Emirati-German
Energy and Climate Partnership
الشراكة الإماراتية الألمانية في مجال الطاقة والمناخ

Exploring the Potential of Wind Energy in the United Arab Emirates

Prepared on behalf of the German Federal Ministry for Economic Affairs (BMWK) in cooperation with the UAE Ministry of Energy and Infrastructure (MOEI)

Imprint

Publisher
Emirati-German Energy and Climate Partnership

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Albrechtstraße 10c
10117 Berlin
Germany
www.guidehouse.com

Date
November 2023

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This publication is commissioned on behalf of the Federal Ministry for Economic Affairs and Climate Action. Guidehouse supports the Federal Government in various projects to implement the energy and climate policy goals within the framework of the energy transition.

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Abbreviations

CAPEX	Capital expenditure
CO_2	Carbon dioxide
COP28	28th UN Climate Change Conference
CSP	Concentrated solar power
EEZ	Exclusive Economic Zone
EU	European Union
GW	Gigawatt
IEC	International Electrotechnical Commission
kWh	Kilowatt-hour
LCOE	Levelized costs of electricity
LCOH	Levelized costs of hydrogen
MENA	Middle East and North Africa
Mt	Megaton
MW	Megawatt
PV	Photovoltaic
RNFBO	Renewable Fuels of Non-biological Origin
TWh	Terawatt-hour
UAE	United Arab Emirates
US	United States

Executive Summary

This study shows that the United Arab Emirates (UAE) offers favorable onshore wind conditions to accommodate up to 80 gigawatts (GW) of generation capacity.

The Western and Southwestern part of the UAE with an area of about 16.500 km² offers moderate wind conditions with a mean wind speed of at least 7.5 m/s at 150 m height. State-of-the art wind turbines for moderate wind conditions have a generation capacity of up to 7.2 megawatts (MW) and lifetimes between 20-25 years. Based on state-of-the-art wind turbine technology and typical wind farm layouts, around 11.200 wind turbines could be deployed. Even when using only 60% of the area with mean wind speed above 7.5 m/s, the onshore wind energy potential would still be higher than the total electricity consumption of the UAE in 2021.

The offshore wind energy potential in the UAE is limited because of low wind speeds and high technology costs.

Investment costs for offshore wind energy plants are significantly higher than for onshore wind energy. This is even more the case for floating than for fixed-bottom offshore wind energy plants. Even if technology costs continue to fall, they will probably remain higher than for onshore wind for the foreseeable future. In many countries, low levelized costs of electricity (LCOE) can still be achieved with offshore wind energy due to the higher wind speeds on sea. The substantial investment costs of offshore wind are offset by the high wind speeds on sea leading to attractive overall LCOE. This would not be the case for the UAE as wind speeds in territorial waters are lower than on land.

The development of onshore wind diversifies the energy mix and supports the system integration of renewables.

Onshore wind can help to better balance supply and demand characteristics in a system with high share of renewables. It can provide clean electricity when the sun is not shining. As a result, with a more diversified mix of renewables including onshore wind, residual load will be less often and less costly to serve.

Combining wind and solar resources allows for a higher utilisation of electrolysers to produce renewable hydrogen, resulting in lower levelized costs of hydrogen (LCOH).

Europe as a future reliable partner for imports of hydrogen, has set ambitious requirements for renewable hydrogen. Meeting these requirements with only PV will result in high LCOH due to low utilization of the electrolyser. Onshore wind energy can complement PV systems to reach high full load hours for renewable hydrogen production in a cost-effective way. With a view to the rising clean energy demand in the Gulf region and beyond, a timely run up of the value chain for wind technology is a critical chance for the UAE to underline its ambition to become the renewable energy powerhouse of the Middle East and North Africa (MENA) region and a leading hydrogen exporter.

1 Introduction

As host of the 28th UN Climate Change Conference (COP28), the UAE are in the spotlight of the global community to facilitate and promote effective climate action.

Countries across the globe are leveraging technology to decarbonise their economies to limit global warming to 1.5 °C in accordance with the Paris Agreement on climate change.

The UAE are committed to reaching net-zero emissions by 2050.

The deployment of renewable energy solutions is one of the main pillars of the UAE's approach for reducing greenhouse gas emissions. Against the backdrop of the UAE Net Zero strategic initiative announced 2021 the UAE has revised its long-term energy strategy and assessed clean technologies needs to meet rising electricity demand. By 2030, the UAE government wants to at least triple renewable electricity capacity from currently 3.5 GW to up to 14.2 GW.[1]

Large amounts of renewable electricity are required to meet the UAE's growing electricity demand.

Driven by spiking electricity use in industry, growing cooling demand, and electrification of transport, the UAE expect domestic power demand in the year 2050 to be close to three times the current levels. Moreover, the UAE want to become a major supplier of low-carbon[2] hydrogen in key offtake markets, such as Europe, Japan, and South Korea.[3] By 2031 most of the hydrogen produced in the UAE should be renewables-based, that is around 1 Metric Tonnes Per Annum (MTPA) of the 1.4 MPTA low-carbon hydrogen production target.

The use of all available renewable energy resources will be key for a fast, successful energy transition and for meeting future electricity demand.

Renewables expansion in the UAE so far has been focused on solar technologies. Aside from being blessed with high solar irradiation, the country also has wind energy potential that is largely untapped. Technological advances and cost decreases have made wind electricity an economically viable option also in areas of relatively low wind speeds.

Wind energy deployment could bring about significant benefits for the UAE.

This study assesses the country's potential for wind power generation from both onshore and offshore plants and contrasts it to other regions. Based on the potential identified, it discusses the future role wind energy can play for the UAE, considering its benefits for decarbonisation, energy diversification, system integration, and green hydrogen production. Finally, it derives recommendations for policy makers how to capitalise on the UAEs wind energy potential and making it a steppingstone on the country's path to net zero.

2 Onshore Wind Energy Potential in the UAE

In the Middle East, the first onshore wind energy projects have been successfully implemented. The 117-Megawatt (MW) Tafilah Wind Farm is the first commercial utility-scale wind power project in the Middle East, and largest privately financed wind farm in the Hashemite Kingdom of Jordan. The USD 287 million project became operational in 2015.[4] In the Sultanate of Oman, the first windfarm started operations in 2019 in Dhofar with a capacity of 50 MW.[5] In 2021, the Kingdom of Saudi Arabia commissioned its first utility-scale wind farm with the 400 MW Dumat Al-Jandal plant.

Compared to other countries in the region, onshore wind energy in the UAE is still in its infancy. The first and up to today single wind turbine in the UAE started producing electricity in 2008 on Sir Bani Yas Island in Abu Dhabi. The turbine is 65 m tall and has a capacity of 850 kilowatts. In 2021, Dubai Electricity and Water Authority (DEWA) preliminary identified Hatta as a potential site for a 28 MW wind farm. DEWA launched a feasibility study based on an one-year measurement of the wind speed in Hatta.[6] In October 2023, the UAE Wind Program was commissioned by Masdar with 103.5 MW capacity at locations in Abu Dhabi (Sir Bani Yas island, Delma island, Al Sila) and Fujairah (Al Halah). The program aims to demonstrate the viability and competitiveness of wind energy in the UAE. 23 turbines with 4.5 MW capacity each have been deployed.[7]

This chapter assesses the UAEs potential for onshore wind energy. It first examines the geographic and meteorological wind conditions in the UAE on land (section 2.1). Based on this, it estimates the technical potential for onshore wind energy (section 2.2).

2.1 Onshore wind resource assessment

UAE's total land area is nearly 82,880 km².[8] Looking at the total area, there are on the one hand regions that are generally not suitable for onshore wind energy, because of physical and technical constraints (e.g., slopes, altitudes), already existing constructions (e.g., infrastructure, buildings) or areas with legal constraints. On the other hand, areas can be identified that are particularly attractive for the development of onshore wind energy due to favourable wind conditions. This study assesses the latter to estimate the geographic and technical potential for onshore wind in the UAE.

2.1.1 Spatial resolution of wind conditions

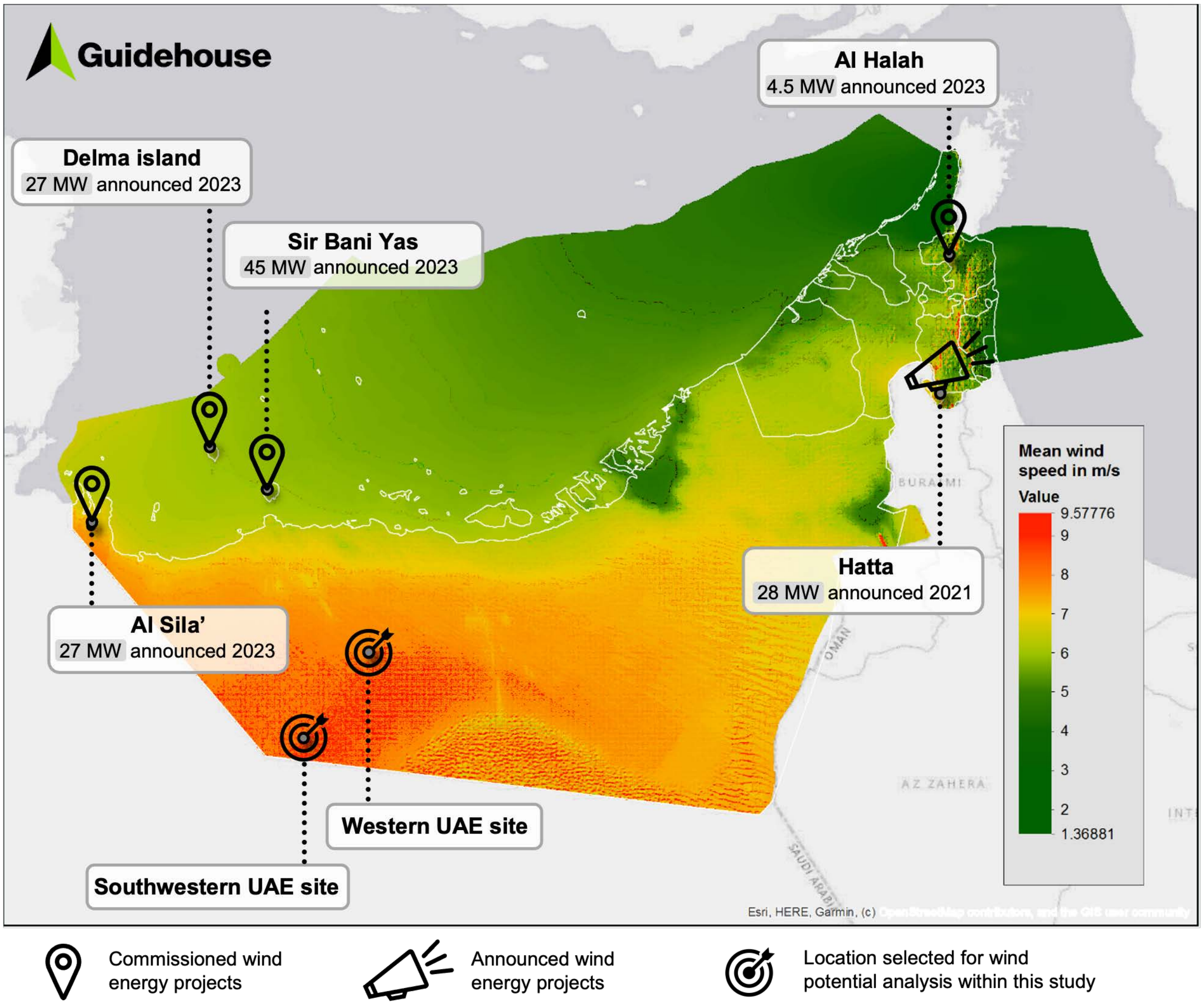
High mean wind speeds indicate sites with better wind resources and imply low electricity generation costs. For a preliminary assessment of the onshore wind potential, the spatial resolution of the mean wind speeds gives a good indication of the magnitude of favourable sites within a country.

On average, the UAE has a mean wind speed of 7.74 m/s. However, there are large differences in how the mean wind speeds are distributed across the country. Figure 1 presents the annual mean wind speeds across the UAE 150 m above ground level. It is apparent that the inland, i.e., the Rub Al Khali desert, is composed of a large area with higher wind speeds that decrease toward the coast and the northeast.

The best conditions for wind energy in the UAE are in the West and Southwest between the western border and Liwa oasis (see heatmap in Figure 1).

In these areas, average wind speeds of 7.5 to 8 m/s at 150 m can be found. In some smaller areas, average wind speeds of up to 9 m/s can also be reached.9 There are also small patches of strong winds in the Al Hajar mountains. Wind speeds are significantly lower along the coastline, around the cities of Dubai and Abu Dhabi at the Arabian Gulf and especially along the UAE's coast facing the Gulf of Oman. In general, large parts of the Emirate of Ras al-Kaimah in the northeast are characterised by low wind speeds.

Figure 1: Mean onshore wind speed in the UAE (m/s) at 150 m with location of the two exemplary sites and wind energy pilot projects[10]

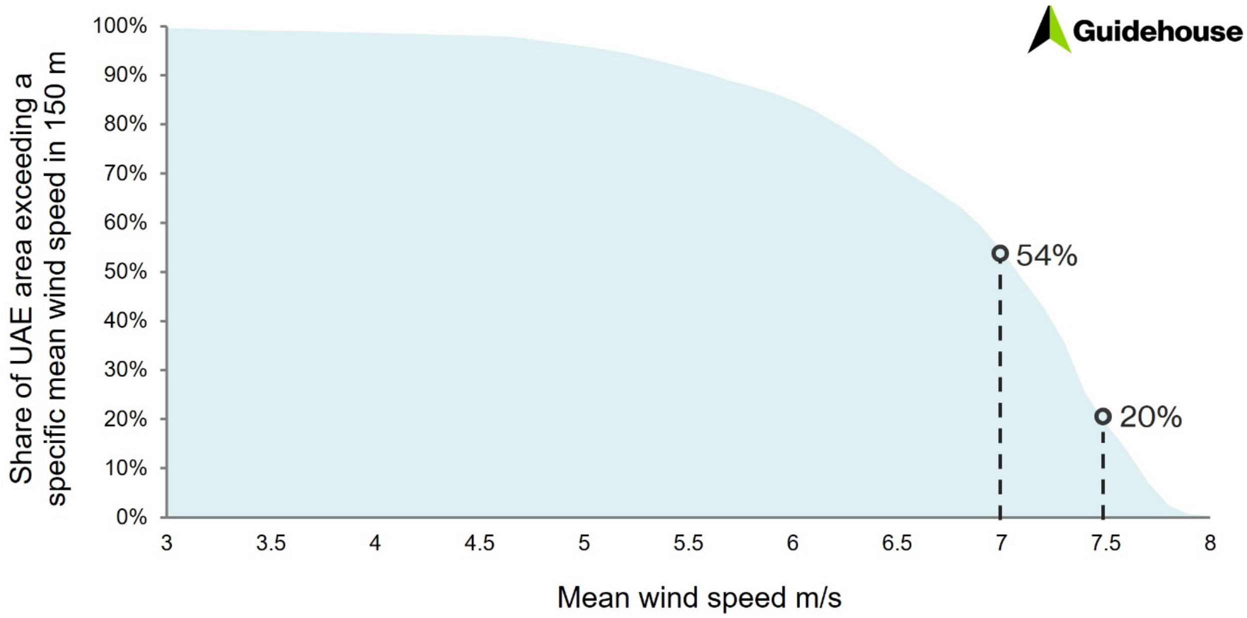


The surface characteristics of the regions in the UAE are well suited for wind energy. Surfaces with a low roughness, like the sparsely populated desert in the Southwest of the UAE, are another good indicator for a potential wind energy site. In large areas with little to no buildings, trees or other obstacles, the wind is not disturbed or stirred up. Therefore, wind turbines with lower hub heights can be built, which has a financial benefit. On the other hand, ground conditions pose a risk to wind energy viability, in particular large sand dunes.

The average wind speeds in the UAE can be compared with regions in Germany where wind turbines are already installed. Of the Gulf countries, in particular Kuwait, Saudi Arabia, and Oman, are often discussed as countries with attractive onshore wind resources.11 Indeed, these countries have larger regions with onshore wind speeds over 7 m/s at 150 m according to the web-based application Global Wind Atlas.12 However, in Germany where wind energy already contributes to a significant share of electricity (18% in 2022)[13], several wind farms are built in areas with wind speeds below 7 m/s. In the United States (US), it is stated that at least an average annual wind speed of 5.8 m/s is required for utility-scale turbines.14

On 54% of the UAE onshore territory mean wind speeds at 150 m above ground are around 7 m/s or higher. This corresponds to an area of around 45,000 km². The prevalence of different mean onshore wind speeds across the UAE is illustrated in Figure 2.

Figure 2: Share of UAE area exceeding a specific mean wind speed at 150 m



2.1.2 Temporal wind patterns

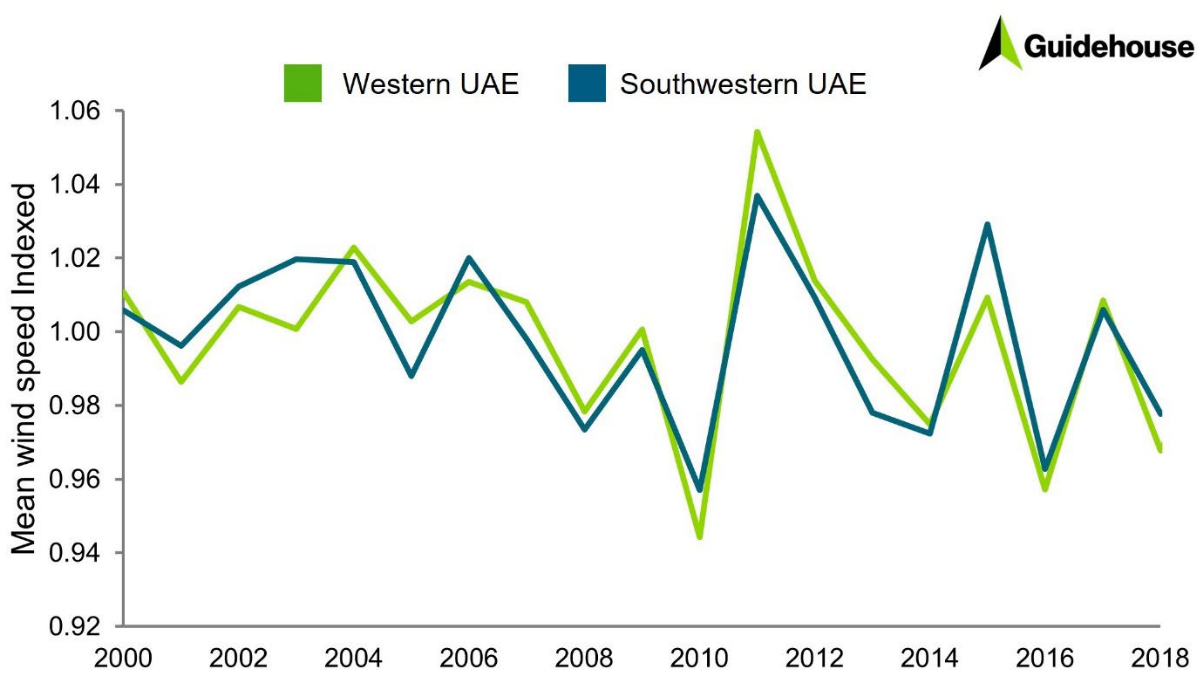
For two wind sites, hourly wind data of almost 20 years was examined. Based on the spatial analysis in section 2.1.1, further analysis of the temporal availability and distribution of mean wind speed for the most promising region provides a better picture of UAE's onshore wind resources. Two exemplary wind sites were chosen, one in the **Western UAE** and one in the **Southwestern UAE** (see Figure 1).

Yearly differences

The indexed average wind speed over several years shows that wind speeds remain very constant in the UAE. Relatively constant wind conditions are favourable as they reduce the risk for years with low energy yields and thus the financial risk for project developers. To assess the consistency of wind speeds, the average wind speed from 2000 to 2018 is calculated for both sites. This average value is used as an index for the years 2000 to 2018. Figure 4 shows that the average wind speeds for each year deviate upwards and downwards by usually 1 to 2%, but 5 to 6% max.

For further analysis, the year 2017 is taken as the reference year with a mean wind speed index for both locations close to the long-term average.

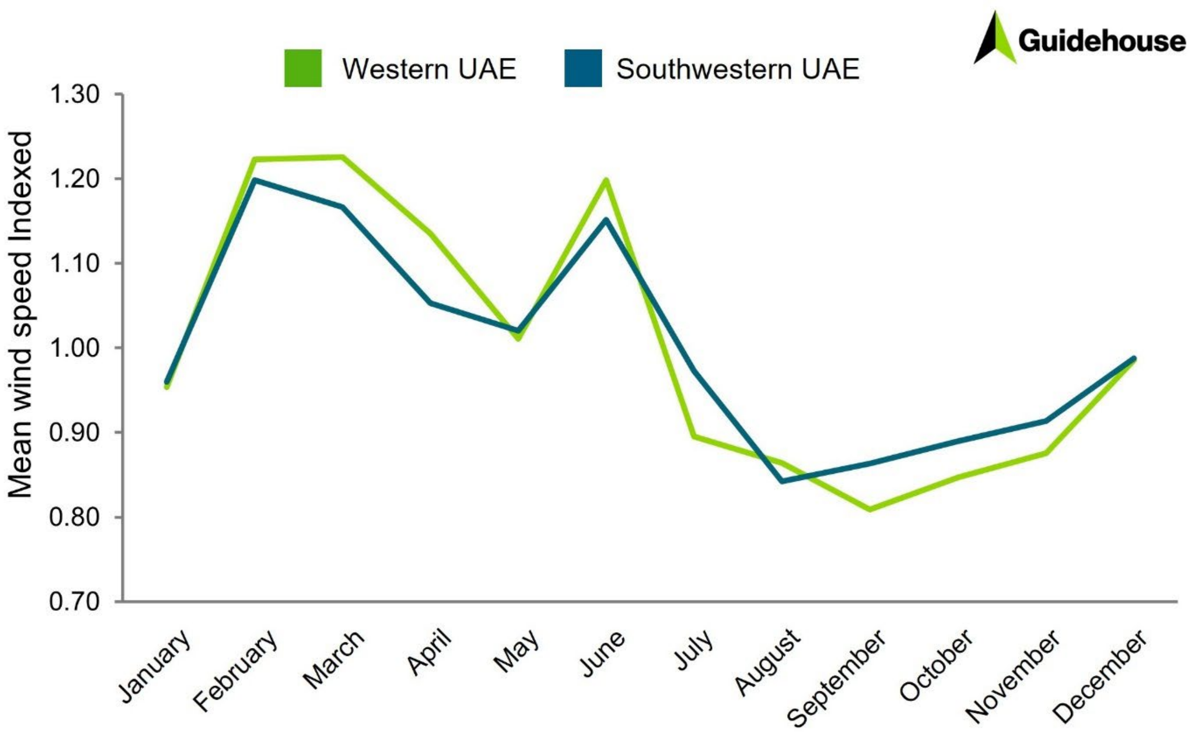
Figure 3: Indexed mean wind speed from 2000 – 2018 in Western UAE and Southwestern UAE



Monthly differences

During the summer the winds are weaker than during the winter. Figure 4 shows the mean wind speeds per month for the two locations, indexed for the year 2017. The trend is similar at both sites with wind speeds above the yearly average between February and June and below the yearly average in July to January. Variations in wind speeds range from 81% in September to 123% in March in Western UAE, and from 84% in August to 120% in February in Southwestern UAE. Lowest wind speeds can be seen between August and October. The analysis of the wind speeds of other years shows a similar pattern.

Figure 4: Indexed mean wind speed per month in 2017



Daily differences

The wind conditions in the UAE complement well with energy production from photovoltaic systems. Both regions analysed show a similar pattern throughout the year. The wind speed typically decreases between 8 and 11 reaching the lowest point in the afternoon and increases again in the evening. In the Southwestern UAE region, this trend is more pronounced than in the Western UAE region. Wind conditions at night are consequently better than during the day, which complements well with energy production from photovoltaic systems, which produce electricity only during the day.

For the reference year 2017, the hourly mean wind speed is determined for every month. Based on this, the daily course of wind speeds over a year can be represented for a region. Figure 5 shows the indexed mean wind speed for the site in Western UAE, Figure 6 for the site in Southwestern UAE.

Figure 5: Mean wind speed over one day for the year 2017 – Western UAE

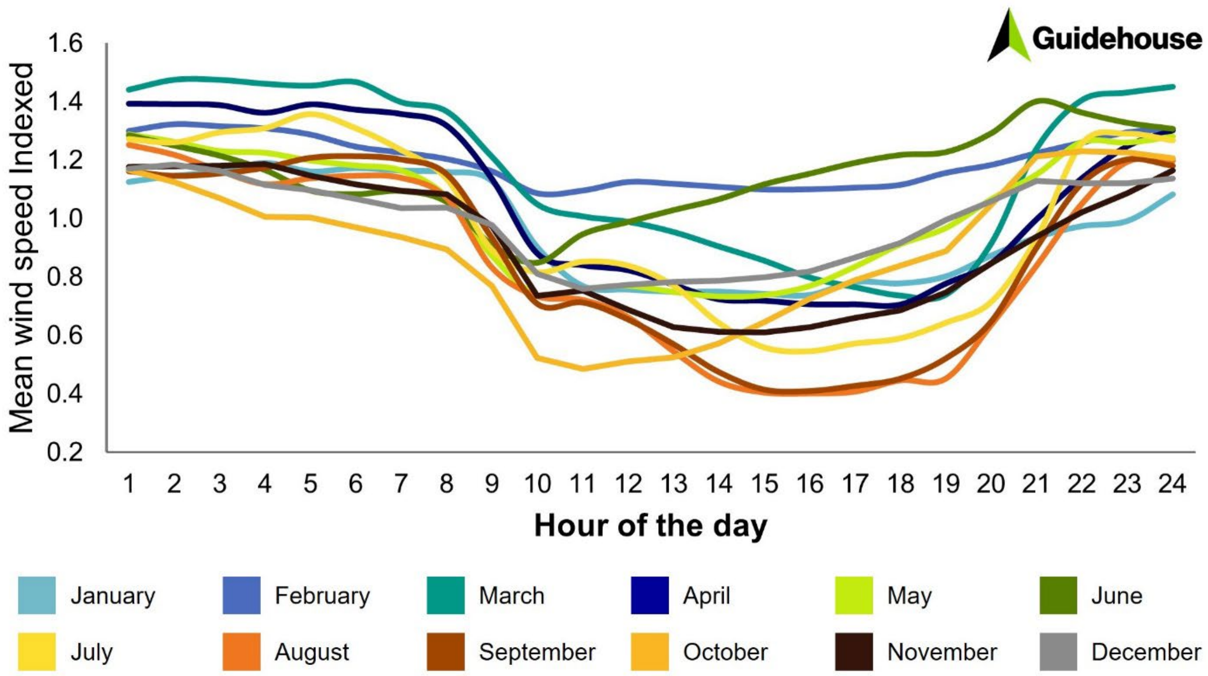
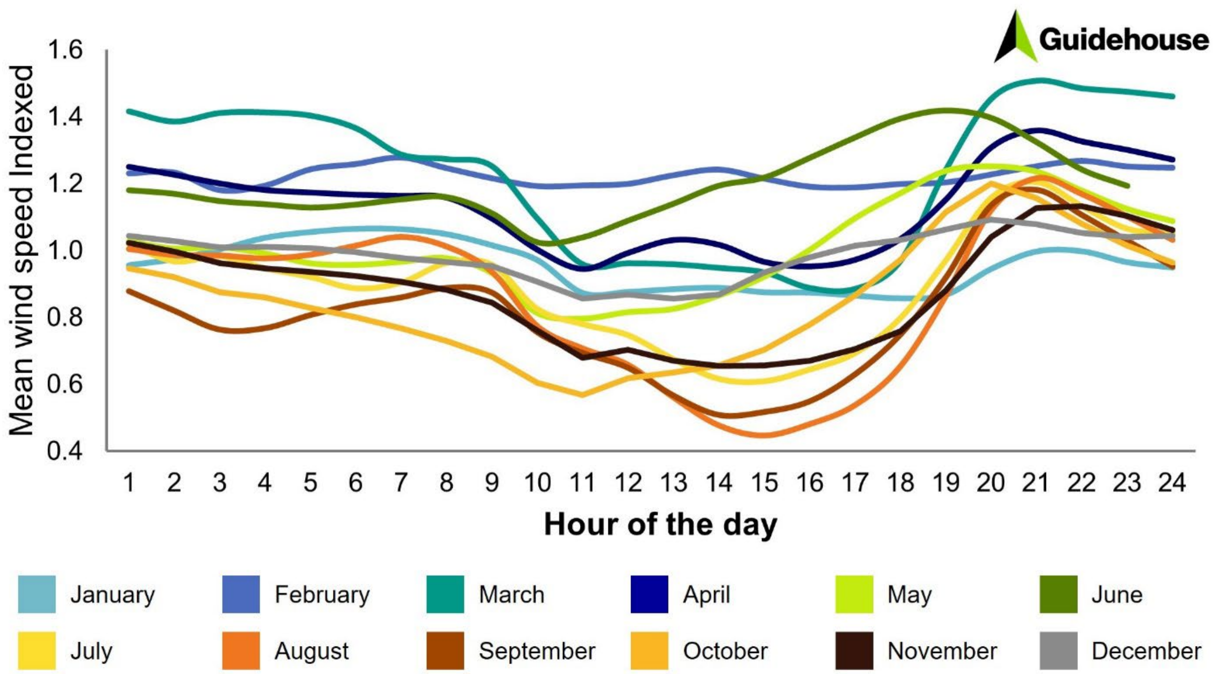


Figure 6: Mean wind speed over one day for the year 2017 – Southwestern UAE



2.2 Technical onshore wind energy potential

For around 20% of the UAE onshore territory, mean wind speeds are above 7.5 m/s at 150 m, a total surface area of more than 16,500 km². These wind conditions are mainly located in the Southwestern UAE as shown in Figure 1. To put the figures in perspective: The German government aims for about 160 GW onshore wind capacity by 2035. The land area needed to deploy the targeted 160 GW in Germany is estimated to be about 7,100 km² split into many smaller sites due to a high population density and many small settlements.[15]

The desert area in the Southwestern UAE with favorable wind conditions is scarcely populated and framed by existing road infrastructure. The area is confined in the North by the highways E11 and E15, in the East by highways E45 and E90 and in the South and West by the roads at the national borders. Highway E15 leads through the large potential area. Building density is very low and concentrated along the roads. For the assessment of the technical potential, it is assumed that the deployment of wind turbines is feasible in the entire area.

Wind conditions in the Southwestern UAE are classified as moderate according to international standards. The International Electrotechnical Commission (IEC) categorizes wind conditions into five classes based on mean wind speed at hub height using the IEC 614001 standard. For the Southwestern UAE, wind conditions are classified in class IEC III representing moderate wind conditions with mean wind speed between 7 m/s and 8.5 m/s.

State-of-the art wind turbines for moderate wind conditions have a generation capacity of up to 7.2 MW and lifetimes between 20-25 years. To harness the UAE's wind energy resources, wind energy turbines suitable for IEC III wind conditions have been identified from different manufacturers.[16] Based on the technical parameter of the identified wind turbines, a state-of-the-art mock-up turbine is defined with the following characteristics:

- Rated power capacity: 7.2 MW (operational: 6.6 MW)
- Rotor diameter: 171 m
- Cut-in wind speed: 3m/s[17]
- Cut-out wind speed: 25m/s[18]
- Lifetime: 20-25 years

80 GW of wind generation capacity could theoretically be deployed in the Southwestern UAE. For spacing between the turbines, the distance between the wind turbines is assumed to be four times the rotor diameter.[19] This implies 684 m of radial distance for the layout of the wind turbines. Hence, the identified area in the Southwestern and Western UAE would theoretically allow for the deployment of up to 11.200 wind turbines with the characteristics specified above. Assuming 3,000 full load hours[20], the potential annual wind energy output can be estimated to 240 terawatt-hours (TWh). Even when using only 60% of the area with mean wind speed above 7.5 m/s, the onshore wind energy potential would still be higher than the total electricity consumption of the UAE in 2021.[21]

3 Offshore Wind Energy Potential in the UAE

Currently, there are no offshore wind energy plants installed in the UAE or in other countries of the Gulf region. Saudi Arabia recently announced plans to install a 500 MW offshore wind park.[22] No other concrete projects are announced.

Relevant for the assessment of offshore wind is the area of territorial waters of the UAE. The UAE has a long coastline of about 650 km to the Arabian Gulf and about 70 km facing the Gulf of Oman. The Exclusive Economic Zone (EEZ) of UAE is of 58,292 km².[23] This area describes the theoretical geographical potential to develop offshore wind energy. In order to evaluate the actual feasibility and attractiveness of offshore wind energy plants in territorial waters, the study assesses the offshore mean wind speeds and water depth.

Water depth

The Arabian Gulf is generally a shallow sea, while the shore towards the Gulf of Oman is steep. Especially on the coastal side towards the Arabian Gulf, the sea is generally very shallow and reaches a maximum depth of around 70 m at the outer northeast borders of the territory. In the coastal region, the water is in large parts only 5 to 15 m deep. There are also coastal sections with a water depth of less than 5 m.[24] The average water depth of the Arabian coast is about 36 m.[25] In contrast, the coastal side facing the Gulf of Oman promptly reaches depths of over 80 m.[26] In Germany, most offshore wind turbines are located in water depths of 30 to 35 m.[27] In Europe offshore wind turbines are installed in about 20 m water depth on average. Offshore wind plants in Asia, by contrast, are on average installed closer to the coast and in a water depth around 10 m.[28] There is a relatively constant trend in recent years to build offshore wind turbines further from shore and in deeper waters. The reasons are manyfold, including technological improvements in support structures and near-shore site scarcity.[29]

In terms of water depth, UAE's territorial waters in the Arabian Gulf are suitable for offshore wind plants. The water depth is a critical factor for offshore wind energy development because it determines, among other things, the substructure of the wind power plant and thus significantly the overall costs. Currently, the most used substructure are fixed-bottom wind turbines. They can be installed up to a water depth of 50 to 60 m. Beyond that line, fixed-bottom offshore wind turbines have no economic justification for their use. Instead, floating offshore wind turbines are currently being increasingly tested to harvest energy in deeper waters. However, floating offshore wind turbines are not yet being produced or deployed at large-scale. Only a few pilot projects are installed worldwide.[30] Water depths of less than 50 m are therefore currently the most favourable. In terms of water depth, the EEZ of the UAE to the Arabian Gulf with large areas below 40 m is thus quite suitable for the development of offshore wind energy. Accordingly, the deeper waters of the Gulf of Oman are less suitable. Nevertheless, water depth is not the only decisive criterion for the development of offshore wind energy.

Mean offshore wind speed

Low wind speeds in UAE's territorial water do not justify high capital expenditure costs (CAPEX) for offshore wind energy. Figure 1 in Chapter 2.1.1 displays the static wind conditions, i.e., mean wind speeds at 150 m height, in UAE's territorial waters. Wind speeds in the northern area of the Arabian Gulf are generally lower than in the central area and west of Qatar. The wind speed further decreases towards the Strait of Hormuz. Average wind speeds at a height of 150 m in UAE's EEZ in the Arabian Gulf range from 3 to a maximum of 6 m/s. Most of the EEZ area in the Arabian Gulf has an average wind speed of about 5 m/s. In Germany, offshore wind speeds reach over 10 m/s at heights of 100 m.[31] The constantly higher offshore wind speeds promise higher energy yields and are the main reason why offshore wind turbines are built around the world. The higher energy yield justifies higher CAPEX for offshore wind plants. CAPEX of fixed-bottom offshore wind turbines can be more than two times higher than those for onshore wind turbines without considering the often highly expensive grid connection costs.[32] Unit investment costs for floating offshore wind turbines can be even more than four times higher.[33] Sites with wind speeds over 7 m/s are considered as economically viable for offshore wind.[34]

Wind conditions in the UAE are less favorable offshore compared to onshore

In the UAE, the opposite of what is the case in many other regions around the world can be observed – the mean wind speeds offshore are lower than on land. Based on the preliminary assessment in this study, **the offshore wind potential in the UAE is estimated to be low in light of current technology costs.** Offshore wind energy development would be more expensive than making use of the extensive onshore wind energy potential assessed in chapter 2. Thus, no further assessment of the time-resolved offshore wind conditions is performed. Khaled et al. (2018)[35] conducted a more in-depth, time-resolved, assessment of offshore wind resources for the Arabian Gulf. They also concluded that the UAE has the lowest offshore wind potential compared to the other Gulf countries.

4 Future role of wind energy for the UAE

When talking about renewable energy deployment in the UAE and the Gulf region in general, the focus is primarily on the expansion of solar power plants. Indeed, it is impossible to discuss the role of wind energy in the region without acknowledging the region's abundant solar energy resources that give solar power plants, especially PV, a strong competitive advantage. As a result, solar has been the focus of the UAE's domestic renewable energy expansion until recently.

Onshore wind energy can play a valuable role for the UAE's long-term decarbonisation strategy

The UAE offers favorable onshore wind conditions, while offshore wind resources are limited. Only recently the topic of developing wind energy in the Gulf region has gained interest among policy makers and in academia. Countries where the role of wind energy is more frequently discussed are Kuwait, Saudi Arabia, and Oman, because of their particularly good onshore wind conditions.36 However, this study has shown that the UAE also offers favorable onshore wind conditions in terms of wind speed and wind patterns. The analysed wind patterns are even more balanced over the course of a day and year than in Germany, where wind energy is seen as a corner stone of a fully decarbonised electricity system. In contrast to other countries, the wind speeds offshore in the EEZ of the UAE are lower than on land. Hence, the study concludes that offshore wind energy is not an economically viable option in the UAE.

The cost of wind energy is continuously declining due to technological improvements. Advances in wind turbine design allow reaching higher capacity factors, resulting in a 68% reduction in the global weighted average cost of electricity for onshore wind projects between 2010 and 2021.[37] Although the cost of solar and wind energy projects has increased over the past two years due to increased prices of raw materials, higher energy cost for transportation, and a rise in financing costs, it is generally predicted that the downward trend will resume.[38] A forecast from DNV predicts the regional investment cost per capacity unit for onshore wind energy in the Middle East and North Africa to fall by 25% until 2050.[39] Costs are also falling for offshore wind plants. From today's point of view, however, offshore wind energy is seen as less relevant for the UAE, due to the comparatively high technology costs paired with rather low offshore wind speeds in the UAE.

Adding onshore wind to the renewable energy mix will benefit the power system

Installed renewable energy capacity in the UAE is mainly solar PV. The development of solar projects in the UAE to date has resulted in around 3.2 GW of solar and concentrated solar power (CSP) capacity installed. Another 10.8 GW of renewable energy projects need to be installed by 2031 to reach the policy target of 14 GW of renewable energy capacity. Given the very low cost, especially for solar PV plants, a solar-focused strategy can seem plausible, but may become a challenge when looking at the long-term decarbonisation trajectory which targets a national renewable energy share of 44% in 2050.

Onshore wind energy can complement solar energy in the power mix. Solar energy is only available when the sun is shining. Increasing shares of solar power in combination with inflexible base load power plants, e.g. nuclear, could result in large amounts of surplus electricity being generated during the day. To balance demand by night, emission intensive peaker plants (typically oil- or gas-fired) or costly energy storage facilities would be needed. Onshore wind energy can thus be a viable option to diversify the renewable energy portfolio in the UAE. Residual load will be less often and less costly to serve in an energy system that includes onshore wind.

Although wind energy in the UAE is more expensive than solar on a cost per kWh basis, it is likely cheaper than battery storage or CSP. Onshore wind energy can reduce the need for conventional peaker plants and expensive storage options. CSP plants combined with thermal storage units are currently the prioritized option to balance electricity demand by night. CSP plants consume large amounts of water for cooling. This poses a challenge for the largescale roll-out of the technology in a region where water is already scarce and expected to become scarcer due to climate change. The cost of this solution has recently dropped to LCOE of less than 8 US cents per kilowatt-hour (kWh) for projects in the UAE (compared to the bid price of the Al Dhafra PV plant at 1.32 US cents per kWh).[40] In comparison, a recent study assumes LCOE for onshore wind in the Middle East and North Africa between 5-6 US cents per kWh.[41] The winning bid for Saudi Arabia's first utility-scale wind farm claims LCOE of 2.13-3.39 US cent per kWh.[42]

Adding onshore wind to the renewable energy mix will benefit the upcoming hydrogen economy

UAE's hydrogen ambitions have a large impact on the national energy system. In their Hydrogen Leadership Roadmap[43], the UAE lay out their competitive advantage to build a low-carbon hydrogen economy. Hydrogen not only plays a role in the UAE's domestic decarbonization but also offers export opportunities. The roadmap targets a 25% market share in major markets, with European countries, specifically Germany, as key import markets of hydrogen derivates and other green hydrogen-based products such as steel. These ambitions will lead to a substantial increase of electricity demand for electrolysers in the UAE. How this electricity will be generated depends, amongst other things, on the hydrogen requirements in import markets.

Europe can become a reliable partner for the offtake of hydrogen-based products. European Union (EU) Member States are subject to binding targets and quotas for green hydrogen consumption that will create sustainable offtake. For example, the Renewable Energy Directive III, which is currently being finalised, will update the binding climate and renewable targets for the transport, industry, and aviation sectors, thus ensuring a steady increase in demand for so called Renewable Fuels of Non-biological Origin (RFNBOs), such as hydrogen, over the coming years.

European regulation defines ambitious criteria for the production of green hydrogen. To meet the defined demand side targets, hydrogen and its derivatives must be produced according to a set of sustainability criteria to safeguard climate benefit.[44] They determine the requirements for using renewable electricity in the production of RFNBOs and set a threshold for the lifecycle greenhouse gas emissions savings of RFNBOs (3.4 kg of CO_2 per kg of hydrogen). The former can be especially crucial for the design and operation of hydrogen projects in the UAE. The criteria are quite restrictive in determining under which circumstances electricity input for hydrogen production is considered fully renewable. Possible options include a direct line connection between renewable power plants and the electrolyser, or sourcing of renewable electricity via the grid.

Electrolysers must be operated at high full-load hours to achieve a cost-effective green hydrogen production. Solar PV in the UAE only provides power for 1,700-1,800 full load hours per year.[45] Especially in the early phase with high electrolyser system cost, an increase in full load hours to around 4,000-5,000 hours per year can drastically reduce the levelized cost of green hydrogen.[46] Given the diurnal generation patterns, other electricity sources will be needed to achieve such high full load hours. If taking grey electricity from the grid, producers will not be able to sell the green hydrogen share to EU markets.[47] Thus, other options for sourcing additional renewable electricity will be needed next to solar PV.

Combining wind and solar energy can allow meeting sustainability criteria in a cost-efficient way. Although wind energy in the UAE is more expensive than solar on a cost per kWh basis, it is likely cheaper than battery storage or CSP. Wind energy can therefore play an important role for the UAEs future hydrogen production by minimising need for battery storage or other options during night-time while keeping the emission intensity of the final product below the crucial threshold. A cost-optimal combination of wind and solar resources for green hydrogen production, i.e., where further cost reductions from higher full load hours no longer prevail over the cost increase from sourcing wind electricity, should be targeted.

5 Policy Recommendations

An enabling policy framework is key to harness the identified onshore wind energy potential in the UAE. As the UAE has successfully phased out energy subsidies, financial support policies are not considered for the policy recommendations. The following best-practice policies have been compiled for the UAE regulatory environment to enable the expansion of wind energy.

Introducing a national carbon pricing scheme that includes the power sector has the potential to accelerate the expansion of renewables. Carbon pricing is an effective market-based instrument to reduce carbon emissions that is based on the polluter pays principle. Introducing a price for carbon is widely considered the single most efficient way for countries to reduce their emissions and facilitate investments in low-carbon energy and innovation. International collaboration, e.g., in the framework of the Climate Club[48], can accelerate the implementation of carbon pricing through knowledge exchange and best practices.

Conducting a comprehensive wind energy resource assessment is needed to better qualify the role of wind in the UAE. The assessment should address cost, benefits, and the environmental impact of wind energy in view of the net-zero 2050 target and intermediary objectives. To substantiate the existing (often modelled) data on wind speeds and help to identify priority regions for the development of wind energy projects, physical wind speed assessments for onshore and offshore areas should be carried out.

Capacity targets for wind in 2030, 2040 and 2050 can accelerate the deployment of wind energy in the UAE. Based on the wind energy resource assessment, realistic capacity targets can be derived. They provide guidance and investment certainty to energy utilities in order to deploy wind energy projects. Specific targets for wind energy also contribute to a trustful environment for investments in wind turbine manufacturing for local value creation and are imperative for the proactive grid planning of system operators.

Proactive power grid planning and expansion to areas designated for wind energy are indispensable. The need to reinforce existing and build out new transmission grid infrastructure can be determined through long-term energy system modelling. Interconnections to Oman, Saudi Arabia and India could enable electricity trade and facilitate system integration of renewable electricity in the long run.

Technology-specific auctions are an internationally proven instrument for renewable energy capacity procurement, including wind. The UAE's proven tendering practice for allocating Independent Power Projects to private companies can be applied to develop wind projects. Hybrid auctions to contract "Independent Hydrogen Producers" combining wind and solar as generation technologies could be considered to allow higher utilisation of green hydrogen electrolysers. To enable private sector engagement, grid connection should be guaranteed before the commissioning of new generation capacity.

Pilot projects in the Southwestern desert region can create lessons learned regarding specific physical and technical issues, e.g., sand dune movement and heat.

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Endnotes

[1] Reuters (2023a)
[2] Low-carbon hydrogen includes hydrogen produced from renewable energy (green) and nuclear energy (pink) as well as hydrogen produced with Carbon Capture, Utilization and Storage (blue).
[3] Reuters (2023b)
[4] Masdar (2023a)
[5] Masdar (2023b)
[6] Energy Utilities (2021)
[7] Masdar (2023c)
[8] Dubai Protocol Department (2023)
[9] DTU (2023)
[10] Source: Global Wind Atlas 3.0, a free, web-based application developed, owned, and operated by the Technical University of Denmark (DTU). The Global Wind Atlas 3.0 was released in partnership with the World Bank Group, utilising data provided by Vortex, using funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalwindatlas.info
[11] Connelly, C. and Xydis, G. (2021)
[12] DTU (2023)
[13] Bundesministerium für Wirtschaft und Klimaschutz (2023)
[14] U.S. Energy Information Administration (2023)
[15] Guidehouse, Fraunhofer IEE, Stiftung Umweltenergierecht and bosch & partner (2022)
[16] Selected wind energy turbines for IEC III conditions:
- Manufacturer: Vestas, Model: V172-7.2. For additional information: www.vestas.com/en/products/enventus-platform/V172-7-2-MW
- Manufacturer: Siemens Gamesa, Model: SG 6.6-170. For additional information: www.siemensgamesa.com/products-and-services/onshore/wind-turbine-sg-5-8-170

[17] The **cut-in wind speed** defines the point when the wind turbine starts to generate electricity from turning.
[18] The **cut-out speed** defines the point when the wind turbine must be shut down to avoid damage to the equipment.
[19] Umweltbundesamt (2013)
[20] Equivalent to a capacity factor of 34%
[21] UAE electricity consumption in 2021 was reported at 141.8 TWh
[22] Power Technology (2021)
[23] United Arab Emirates Ministry of Climate Change & Environment (2018)
[24] Hereher, M. E. (2020)
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[28] Díaz, H. and Guedes Soares, C. (2020); U.S. Department of Energy and Office of Energy Efficiency & Renewable Energy (2022b)
[29] U.S. Department of Energy and Office of Energy Efficiency & Renewable Energy (2022b)
[30] National Renewable Energy Laboratory (2020); Barooni, M. et al. (2023); Global Wind Energy Council (2023)
[31] DTU (2023)

[32] U.S. Department of Energy and Office of Energy Efficiency & Renewable Energy (2022a); U.S. Department of Energy and Office of Energy Efficiency & Renewable Energy (2022b)
[33] DNV (2022)
[34] BVG Associates and WindEurope (2017); Energy Sector Management Assistance Program (2023)
[35] Al-Salem, K. et al. (2018)
[36] Connelly, C. and Xydis, G. (2021)
[37] International Renewable Energy Agency (2022)
[38] International Energy Agency (2023)
[39] DNV (2022)
[40] United Arab Emirates' Government portal (2022)
[41] DNV (2022)
[42] Almutairi, K. and Alahmadi, R. (2022)
[43] United Arab Emirates Ministry of Energy & Infrastructure (2021)
[44] These requirements are described in the Delegated Acts on Articles 27[44] (on renewable electricity sourcing) and Article 28 (on hydrogen emissions reduction and calculation)[44] of the Renewable Energy Directive II.
[45] Solargis (2023)
[46] Guidehouse (2022)
[47] As per EU sustainability criteria, electrolysers are – in principle – allowed to source renewable power via the grid, if they have concluded a Power Purchase Agreement (PPA) with a renewable energy plant for that amount. If grey electricity is sourced from the grid, e.g., to produce grey hydrogen at times of low renewables generation, the greenhouse gas balance of the hydrogen produced by the entire plant (including the green batch) would increase (as per the EU greenhouse gas calculation methodology) because gas power plants are still dominating the electricity mix in the UAE. Consequently, producers will no longer be able to sell the green hydrogen batch to EU markets.
[48] The **Climate Club** aims to support the rapid and ambitious implementation of the Paris Agreement to limit global warming to 1.5°degrees. As an inclusive forum of states, the Climate Club pursues to accelerate the decarbonisation of industries, further develop emissions reduction measures and counter the risk of carbon leakage. Committed developing and emerging countries that join the Club are to receive support to push ahead with the transformation of their industries with a view to attaining climate neutrality.