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PERSPECTIVES

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Preparing for the future: Solar energy and bioeconomy in the United Arab Emirates

Abstract
Solar energy and the bioeconomy are emerging as two new important assets of the United Arab Emirates' economy. The consequences identified in this study offering guidelines to foster their practical development span from higher education and international student recruitment, through new entrepreneurship from local and foreign entrepreneurs and investors.

1 | INTRODUCTION

Located along the southeast coast of the Arabian Peninsula, the United Arab Emirates (UAE) comprises seven emirates covering an overall area of around 84 000 km^2. With a population of almost 10 million (from 1 million in 1980), the country is the world's seventh largest crude oil producer (2.97 million barrels per day in 2018) and holds the seventh largest natural gas reserves globally with 12.11 billion m^3 of natural gas exports only in 2018.[1]

The UAE started to diversify its economy several years ago, and today, about 30% of the country's gross domestic product (GDP) is directly based on oil and gas output.[1]

Starting from the late 1990s, a new tourism and hospitality industry was created almost from scratch,[2] Today, the country operates two of the world's largest airline companies. Hosting almost 89 million international passengers in 2018, Dubai International Airport ranked first in the world's ranking of international airports by total international passenger traffic,[3] when the number of international visitors received by Dubai almost reached 16 million (15.92 million visitors).[4] Five years before, in 2013, the figure amounted to 10.4 million.[5]

Higher education is another sector in which, thanks to public and private investments, the number of higher education institutions went from no tertiary education available in the country prior to 1976 to current around 180 tertiary institutions.[6]

Currently focusing efforts on international student recruitment (particularly from the Indian Subcontinent and from Africa) thanks to its geographic position as well as to the international standing of the educational offer,[6] starting in the early 2000s, the country became in a few years also the "largest higher education hub of international branch campuses globally."[7]

In this context of rapid change, expanding the adoption of solar energy to generate electricity and heat was one of the first objectives of the country's new policies aimed to foster social and economic development. Today, the UAE hosts in Abu Dhabi the headquarters of the International Renewable Energy Agency (IRENA), whereas the "Noor Abu Dhabi Solar Park" completed in early 2019 in Sweihan, with its nominal power of 1.177 GW, is currently one of the world's largest solar photovoltaic power stations.

Along with renewable energy, health and water are three of the seven science-dependent sectors in which the UAE plans to feature among the world's most innovative countries according to the "Vision 2021" long-term plan setting in 2010 the key themes for the country's social and economic development.[8] Transport, education, technology, and space are the other four sectors identified by the plan.

In brief, by 2021 when the UAE will celebrate the golden jubilee of the union realized in 1971, the UAE aims to "benefit from a sustainable and diversified economy, flexible in adopting new economic models, and capitalising on global economic partnerships to guarantee long-term prosperity for current and future generations of Emiratis."[9]

In a global context of unprecedented progress in both clean energy and in the bioeconomy, solar energy and the bioeconomy will emerge as two key assets of the overall country's forthcoming economy.

The consequences identified in this study offering guidelines to foster their practical development span from higher education and international student recruitment, through new entrepreneurship from local and foreign entrepreneurs and investors.

2 | SOLAR ENERGY IN THE UAE

In the UAE, clear sky conditions exist throughout most of the calendar year (monthly average clearness index in Abu

Dhabi at a constant value of approximately 0.58),[10] with an yearly average daily energy input of 513 kWh (18.48 MJ)/m^2/d.

This means that, at today's low cost of solar photovoltaic (PV) energy due the global boom of the this technology,[11] the UAE can rely on PV energy to meet most of its today's and tomorrow's electricity needs without the need to deploy expensive Feed-in-Tariff incentives as it happened in Germany, Italy, and Spain in the early 2000s; but rather by deploying utility-scale and distributed generation solar photovoltaic and solar thermal plants.

2.1 | Utility-scale PV electricity generation

The UAE already benefits from today's historic low cost of PV energy, having directly switched to power purchase agreement (PPA) renewable energy contract schemes. For example, owned by a special purpose vehicle company comprising Abu Dhabi Water and Electricity Authority and two private companies from Japan and China, the 1.177 GW “Noor Abu Dhabi Solar Park” (Figure 1) started operation in early 2019.

In early 2017, the consortium due to manage the solar park won the 25-year PPA bid for the generation of 1.177 GW offering a selling price of \$0.0242/kWh,[12] with a 1.6 times higher price paid during the peak demand months of June to September, for an overall levelized cost of electricity of \$0.0294/kWh.[13]

In 2017, the UAE launched its first unified energy strategy (“Energy Strategy 2050”), according to which the nation aims to have renewable energy sources contributing to 44% of its total energy demand by 2050.

In closer detail, along with a 40% reduction in the energy demand (vs the “business as usual” scenario) thanks to improvements in energy efficiency, by 2050 the strategy targets an energy mix combining renewable energy with nuclear, coal, and natural gas thermoelectric generation to meet the UAE's projected energy needs as follows[14]:

44% renewable energy
38% natural gas
12% coal
6% nuclear power.

Yet, contemporary planning is flexible in nature: At today's fast pace of decline of both PV energy and energy storage in Li-ion batteries and in solar hydrogen,[15] we argue herein, by 2050 the country will have no difficulty to meet all of its energy demand by solar energy only.

Indeed, the Dubai Emirate already set a 75% renewable energy target by 2050 (translating into a production capacity of 42 GW of renewable energy capacity by 2050). On June 2019, the Emirate issued the first request for proposal for appointing consultants to investigate the feasibility of solar PV plants floating even in its inner ocean waters.

The same Emirate has already awarded the first 1000 MW of the 5 GW “Mohammed bin Rashid Al Maktoum Solar Park,” a solar park using both PV and concentrated solar power (CSP) technologies, over a total area of 77 km^2 about 50 km south of the city of Dubai.

Bids for 1000 MW of PV power have already been awarded under a 25-year PPA. Comparison between the \$0.0584 kWh tariff for the phase II of the latter project concerning 200 MW commissioned in 2016,[16] and the \$0.0294/kWh tariff of the “Noor Abu Dhabi Solar Park” renders the pace of the cost decline of solar PV energy.

At the current rate of progress and installation of new solar parks, reviewing the state of the art concerning UAE's large solar parks would provide rapidly obsolete information. It is more relevant to notice that phase II of the aforementioned 200 MW solar park took place by installing more than 2.3 million large (12 m × 6 m) thin film solar modules over an area of 4.47 km^2 with 1.5 million man-hours without a single worker injury during project execution.[17]

This shows that a few months of work (works lasted 12 months and the solar park was inaugurated on March 2017) of an educated workforce comprised of more than 900 workers guided by managers and engineers of international standing are enough to complete construction of utility-scale PV plants capable to generate significant amounts of electricity.

Under these conditions, the last obstacle for the full transition to solar energy for countries like the UAE receiving huge amounts of solar irradiatiance, while having access to similarly large desert areas, is the access to economically viable utility-scale storage solutions.

Energy storage in today's digitally controlled Li-ion battery energy systems already provides the flexibility to better integrate intermittent solar PV energy into the electric grid and ensure high-quality power for consumers.

FIGURE 1 The Noor Abu Dhabi 1.177 GW solar park in Sweihan, UAE, comprises 3.2 million PV modules. [Photograph via Google Earth, June 2019]

One single example is enough herein to understand its relevance to UAE's energy transition, namely the 25-year PPA at a price of $0.1085/kWh signed by an electric cooperative with the project developer which built and owns a 28 MW solar PV station paired to 100 MWh battery energy storage capacity in the Hawaii's island of Kaua'i (Figure 2).

Fully analogous to a thermoelectric power plant, but requiring no fuel and generating no waste and no toxic emissions, the new solar unit coupled to eight independently controlled battery energy storage systems containing more than 17 000 Li-ion batteries (cobalt-free) provides approximately 11% of Kaua'i's power, bringing the island's share of renewable power to more than 50%.

Indeed, in early 2019 the city of Abu Dhabi started to operate a set of 15 sodium-sulfur battery systems (twelve 4 MW systems and three 20 MW systems) deployed across 10 locations (but controllable by the transmission system operator as a single system) adding 108 MW of power and 648 MWh of capacity, namely energy to provide 108 MW of backup power for 6 hours in case Abu Dhabi's electricity grid failure.[18]

The investment in the battery energy storage system enabled significant savings, because deploying 1 MW of battery energy storage allows to increase the energy availability “by about 10% avoiding the investment in about 1.1 MW of combined cycle (gas and steam) thermal power plants,”[18] while the operation and maintenance costs for battery systems are “significantly lower than equivalent costs for thermal generation plants.”[18]

2.2 | Distributed generation

In general, the availability of affordable battery energy storage systems enables the shift to off-grid distributed generation, starting from street solar lighting systems with PV modules and digitally managed storage systems.

In the first decade of the 2000s, selected UAE locations pioneered the use of solar lighting systems, namely of off-grid street lights using light-emitting diodes (LEDs) as light sources powered by batteries charged during the day by one or more integrated PV modules.[19]

One remarkable example is the set of solar lighting poles installed in a road of Masdar City able to resist to several days of sand storm thanks to advanced maximum power point tracking, temperature compensation, and battery state of charge algorithms capable to manage the fixture's light output and adapt to low power input conditions due to dramatically reduced sunlight during sandstorm days.[20]

A decade later, several million of these systems are being installed across the world, not only in developing countries with regions not yet served by the electricity grid, but also in affluent countries where the ever-increasing electricity bills are no longer economically sustainable.

The technology has evolved rapidly also from the aesthetic point of view. Today, for example, the solar cells are also integrated in the mast resulting in solar lights nicely integrating with the urban built environment to illuminate parks (Figure 3), parkings, pedestrian areas, streets, and commercial and residential areas.

The 92 lights lately installed in 12 parks in Dubai, for example, are particularly well suited for the UAE as the vertical integration of the solar cells limits silting and the need for cleaning, whereas the selected battery technology (NiMH) ensures prolonged resistance to very high temperatures, resulting in 10 years of guaranteed operation without battery replacement.

Similar progress will concern rooftop solar PV finally growing at fast pace in the whole country with around 200 MW of rooftop solar connected to the UAE grid in 2018 (mostly at government, commercial, and industrial buildings).[21]

We have recently suggested how, at today's historic low prices of PV systems, the general adoption of rooftop solar

FIGURE 2 The 28 MW solar PV park coupled to 100 MWh battery storage system in Hawaii's island of Kaua'i. [Image courtesy of AES Distributed Energy]

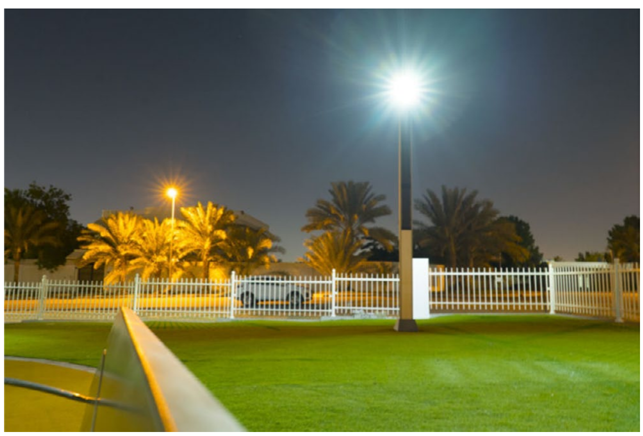

FIGURE 3 One of the solar street lighting systems with children's playgrounds installed by the Municipality of Dubai in 12 parks in the city's main residential areas. [Image courtesy of Sunna Design]

energy in Mediterranean countries requires proactive and creative role of policy makers, called to simplify and update old construction regulation making long and costly the permit process to functionalize buildings with solar modules, as well as to exchange energy with the grid.[22]

Indeed, as noted by a research manager at Middle East Solar Industry Association (MESIA) at the end of 2018, "while Abu Dhabi and Dubai have net metering schemes in place, the other Emirates do not have such mechanisms in place just yet, so the regional governments must take action to help boost rooftop solar proliferation in the country."[21]

Together with battery energy storage, accumulating the self-generated PV electricity in solar hydrogen allows to provide emission-free electricity and heat to entire buildings.

Again, one single example is enough to understand why this technology will shortly find widespread utilization also in UAE. In autumn 2019, the world's first multistory houses will be inaugurated in Vårgårda, Sweden.

Here, a first block of 30 energy self-sufficient flats now will run entirely on solar energy and stored solar hydrogen. Eventually, all 6 council houses (172 flats) currently being refurbished by the Vårgårda housing company will entirely rely on the electricity generated by the 109 kW rooftop PV systems installed on each expanded and refurbished building.[23]

At high Sweden's latitude, each PV system is expected to generate 87.000 kWh/y, mostly generated between April and September. Electricity not immediately consumed is used to locally produce via water electrolysis 10 400 Nm^3 H_2 per house which are and stored under pressure in composite reservoirs.

Hydrogen has high energy density (40 kWh/kg), and the amount of H_2 locally produced at low cost and stored for winter needs is enough to supply the off-grid houses for the whole year with emission-free electricity and heat in the form of hot water generated by hydrogen fuel cells.[23]

What is also relevant is that the complete system solution enabling 24 hours supply of high-quality energy from renewable solar energy only for 365 days (8760 hours) is a combination of a number of key technology components with digital technology and system logics,[24] developed in this case by the complete solution provider, acting as a system integrator.[23]

In this way, Sweden which like many other countries is struggling with a large number of outdated and energy inefficient housing estates and has shown how in practice solar energy and hydrogen generation (via electrolysis) and recombination (in fuel cells) technologies can solve practical problems of large societal relevance such as energy consumption in buildings.

If this can be done in a region of Sweden, where the average annual sum of global horizontal irradiation (GHI) does not reach 800 kWh/kWp,[25] it will be easier and less costly in UAE where the same photovoltaic power potential (measured between 1999 and 2016) approaches 1800 kWh/kWp.[23]

3 | BIOECONOMY IN THE UAE

In the bioeconomy, useful energy is obtained from renewable energy sources whereas the valued substances currently mostly obtained from oil are rather derived from biological resources.[26] When said biological resources are of marine origin, the "blue bioeconomy" term is also frequently used.

Prior to the discovery of commercial petroleum in 1958 (onshore in the Bab-2 well and offshore at Umm Shaif), fishing in the UAE was a crucially important domestic source of food production, otherwise restricted by desert conditions of a large portion of the overall territory.

Sixty years later, fisheries continue to be an important domestic source of food production,[27] even though the overall amount of fish caught significantly declined to 75 287 tonnes in 2017.[28]

Remarkably, one of the reasons explaining the 24% decline in UAE's fishing between 1999 when it was estimated at 118 000 tons (with 7681 fishing boats registered) and 2008 when it reached 90 000 t (with 5571 fishing boats) was the high cost of diesel fuel which led "fishermen to reduce their trips to avoid costs."[29]

On March 2017, Abu Dhabi hosted the *4*th *Forum on Innovations in Agriculture*. The conference focused on the blue bioeconomy, namely on the benefits from using underutilized, renewable and abundant marine biological resources.

Addressing the audience, a government representative explained the numerous measures taken by the country to promote sustainable fisheries, food security, and food diversification in the UAE. To address overfishing and protection of the marine environment, new legislation and new investments in monitoring and research were deployed.[30]

The leftovers of fish, and of blue fish such as anchovy in particular, are a rich source of omega-3 polyunsaturated fatty acids easily extracted with limonene,[31] an edible biosolvent exerting multiple health benefits.

Widely consumed across the world as dietary supplements, omega-3 nutrients of marine origin are generally much less consumed (very low mean consumption, <100 mg/d)[32] in Sub-Saharan African and Asian regions as well as North Africa/Middle East, including the UAE, representing 66.8% of the world adult population.

Remarkably, a recent global survey of the omega-3 fatty acids, docosahexaenoic acid, and eicosapentaenoic acid in the plasma lipids of healthy adults revealed that populations of Japan, Scandinavia, and areas with populations "not fully adapted to Westernized food habits"[33] have the highest omega-3 blood levels (Figure 4).

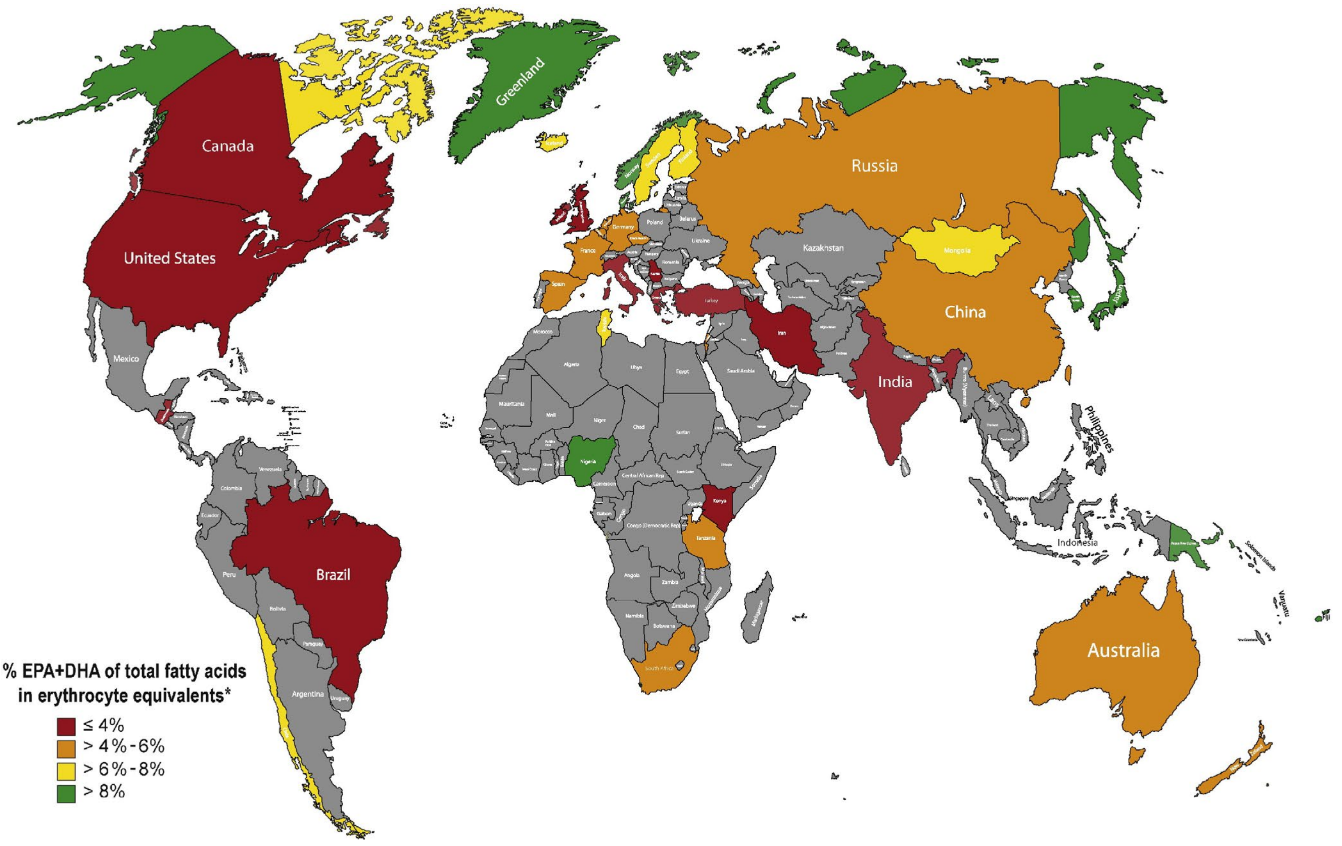

FIGURE 4 Global blood levels of the sum of eicosapentaenoic acid and docosahexaenoic acid. [Reproduced from Ref.[33] with kind permission]

Though depending on several factors including high personal income (wealth) and the quality of the respective national health services, it is instructive to notice that Japan and Scandinavia are amid the countries and regions with the longest life expectancies.

Fish processing by-products are usually discarded as organic waste.[34] On the other hand, driven by the growing awareness regarding omega-3 health benefits, the fish oil global omega-3 supplements market, valued at $27.60 billion in 2016, is expected to reach $57 billion by 2025.[35]

The diversified fisheries of UAE are likely to start soon to source valued omega-3 ingredients using innovative green technology from fish leftovers,[31,34] with significant environmental, economic, and social benefits for the whole country.

Getting to agricultural residues, over 1.5 million tonnes of agricultural and landscaping residues were estimated to be produced in United Arab Emirates, most of which is date palm waste in the form of dry leaves.[36]

Mostly composed of cellulose, hemicellulose and lignin palm, fronds are an excellent raw material suitable for furfural production. Scholars based in Malaysia reported in 2016 an entirely biobased process based requiring only ethanol (in supercritical state) and formic acid to afford furfural from palm oil fronds in 35.8% yield.[37]

Commercially used as a platform chemical since 1920s, and currently produced at 280 000 t/a rate exclusively from food crop residues and wood waste, furfural is an exceptionally versatile platform chemical.[38] Reducing its cost through easily scaled new green chemistry processes would even allow to restart production of nylon-6,6 as it happened during 1950s until the process was discontinued in 1960s when oil-derived tetrahydrofuran, the key intermediate, became available.

Another example rendering the bioeconomy potential in the UAE is *Opuntia ficus-indica*, a drought-tolerant cactus plant widely present also in the UAE where since the early 2010s the Dubai-based International Centre for Agricultural Research in the Dry Areas has been promoting it as a cheaper and water-efficient animal feed.[39]

Beyond affording exquisite fruits (prickly pears or barbary figs) for human consumption, and stems (cladodes) containing >90% water used as excellent forage, the plant has lately become a source of valued ingredients increasingly used in nutraceutical, personal care, and cosmetic products.[40]

In Tunisia, for instance, some 800 farming companies supply barbary figs coming from 2500 hectares to companies that extract the oil from the fruit's seeds. The oil is widely considered the best "beauty oil" available today to cosmetic companies, and annual revenues of Tunisia's barbary fig seed oil currently exceed $80 million.

4 | GUIDELINES AND PERSPECTIVES

Three main guidelines aimed at UAE science policy, and policy makers emerge as a consequence of the rapid progress in clean energy and bioeconomy briefly discussed in this study.

1. Newly developed education in solar energy[41] and in energy management,[42] reshaped so as to integrate clean energy science and technology with management and economy, should become a key asset of UAE's higher education institutions. Targeting graduates in physical science and engineering, as well as in economic disciplines including management, said cross-disciplinary courses would attract both local and international students as the lack of an adequate educational offer in both solar energy[43] and energy management[44] is a well-known global issue affecting many countries.
2. Practically oriented education in green chemistry focusing on the achievements and the obstacles to green chemistry in today's chemical industry[45] would further diversify and enhance the attractiveness and relevance of the educational offer of UAE's universities. Along with solar energy photovoltaic and photothermal technologies, indeed, green chemistry and biotechnology are the scientific and technology enablers of the bioeconomy.
3. To strengthen economic activity in the bioeconomy and in solar energy, entrepreneurs and managers active in the UAE should be proactively involved. What is recommended here is the activation of short and practice-oriented meetings aimed at UAE managers and entrepreneurs called to catch the opportunities offered by new clean energy and bioeconomy solutions.

Business opportunities abound. Alone, distributed generation via the city rooftop solar has huge occupational and economic potential.[46] There is no shortage of new technology nor of affordable solutions. What is evident in most world's countries with regard to clean energy and the bioeconomy is the shortage of talented young scientists, engineers, and even managers to meet the global market demand.

"How will the emerging bioeconomy secure the necessary people in light of impending retirements, work age gaps, and lack of youth interest in science, technology, engineering and mathematics?,"[47] biotechnology scholars in the US lately asked.

Noting that the speed of change is too rapid for the conventional educational system being able to react and provide the needed young talents, the same scholars suggested the development and uptake of informal learning comprised for example of full immersion into the operation of a biorefinery via experimentation and learning in a virtual reality environment.

In this context of accelerated change, the United Arab Emirates with their central geographic position between Asia, Europe, and Africa are eminently poised to become an educational and industrial hub in the "next major economic wave in human activity"[47]: the nature- and solar-driven bioeconomy.

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KEYWORDS

bioeconomy, higher education, hydrogen, solar energy, UAE

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