable and renewable integrated energy supply for our hemisphere.

The coastal plateaus that spread from Morocco through Mauritania and Senegal represent one of the largest, least populated and windiest areas available worldwide, for the massive production of wind energy. These sites that are within reach of the European electricity grids can yield an expected yearly production of more than 4500 Full Load Hours, where recent wind measurements have been made. As a comparison, in Germany the world leader in wind power, the average productivity figures do not exceed 1900 FLH. The size of the Saharan plateau’s as wind catchments areas boasting far superior productivity figures is huge as the sole coastline, just to mention, spreads for over 3000 Km.

Figure 1. Arial view of Saharan coastal plateaus (source Sahara Wind Inc.)

The Sahara wind resource that extends over thousands of kilometers of eroded plateaus and desert seacoasts, will take many years in order to be accurately evaluated. It represents to date, probably one of the world's largest untapped sources of wind energy. The size of this territory, the availability of the wind, and the relative geographical proximity of this region to Europe as one of the world's largest integrated electricity market provides tremendous development perspectives for the region’s future and the wind energy industry overall.

In such context, the North West African vast endogenous wind resources are likely to provide significant opportunities for the region to cover domestic energy needs while supplying much larger electricity markets, namely that of the European Union to which these resources are currently linked via electricity gridline connections through the Iberian Peninsula. Provided an appropriate framework is developed, the broader North West African region could seize the industrial opportunities associated with the manufacturing of various equipment parts for the large scale wind-project envisaged, to ensure full integration of local industries that are likely to lower individual component costs while generating jobs and boosting local labor markets (www.saharawind.com).

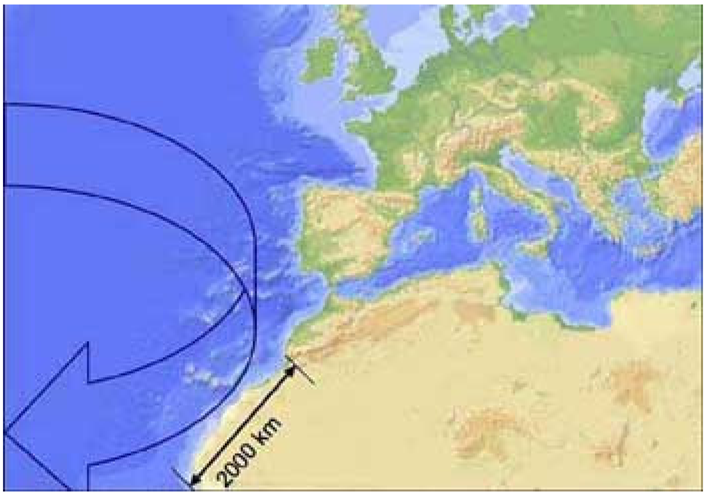

Figure 2. Global trade winds over North West Africa

2. Harnessing wind energy and its industry into regional energy markets:

Although the Trade Winds that extend from Morocco through Senegal represent the largest wind potential available on earth, their erratic nature undermines any optimal utilization possibilities, to the extent that only a marginal proportion of that wind energy can be fed into the region's weaker grids infrastructure. This prevents local industrial and economic integration from taking place on any significant scale. Thus, a conventional approach to wind energy developments to feed smaller local electricity markets cannot enable a viable wind energy industry to be established, which could be essential for tackling the regions economic challenges currently under pressure from Sub-Saharan migrant populations. A large renewable energy industry accompanied by many social benefits and job creations could indeed improve the region's economics particularly as it would be based on the sustainable utilization of one of the world's largest wind energy resources.

2.1 Technical limitations: Grid stability

With a total 4,508 MW of installed capacity, the size of Morocco electricity grid which represents North West Africa's largest, is a relatively small grid that can hardly cope with very large amounts of wind generated electricity before encountering grid stability problems unless precautions are taken. Common issues associated with high wind penetration rates such as generation intermittency, dispatching, power margins, reactive compensation, voltage, frequency regulation, flickers, harmonics, and all other effects are likely to create significant challenges on Morocco's grid. This problematic would be even more acute in Mauritania which has a grid extending over a very large territory (about twice the size of a country like France) with an installed capacity of less then 120 MW. Thus, it is important to mention that unless wind energy developments are part of a regionally integrated, comprehensive strategy where state of the art energy technologies can be engaged, spare threshold capacities must be kept available for the grid infrastructure not to saturate.

2.2 Industrial integration

Unless a common strategy is developed, through elaborated energy research platforms with key local stakeholders brought together in a well-coordinated framework of action, experience has often shown that efforts aimed at introducing (new) wind energy technologies in developing countries amounts ultimately to the simple export of equipment through concessionary sources of financing and export credit packages. These policies have done very little in terms of local capacity building and industrial integration, for a technology that could have been promising in terms of economic returns, addressing energy security, and the creation of an accessible integrated industrial activity.

Ignoring a domestic wind power industry that was already building wind turbine prototypes of up to 250 kW of rated power five years ago, Egypt's public utility resorted to import 60 MW of Danish wind turbines that were barely twice that size. The utility's further expansions involved the purchase of several hundred Mega Watts of wind turbines for the Zafarana desert region involving Danish, German and Japanese manufactured machines financed through their respective concessionary loans or export credit packages. With the growing size of the individual wind turbines whose technologies are less likely transferable and the saturation of Egypt's smaller electricity grid to further wind developments, the Egyptian utility has prevented any industrial integration from taking place, displacing some of the country's energy dependency from hydrocarbons to actual wind turbine imports, while making their servicing rather costly.

If lessons are not drawn from the aforementioned to develop a comprehensive and more sustainable approach, regional utilities from Morocco through Senegal may be led to follow the very same path whereas most wind turbine components can be easily integrated within the region's existing industrial infrastructures and know how. Morocco's industries for instance already manufactures, assembles and exports a variety of industrial components into world markets ranging from preassembled control cables, electro-switching equipment, transformers, spare parts, to automobiles.

As it is common practice within the wind industry, a first step toward developing wind energy in a remote market begins generally with the on-site manufacturing of wind turbine blade components that are too bulky, labor intensive and fairly simple to build using simple moldings and wood epoxy coating techniques. It is rather compelling to notice in our case that the very molds used for building the so called "Cayucos" (long polyester vessels currently used in smuggling illegal immigrants out of Mauritania and Senegal into the Canaries Islands) are almost identical to the ones that would be required in the manufacturing of wind turbine blades. Thus the capacities do exist in the region; they just need to be appropriately mobilized and integrated for far ranging, better suited, more sustainable economic purposes.

2.3 Regional energy markets

Since this region is located on the edge of one of the largest electricity grids (the European Union's grid), its vast renewable energy potential could be used to produce significant amounts of cheaply generated wind energy that could end up supplying European commercial electricity markets through appropriate electricity transfer infrastructures utilizing High Voltage Direct Current lines as envisioned by our large wind energy development project (www.saharawind.com). This however, will require an effect of scale; and developing mechanisms to firm this energy locally is very important initially, as it lays in the critical path of major alternative energy developments.

Figure 3. Comparison Left, power line: HVDC, 3,000 MW, +/- 500 kv bipole. Right, High Voltage AC 400 MW line. (Pacific Direct Current Intertie PDCI near Bishop, CA).

As of today, no technology currently exists for enabling the uptake of significant wind energy potentials on a reliable basis. Being erratic by nature countries that have achieved the highest wind penetration rates did not manage to cover 25% of domestic energy consumptions while relying on extremely high interconnected backup capabilities (Denmark). Taking the same proportions in the Saharan region in countries like Mauritania or further into sub-Saharan Africa, will as mentioned previously, translate into very little installed wind power capacities.

Therefore research ought to be conducted into alternative options for integrating widely available wind/renewable energy resource into grids and or other viable energy infrastructures. Such combinations are likely to take advantage of the significant breakthroughs expected to happen in the near future, regarding hydrogen energy technologies particularly through its association with large sources of renewable energies.

3. Hydrogen, a revolution in energy technology developments

Because of the world's current energy deadlock, and regardless of any environmental considerations, the 21st century is bound to be one where energy breakthroughs will have to be found in order to preserve mankind's economic activities and making them a little more sustainable. As an alternative to hydrocarbons, hydrogen promises to become a universal energy carrier in the future. Therefore and particularly since the technologies already exist, any applied research conducted on hydrogen energy technologies are likely to be very promising in terms of results as they are of strategic dimension. Thus, in order to introduce these state of the art technologies, our initial steps are aimed at building up capacities, training engineers, doctoral and postdoctoral students, who are likely to reinforce more sustainable energy generation system, through our ambitious and wide ranging cooperative project development activities.

3.1 Integrated regional applied research projects

Developing a new energy economy will require a global strategy to be progressively implemented. The introduction of these technologies at an early stage, through regional applied research projects will likely contribute to establish and identify areas where the potential breakthroughs can become significant in the future. The region disposes of a qualified pool of university professors, engineers and scientists that currently lack appropriate research infrastructures. Equipping and networking the two main research institutions in Morocco and Mauritania through the financing of Wind/Hydrogen/fuel cell test benches as we envision could be considered as a first step towards a successful, gradual introduction of state-of-the-art energy technologies. While this will also prevent any research and technological gaps to widen between countries that dispose of large research facilities and others that do not, the networking of these facilities and their activities are necessary for developing a comprehensive approach towards new sustainable energy alternatives. For that matter, the Hydrogen Economy vision of the International Partnership for the Hydrogen Economy – IPHE- clearly states that energy systems of the future must be cleaner, much more efficient, flexible, and reliable to meet the growing global demand for energy. Besides offering a potential solution to satisfy global energy requirements while reducing (and eventually eliminating) carbon dioxide (and other greenhouse gas emissions) and improving energy security, a hydrogen economy is one in which hydrogen is produced cleanly and cost-effectively.

3.2 Hydrogen applied research, context and new energy development possibilities

Mauritania and Morocco's energy challenges are part of a broader energy context pertaining to energy access, resource limitations and sustainability issues. Further, the region's decentralized grid infrastructures require site specific solutions. Integrating the production of hydrogen as an energy carrier utilizing regional electricity market opportunities and its vast renewable energy potential provides an ideal testing ground for applying the latest research and technological breakthroughs in the development of a renewable driven hydrogen economy. As no applied research programs in hydrogen or fuel cells currently exists in both countries, this would contribute to bridge hydrogen technology divides, highlighting a comprehensive approach to the role of hydrogen (and hydrogen applied research) in fulfilling sustainable development objectives. Hydrogen is scalable, and can be worked into modules, small medium and large integrated applications. Applied hydrogen research will reinforce a complementary vision in handling intermittent sources of energy (wind) both in decentralized productions of energy and in possible future massively centralized large scale Wind/HVDC transfer infrastructures. Involving domestic scientific communities at an early stage may contribute to develop newer, wide-ranging approaches that may be better integrated to the regions real potentials. Hydrogen could be integrated to the region's industries and main export commodities; mining, phosphate processing and fertilizer industries (already big customers of electrolysers worldwide). Wind-electrolysis in Morocco and Mauritania's (trade wind regions) can be duplicated on a large scale and produce hydrogen at competitive costs. Hydrogen from fossil fuel reforming represents the vast majority of today's hydrogen production, emitting six tons of CO_2 per single ton of hydrogen in the process. It is therefore important to differentiate hydrogen production alternatives at an early stage (carbon and non-carbon generated hydrogen) and encourage countries with similar potentials to collaborate and exchange expertise through excellence centers located in their universities. This will expand applications and developments further into sub-Saharan Africa with hydrogen and fuel cell technology solutions. Such vision supported by NATO would provide a strategic approach to renewable energies which, coupled with a sustainable integrated hydrogen economy, could contribute to building tomorrow's energy solutions.

3.3 Hydrogen technologies to improve security in the region

North West African countries dispose of skilled human capacities and a scientist pool capable of getting involved and conducting such applied research. It is essential to foster regional (south/south) collaboration in clean energy technologies for tackling energy access, environment and sustainable development issues. Collaboration between Morocco and Mauritania's scientific communities is very important in providing focus, sensitizing and developing alternatives to handle the economic consequences of high energy dependencies or limited energy access which could in the long run if combined with environmental challenges causes, such as land degradation, desertification and demographic pressure, generate economic distress. Both largely agricultural based societies are indeed threatened by environmental challenges. Building scientific capacities, and developing a vision that can generate a dynamic around fast growing energy and sustainable industries (wind energy has 25% growth rates worldwide focused essentially in Europe) could in the long term, become an alternative in fixing migrant population, and contribute to their social integration. Further integrating hydrogen production and the development of fuel cell research could contribute to improve decentralized electrification prospects and fixing populations as well, thus reducing migration fluxes which are currently the region's main security challenges.

3.4 Hydrogen, the missing link in solving renewable energies intermittency

Throughout Sub-Sahara Africa, electricity grids are still decentralized whereas wind resources are widely available in both Morocco and Mauritania. Access to energy is a key social priority. Hydrogen can improve renewable energy absorption of grids as a decentralized energy source of non-fossil origin fostering sustainable development (capacity is built on-site). Hydrogen is a new process, which will be used in small scale but it can also grow in size and end up ultimately being integrated with large wind infrastructures to supply electricity markets with appropriate electric HVDC line infrastructures. So in a way, hydrogen is complementary to both remote decentralized or large scale energy firming applications, actually facilitating the transition from decentralized to centralized energy evacuation networks. Traditional centralized electric generation from fossil fuels are not adapted to supply weak AC grids with lack of loads to supply and long distances to cover. Losses can be as high as 70% over a few 100 km in standard AC grids whereas hydrogen related technologies enables more decentralized approaches and novel integration perspectives.

The Norwegian Utsira island wind/hydrogen energy demonstration project is very recent as it highlights stand alone insular systems which addresses the possibilities of utilizing hydrogen as a storage medium for intermittent sources of renewable energies (i.e. wind energy). In our case however, we have the possibility to evaluate the utilization of hydrogen for the very same purposes while assessing a more progressive, complementary integration of this technology to large scale transmission networks that are likely to be integrated in the region. Being located at the edge of a very large European electricity market, the role and utilization of hydrogen could be catalytic, as it may in both cases facilitate the transition from decentralized to centralized energy evacuation networks.

4. A phased approach to integrating hydrogen technologies

4.1 Initial step: equipping public lab facilities

The objective of the project is to reinforce capacities by fostering a regional collaboration between Morocco and Mauritania through facilities that will be interconnected with other research centers. By equipping existing laboratory facilities, the scientists, engineers and doctoral students in the main public university/research centers will be able to evaluate the integration possibilities of wind into grids, wind/hydrogen electrolysis, stationary fuel cell technologies and their applications in weak grids and/or isolated sites. This will be part of a project aimed at highlighting the region's vast trade wind energy potential and developing ways to integrate this resource within the countries' infrastructures, economies and into a broader sustainable energy vision being developed world wide (www.iphe.net). The interactions between hydrogen as renewable energy storage, grid stabilization and the maximization of renewable energy intakes on remote or weak grid conditions will be studied and evaluated. Non-energy applications of hydrogen can be looked into as well as the labs will be connected to wind measurement instruments on coastal desert sites disposing of high wind potentials. Production scenarios of commercial hydrogen for non-energy uses will be looked into as well, through the laboratory analysis of data gathered. Wind modeling software would then determine the electricity and hydrogen production that can be generated over wider areas by extrapolating the results.

4.2 Wind mapping-hydrogen production techniques

Developing a new comprehensive vision of sustainable energy production, utilizing the latest state of the art energy technologies will enable us to forecast and model sustainable consumption trends with plenty of renewable resources. Utilizing wind mapping techniques within the hydrogen applied research centers will facilitate the assessment of hydrogen production possibilities on a wider scale. Mapping techniques and regional computer models could be applied that are similar to the U.S. model for market expansion of wind energy and hydrogen production from wind and other sources over the next 50 years in the region. The loads and resources being more easily assessed, a Wind-Hydrogen Deployment Systems (WinHDS) model can be developed to forecast the expansion of generation and transmission capacity in the region spanning the next 50 years and minimize system-wide costs of meeting loads, reserve requirements, and emission constraints. While all major types of conventional generators will be included, the WinHDS model will address market issues of greatest significance to wind—specifically issues of electricity transmission and intermittency.

4.3 Second Step: the Sahara Wind-Hydrogen Pilot/demo project

This applied research could serve as basis for the Sahara Wind-Hydrogen demonstration project that Sahara Wind Inc. intends to build as part of its large scale commercial wind energy developments currently under way, and carried out in conjunction with several multilateral development institutions. Being faster to set up then successive wind power capacities aimed at feeding large commercial electricity markets, the hydrogen production perspectives to be developed with the support of the United Nations Industrial Development Organization are likely to demonstrate the complementarities that the hydrogen economy provides in the development of sustainable energy systems. The Sahara Wind-Hydrogen Energy Project in Tarfaya is likely to provide an operational research platform that addresses innovative and sustainable hydrogen production technologies with several industry and research partners with appropriate levels of funding around this pilot project.

Several interesting and complementary options available in the recent research conducted in the US and Europe have highlighted several key aspects of the wind / hydrogen association, namely;

- The characterization of co-operation of wind turbines and electrolizers, in some instances coupled.
- The wheeling of power from wind turbines to electrolizers on strong transmission networks.
- The use of hydrogen as a storage mechanism in small scale remote wind and PV applications.

Although each of these activities represent important investigations, they only go part of the way in addressing the technical challenges when developing a large wind based hydrogen production system. Looking into these perspectives, two different possibilities are available. It is important to mention that merging their respective advantages represents the most compelling of all options. The first option would consider Wind turbines that are designed to produce hydrogen directly, either independent of the grid or at least independent from a power processing perspective, the second being wind turbines that are connected to a transmission network and may, depending on loading and resource, produce either hydrogen or electricity for direct sale. The Sahara Wind-Hydrogen Energy Project located in Tarfaya is likely to provide an operational research platform that addresses the latter of these two options.

It is nevertheless important to expect that such wind / hydrogen park would be installed in a manner that the total rating of the installed wind capacity would be much larger than the available grid capacity is able to absorb. Indeed, a wind farm designed to produce hydrogen should not mobilize any further investments into transformer stations and secure grid capacities, when only a fraction of its global output is expected to be fed into the grid. Hence, this would result in large buffered power generating sources which, connected to a weak grid, provide significant energy handling capabilities likely to enhance the systems stability and reliability. Such approach, even if it is internal to the wind farm, enables a significant valorisation of the fluctuating wind energy resource in addition to the use of complementary mechanisms such as power conditioning schemes and other optimized transfer infrastructures likely to be envisioned in the Tarfaya region.

The application of the results, their expansion and replication into remote grids will be carried out in the region by Mauritania's electric utility, its agency for rural electrification (ADER), and Morocco's utility (ONE) along with other public structures with whom Sahara Wind Inc is already engaged in years of collaborative project development work aimed at large scale wind energy integration. Finally, the integration of non-energy hydrogen applications is likely to be of interest to both countries' main industrial conglomerates operating in the mining, phosphate processing and fertilizer industries.

4.4 Developing local hydrogen end user markets:

4.4.1 Phosphate mining and processing industry

Morocco's first export commodity and foreign currency earner remains the phosphate industry. Disposing of the world's largest mineral reserves, Morocco is currently the world's leading Phosphate exporter. The availability of Oxygen, a hydrogen by-product in the water electrolysis process would enable Morocco's phosphate based industry to eliminate all SO_2 emissions (estimated at 2.5 Million tons/year) from its sulfuric acid production facilities. The availability of hydrogen would also enable local production of ammonia, an essential component required in the production of fertilizers that is currently imported. Ammonia can also be used as stable storage means for hydrogen, which is much easier to handle then pure hydrogen in its gaseous form. In Mozambique for instance, fertilizer industries are already utilizing surpluses of renewable hydro-generated electricity to produce hydrogen through electrolysis for fertilizer products. Instead exporting mostly raw phosphates, the utilization of any available hydrogen would enable Morocco to develop and integrate its fertilizer industry most comprehensively, beyond exporting solely phosphate based fertilizers. Finally, in the process for the current production of phosphoric acid, utilizing phosphor gypsum in Morocco the availability of hydrogen could enable a joint production of clean Portland cement, without any CO_2 emissions. The production of cement could create a significant added value in the production of phosphoric acid (prices of cement being generally linked to costs of energy) and will avoid the environmental nuisance in the current dumping of over 12 Million tons/year of phosphor-gypsum into the Atlantic Ocean.

4.4.2 Fishing, mining and other industries

The active regional fishing industry and labor intensive processing plants in the region could make use of significant amounts of hydrogen in their respective processes. Their needs for a firm source of energy are high and the use of chemical derivatives from the local phosphate processing could be also considered. The region's mining and mine processing plants, besides requiring a reliable source of energy, could consider the use of hydrogen and other hydrogen related chemicals that are generally part of mineral-ore refining processes that contribute significantly to the added value of raw mining exports commodities. Finally, as all these activities do generate larger pools of labor employments, the agglomerations of the regions are likely to grow in size and require larger amounts of fresh water supplies for urban consumption. As most of the cities on the Saharan coastline already get their water produced through reverse-osmosis desalination processes, any electricity generated from large integrated wind energy operations would reinforce further fresh water supply capabilities of these cities, making them more autonomous from expensive fossil fuels energy imports.

Conclusions:

The aforementioned activities are essential in evaluating the possible utilization of hydrogen technologies to enhance the critical uptake of renewable energy in the weak grids infrastructures of the region. While the Sahara Wind-Hydrogen demo/pilot project is likely to be included into the International Partnership for the Hydrogen Economy's future list of collaborative projects involving several IPHE member countries, these activities could also bridge hydrogen production technologies with the needs of different countries, particularly developing countries to determine how technology transfer will be affected. Finally, the objective of the project is to build capacity and enable applied research to be conducted on hydrogen energy technologies in both Morocco and Mauritania, and stimulate wider regional cooperation to support large scale production of carbon free hydrogen from wind-electrolysis on an unprecedented scale.

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