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Scaling-up the Wind Industry: Building Integrated Wind-Energy Driven Economies

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From its operating 380 MW wind power base, Morocco's wind capacity will reach 800 MW by the end of 2014. In addition, a 1000 MW Integrated Wind Energy initiative from the country's public utility company aims at putting 2 GW of wind capacity online by 2020. With a 7% averaged domestic power demand growth, Morocco's Renewable Energy Law 13-09 which enables wind-electricity to be wheeled directly to industrial end-users will also add wind capacities during this timeframe. To satisfy these needs and supply North Africa's urban centres from the exceptional Atlantic Trade Winds blowing over the Sahara desert coastline, a High Voltage Direct Current (HVDC) transmission line will be needed. Within such context, the Sahara Wind Project's 5GW HVDC line is likely to enable excess intermittent wind power flows to be exchanged with Europe. While ONEE's 1000 MW Integrated Wind Energy Initiative provides an enhanced local wind manufacturing base for this to happen, additional benefits will be drawn from the country's Renewable Energy Law 13-09. Besides its aforementioned export clause, the transfer of Wind-electricity directly to industrial end-users will open new opportunities to match power generation with demand. Mineral-exporting industries represent the main electric loads to supply in the Sahara desert. Originating from the Oceanic trade winds, the transformation of the world's most significant Phosphates reserves becomes a key element of global sustainability. With World Food Security at stake -since 90% of the Phosphates are used as fertilizers- the large-scale, cost-competitive incorporation of wind energy used in energy intensive value-added mineral transformation processes is likely to significantly improve resource efficiencies. With the possibility of transforming Mauritania's major iron-ore deposits into steel derivatives through hydrogen direct reduction processes (using wind-electrolysis), this energy-water-mineral and global food nexus becomes a central issue in the years to come. They represent multi-generational global sustainable development imperatives that will mobilize the region's industries for some time. Initiated within such context through an end-user-driven academic partnership, Africa's first 30 kW wind-hydrogen storage systems are powering two of Morocco and Mauritania's Universities. From this initiative, a variety of applications ranging from access to potable water, to local mineral processing and green mobility can be developed. To that extent, a regional wind resource assessment network deployed with the help of telecom operators in both countries will facilitate the deployment of integrated wind-energy driven industrial applications in support of the Sahara Wind Project.

I- Regional framework capacities building for the Sahara Wind Project

Connecting 5 GW of wind capacity to a high-voltage direct current line to supply North African and European electricity markets on pure economical grounds sidestepped a variety of technical challenges. Starting with a threshold capacity of 400–500 MW near Tarfaya in the South of Morocco, the Sahara Wind project enables the phased deployment of over 5 GW of wind energy connected to a high voltage direct current line [1]. Submitted to multilateral funding institutions in 2005 with the endorsement and backing of the Government of Morocco and the electric branch of its public utility ONEE operating the grid infrastructures, the Sahara Wind Project enabled multilateral institutions such as the World Bank and the African Development Bank to consider wind energy as an effective driver for economic development. As a result, funding from multilateral institutions was subsequently provided to public institutions associated to this project development framework.

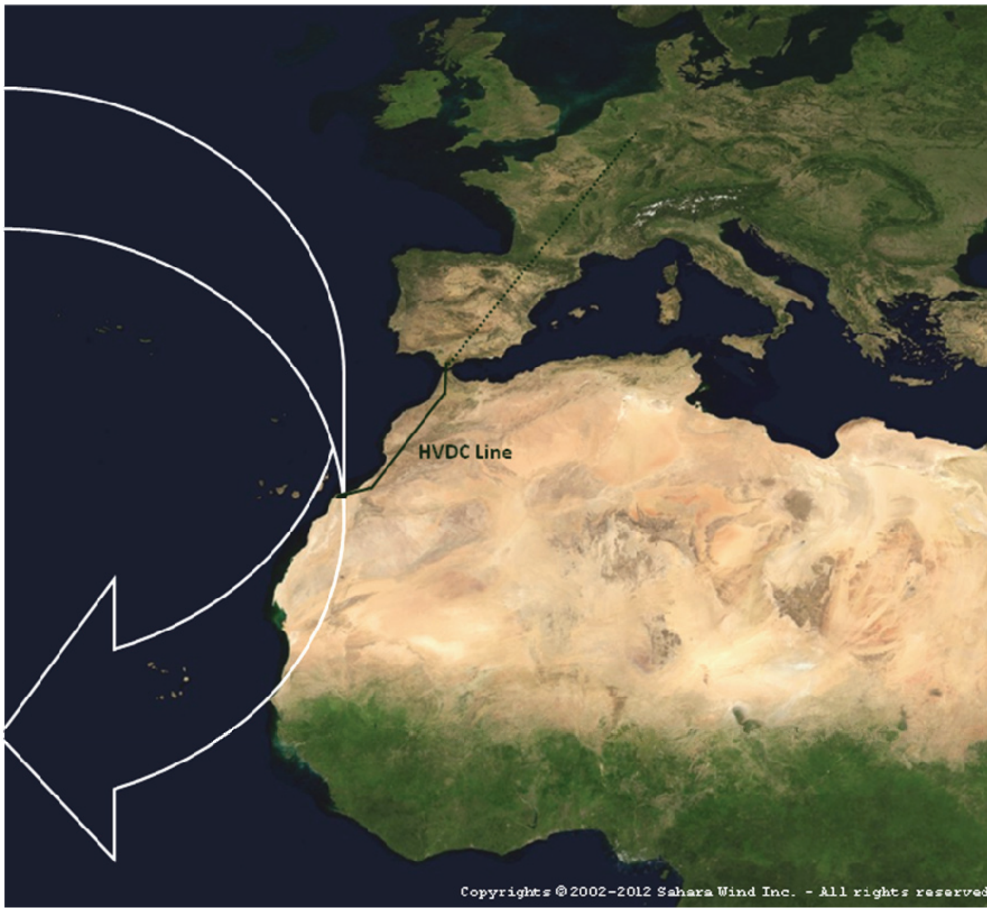

Figure 1: Atlantic trade winds over the Sahara desert powering the Sahara Wind project 5GW HVDC line

The Sahara Wind Project's 5 GW HVDC transmission line aimed at supplying regional power markets on pure economic grounds opened significant development perspectives to the region. As these can effectively address some of North Africa's social challenges, building regional capacities on the access to wind technologies quickly turned into a security imperative.

a. Access to wind energy: a joint research priority for Morocco and Mauritania

From the year 2006, Sahara Wind initiated regional capacity building activities to support real-time integrated applications aimed at tackling energy scarcity while fostering sustainable development. Under the scientific collaborative mechanisms of the North Atlantic Treaty Organization (NATO), access to wind energy was selected as a joint research priority theme by academic institutions of Morocco and Mauritania. Carried out by 18 institutions from 6 countries, the 'Sahara Trade Winds to hydrogen: Applied Research for Sustainable Energy Systems' Science for Peace SfP-982620 [2] project enabled smaller wind turbines to be deployed within the region's universities. Introduced through its green campus concept, Africa's first wind-hydrogen storage system was commissioned at the University of Al Akhawayn of Morocco in 2012. While the second one awaits the completion of Mauritania's new campus facility, a variety of end-use applications have been developed. Under these settings, excess wind-electricity is stored in the form of Hydrogen generated through electrolysis. When fed trough a fuel cell, hydrogen provides a spinning reserve for grid back-up as well as an emergency power supply source to the campus.

Beyond these possibilities [3], telecom operators interested in developing permanent power solutions for their distributed mast tower infrastructures partnered in the project as well. Utilizing University campuses as live test facilities for their equipment, telecom operators of Morocco and Mauritania agreed in exchange to provide access to their extensive mast tower telecommunication networks. Spaced at regular intervals, telecommunication towers have been fitted with wind measurement instruments on relevant sites throughout the Sahara coastline. This wind monitoring system currently spreads from Morocco through Mauritania over a distance exceeding 2000 kilometers. It enables a valuable regional wind resource assessment to be carried out at minimal costs (Figure 2).

Figure 2: Telecom towers with MAESNET Anemometers pointed towards the trade winds

On the grounds of the Ecole Normale Supérieure des Arts et Métiers – ENSAM of Meknès in Morocco, industrial engineering programs on small wind turbine parts led to the design and testing of in-house built prototypes. These wind energy, grid management and storage technologies are likely to play an essential role for mobilizing and training a new generation of engineers in the future.

b. Deploying regional integrative demonstration systems

Partnering with Morocco and Mauritania's public utilities, the Sahara Wind Project's academic network secured a planning grant from NATO for the 'Production of drinking water in arid regions using renewable energies'. Aimed at enhancing access to drinking water on a regional basis, the project's initial steps consists in deploying chlorinated solutions generated through wind-electrolysis within Morocco's main water treatment facility (Africa's second largest). Used as a stabilizing load in high wind-penetration sites, wind-electrolysis co-generated chlorine or hypochlorite, are indispensable elements in water treatment solutions for producing clean, drinking water [4]. By engaging simultaneous demonstrative and capacity-building objectives within an industrial framework to access endogenous renewable energies, this project highlights the role of stand-alone fully integrated water treatment processes. As the project is located at the headquarters of Morocco's Electric and Water Utilities (ONEE) hosting the International Institute for Water and Sanitation, the importance of integrative industrial processes can be showcased when accessing renewable energies. Introduced as a green corporate-headquarter concept, co-generated hydrogen will be used as spinning reserve, emergency backup power, and even in clean-mobility applications. In associating local automotive industries, hydrogen fuel-cell powered vehicle prototypes are to be built and tested on-site as well. As a result, access to renewable energies can be addressed through a broader synergetic context focusing on the production of drinking water and the multiple uses of renewable hydrogen. The operational feedback gained will facilitate the deployment of integrated solutions in support of Morocco and Mauritania's utilities. Their dispatching within the weaker grid infrastructures found in the Sahara/Sahel region -where extended logistics makes the safe transport of chlorine difficult- is likely to enhance access to potable water. On the Saharan coastline, where water is already extracted via energy-intensive desalination processes, trade wind-powered applications are quite relevant as they represent one of the easiest ways to dispose of excess intermittent wind-electricity.

Within these regional collaborative settings, partnerships will be extended into subsequent pilot projects. Initiated with the power and water utilities, these can be gradually extended to energy-intensive mining industries. This will open possibilities for developing wind-powered integrated processes aimed at sustainably transforming the regions significant mineral deposits, generating higher local values.

II- Processing the planet's largest reserves: Morocco's Phosphate industry

a. The origin of the world's largest Phosphate deposits

Through wind friction over its surface, the trade winds shaped the Atlantic Ocean currents for millions of years [5]. By streaming dead animal carcasses and organic debris towards the African coast, these ended-up being trapped at the bottom of Morocco's Atlas Mountain range. Their accumulation resulted today in the deposit of 75% of the world's known Phosphates reserves [6]. Used essentially in the production of fertilizers, their processing into higher value-added derivatives requiring Phosphoric acid and Ammonia provides an unprecedented opportunity to take advantage of the trade winds.

b. Transforming phosphates: feedstock imports versus energy-intensive processes

As Morocco holds the largest export market shares of global phosphates rock and phosphoric acid, producing the latter currently relies on Sulfur imports. Besides these, Morocco's state-owned Phosphate conglomerate –Office Chérifien des Phosphates (OCP Group) - which supplies 20% of world fertilizers, needs to import significant amounts of Ammonia. With Nitrogen picked from ambient air, hydrocarbon reforming to extract Hydrogen is a widely used process to generate Ammonia (NH_3). As a result, most of the Hydrogen needed as feedstock in the 140 million tons of Ammonia produced each year comes from fossil-fuels. As fertilizer industries -essential to world food security- represent the main end-uses for Ammonia, developing sustainable ways to generate Hydrogen becomes a critical issue. This is all the more important since Hydrogen represents a promising energy carriers which can be used for storing intermittent renewable energies (such as wind) and applied as a carbon-free ground transportation fuel. Coupled to Morocco's phosphate-based fertilizer industry, Hydrogen from wind-electrolysis could therefore play a constructive role in initiating a broader renewable energy transition.

Indeed, as hydrochloric acid can substitute sulfuric acid in the wet process preparation of phosphoric acid, new synergetic changes are possible. The production of hydrochloric acid -a mix of Chlorine and water- requires no other feedstock but earth's most basic elements; namely water and salt (NaCl) mixed in a brine where electrical currents is applied. With the availability of cheap wind-electricity, Chlorine can be co-generated with hydrogen in addition to caustic soda as by-products in the Chlor-alkali electrolysis process. As Chlorine is needed in phosphoric acid production, the electrolytic hydrogen can be recycled into ammonia, substituting thereby fossil-based ammonia imports in the production of fertilizers. Considering the extraordinary scale of the region's phosphate and trade wind resources, other synergetic processes could be derived as well. By facilitating a local absorption of the trade winds into the region's weaker grids, these flexible electro-chemical processes will be essential in the operational balancing of the Sahara Wind project's GW size HVDC line.

Figure 3: Phosphate rock conveyor belt adjacent to a 125 kV power line near Phosboucraâ

Prices for phosphate rock, sulfur and ammonia, the primary inputs for the production of solid phosphate fertilizers, increased significantly over the past five years. As rock prices more than tripled since 2005, this resulted in higher production costs for the approximately 30 percent of global producers that rely on purchased rock. Since the price of solid phosphates has historically followed the costs of non-integrated producers closely, their higher costs will provide good margin opportunities for producers with their own supply of rock [7].

Significant increases in sulfur prices created conditions for resurgence of other phosphoric acid production alternatives such as electro-thermal processes. In China, for example, the nature of energy production, largely based on hydroelectric generation at a local level, supplied inexpensive power to phosphoric acid plants for many decades. Since thermal acid production is very energy intensive, this advantage has been decisive in China's large thermal phosphorus production capacity. The country's global lead in wind energy generation, which comes with non-negligible grid stability and balancing issues, predisposes wind most favorably in the transformation of phosphates.

c. Transposing China's approach in processing Morocco's Phosphates

While a comprehensive analysis is likely to shed some light in an increasingly resource constrained world, the development of patents and technologies on processes to open these opportunities is of paramount importance. As highlighted during Morocco's first comprehensive R&D meeting with academia held in 2013, China maintained the lead in the numbers of patents around phosphates processing. Matching several times Morocco's processing capacities, China is the world's largest player in phosphates industries. In consuming one-third of the world's ammonia (whose physical properties requiring pressurized containers makes it costly to transport), China is the largest ammonia producer. As the extent of its wind energy leadership is unprecedented, China's example may be indicative on how strategic these integrated industrial renewable energy-intensive combinations can be.

In meeting 96% of its primary energy needs through fossil fuel imports, Morocco is a highly exposed and dependent country. Beyond OCP group's internal policies, Morocco cannot ignore sustainability issues in the energy-intensive processing of its phosphates reserves (the world's largest). In dedicating its earlier Phosphoric acid production facilities for Research and Development work, OCP group intends to tackle this matter with utmost importance. As a priority research area for Morocco under the North Atlantic Treaty Organization (NATO) Science for Peace frameworks aimed at improving regional access to wind energy, OCP group participated in the 'Sahara Trade Wind to Hydrogen' applied research project. From its inception in 2006, through its now dissolved Centre d'Études et de Recherches des Phosphates Minéraux (CERPHOS) branch, OCP group has been involved in the scientific networks co-funded by the Sahara Wind Project. As a result, wind measurement instruments have been installed on telecommunication towers adjacent to OCP Group's phosphoric acid plants. Backed by Morocco's Renewable Energy Law 13-09 [8] which enables Wind electricity to be wheeled directly to industrial end-users in follow-up projects, these measurements will help configure the deployment of wind-driven pilot installations. Within such context a 1.2 Billion USD development is planned after 2015 in a facility located in Phosboucraâ, on the Sahara trade wind coastline (Figure 3). The investments include an integrated chemical complex to produce a broad range of fertilizer products with high flexibility to respond to changes in market pricing for raw phosphate rock [9].

III- Mauritania's iron-ore industry:

a. Origin and importance of Mauritania's iron-ore

Initiated since 1952, and accounting for 28% of Mauritania's GDP which provides over 50 % of the country's total exports in value, iron-ore mining is Mauritania's main industry. The National Mining and Industrial Company (SNIM) of Mauritania in charge of this activity, disposes of reserves estimated in the Billion ton range in the North-West of the country. As Mauritania's largest industrial conglomerate, and Africa's second largest iron-ore exporter, SNIM owns one of the world's longest railroad tracks (650 km) dedicated to ship iron-ore from Zouerate to the port city of Nouadhibou. With the expansion of its harbor, SNIM aims at tripling its current 13 Million ton/yr iron-ore exports to over 40 million ton/yr by 2025 [10].

b. Prospects for integrative value-added processing of the region's iron-ore

Beyond this capacity expansion, as exports are split between Europe and China, Mauritania's iron-ore markets will gradually require local processing. Europe's environmental regulations limiting iron-ore dusts in its harbors have already led SNIM to consider pre-processing alternatives for its ore exports. For this to happen, an effect of scale will be needed. Due to its rather modest size, Nouadhibou's harbor disposes of limited power generating capacities. This prevents any energy-intensive processes from being engaged locally. The example of the SAFA foundry is quite indicative of the situation. As a subsidiary of SNIM, SAFA disposes of several electric arc furnaces and steel induction ovens. Used for making spares for its parent company, their operations are hampered by the city's lack of power generating capacities.

Being located on the Sahara trade wind coastline, Nouadhibou disposes of an outstanding, if not exceptional wind resource. From wind measurements taken on-site as part of our regional collaborative frameworks with the University of Nouakchott, the recorded wind speeds could generate wind-electricity at very competitive costs. Due to its availability (with over 45% capacity factor), high wind energy penetration rates can be achieved. Provided as firming mechanism, a variety of synergies can be engaged for the production and storage of valuable feedstock. From initial utility desalinated water and water treatment applied solutions, these can gradually be extended to cover the local value-added, energy intensive processing of iron-ore. Taking the University of Nouakchott's green campus wind-hydrogen storage system as an example, integrated electrochemical processes such as iron-ore Hydrogen direct reduction processes can be tested. Smaller in capacities, direct-reduced iron plants would enable the local absorption and firming of erratic wind-electricity generation. This in turn, could lead to the development of a high-grade, sustainable carbon-free steel industry.

c. Current strategies engaged in building capacities towards renewables

As the University of Nouakchott extended its mineral engineering department processing, the training and development of pilot applications with the country's iron-ore conglomerate SNIM, is likely to be facilitated. Both institutions already made significant investments in renewable energy technologies. Besides its Hydrogen wind-electrolysis system and as Mauritania's largest University, the University of Nouakchott was endowed with a 30 million US$ Grant from the United Arab Emirates to build a 15 MW Photovoltaic system near its new campus. This facility added 10% of Mauritania's entire electric generating capacity. Besides considering a 3MW Photovoltaic array, SNIM already commissioned Mauritania's first wind farm consisting of 16 wind turbines built for a cumulative capacity of 4.5 MW. Within such context, a fruitful collaboration can be foreseen.

IV- Regional context for the Sahara Wind Project

In addition to the possibility of transforming Mauritania's large iron-ore deposits of into steel derivatives using similar electro-chemical processes, this energy-water and global food nexus will likely become a central issue in the years to come. They represent multi-generational global sustainable development imperatives that will mobilize the region's industries for some time.

Since large shares of national budgets are dedicated to the education sector in both Morocco and Mauritania, the development of sustainable energy consumption schemes remains a critical issue. Political support for these perspectives is significant as these technologies can address the region's current economic challenges. Fossil fuels dependencies are indeed responsible for most of Morocco's and to a lesser extent Mauritania's structural trade deficits. The appropriation of wind technologies will therefore contribute to mobilize the region's youth in the development of a more inclusive energy economy capable of addressing North Africa's current underemployment challenges.

While the 1000 MW Integrated Wind Energy initiative of Morocco's utility ONEE [11] co-funded by the African Development Bank will provide an enhanced local wind manufacturing base for this to happen, additional benefits will be drawn from the country's Renewable Energy Law 13-09. By enabling Wind electricity to be wheeled directly to industrial end-users this law is likely to improve the integration of wind energy into the region's smaller grids. Besides its aforementioned export clause, the transferring of wind-electricity directly to industrial end-users opens new opportunities to match power generation with demand.

V- Conclusion: Building resource-backed inclusive wind-energy driven economies

Alike what has been done with China's Phosphate industry, the development of integrated industrial applications based on the earth's most significant phosphates reserves, will enable a renewable energy transition to be initiated. Using sea water as feedstock, the large-scale, cost-competitive incorporation of wind energy to support endogenous energy intensive value-added mineral transformation processes will substantially improve resource efficiencies. With Food Security at stake -since 90% of the Phosphates are used as fertilizers- the carbon free upgrade of the world's most significant Phosphates reserves becomes a key element of global sustainability.

Pooled to Morocco's phosphates industries, the value-added processing of Mauritania's iron-ore deposits is likely to complement this approach and enable a regional bottom-up deployment of renewable energies.

As electricity demand grows at 8% per year in Morocco [12] and Mauritania -provided current growth rates are maintained- the electricity consumption of the region is likely to be quadrupled within 20 years. Besides improving local access to wind-electricity, the Sahara Wind Project High Voltage DC line will transfer substantial amounts of cost-competitive green electricity to North African load centers. The latter will be indispensable to cover North Africa's growing electricity needs enabling the region to sustain its economic development.

Beyond these markets, as the North of Morocco is separated from Europe by the merely 14 kilometers wide strait of Gibraltar, the Sahara Wind Project's HVDC transmission line enables excess intermittent wind power flows to be exchanged with the Iberian Peninsula. The legal basis through the export clause of Morocco's renewable energy law 13-09 or the European Union's Article 09 Directive for meeting the 2020 renewable energy targets, already allow these exchanges to happen.

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