GEOENGINEERING PROJECTS IN AFRICA INTENSIFY ALONG WITH OIL AND GAS EXPANSION

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Photo Credit: Antoinette Plessis

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The African continent – home to about one-fifth of the world's population and a great variety and diversity of other living creatures – has by far the lowest per capita emissions in an intercontinental comparison and is responsible for less than four percent of cumulative global greenhouse gas emissions (GHGs). In comparison, China has emitted six times the amount of greenhouse gases, the USA five times and the European Union three and a half times the amount. Although Africa has both historically contributed the least to global warming and currently has the lowest emissions, Africa is the most vulnerable continent to the impacts of climate change under all climate scenarios above 1.5 degrees Celsius. Even if warming can be limited to 1.5 degrees Celsius, the projected impacts in parts of Africa are already substantial, e.g., a doubling of annual heat waves, megacities in which people are exposed to deadly temperatures or losses in agricultural yields. The continent's vulnerability to the impacts of the accumulation of greenhouse gases in the atmosphere, for which it is least responsible, is reflected in many

of the Nationally Determined Contributions (NDCs) of African countries. In the NDC's, the Parties to the Paris Agreement set out measures to reduce national emissions and adapt to the impacts of climate change. Most African countries strive to address climate change through mitigation and nature-based solutions. Geoengineering – a term that refers to large-scale interventions in the Earth's soils, oceans and atmosphere aimed at reducing the impacts of climate change rather than addressing its root causes – currently plays a role in the NDCs only in isolated cases. The fact that geoengineering has so far played a rather subordinate role in Africa is also shown by the project map of the XPrize competition for carbon removal, which offered prize money for geoengineering processes to capture and store CO_2 from the atmosphere and oceans – only a small number of project applications were received from the African continent. This largely accords with the situation illustrated on the interactive geoengineering map. The map, produced by the ETC Group and the Heinrich Böll Foundation, documents geoengineering projects and experiments worldwide. There are currently over 1,800 known geoengineering projects and experiments registered on the map. Of these planned, ongoing, completed or cancelled projects, about five percent are located on the African continent. Among these projects, slightly more than a thousand are ongoing and planned projects; of these, the African share is about three percent. An evaluation of known African geoengineering projects conducted in early 2021 found that the majority of projects to date are research projects initiated and funded by public and private donors from North America, Europe and Australia. This trend is continuing. At the same time, it is becoming apparent that fossil fuel companies are increasingly interested in extending the life of their fossil fuel projects with the help of carbon capture and storage (CCS). Egypt is particularly affected by this, but CCS projects are also being planned and examined for their feasibility in other countries.

THE ROLE OF GEOENGINEERING IN THE NDCS OF AFRICAN COUNTRIES

Fifty-one Nationally Determined Contributions (NDCs) were submitted from the African continent. Algeria is among the many countries that clearly indicated in their NDC the contrast between the low share of climate-relevant emissions and the greater vulnerability to the impacts of climate change. Geoengineering plays no role or only a minor role in the NDCs. Most of the planned actions included the promotion of ecosystem-based approaches and emission reduction measures as a strategy for mitigating climate change and biodiversity loss. Here is a brief selection of the measures:

- Benin plans to promote the development of agroforestry as a measure to build carbon absorption capacity.
- Central Africa strives to protect its forest and grassland ecosystems as important carbon sinks.
- The Democratic Republic of Congo plans to adapt its forest management to climate change, including through: inventories, developing monitoring systems, conservation measures, involving local communities and Indigenous peoples, initiating pilot projects on non-timber forest products with local communities and Indigenous peoples, reforestation of species with high ecological, economic and cultural value.
- Gabon is committed to improving the protection of its marine ecosystems by 2030. The protection of whales and sharks will also be strengthened, as they play a key role in maintaining the balance of marine ecosystems that sustain and promote carbon sequestration.
- The Gambia plans to cover existing landfills and capture the landfill gas methane.
- Kenya announced the rehabilitation and conservation of degraded forests and the greening of infrastructure such as roads, railway lines and dams.
- Sierra Leone committed to conserve mangrove and seagrass resources in the Sierra Leone and Bonthe-Sherbro estuaries.
- Zimbabwe is focusing on climate-friendly agriculture, including conservation tillage and the integration of legumes into crop rotation to significantly reduce the need for and production of nitrogen fertiliser.

In one case, the use of a geoengineering technology is explicitly excluded:

- Rwanda's NDC comments on carbon capture and storage (CCS) as follows: *„Technically possible by highly unfeasible options (e.g. carbon capture storage) were not considered."*

Four African countries have named CCS as a possible measure in their first NDC:

- In both Egypt and South Africa, CCS is no longer included in the updated NDCs. In both countries, however, there are currently projects to introduce CCS at fossil production sites (please see section 5 & 6).
- In the third country, Malawi, *"the application of carbon capture and storage (CCS) to future grid-based thermal power plants from 2030 onwards represents the largest share of the identified*

GHG reduction potential, with almost half of all sectoral mitigation by 2040". So far, there is no evidence of ongoing or planned CCS projects in Malawi.
- Lesotho is pushing for a transformation in which low-carbon energy technologies are expected to play a crucial role, including the "*widespread deployment of various types of renewable energy, carbon capture and storage and new transport technologies*". In Lesotho, too, there are no indications of ongoing or planned CCS projects so far.

Tunisia seeks access to technological innovations that enable the transition to a low-carbon economy. The Tunisian NDC describes CCS as a technological niche in which it wants to position itself through involvement in research initiatives and industrial applications.

In the South Sudanese NDC, the Ministry of Petroleum is declared responsible for implementing measures to reduce the carbon footprint of petroleum extraction and refining processes. However, geoengineering technologies are not explicitly mentioned. Neither in Tunisia nor in South Sudan is there any evidence of planned or ongoing CCS projects.

Two countries mention carbon capture measures in the marine context in their NDCs:

- Cape Verde aims to explore "*ocean-based natural carbon sequestration, which proves harmless to the maritime resources, coastal communities and sea ecosystems*" and "*identify and support high-impact research on marine resources and marine biology in collaboration with international research centres (incl. seagrass, algae, plankton to provide food or medication, capture carbon, or substitute fuel, plastics, feedstocks…)*". A marine geoengineering trial will take place off the coasts of Cape Verde next spring (please see section 9)
- Mauritius aims to make its fisheries and aquaculture more climate-friendly, including through reduced fuel, energy, feed and nutrient consumption. It also plans to conduct "*research regarding the potential of aquaculture for carbon sequestration and renewable aquatic energy (algal biofuels, hydropower and other aquatic-based energy systems that exploit the energy potential of tides, currents, waves and wind)*". So far, there is no evidence of projects in Mauritius that aim to capture carbon through the production of algal biofuels. Research on biofuel production with microalgae has been carried out in Mauritius for several years, for example on the potential of different microalgae present in Mauritian waters, such as *Rhexinema paucicellulare*.

AFRICAN APPLICANTS AT THE XPRIZE COMPETITION FOR CARBON REMOVAL

Since 1994, the foundation XPRIZE organized competitions to promote technological development in various fields of (industrial) research. In 2021, the US$ 100 million XPRIZE for Carbon Removal, funded by Elon Musk and the Musk Foundation, was launched. The global competition runs over four years and invites individuals and teams to develop and demonstrate solutions for capturing CO_2 from ambient air or from the oceans and to theoretically lock the captured CO_2 permanently away. 'Nature-based solutions' are eligible too. The competition map shows that 1,132 teams have applied for the prize money so far. Of these, fourteen applications came from the African continent, including applications from Cameroon, Egypt, Kenya, Mauritius, Namibia, Nigeria, Tunisia, Senegal and South Africa. Six teams dealt with the capture of CO_2 from ambient air, three teams each with rock-based or ocean-based solutions and one team each with biochar and bioenergy with carbon capture and storage (BECCS). Ten of the fourteen projects appear to have been discontinued with their elimination from the competition because no further details on them have been found, among them the Egyptian projects SemiCO2ductor and Sycamore, Terra-Nebula and Riven from South Africa, the Nigerian project ELDACS, ATMOS from Senegal, the Tunisian project The Protector, NAVR-GRACE from Cameroon, 3CA-Green Technologies from Namibia and the Microalgae Team from Mauritius.

The Nigerian project Salubata, which had applied with shoes made from recycled PET, turned out to be headquartered in Paris.

A short description of the Nigerian project SectionX was provided on the XPrize map, but no visible traces of the project were found outside the map. SectionX aims to develop small units that can be placed on the roof of vehicles to use the airflow from moving vehicles to capture CO_2. The further handling of the captured CO_2, whether the filters are recyclable and how the CO_2 is separated from the filter is not addressed in the brief description.

The Kenyan project Mombasa Environmentally Conscience Organization, founded by Robin Kariuki, seeks to capture CO_2 at power plants, for example biomass combustion, and mineralise it using alkaline residues. No site has been found where this technology is already in use; it is uncertain how far the approach has been developed and whether work will continue on this project after it has been eliminated from the competition.

The Kenyan project Takachar won one of the prizes for student teams. The

team has improved the production of biochar through control technology. The proposal involves decentralised biochar reactors, aiming to give rural smallholder farmers access to carbon removal credits. First and foremost, Safi Organics, the company behind the team, wants to enable smallholder farmers to produce local fertiliser or soil conditioner on the basis of local plant residues. Whether the production and application of the produced biochar will bind CO_2 in the long term is debatable, as the properties and behaviour of biochar in the soil depend, among other things, on the raw material, the production process and the climatic conditions. However, since the project gives rural smallholder farmers independence from the large fertiliser manufacturers and avoids long transport routes for the fertilisers, some CO_2 emissions are avoided in this respect.

IMPACT OF THE WORLD BANK CCS TRUST FUND ON CCS DEVELOPMENT ON THE AFRICAN CONTINENT

The World Bank CCS Trust Fund to support CCS in developing countries was established in 2009 with financial support from the Global CCS Institute and the UK and Norwegian Government. The fund's goal is to initiate programmes to support CCS development and deployment in developing countries. So far, the programme has been active in Algeria, Botswana, China, Egypt, Jordan, Kosovo, Mexico, Morocco, Nigeria, South Africa and Tunesia, and is currently being developed in India and Indonesia. The programme aims to address legal issues, identify opportunities for CO_2 storage and support government roadmaps for CCS development. It also provides training, education and capacity building. Phase I of the funding programme was completed in 2015. In phase II, the CCS Trust Fund aims to establish CCS pilot projects in Mexico, Nigeria and South Africa. The Fund's budget is over US$ 50 million, with the British government contributing by far the largest share.

In Botswana, the funding programme was discontinued in 2015, after the completion of phase I. In Botswana, the World Bank pursued the following objectives:

- identification of potential CO_2 storage sites for the storage of CO_2 captured from coal-fired power plants;
- assessment of institutional and legal arrangements for CCS deployment in the country and make recommendations;
- training, education and capacity building, as well as a key person study tour.

The World Bank CCS Trust Fund had US$ 1.4 million in funding available in Botswana. No CCS project in Botswana is known to have been developed

or is planned as a result of the programme.

In Algeria, Morocco and Tunisia, the World Bank CCS Trust Fund has also made funds available for the programme, but also discontinued it after the completion of phase I. In the Maghreb region, the programme aimed to address legal issues, identify opportunities for CO_2 storage and support government roadmaps for CCS development. It also provided training, education and capacity building.

During the same period, with the same objectives and components, the programme was also implemented in Egypt. In 2012, the World Bank programme recommended in a report to conduct enhanced oil recovery (EOR) in Egyptian oil fields using captured CO_2 from Jordan. EOR involves pumping compressed CO_2 into ageing oil fields to extract otherwise inaccessible oil, thereby significantly increasing oil production and CO_2 emissions. Meanwhile, there are plans for CCS projects at several locations in Egypt (please see section 5). The extent to which these developments can be attributed to the World Bank programme is not disclosed – but a connection is conceivable.

In Nigeria, the World Bank CCS Trust Fund aims to assess and map potential CO_2 sources and storage sites, address legal issues, support a national roadmap for CCS and carbon capture use and storage (CCUS) development and a pilot project. It also provides training, education and capacity building. The programme has been running in Nigeria since 2009 and is scheduled to be completed in 2024. A CCS pilot project was announced in September 2021. However, the exact location and timeline for implementation are not yet known or publicly available, but it is likely that a site owned by the Nigerian National Oil Corporation (NNPC) will be chosen. The NNPC is a joint venture between the Nigerian federal government and a number of foreign multinationals, including Royal Dutch Shell, ExxonMobil, Agip, Total and Chevron. In addition to the CCS pilot project, the Nigerian government has announced the assessment of four CCUS hubs and to "*develop a regulatory framework, engage stakeholders, undertake capacity building, and assess policy measures to stimulate CCUS*". These initiatives are supported by the World Bank CCS Trust Fund with US$ 8.5 million and also by the International Energy Agency (IEA). In 2021, the IEA has recommended Nigeria to implement CCUS and EOR activities and is actively working with the Office of the Nigerian Vice President to develop and build CCUS capacity. The New York-based Columbia Center on Sustainable Investment and British researchers recommended to the Nigerian government to introduce and subsidize CCS and/or CCUS.

In South Africa, the South African Centre for Carbon Capture and

Storage (SACCCS) was established in 2009, with the launch of the World Bank CCS Trust Fund programme. SACCCS is a state-owned institution with the mandate to explore the technical potential of CCS in South Africa. It was hosted by the South African National Energy Development Institute (SANEDI) until 2020, when it was transferred to the South African Council for Geoscience (CGS). In 2010, CGS and the Petroleum Agency of South Africa published the "Atlas on Geological Storage of Carbon Dioxide in South Africa" and identified a potential storage volume of approximatively 150 gigatonnes in deep saline formations, unmineable coal seams and depleted oil and gas reservoirs. A CCS Roadmap was endorsed by the South African Cabinet in 2012. SACCCS also produces various research reports on CCS, CCU(S), worked with local stakeholders and organized workshops to inform stakeholders. The centre intends to develop a full-scale CCS beyond 2025 and announced the first CO_2 injections already for 2017. The injections were repeatedly postponed, e.g., because a decision on the CCS project site had not yet been taken. At that time, the Zululand basin north of Durban on the South African east coast was one of the possible pilot trial sites However, the plans are being pursued and will now be implemented as a pilot project together with the CGS by ~2024. According to SANEDI "*the selected pilot site is 9 km from Leandra in Mpumalanga in close proximity to emission sources of the Sasol Secunda plant and Eskom power stations. Storage will be in a basalt formation, a layer of porphyritic lava is targeted for the storage, the olefin rich rock in the layer is expected to react quickly with CO_2. The pilot project aims to store 10 000 tons of CO_2 at the site, CO_2 will be transported by truck to the site during the pilot phase*". Where the CO_2 will be captured has not yet been made public.

The World Bank CCS Trust Fund has been supporting these plans with almost US$ 30 million since 2009. In the first phase of the Trust Fund programme, from 2009 to 2015, US$ 1.35 million was provided and in the second phase, from 2016 to 2024, US$ 27.4 million. The South African government supported the project with US$ 15 million until 2016.

CCS and CCUS fall into the category of Carbon Dioxide Removal (CDR) geoengineering technologies that hypothetically aim to remove greenhouse gases from exhaust gases and the atmosphere. CCS aims to bury the captured CO_2 underground, e.g., in old oil reservoirs or saline aquifers. Theoretically, it should be stored in such geological formations for the long term, but the captured CO_2 could leak for many reasons, e.g., underground movements. CCUS aims to "store" the captured CO_2 in manufactured goods, such as synthetic fuels or chemicals, however, the CO_2 is re-emitted once these products are consumed. Despite decades of research and extensive funding, these two CDR technologies cannot demonstrate any positive impact on the climate – the same applies

to all other known geoengineering technologies.

MANY NEW CC(U)S AGREEMENTS IN EGYPT

In Egypt, projects for four new CC(U)S projects have been announced since September 2021.

In July 2022, German Wintershall Dea and the Egyptian Natural Gas Holding Company (EGAS) have signed a Memorandum of Understanding (MoU) to explore opportunities in the areas of CCS and hydrogen. Over a period of two years, the two companies will jointly search for possible areas of application for CCS in the plants operated by Wintershall Dea and EGAS in Egypt. In addition, the production of blue hydrogen – hydrogen production from natural gas in combination with CCS – will be considered. "*The state-owned EGAS manages the country's natural gas exploration, production and delivery, inclusive of the giant Zohr offshore field. Wintershall DEA has worked for decades in development of onshore and offshore gas assets in Egypt*".

In June 2021, Italian ENI, the Egyptian Electricity Holding Company (EEHC) and EGAS signed an agreement to assess the technical and commercial feasibility of blue hydrogen (hydrogen production from fossil gas in combination with CCS) and green hydrogen (hydrogen production based on renewable energy) in Egypt. "*Eni has been present in Egypt since 1954, where it operates through the subsidiary IEOC. The company is currently the country's leading producer with an equity hydrocarbon production of approximately 360,000 barrels of oil equivalent per day*." In May 2022, the Egyptian government and Eni announced plans to implement a pilot CCS project in the Meleiha field in northern Egypt at a cost of US$ 25 million. The project will proceed in three phases. In the first phase, 0.35 million tonnes of algae-based biofuel will be produced and this production is expected to avoid 1.2 million tonnes of CO_2 annually. The second phase plans to produce 0.075 million tonnes of biodegradable plastics and aims to avoid 0.045 million tonnes of CO_2 annually. In the third phase, plastic waste will be recycled and used as raw material for polyethylene production. For each tonne of polyethylene, the project hopes to avoid two tonnes of CO_2. How the amounts of CO_2 saved were calculated is not known. The fact that the production of 0.35 million tonnes of algae-based biofuel is supposed to avoid 1.2 million tonnes of CO_2 is incomprehensible, because as soon as the biofuel is consumed, the CO_2 it contains is released. Moreover, the production of algae is energy-intensive. Apart from CO_2, algae require large amounts of nutrients – nitrogen is one of the main nutrients and is particularly energy-intensive in production. Other production factors, such as water temperature, must be constantly regulated. In

addition, the water in the tanks must be constantly moved, otherwise the algae sink and can no longer carry out photosynthesis. It is not conceivable that CO_2 is reduced through the production of algae, the further processing into biofuels and the consumption of the biofuels – it is more likely that additional CO_2 is released. Similarly, the second and third project phases are also energy-intensive. Eni has announced that it will provide further details on this initiative at the COP 27 climate summit in Sharm El Sheikh, Egypt in November 2022.

In September 2021, EGAS and ECHEM signed a MoU with Japan's Toyota Tsusho to study the economic feasibility of converting from current grey ammonia to blue ammonia (ammonia production from fossil gas combined with CCS) using Japanese technology. In August 2022, the results of the study were presented and discussed at the Egyptian Ministry of Petroleum and Mineral Resources. According to the study, CCS could be used to capture CO_2 emissions at two Egyptian fertilizer factories:

- Abu Qir Fertilizers and Chemical Industries Company, a large nitrogen fertilizer producer in Abu Qir Bay, east of Alexandria;
- Misr Fertilizers Production Company (MOPCO), a manufacturer with three fertilizer production sites in the Damietta region of northeastern Egypt.

The captured CO_2 is to be transported to old oil and gas fields for underground injection, whether or not this CO_2 will be used for EOR remains unclear. At the end of the meeting, it was decided to conduct further studies to further clarify the feasibility of the proposed CCS projects.

It was also announced that eleven more MoUs were signed during the Egypt International Petroleum Conference and Exhibition in February 2022 in the presence of the Minister of Petroleum and Mineral Resources, Tarek El Molla. Not many details are known about the contents of these MoUs, but they seem to concern new fossil fuel production and processing sites and CCUS. According to press reports, the ministry is now working on the preparation of studies on the potential projects. Possible partners in these MoUs include Honeywell, Baker Hughes and Mitsubishi.

FURTHER CCS PLANS BY FOSSIL FUEL CORPORATIONS IN AFRICA

In Algeria, Wintershall Dea and Sonatrach cooperate in the Reggane Nord project region since 2002. Reggane Nord (Groupement Reggane Nord, GRN) comprises six gas fields over an area of 1,800 square kilometres in the

southwest of the Sahara Desert. The GRN shares are held by Sonatrach (40%), German Wintershall Dea (30.75%) and Spanish Repsol (29.25%). Sonatrach is an Algerian state-owned company and the largest oil and gas company in Africa. In 2020, Wintershall Dea and Sonatrach have signed a MoU to explore new opportunities in the field of gas production. In 2022, the MoU was expanded and includes now also CCS and hydrogen. There is still no further publicly available information on the scope, technical design and timetable of the planned CCS projects.

This project is the second known CCS project in Algeria. Sonatrach launched the first Algerian CCS project in 2004 jointly with BP and Statoil. The In Salah CO_2 Storage Project aimed to inject 17 million tonnes of CO_2 in the saline Krechba Formation in central Algeria. The CO_2 was captured in the nearby In-Salah-Oil-Field. In the end, the planned 17 million tonnes were not achieved, and the project was discontinued after 3.8 million tonnes had been injected. In 2011, the project was abandoned, because the storage site was no longer considered safe, after a surface uplift over all three injection wells and CO_2 leakage from a nearby well had been detected. It is possible that the surface uplift and earthquakes are linked to the 3.8 million tons injected. According to The Human-induced Earthquake Database, 9,506 earthquakes were recorded at the In Salah injection site from 2009 to 2011, with a maximum earthquake magnitude of 1.7 Mmax. The In Salah project received financial support from the US Department of Energy and the European Union.

In Mozambique, ExxonMobil announced plans to add carbon capture technology to a fossil gas project and discussed its plans with the Mozambican Government in November 2021. A final investment decision on the gas project has not yet been taken.

In Ghana, Ghanaian Base Energy, a CH Group subsidiary with three existing oil and gas discoveries in the Ghanaian Tano fields, announced plans to explore CCUS opportunities. Concrete plans have not yet been announced.

In South Africa, the electricity utility Eskom Holdings SOC Ltd announced plans to develop a 3,000-megawatt gas-fired power plant in Richards Bay. Richards Bay is a town in KwaZulu-Natal and one of South Africa’s largest ports with an extensive industrial structure, e.g., for the production of aluminium, titanium and paper. The combined cycle gas power plant (CCGPP) project is scheduled to start commercial operation in 2024. The project has been delayed due to court proceedings over deficiencies in the environmental permit for the construction of

the project. The initial environmental permit had not fully considered the use of renewable energy as an alternative, and public participation was also flawed. In October 2022, the South African High Court in Pretoria ruled that the proposed CCGPP project was conditional on "*the implementation of mitigation measures such as the switching to alternative biofuels and carbon capture and storage*". There are currently no public statements on whether and how Eskom, South Africa's main electricity producing company, will implement this requirement.

The African Energy Chamber, the "*voice of the African energy sector*" is advocating to encourage CC(U)S in the African oil and gas industry and states that such technology is critical "*to optimize production and environmental impact*".

It is not clear on what basis the recommendations of the African Energy Chamber and the South African High Court for CC(U)S were made. For CCUS, the potential for CO_2 as a feedstock for industrial processes is minuscule relative to global CO_2 emissions. Moreover, CCUS processes entail a high energy demand, and CCUS products release most of the carbon after a short time. Although CCS had already been developed half a century ago and large amounts of public and private money have been invested in research and projects, CCS still remains a hypothetical approach. None of the major CCS projects that have been highly praised in the last decade have lived up to expectations, such as the Australian Gorgon project, the Canadian SaskPower project or the US-based Petra Nova project. In addition, many other CCS projects around the world have failed. Technical problems and high costs are commonplace and, most importantly, safe storage of the captured CO_2 is not guaranteed. In April 2022, the Institute for Energy Economics and Financial Analysis (IEEFA) stated: "*The extent of the technical failure of Gorgon CCS cannot be overstated. It prompts the question: if the engineers from the project backers – the super major oil companies Chevron, Shell and Exxon – cannot get CCS to work as forecast, who can?*"

GEOENGINEERING TRIALS IN THE ENERGY INTENSIVE DIAMOND MINING INDUSTRY IN SOUTHERN AFRICA

De Beers Group is the world's largest diamond producer and trader and headquartered in London. Project Minera was launched by De Beers Group in 2015 and aimed to look into carbon mineralization/enhanced weathering. The project tested options to store CO_2 in kimberlite rock, a mine tailing from diamond mining and involved R&D, laboratory trials and field experiments at three diamond mining sites in Southern Africa: Venetia mine in South Africa, Jwaneng mine and Orapa diamond mine in Botswana. Project Minera cooperated with five universities from Canada

and Australia. De Beers' successor project CarbonVault aims to accelerate carbon mineralisation processes by conducting R&D, laboratory testing and field testing. De Beers Group's Venetia diamond mine opened in 1992 and is situated in the north-east of South Africa. Orapa diamond mine was discovered in 1967, started production in 1971 and is located in north-eastern Botswana. The mine is owned by De Beers Group and the government of Botswana. Jwaneng diamond mine was discovered in 1971, started production in 1982 and is situated in south-central Botswana.

The South African Tailings for use in Carbon Capture and Storage project (SAT4CCS) started in 2019. The project is led by staff from the universities of Pretoria, Southampton and Cape Town and aims to assess the suitability of South African mine tailings for the mineralisation of CO_2. Mine sites with suitable rock types are to be recorded. In addition, the project will search for methods to accelerate the speed of the reaction between rock and CO_2, for example by increasing temperature and pressure, by using biotechnologies, microbial processes, the use of additives and sorbents or a combination of several of these methods. A consortium of mines has formed to volunteer in collaborating with the research project by providing access to tailings samples and data, among them the Ekapa diamond mine. The SAT4CCS researchers cooperate with the UK Greenhouse Gas Removal by Enhanced Weathering (GGREW) project and De Beers. Discussions are also being held with the South African Centre for Carbon Capture and Storage (SACCCS). The SAT4CCS project is financed by the universities of Pretoria, Southampton and Cape Town, GGREW and De Beers.

RESEARCH INTO SOLAR RADIATION MANAGEMENT (SRM) – DECIMALS

The DECIMALS Fund (Developing Country Impacts Modelling Analysis for SRM) was launched and is run by the UK-based The Degrees Initiative. The research fund aims to expand the discussion on SRM around the globe. To do so, the fund provides funding to enable scientists in the Global South to model SRM approaches and analyse the potential impacts of SRM on their regions. Launched in 2018, a total grant of US$ 0.43 million was shared between eight research teams. In 2022, the annual budget has been increased to US$ 0.075 million per research team and the number of teams to eleven. On the African continent, DECIMALS research is taking place at four sites, in Benin, Ivory Coast, Kenya and South Africa. At all DECIMALS project sites, the deployment of SRM is modelled using models developed in the Global North:

- In Benin, the DECIMALS researchers model the use of SRM in the northern Gulf of Guinea.

- The DECIMALS team in Ivory Coast models the impact of SRM on temperature and precipitation in West and Central Africa.
- In Kenya, the use of SRM in East African areas with weather extremes is being modelled.
- The South African DECIMALS team is modelling the use of SRM in agricultural production in Southern Africa.

The African Technology Assessment Platform describes The Degrees Initiative as being "*led by prominent advocates of geoengineering techniques and claims to have taken "the SRM conversation to the global South." As geoengineering proposals are by and large created by northern countries with high emissions in order to avoid reducing their own emissions, they create "research support" projects involving researchers in Africa in order to push the idea that geoengineering is of interest to the global South.*"

In January 2022, a group of concerned senior climate scientists from around the world called for an international solar-geoengineering non-use agreement, as SRM poses unacceptable risks if ever implemented, this group included scientists from Ghana, Kenya, Nigeria and South Africa.

MARINE AND ALGAE-BASED GEOENGINEERING PROJECTS

Four projects are known in this category. One commonality between these projects is that they were initiated in Europe but are to be implemented on the African continent.

Seafields Solutions Ltd. was founded in the UK in 2021. The company's goal is to cultivate the fast-growing and invasive seaweed Sargassum in the open sea. The harvested seaweed is to be pressed into bales and sunk into the deep sea with the aim of storing carbon in the long-term, although it is still unclear what happens to the bales on the seabed. The project aims to supply the seaweed with nutrients through artificial upwelling – this involves pumping nutrient-rich water from the deep sea through pipes that are up to several hundred metres long to the sea surface, which is relatively nutrient poor where Sargassum is to grow floating freely in the water. In spring 2023, Seafields Solutions plans to test its artificial upwelling technology for its project off the coast of Cape Verde. The exact location and scale of the tests is not yet publicly available. The next step is to set up a pilot project to test the project proposal in the South Atlantic. This project is expected to start by 2023 in the open ocean near Ascension Island. Seafields cooperates with the German Helmholtz Centre for Polar- and Marine Research and the American Carbonwave.

Brilliant Planet is headquartered in London, UK, and was founded in 2013. After years of R&D and pilot testing, the company aims to construct a 30-hectare commercial algae demonstration plant on the Moroccan coast in the Sahara Desert. The site has already been used for pilot testing on a three-hectare section of desert since ~2019. The algae plant must be built near the coast, as seawater will be pumped into the plant. The seawater serves as a nutrient and CO_2 supplier for the algae. After about 20-30 days, the algae is harvested and the water is returned to the sea. Afterwards, the harvested algae is to be dried and then buried under Sahara sand, one to three metres below the surface, to store the absorbed carbon. The company's marketing concept is carbon credits to be sold to emitting companies.

Kelp Blue is headquartered in the Netherlands and plans to establish large-scale kelp plantations in a coastal area in Namibia. In 2021, the Namibian government granted permission to establish a pilot operation in Luderitz in southwestern Namibia. By 2029, Kelp Blue plans to cultivate 70,000 hectares of kelp with an annual harvest of 120 tonnes.
Kelp Blue's biotech division is responsible for processing and marketing. The company's goal is to manufacture kelp-based products for crop production, replacement of plastics, animal feed supplement, fibres for textiles, pharmaceutical, nutraceutical and cosmetic applications – i.e., there is no long-term storage of CO_2.

Omega Green is headquartered in the Netherlands and aims to combine algae production and CO_2 capture by injecting flue gas into the algae culture system. The company has established production systems at three sites, the largest of which is located in Morocco and covers an area of one hectare. At its Morocco site, waste gases from the cement industry are to be fed directly into the algae facility. It is not disclosed how the algae – which may be contaminated with pollutants from the flue gases – are intended to be used or marketed.

Marine and algae-based geoengineering projects are associated with numerous and sometimes unpredictable risks to the marine environment, e.g., threats to the marine food web, oxygen depletion, increased release of methane, potential effects on marine biochemical processes, harmful toxin-producing algal blooms as well as potential transboundary effects on fisheries, coastal communities and weather patterns.

10 OUTLOOK

The African continent has been in the news more often recently with major discoveries of oil and gas deposits and plans for the expansion of the fossil fuel infrastructure. For example,

- In September 2022, the Nigerian National Petroleum Company Ltd and Morocco's National Office of Hydrocarbons and Mines have agreed to increase their gas infrastructure by 5,600 kilometres. The gas pipeline project is to start at a compressor station on Brass Island, Nigeria, from where it will run offshore to Dakhla, Morocco. The pipeline will then run onshore to northern Morocco, ultimately connecting to the Maghreb-Europe pipeline.
- An oil field in the Gulf of Suez was discovered off the Egyptian coast during this year's Egypt Petroleum Show, which is considered the largest discovery in the Gulf of Suez in the last twenty years.
- The largest discovery in the last twenty years was also reported this year from Sonatrach in Algeria, involving a gas field in the Sahara desert.
- The Uganda National Oil Company is planning a new pipeline, the 1,443-kilometre East African Crude Oil Pipeline (EACOP).

Interest in fossil fuel resources from the African continent has grown, especially in Europe. The climate crisis should be a sufficiently compelling reason to leave the fossil fuels in the ground, but there are many other reasons:

- Energy Transition explains that "*Nigeria has spent billions and billions exploiting its oil and gas reserves in recent decades, but nearly half of the country still lives without electricity access. Hydrocarbon earnings have been lost to corruption while oil spills by Shell Nigeria and others have destroyed environments and livelihoods*".
- Extraction projects (not only) in Mozambique have forcibly displaced communities, expropriated land, destroyed livelihoods and the environment, e.g., 557 households had to be resettled for the construction of the onshore Afungi LNG park.
- A European Parliament resolution linked the violation of human rights in Uganda and Tanzania to investments in fossil fuel projects.
- Nnimmo Bassey, the director of the Health of Mother Earth Foundation in Nigeria, states: "*Decades of oil and gas extraction on the continent has fed foreign markets and only muddied the water, built violence, and left the people in the cold and in the dark*".
- There are several reports of oil spills that have caused major damage but have not been cleaned up, e.g., caused by Shell in Nigeria.

The introduction of CCS and CCUS is also likely to result in such

problems continuing and possibly even intensifying. In addition, there are new risks associated with CC(U)S as well as high financial and energy costs. In August 2021, fifty organisational signatories called on the African Union, all regional bodies and national African governments "*to adopt an develop just recovery plans at the regional and national level*" to ensure the "*Just Recovery Energy Plan for a 100 percent renewable energy independent Africa*".

East Africa

Project	Type of GE	Status	Country
DECIMALS Fund: Kenya	Major research project	ongoing	Kenya
The Climate Foundation: Zanzibar	Artificial upwelling	cancelled	Tanzania
Rufiji Cluster	BECCS (Bio-Energy with Carbon Capture and Storage)	cancelled	Tanzania
MCDI & The Climate Foundation: Tanzania	Artificial upwelling	cancelled	Tanzania

North Africa

Project	Type of GE	Status	Country
Reggane North CCS project	CCS (Carbon Capture and Storage)	planned	Algeria
In Salah CO_2-Storage Project	CCS (Carbon Capture and Storage)	completed	Algeria
World Bank CCS Trust Fund: Maghreb region	Major research project	completed	Algeria, Morocco, Tunesia
EGAS: CC(U)S plans with Eni	CCUS (Carbon Capture Use and Storage)	planned	Egypt
Abu Qir Blue Ammonia CCS	CCS (Carbon Capture and Storage)	planned	Egypt

MOPCO Blue Ammonia CCS	CCS (Carbon Capture and Storage)	planned	Egypt
EGAS: CCS plans with Wintershall Dea	CCS (Carbon Capture and Storage)	planned	Egypt
World Bank CCS Trust Fund: Egypt	Major research project	completed	Egypt
Omega Green Morocco	Algae projects	ongoing	Morocco
Brilliant Planet – Morocco	Algae projects	ongoing	Morocco
ONC / ONF: Ocean fertilization near El Jadida	Ocean fertilization	cancelled	Morocco

Trials off the North African coast (on Gran Canaria, Spain)

Project	Type of GE	Status	Country
Planktos (Canary Islands)	Ocean fertilization	cancelled	Canary Islands, Spain
Ocean-Based Climate Solutions, Inc (Canary Islands trial)	Artificial upwelling	planned	Canary Islands, Spain
Ocean artUp: Gran Canaria	Artificial upwelling	completed	Canary Islands, Spain
OceanNETs (field trial in Spain)	Enhanced Weathering	completed	Canary Islands, Spain

South Africa

Project	Type of GE	Status	Country

Orapa diamond mine	CCS (Carbon Capture and Storage)	ongoing	Botswana
Jwaneng diamond mine	CCS (Carbon Capture and Storage)	ongoing	Botswana
World Bank CCS Trust Fund: Botswana	Major research project	completed	Botswana
Kelp Blue – Namibia	Algae projects	ongoing	Namibia
Venetia diamond mine	CCS (Carbon Capture and Storage)	ongoing	South Africa
Phakwe Richards Bay Gas Power 3 CCPP	CCS (Carbon Capture and Storage)	planned	South Africa
South African Centre of Carbon Capture and Storage (SACCCS)	Major research project	ongoing	South Africa
SACCCS pilot trial	CCS (Carbon Capture and Storage)	planned	South Africa
LanzaTech & Swayana Ltd.	CCUS (Carbon Capture Use and Storage)	cancelled	South Africa
SAT4CCS	Major research project	ongoing	South Africa
DECIMALS Fund: South Africa	Major research project	ongoing	South Africa

West Africa

Project	Type of GE	Status	Country
DECIMALS Fund: Benin	Major research project	ongoing	Benin
Seafields: Cape Verde trial	Algae project	planned	Cape Verde
African Biochar Partnership (ABP)	Biochar	ongoing	Cape Verde

DECIMALS Fund: Ivory Coast	Major research project	ongoing	Ivory Coast
Nigeria CCS pilot trial	CCS (Carbon Capture and Storage)	planned	Nigeria
World Bank CCS Trust Fund: Nigeria	Major research project	ongoing	Nigeria