

## Sahara Winds inclusive, proprietary project concept

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### SUMMARY

Introduced in 2002, the Sahara Wind 5 GW-HVDC transmission project's objective was to scale-up wind energy in order to compete against fossil fuels on price parity and create a more inclusive renewable energy economy. To achieve this, a dual scale-up and integrative track was pursued. Scaling-up required conceptual (on-line) visibility. Feeding cheap wind-electricity to regional markets boosts industrial competitiveness and reduces dependence on fossil fuels. While carbon emission reductions in power, industry and transport sectors are critical global climate objectives, the Atlantic trade winds had to be considered as a strategic energy alternative. Hence, to reinforce regional integration within Africa, Sahara Wind teamed-up with Morocco and Mauritania's academic institutions. It obtained funding from NATO's collaborative projects under its energy and environmental security topics. Prior to that, the Sahara Wind project concept was secured with relevant public national and multilateral institutions on a local, regional as well as global scale. Sahara Wind's integrative pathway was consolidated by the Atlantic trade wind's historical dimension, on top of its paleontological footprint which, by shaping ocean surface currents for millions of years led to the accumulation of 71% of the world's known sedimentary phosphates deposits [1] on North African Atlantic shores. Essential to world food security, their energy-intensive processing as fertilizer represents 90% of phosphate uses. Their decoupling from fossil fuel-based processes is detailed in this paper. Although transferring a wind industry is economically justified for a 5 GW project, the supply of remote power markets makes local project integration an essential objective. Through scalable processes with very few state-owned conglomerates involved, a similar approach can also be used to upgrade Mauritania's iron-ore exports into carbon-dioxide-free steel production. Provided sensible regional integration issues are addressed, efficiency gains and social inclusivity objectives are likely to generate jobs. This will mobilize Africa's youth prone to migration. It also changes paradigms on how energy and natural resources are accessed on the continent. Leads for resolving regional disputes hampering North Africa's economic integration are also achievable through a comprehensive, integrative pathway. In retrospect and as a legacy of the trade winds which shaped much of today's globalized world, phosphates are non-substitutable and essential for life. We ought to use them responsibly.

**Keywords:** *Trade winds, Phosphates, Electrolysis, Hydrogen, Fertilizer, HVDC.*

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### NOMENCLATURE

#### Symboles :

W Power, Watts

HVDC High Voltage Direct Current

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### 1. INTRODUCTION

To secure water for agricultural operations in the Sahara desert, the Sahara Wind project founder installed Morocco's first 50kW wind turbine in 1995. Back then, older oil-exploration wells tapped fossil water aquifers that were not replenished. On-site wind measurements confirmed the exceptional quality of the Atlantic trade winds that could be used for seawater desalination. This was reported to Morocco's head of state in 1994. Today, powered mostly by wind to supply water for drinking, irrigation, and the recharging of aquifers, Agadir's

275,000 m<sup>3</sup>/day desalination plant under construction, is the world's largest. Morocco's power generation mix remains - as of today - mostly coal-fired. Besides high CO<sub>2</sub> emissions, a 96% dependence on imported fossil fuels crippled by a rising demand, exposed rural populations with limited access to electricity. Remote from North Africa's load centers, the Atlantic trade wind's relative proximity to larger regional electricity markets provided sound economics for a regional power dispatch justifying an HVDC transmission line infrastructure. This had to become visible for industry, regulators, legislators and the media. As original project developer established in 2002, Sahara Wind sidestepped sensitive regional issues to gather collaborative support for its concept from local governments, utilities and multilateral institutions. The PIMS#3292 'Morocco: Sahara Wind Phase I/Tarfaya (400-500 MW) on-Grid Wind Electricity in a Liberalized Market' [2] threshold capacity with terms of references for a 5 GW-HVDC line submitted to multilateral institutions in 2005, paved the way to significant investments in Morocco's renewables. Unmatched to date, Morocco's 850 MW integrated wind tender remains the world's most competitive at 30\$/MWh [3]. It includes a blade factory with up to 70% investments spent locally. To reinforce its project concept Sahara Wind established a paleontological link between the Atlantic trade winds and 71% of the world's phosphate deposits (USGS-2018), whose exports offsets Morocco's fossil fuel imports. More efficient wind-powered phosphate-rock upgrades can dissociate fertilizers from fossil fuels and cogenerate renewable hydrogen as feedstock for ammonia. Hydrogen can also be used as electro-mobility fuel. A similar approach can be pursued in Mauritania, where wind-generated hydrogen can direct-reduce the country's iron-ore deposits into steels. This is achievable in a carbon emission-free process.

## 2. SAHARA WIND PROJECT SYNERGIES AND IMPLEMENTATION ACTIVITIES.

To secure its concept and establish a formal project framework, Sahara Wind Inc. was registered as a private company in 2002. As original project concept developer for the Sahara Wind project, Sahara Wind Inc. submitted in partnership with CDER the Joint UNDP-GEF-World Bank PIMS # 3292 'Morocco: Sahara Wind Phase I/Tarfaya (400-500 MW) on -Grid Wind Electricity in a Liberalized Market' threshold capacity in 2005. The latter included Terms of References for the 5GW-HVDC line established with Morocco's utility ONEE for evacuating power to regional markets. This project was used as background Intellectual Property Rights to the NATO Science for Peace 'SfP-982620 Sahara Trade Winds to Hydrogen' applied research agreement, endorsed by governmental institutions of Morocco and Mauritania. Additionally, key partners of this NATO funded project included the United States (US State Department), France (CEA), Germany (NRW- Ministry of Economic Affairs & Energy) and Turkey (UNIDO-ICHET).

Sahara Wind's demonstration activities focused on capacity building in Morocco and Mauritania. For that purpose, a wind measurement network was established with telecom operators of Morocco and Mauritania. The system was complemented by Africa's 1st 35kW wind-hydrogen system commissioned at Al Akhawayn University [4] with the 2nd delivered at the University of Nouakchott. A similar green corporate headquarters at Morocco's power and water utilities ONEE located on Africa's second-largest water treatment station was also planned under a subsequent NATO grant. The participation of CERPHOS, the R&D branch of Morocco's phosphate OCP group was instrumental in the elaboration and launch of the NATO SfP-982620 project. Their involvement had to be discontinued upon CERPHOS's dissolution by OCP group's new management team.

In addition to its large-scale, the Sahara Wind project is replicable. This makes it highly strategic. Being transformative, multi-stakeholder interferences makes its implementation difficult. Industrial ties to political establishments tend to leverage short-term vested interests. Largely dominated by resource-backed rent economies, these often diverge from global, more sustainable ones. As a result, protagonists in US presidential elections interfered in Sahara Wind's inclusive capacity building activities. This was the case with the abrupt

cancellations of the field reportage on the NATO SfP-982620 project to be displayed at the NATO Chicago Summit of head of States in 2012, as well as Sahara Wind's participation -as a Moroccan company- to the Clinton Global Initiative Middle East & Africa meeting in Marrakech, Morocco in 2015. The latter event, held against a 12 Million Dollar payment [5] received by the Clinton Foundation as revealed by Wikileaks, proved to be extremely damaging to the Hillary Clinton campaign as she personally conceded, in her 'What Happened' published book [6].

To overcome these challenges, Sahara Wind pursued a broad-ranging set of activities based on its concept promotion, demonstration and the establishment of a project framework. The Sahara Wind project has obviously been presented at multiple conferences and venues (<http://saharawind.com/en/latest-news>), and reached-out to global policymakers for a number of years.

### 2.1 Paleontological footprints of the Atlantic trade winds: the planet's largest phosphate reserves

Resulting from the combined effect of the earth rotation and its temperature differences, planetary trade winds generate - by surface friction - large circular currents over the Atlantic Ocean. Ever since their apparition some 70 Million years ago, their effects can be consistently tracked through geological sedimentary deposits. During this paleontological time-scale (70 to 40 million years ago) referred mostly as the Eocene epoch, trade wind-induced currents pushed large quantities of planktons towards the North African coast.

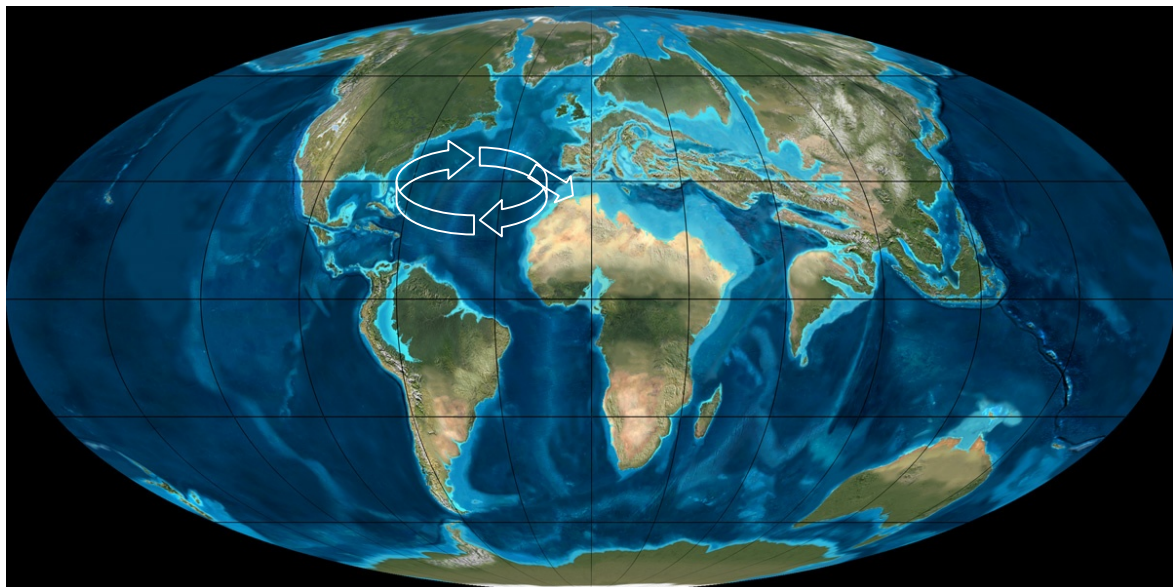


FIGURE 1. Trade Wind-induced currents 50 Million years ago (Eocene-Ypresian epoch) [7]

Independent from climate cycles, the trade wind-induced currents geographically split, dispersed and slowed down by diffusion over North African coastal basins. This led to a substantial concentration of plankton in shallow waters which attracted a very rich biotope. The accumulation of layers of fish remains (mostly Chondrichthyes active in this area) benefited from good conditions for their subsequent phosphatisation. Today, they compose most of 71% of the world's known sedimentary phosphates deposits [1]. Submerged during the Paleocene & Eocene Epoch, as illustrated by yellow triangles on the map over the mining sites of Khouribga, Benguerir, Youssoufia and Boucrâa, these sites represent the largest commercially mined phosphate-rock deposits available worldwide.



FIGURE 2. Phosphate-rock deposits 50 Million years ago (left) and actual sites (right)

Used essentially in the production of fertilizers, Phosphate-rock requires an upgrade into higher value-added derivatives for plant uptakes, such as Phosphoric acid. As Ammonia, which is synthesized through energy-intensive processes, is also needed in the formulation of fertilizers according to the plant's NPK Nitrogen-Phosphorus-Potash elementary requirements, an unprecedented opportunity arises to take advantage of the trade winds.

## 2.2 Renewable Hydrogen, Ammonia and endogenous phosphates fertilizer upgrades

Morocco holds the largest global export market shares of phosphate-rock and phosphoric acid. Producing the latter via common wet-base sulphuric acid processes relies on the availability of sulphur. Supplying 20% of the world's fertilizer market and lacking feedstock, Morocco's Office Chérifien des Phosphates (OCP Group), imports significant amounts of ammonia as well as sulphur. Both are derived from fossil fuels. 95% the Ammonia ( $\text{NH}_3$ ) found in the market is indeed generated from hydrocarbons steam reforming. This carbon-intensive process extracts Hydrogen from hydrocarbons and combines it with Nitrogen from ambient air (which is made of 78% dinitrogen  $\text{N}_2$ ). Over 2% of the world's primary global energy demand is consumed for that purpose. As fertilizer industries -essential to world food security- represent the main end-uses for ammonia, wind-electrolysis generated hydrogen can play a transformative role, as a storage medium in today's renewable energy transition. According to the renewable energy division of the International Energy Agency [8], recent cost reductions in renewable energies, makes large-scale ammonia production plants based on water electrolysis competitive in areas with world-best combined solar and wind resources. Morocco represents one of these cases.

## 2.3 Hydrochloric acid wet-base processing for Phosphoric acid with co-generated Ammonia

With the availability of cheap wind-electricity, chlor-alkali electrolysis requires water and salt ( $\text{NaCl}$ ) mixed in a brine as sole inputs. Hydrogen and caustic soda are generated as by-products. Whereas chlorine can substitute sulphur and sulphuric acid in the production of phosphoric acid, co-generated electrolytic hydrogen can be transformed into ammonia. Prices of phosphate-rock, sulphur and ammonia - the primary inputs for the production of phosphate fertilizers - fluctuate significantly. Considering the extraordinary scale of the region's phosphate and trade wind resources, price stability in fertilizers markets can thereby be secured. Since phosphate-rock prices historically follow costs of non-integrated producers, this also provides good margin opportunities for producers with their own supply of rock [9].



### 3. RESULTS: EXISTING WIND-POWERED PHOSPHATE PROCESSING

Over 554 MW of Morocco's 1 GW current wind capacity operates on the Atlantic trade wind-blown Sahara coastline. Besides urban load centres such as Laayoune and Boujdour that are supplied by wind-electricity, the bulk of the region's electric loads consists in reverse-osmosis desalination plants. In addition to conveying phosphate-rock, they also power their screening and washing prior to exports.



FIGURE 3 Phosphate-rock conveyor belt adjacent to a 125 kV power line near Phosboucraâ

As wind capacities exceed by far the region's loads, local electricity-intensive phosphate-rock upgrades into fertilizer becomes economically viable. Morocco's Renewable Energy Law 13-09, enables wind-electricity to be wheeled directly to industrial end-users. The Phosboucraâ phosphate-rock export terminal is for that matter powered by several wind farms, such as the Foun El Oued 51 MW wind farm (below), adjacent to it.



FIGURE 4. Foun El Oued Wind farm Turbines over Phosboucraâ export terminal (in the background)

Provided that extensions of the 1.2 Billion USD fertilizer plant under construction at the Phosboucraâ terminal are powered by wind, an ideal setting arises for carbon-free upgrades of phosphates into fertilizers. This

investment includes an integrated chemical complex aimed at producing a broad range of fertilizer products with high flexibility to respond to changes in market pricing for phosphate-rock [10].

By scaling-up wind generation capacities and facilitating their absorption in the region's weaker grids, flexible electro-chemical processes will be essential in the operational balancing of the Sahara Wind project's 10 GW-HVDC transmission line.

#### 4. SAHARA WIND PROJECT IMPLEMENTATION AND COSTS

The Sahara Wind 1300 km HVDC transmission project uses state-of-the-art horizontal axis wind turbines. Their type and size will be assessed based on local integration parameters. The project's High Voltage Direct Current line links the Sahara coastline to the Melloussa substation on the strait of Gibraltar where Iberian electricity markets are tapped through undersea cables. Connecting two 5 GW point-to-point AC-DC-AC converting stations on each ends, the double bi-pole HVDC areal line will be oversized for a transmission capacity of 10 GW. As markets and wind potentials are significant, the Sahara Wind project phased roll-out will drive down wind power costs even further.

Components	Capacity	Costs (Million€)
Wind turbines	5 GW	5,000
HVDC Line (double-Bipole-1300km)	10 GW	700
HVDC-undersea cable (14 km)	10 GW	100
AC/DC/AC Converting stations	5 GW	600
Total Costs		6,400

TABLE1. Sahara Wind project indicative costs

Based on the latest 850 MW wind tender, local content on wind investment projects already exceeds 55% and can reach up to 70% [11]. The Sahara Wind project's larger scale provides over 80% spent in local contents. Whereby specific AC-DC-AC converting stations technologies are hardly transferable, all towers, cables, insulators, electrical and civil works of the HVDC line can be sourced locally. Phosphate-rock extraction, screening and washing for exports are already powered at 95% by wind energy on the Sahara coastline [10]. Technology providers are currently testing wind-ammonia and electro-intensive phosphate upgrades into fertilizer namely in phosphoric acid processes (thermal and wet-base hydrochloric acid) in pilot projects. Backed by outstanding wind data production figures, the Sahara Wind project's scale validates on-going research by industry, academia and the IEA's recent studies supporting a transition model for fertilizer industries. With a planned Sub-Saharan Africa-Europe AC interconnection at Nouadhibou, the prospects of direct-reducing Mauritania's iron-ore into pure iron and carbon-free emission steels using wind power, can rely on SAFA's experiences. This local foundry operating a set of electric arc and induction ovens is a branch of Mauritania's iron-ore conglomerate SNIM. The latter is fed by a small 4.4 MW wind farm, while 100 MW are under construction [12]. This provides an ideal setting for introducing CO<sub>2</sub> emissions-free wind powered direct-reduction steel plants that are currently being tested in Sweden [14].

The Sahara Wind project provides therefore good visibility for a wind-industry transfer and local scale-up. Capable of generating electricity at approx. 20€/MWh, the 5 GW Sahara Wind project can mitigate the emissions of 13.5 Million tons of CO<sub>2</sub> per year. The project can grow on its 10 GW-HVDC transmission capacity line. It is also expandable and replicable as trade wind potential, land availability and EU-African

power markets are significant. Disposing of North Africa-Middle East's largest wind capacity, operational in majority on the Sahara coastline, and with an additional 1300 MW under construction, Morocco is likely to meet its 2020 renewable energy targets. Although higher ones have been listed for 2030 at 52% of renewables in the overall generation mix [13], they are still below Sahara Wind's 5GW capacity and its 10 GW-HVDC transmission line extension. In Mauritania, Sahara Wind's capacities built with support from UNIDO, NATO at the University of Nouakchott have been complemented by grants and investments from Arab states of the Persian Gulf. Similar to Morocco's solar plans, and although shy of Sahara Wind's more competitive regional energy transition, these could facilitate individual INDC country achievements of the Paris agreement.

## 5. CONCLUSIONS: GLOBAL PROSPECTS AND REPLICATION POTENTIAL

The Sahara Wind project's inclusive access to the Atlantic trade winds feeds local, regional and intercontinental power markets. Subsequent to its 2002 introduction, China has since built several 10 GW wind power bases connected to long distance HVDC lines. To date, very few projects of similar scales can be built outside of China. African-European gas infrastructures allow for complementary, significant wind capacity to be fed into power grids in a price-competitive, low-carbon mix. In addition to fostering inclusiveness of mineral and fossil fuel extractive industries, energy security is also enhanced through a diversification of supply. As electricity and heat generation are respectively responsible for approximately 25% of global greenhouse gas emissions each, decarbonizing industries, which emit an additional 21% is a key challenge. China's fertilizer and steel industries - the world's largest and worst emitters- can help absorb 20-35 GW of wind energy added yearly to that country's power grid. Backed by outstanding trade-wind resources, the Sahara Wind project provides a business case enabling the development of emission-free fertilizer and steel processing technologies for industry. Pilot projects for CO<sub>2</sub>-free steels in Scandinavia [14] and wind-ammonia in the UK [15][16] are currently tested only under marginal wind conditions. To ensure its food security, China's phosphates demand listed at 130 million tons/year (85 million tons/yr according to industry analysts) [1] is twice the world's international phosphate export market, of which Morocco holds the most significant share. China disposes of the second largest world phosphates reserves (~5%) likely to be depleted within 20 years. Within such context, Morocco's reserves remain a critical global asset. As a legacy of the trade winds, this compels us to access them more responsibly. Upgrading extractive mining operations through cleaner, value-added processing industries will also consolidate the transfer of a more inclusive renewable energy industry. Wind turbine component manufacturing and servicing industries are already established in the region. These may end-up being sourced with local steel, copper, cement, composites etc. in a far cleaner, cheaper and more efficient global economy.

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