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South Africa's Renewable Electricity Potential for Green Hydrogen and Synthetic Aviation Fuels – A Techno-Economic Assessment

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1 Executive Summary

Global demand for sustainable aviation fuel (SAF) is set to rise sharply, with the EU's ReFuelEU Aviation regulation targeting 70% SAF by 2050 and a 35% sub-target for synthetic fuels (e-kerosene). Meeting these targets will require significant deployment of green hydrogen–based power-to-liquids (PtL), favoring locations with abundant, low-cost renewable electricity. This report assesses South Africa's technical potential for renewable power generation—utility-scale photovoltaics (PV), onshore wind, and concentrated solar power (CSP)—as a foundation for green hydrogen and synthetic aviation fuel production.

Using the Enertile Renewable Potential Calculator 2.0, South Africa is spatially resolved into 28,872 tiles (6.5 × 6.5 km), with land use from GlobCover 2009 and hourly weather profiles from ERA5 (weather year 2010). Potentials are aggregated into cost steps by LCOE, with wind optimized over 47 turbine configurations. Cost assumptions (2018 base) project declining capital costs for PV and CSP through 2050; wind costs vary by configuration. Protected areas (per PACA) and extreme water-stress regions (Aqueduct 4.0) are excluded. Renewable Energy Development Zones (REDZ) are integrated by adjusting land-use factors at the GADM level to prioritize deployment where suitable.

Results show utility-scale PV dominates renewable potential at all cost steps and is the lowest-cost option. Onshore wind offers competitive costs below ~35 €/MWh but the majority of the potentials are beyond ~50 €/MWh, similar to CSP. Excluding protected areas reduces total technical generation potential by 10–14%, with a pronounced impact on wind (≈50% reduction) because high–full-load-hour (FLH) wind sites overlap protected regions. Spatial FLH patterns indicate highest PV performance in the northwest and lower values in the east; onshore wind achieves >3,000 FLH in western and coastal zones. Overall, South Africa's resource profile supports large-scale, cost-competitive green hydrogen production, with PV as the backbone, wind as a complementary resource where permitted, and CSP as a niche contributor. Policy prioritization within REDZ and water-stress constraints will be critical for bankable project siting and robust PtL supply development.

2 Zusammenfassung

Die weltweite Nachfrage nach nachhaltigen Flugkraftstoffen (Sustainable Aviation Fuel (SAF)) wird stark steigen, die EU-Regelung ReFuelEU Aviation setzt bis 2050 einen SAF-Anteil von 70% sowie ein Teilziel von 35% für synthetische Kraftstoffe (E-Kerosin). Zur Erreichung dieser Ziele ist ein erheblicher Ausbau von Power-to-Liquid (PtL) auf Basis von grünem Wasserstoff erforderlich, wobei Standorte mit reichlich vorhandener und kostengünstiger erneuerbarer Energie Vorteile bieten. Dieser Bericht bewertet das technische Potenzial Südafrikas zur Stromerzeugung aus erneuerbaren Energien— Freiflächen-Photovoltaik (PV), Windenergie an Land und konzentrierende Solarthermie (CSP)—als Grundlage für die Produktion von grünem Wasserstoff und synthetischem Flugkraftstoff.

Mit dem Enertile Renewable Potential Calculator 2.0 wurde Südafrika in 28.872 Kacheln (6,5 × 6,5 km) unterteilt. Die Flächennutzung stammt aus GlobCover 2009, stündliche Wetterprofile aus ERA5 (Wetterjahr 2010). Die Potenziale werden nach Stromgestehungskosten (LCOE) in Kostenstufen aggregiert, für Wind wird aus 47 Turbinenkonfigurationen optimiert. Kostenannahmen (Basisjahr 2018) zeigen fallende Investitionskosten für PV und CSP bis 2050, Windenergiekosten variieren je nach Konfiguration. Schutzgebiete (gemäß PACA) und Regionen mit extremem Wasserstress (Aqueduct 4.0) sind ausgeschlossen. Die Renewable Energy Development Zones (REDZ) werden über angepasste Flächennutzungsfaktoren auf GADM-Ebene integriert, um die Entwicklung in geeigneten Gebieten zu priorisieren.

Die Ergebnisse zeigen, dass Freiflächen-PV das erneuerbare Potenzial in allen Kostenstufen dominiert und die kostengünstigste Option ist. Für Wind an Land gibt es Regionen mit sehr günstigen Potentialen (35 €/MWh), der Großteil der Potentiale liegt allerdings—ähnlich wie für CSP— bei Kosten oberhalb von 50 €/MWh. Der Ausschluss von Schutzgebieten reduziert das gesamte technische Erzeugungspotenzial um 10–14%, mit besonders starkem Effekt auf die Windenergie (≈50% Minderung), da windstarke Standorte mit hohen Vollllaststunden häufig mit Schutzgebieten überlappen. Räumliche Muster der Vollllaststunden zeigen den höchsten PV-Ertrag im Nordwesten und geringere Werte im Osten, Wind an Land erreicht >3.000 FLH in westlichen und küstennahen Bereichen. Insgesamt ermöglicht das Ressourcenprofil Südafrikas eine großskalige, kostengünstige Produktion von grünem Wasserstoff, mit PV als Rückgrat, Wind als komplementärer Ressource, wo zulässig, und CSP als Nischenbeitrag. Politische Priorisierung innerhalb der REDZ sowie die Berücksichtigung von Wasserstress sind entscheidend für die Standortwahl und den robusten Ausbau von PtL-Lieferketten.

3 Introduction

Sustainable aviation fuel (SAF) demand is expected to increase significantly in the coming decades, driven by regulatory frameworks such as the European Union’s ReFuelEU Aviation regulation. ReFuelEU sets a target for SAF to account for 70% of all aviation fuel supplied at EU airports by 2050, with a dedicated sub-target of 35% for synthetic aviation fuels (PtL/e-kerosene) [1].

Global demand projections indicate that SAF consumption could reach between 330 and 445 million tonnes by 2050 [2]. A substantial share of this demand is expected to be covered by biogenic SAF pathways, estimated to contribute around 41%–55% of total SAF supply [2]. However, meeting long-term decarbonisation targets will also require large-scale deployment of synthetic aviation fuel production based on low-carbon hydrogen.

Low-carbon hydrogen can be produced either via natural gas reforming combined with carbon capture (blue hydrogen) or via electrolysis. When electrolysis is powered by renewable electricity, the resulting product is referred to as green hydrogen [3]. Because electricity constitutes a major share of green hydrogen production costs—and consequently of synthetic aviation fuel costs, countries with abundant and cost-competitive solar and wind resources have a strategic opportunity to become producers and exporters of synthetic aviation fuels to high-demand regions such as the European Union[4].

South Africa has been widely recognised as a promising candidate for such production, owing to its favourable renewable resource endowment. This report assesses South Africa’s technical potential for renewable electricity generation from photovoltaic, wind, and concentrated solar power technologies as a basis for green hydrogen production and, subsequently, synthetic aviation fuel supply.

4 Methodology and assumptions

4.1 Renewable Potential calculator

The renewable generation potential of utility-scale photovoltaic (PV), concentrated solar power (CSP) and onshore wind projects is assessed using the Renewable Potential Calculator 2.0 within the Enertile modelling framework. South Africa is divided into 28,872 onshore tiles, each measuring 6.5 × 6.5 km. Land-use information from the GlobCover 2009 dataset is spatially matched to each tile [5]. Technology-specific land-use factors are then applied to determine the area available for renewable energy deployment.

Meteorological data from the ECMWF ERA5 reanalysis for the year 2010 is then assigned to each tile and used to compute hourly generation profiles for all technologies [6]. The resulting tile-level potential and generation time series are then aggregated using weighted averages and classified into cost steps based on their levelised cost of electricity (LCOE). Step 0 represents the locations with the lowest costs.

For onshore wind, the Renewable Potential Calculator also performs an optimisation at tile level, selecting the optimal combination of rotor diameter and hub height from 47 predefined turbine configurations. Further information can be found in [7, 8].

4.2 Cost assumptions

The technology cost assumptions are taken from the Long-Term Scenarios project, with 2018 defined as the base year. Cost parameters for PV and CSP are provided in Table 1. The corresponding cost estimates for onshore wind across the selected turbine configurations are illustrated in Figure 1.

Table 1. Capital costs for PV and CSP for the different years.

Year	Utility-scale PV (€/kW)	CSP (€/kW)
2020	579.50	4263.41
2025	505.75	3822.17
2030	432.50	3404.02
2035	389.75	3181.92
2040	354.50	2971.35
2045	343.25	2718.44
2050	334.00	2470.38

Figure 1. Capital cost assumptions for selected wind onshore configurations.

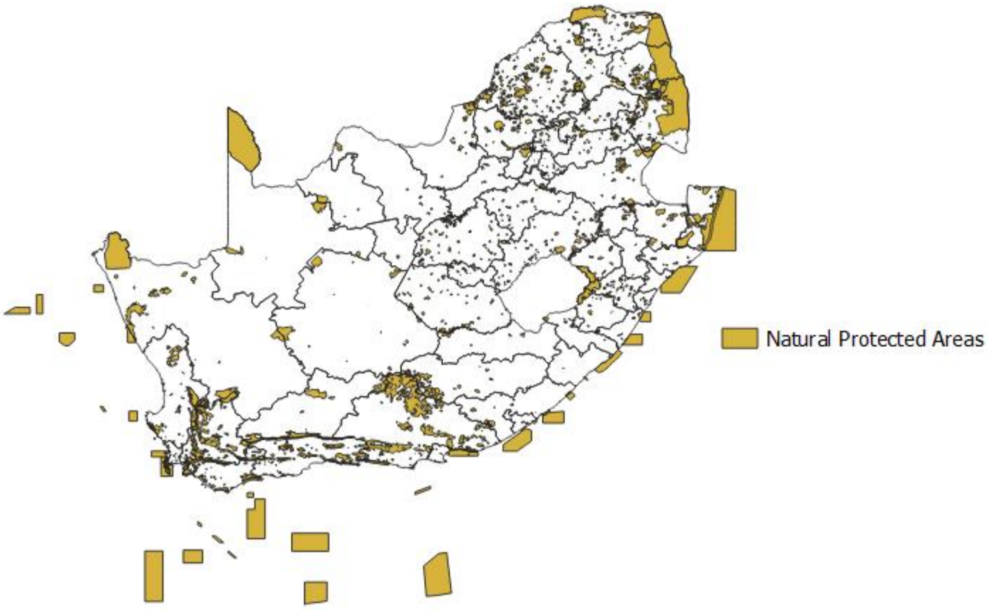
Source: Own representation.

4.3 Protected Areas

The calculation of renewable-electricity potential excludes protected areas. The relevant natural protected areas were identified using the PACA database of the Department of Forestry, Fisheries and the Environment [9]. Figure 2 shows the protected areas in South Africa that were excluded from the calculation. The protected areas considered in this study are:

- National parks
- Natural reserves
- Special natural reserves
- Mountain catchment areas
- World heritage sites
- Protected environmental areas
- Forest Natural reserve
- Forest wilderness area
- Special protected areas

Figure 2. Natural protected areas according to PACA database of the Department of Forestry, Fisheries and the Environment in South Africa

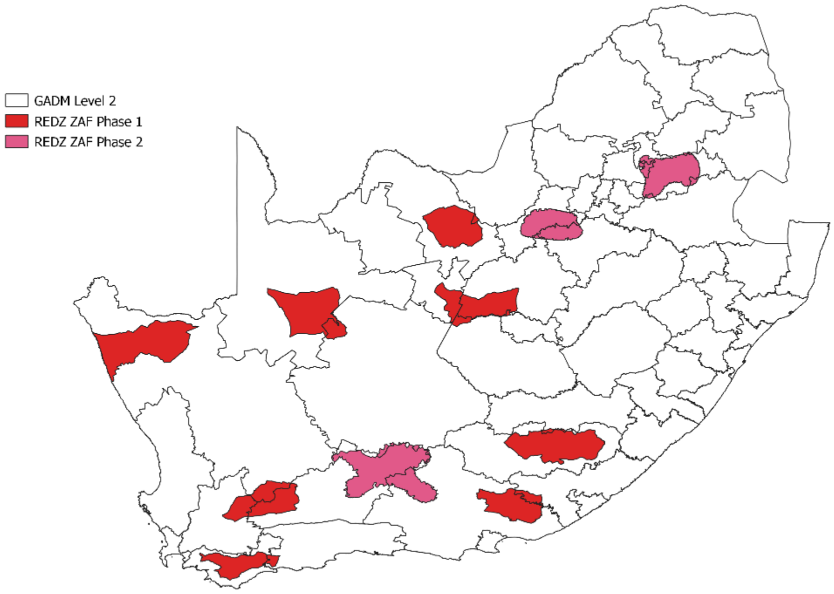


Source: Own representation, data from Ref. [9].

4.4 Geographical division of South Africa and land use criteria

The renewable energy potential for South Africa was calculated using Global Administrative Areas a(GADM) level-2 administrative regions as the spatial basis. In addition, both phases of the Renewable Energy Development Zones (REDZ) were incorporated (see Figure 3) [10, 11]. To avoid increasing the number of spatial nodes—and thereby the computational effort required in subsequent energy system analyses—the REDZ were not modelled as separate units. Instead, their influence was integrated directly into the GADM regions.

Figure 3. GADM level 2 geographic division together with the two phases of Renewable Energy Development Zones (REDZ)



Source: Own representation, REDZ data from Refs. [10, 11].

For each GADM region, the share of its area falling within a REDZ was determined. This share was then used to adjust the land-use factor, reflecting the higher prioritisation for renewable energy deployment in REDZ areas. Four land-use factor categories were applied:

1. no REDZ share,
2. small share,
3. medium share, and
4. large share.

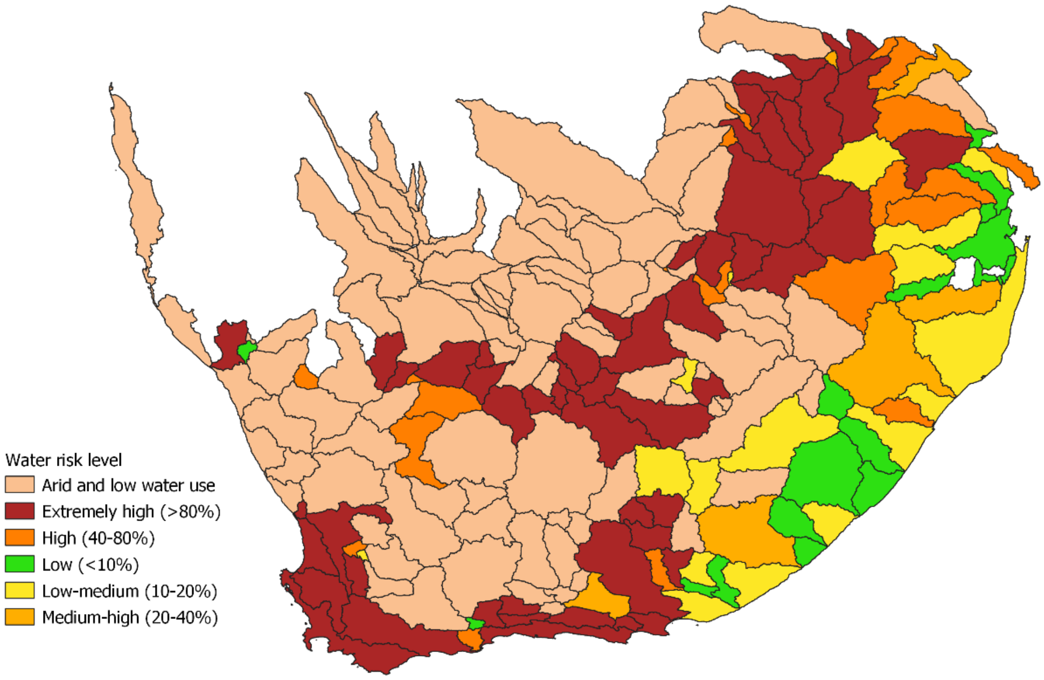
Regions with a larger REDZ overlap were assigned proportionally higher land-use factors, resulting in higher available potential within the overall calculation. The land use criteria can be found in Appendix A.

4.5 Water sources

Data from the Aqueduct 4.0 Water Risk Atlas (Data Dictionary) was used to account for the impact of water scarcity on the production of renewable energy [12]. The Future Water Stress dataset for 2050 was applied using the Baseline Water Stress scenario. Water-stress levels are categorised into five risk classes — Low, Low–Medium, Medium–High, High and Extremely High — with an additional category, Arid and Low Water Use, representing areas with very limited water availability and currently low withdrawal levels.

For this assessment, areas classified as 'Extremely High Risk' or 'Arid and Low Water Use' were excluded from the analysis of potential outcomes. Figure 4 shows the spatial distribution of water-stress categories in South Africa.

Figure 4. Water risk level in South Africa according to Aqueduct 4.0 Water Risk Atlas Data Dictionary



Source: Own representation, data from Ref. [12].

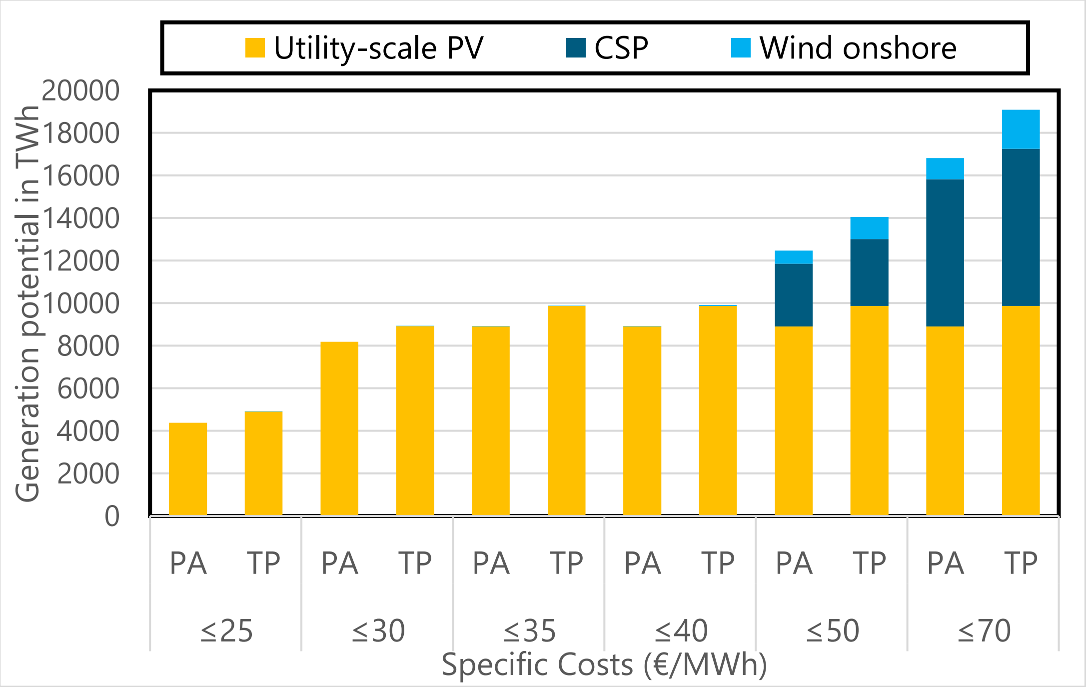
5 Results

Figure 5 shows the potential for renewable electricity generation in TWh, broken down by technology and cost step, for both scenarios excluding Protected Areas (PAs) and the total potential (TP). The potential reduction due to the exclusion of protected areas is between 10% and 14% of the total generation potential. However, excluding the protected areas has a significant impact on the onshore wind potential, which is reduced by around 50%, as protected areas encompass regions where the FLH of wind would be high (see Figure 6).

Utility-scale PV dominates the potential at all cost steps and is also the lowest-cost technology. Wind onshore is available for both scenarios for less than 35 €/MWh; however, together with CSP, it increases significantly, starting at 50 €/MWh.

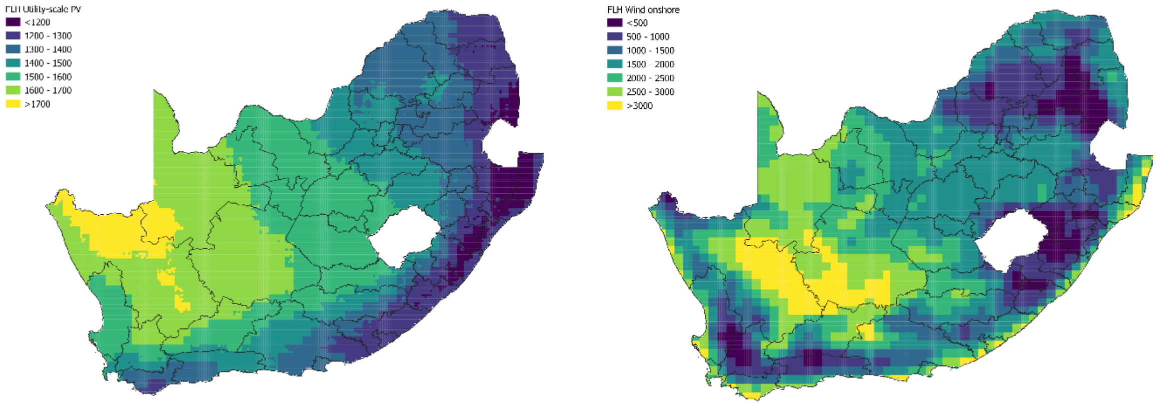
Figure 6 shows the full-load hours for utility-scale PV (left) and wind onshore (right). For utility-scale PV, the northwest region has the highest full-load hours. The eastern part has the lowest. For wind onshore, the western part of the country and small areas next to the coast have full-load hours above 3000.

Figure 5. Renewable electricity generation potential per technology and specific costs



Source: Own representation.

Figure 6. Full load hours for utility-scale PV (left) and wind onshore (right)



Source: Own representation. Please note the different scales.

Appendix A

Table 2. Assumed land utilisation factors for the potential calculation

Land use	Utility-scale PV				Wind on shore				CSP			
	Low	Medium	High	No share	Low	Medium	High	No share	Low	Medium	High	No share
barren	20.4%	22.3%	25.2%	20.0%	20.4%	22.4%	25.6%	20.0%	20.4%	22.3%	25.2%	20.0%
cropland natural	2.0%	2.2%	2.5%	2.0%	20.4%	22.4%	25.6%	20.0%	0.0%	0.0%	0.0%	0.0%
croplands	1.0%	1.1%	1.3%	1.0%	10.2%	11.2%	12.8%	10.0%	0.0%	0.0%	0.0%	0.0%
forest	0.0%	0.0%	0.0%	0.0%	10.2%	11.2%	12.8%	10.0%	0.0%	0.0%	0.0%	0.0%
grassland	10.2%	11.1%	12.6%	10.0%	20.4%	22.4%	25.6%	20.0%	10.2%	11.1%	12.6%	10.0%
savanna	5.1%	5.6%	6.3%	5.0%	20.4%	22.4%	25.6%	20.0%	5.1%	5.6%	6.3%	5.0%
shrubland	5.1%	5.6%	6.3%	5.0%	20.4%	22.4%	25.6%	20.0%	5.1%	5.6%	6.3%	5.0%
Snow and ice	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
urban	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
water	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
wetlands	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
excluded	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

List of Abbreviations

SAF	Sustainable Aviation Fuel
ReFuelEU	EU regulation promoting the uptake of SAF in aviation
PtL	Power-to-Liquids
e-kerosene	Synthetic kerosene
H2	Hydrogen
LCOE	Levelised Cost of Electricity
PV	Photovoltaics
CSP	Concentrated Solar Power
REDZ	Renewable Energy Development Zones
GADM	Global Administrative Areas
ERA5	Fifth-generation ECMWF atmospheric reanalysis dataset
ECMWF	European Centre for Medium-Range Weather Forecasts
PACA	Protected Areas and Conservation Areas (South Africa, DFFE database)
FLH	Full Load Hours
EU	European Union
UK AID	United Kingdom international development programme
ATAG	Air Transport Action Group
WRI	World Resources Institute

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[1] European Comission 2023 *ReFuelEU aviation* https://aviationbenefits.org/media/167495/fueling-net-zero_september-2021.pdf

[2] ICF 2021 *Fueling Net Zero: How the aviation industry can deploy sufficient sustainable aviation fuel to meet climate ambitions* (ATAG)

[3] Bullerdiek N, Neuling U and Kaltschmitt M (eds) 2024 *Powerfuels: Status and Prospects*

[4] Agora Industry, Agora Energiewende 2023 *Levelised cost of hydrogen: Making the application of the LCOH concept more consistent and more useful* (Agora Industry, Agora Energiewende)

[5] ESA 2010 *GlobCover Land Cover Maps* http://due.esrin.esa.int/page_globcover.php

[6] ECMWF 2020 *ERA5* https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5

[7] Franke K, Sensfuß F, Deac G, Kleinschmitt C and Ragwitz M 2021 Factors affecting the calculation of wind power potentials: A case study of China *Renewable and Sustainable Energy Reviews* **149**

[8] Franke K, Garcia J F, Kleinschmitt C and Sensfuß F 2024 Assessing worldwide future potentials of renewable electricity generation: Installable capacity, full load hours and costs *Renewable Energy* **226** 120376

[9] Rudi 2022 *PACA DATABASE: Classification and definition of protected areas and conservation areas* (Department: Forestry, Fisheries and the Environment)

[10] Ahn S-Y, Kim K-J, Kim B-J, Hong G-R, Jang W-J, Bae J W, Park Y-K, Jeon B-H and Roh H-S 2023 From gray to blue hydrogen: Trends and forecasts of catalysts and sorbents for unit process *Renewable and Sustainable Energy Reviews* **186** 113635

[11] UK AID *Energy Catalyst: Country Guide: South Africa* (UK AID)

[12] Kuzma S, Bierkens M, Lakshman S, Luo T, Saccoccia L, Sutanudjaja E and Van Beek R 2023 *“Aqueduct 4.0: Updated decision-relevant global water risk indicators.” Technical Note.* (World Resources Institute)