CHAPTER 1

Introduction and context

CHAPTER 1: Introduction and context

Integrating Author	Babalwa Mqokeli[1]
Contributing Authors	Greg Schreiner[1], Luanita Snyman-van der Walt[1], Rinae Tsedu[1] Liz Day[2], Philip Desmet[3], Albert Froneman[4], Jayson Orton[5], Johan Maritz[1], Doreen Atkinson[6] Shawn Modise[7], Magenthran Ruthenavelu[8], Thulisa Zukulu[8], Jabulani Maluleke[8]
Peer Reviewer	Paul Lochner[1]

[1] Environmental Management Services (EMS), Council for Scientific and Industrial Research (CSIR)

[2] Liz Day Consulting

[3] EcosolGIS

[4] AfriAvian Environmental

[5] ASHA Consulting

[6] Karoo Development Foundation

[7] Northern Cape Economic Development Trade and Investment Promotion Agency (NCEDA)

[8] Transnet National Ports Authority (TNPA)

Recommended citation: Mqokeli, B., Schreiner, G., Snyman-van der Walt, L., Tsedu, R., Day, L., Desmet, P., Froneman, A., Orton, J., Maritz, J., Atkinson, D., Modise, S., Ruthenavelu, M., Zukulu, T. & Maluleke, J. (2026). *Chapter 1: Introduction and context* in Schreiner, G., Mqokeli, B., Snyman-van der Walt, L. Lochner, P. and Tsedu, R. (eds.). (2026). *Work Package 2: Strategic Environmental Assessment for the proposed Boegoebaai Port, Special Economic Zone and Namakwa Region*. CSIR/SPLS/Ems/EXP/2026/0001/A, CSIR: Pretoria: ISBN 978-0-7988-5676-8. Available at Boegoebaai Port | CSIR

Contents

Tables

Figures

CHAPTER 1. INTRODUCTION AND CONTEXT

1.1 PURPOSE AND SCOPE OF THE CHAPTER

This chapter provides the context for the Strategic Environmental Assessment (SEA) of the proposed Boegoebaai Port, Special Economic Zone (SEZ), and Green[1] Hydrogen (GH_2) development in the Namakwa region of the Northern Cape. Its purpose is to:

- Provide the strategic rationale of the GH_2 economy proposed in the Northern Cape.
- Describe the proposed development components of such an economy and their spatial extents.
- Outline the approach and methods adopted by the SEA, including introducing the scenarios and risk/opportunity approach underpinning the assessment.

1.2 STRATEGIC RATIONALE AND REGIONAL SCOPE

GH_2 and its derivative Power-to-X (PtX) products, such as green ammonia and green methanol, could assist South Africa's transition to a low-carbon economy. The high energy density of GH_2 and PtX products, along with the ability to be produced emission-free using renewable energy through electrolysis, makes these energy carriers particularly suitable for decarbonising sectors that are traditionally difficult to abate, such as steel, cement, ammonia, and plastics manufacturing, as well as long-distance transport modes including aviation, shipping, and heavy freight (Department of Science and Innovation (DSI), 2021; International Energy Agency (IEA), 2022).

The Northern Cape Green Hydrogen Masterplan (NCGHM) (2023) proposes that the Northern Cape is well positioned to lead this transition. It is South Africa's largest and most sparsely populated province, with vast tracts of land and a globally competitive endowment of solar and wind resources. These attributes make it ideal for large-scale renewable energy generation, which is a prerequisite for GH_2 production. The province also has a 300 km coastline, and studies are underway to determine the feasibility of developing a deep-water port at Boegoebaai, which would enable strategic maritime trade links to both the Atlantic and Pacific basins. GH_2 presents a transformative opportunity for the Northern Cape, with the potential to drive industrialisation, address unemployment, inequality and poverty, and contribute to global climate change mitigation. Coupled with the province's growing mining sector, it could catalyse a significant shift in the region's and the country's development trajectory (NCGHM, 2023).

The Northern Cape targets include an initial 5 gigawatts (GW) of electrolyser capacity supported by 10 GW of renewable energy generation by 2033, with a long-term vision to scale up to 40 GW by 2050. The realisation of this ambition will require extensive infrastructure development across multiple municipalities, including energy generation sites, transmission corridors, desalination plants, and transport networks. These developments could potentially intersect with sensitive ecological systems, heritage landscapes, and socio-economic dynamics across the Namakwa District.

For this reason, a SEA was initiated through a collaboration between the South African National Energy Development Institute (SANEDI), the Northern Cape Economic Development, Trade and Investment Promotion Agency (NCEDA), and Transnet National Ports Authority (TNPA). Given their experience in SEA, renewable energy, port and GH_2 planning, the Council for Scientific and Industrial Research (CSIR) was appointed to lead and coordinate an independent SEA process.

Given the multiscale scope of the SEA, its processes and outputs were split between two Work Packages: Work Package 1 and Work Package 2. Work Package 1 of the SEA (available at: Individual Chapters | CSIR) assessed the social and ecological sensitivities of the local-scale receiving environment around the proposed port and SEZ development. Its purpose was to inform local-scale feasibility and planning studies

[1] There are many different definitions and perspectives on the concept of "green". Here, we use the term in the narrow sense, meaning a product developed where upstream production facilities are supplied by renewable energy.

and to guide future decision-making processes, including Environmental Impact Assessments (EIAs) and other planning processes related to the port and SEZ.

Work Package 2 (the focus of this report and associated chapters) provides a more strategic, region-wide assessment of the cumulative social, economic, and ecological implications of an expansive GH_2 economy in the Northern Cape, extending beyond the localised footprint considered in Work Package 1. Covering a regional spatial extent of over five million hectares, it encompasses the Richtersveld, Nama Khoi, Kamiesberg, and Khâi-Ma Local Municipalities (Figure 1-1). The regional scope enables the identification and evaluation of systemic risks and opportunities that may not be apparent at the individual project level, providing a robust evidence base to support decision-making across multiple governance and planning frameworks.

Table 1-1: Summary of the SEA Work Packages across different spatial scales, methods, and data collection practices.

	Work Package 1	Work Package 2
Spatial scale	Local (33 500 ha) covering the extent of the proposed port and SEZ.	Regional (>5 million ha) across four Local Municipalities, including the 33 500 ha extent covered by Work Package 1.
Temporal scale	Introspective, fixed view on currently existing sensitivities in the receiving environments of the proposed port and SEZ.	Expansive, forward looking up to 2050 considering existing land-uses and trends in accumulation to any future regional GH2 infrastructure.
Methods	High resolution determination of receiving environment sensitivity with a view to practicing avoidance (top of the mitigation hierarchy).	Determination of the cumulative social and ecological impacts of a regional expansive GH_2 economy across development scenarios within a structured risk/opportunity framework.
Resolution	Fieldwork, coupled with desktop reviews (peer reviewed and grey literature) and other sources where necessary (e.g., interviews).	Desktop reviews (peer reviewed and grey literature, interviews etc.) and other publicly available data and sources.
Application of outputs	Local-scale feasibility and planning studies (especially for the new proposed port) and future decision-making processes, like EIAs and other local-scale planning exercises which may occur in the future.	Regional/national planning documents, through processes like Spatial Development Frameworks (SDFs), Integrated Development Plans (IDPs) and Environmental Management Frameworks (EMFs), national energy planning and any EIA processes that may be undertaken in the region.

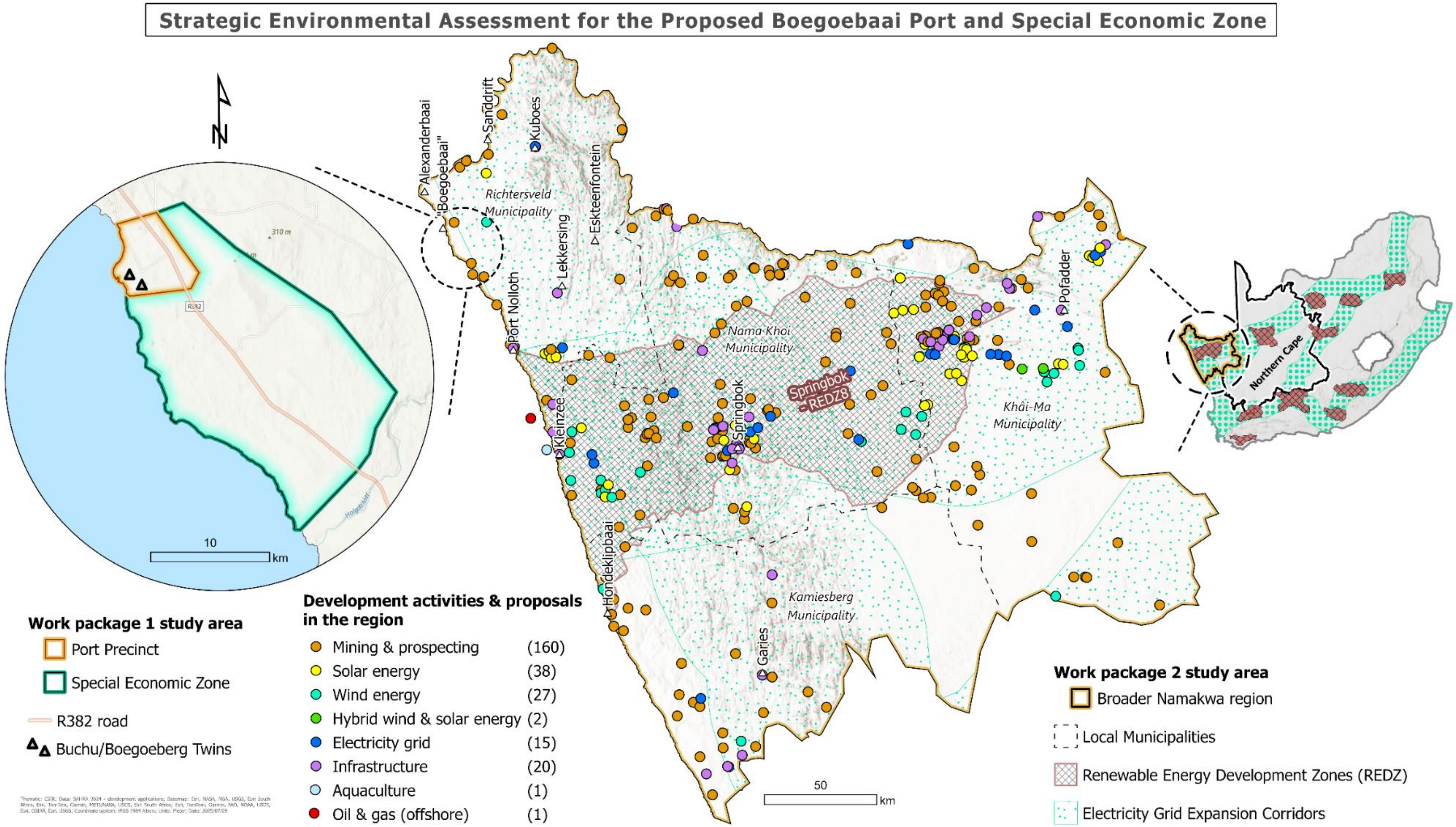

Figure 1-1: The proposed Boegoebaai port, SEZ (Work Package 1 study area) and Namakwa region study area (Work Package 2 study area) in the Namakwa District of the Northern Cape Province. Economic activities include widespread mining and prospecting. The area between Port Nolloth and Alexander Bay, including the land to the west of the R382 where the port and SEZ are proposed, has been mined for diamonds for over a century. A renewable energy sector is also emerging with established Renewable Energy Development Zones (REDZ) and Electricity Grid Infrastructure (EGI) Corridors.

1.3 OVERVIEW OF THE PROPOSED DEVELOPMENT COMPONENTS

This section describes the types and scale of infrastructure and development activities considered within the scope of Work Package 2 of the SEA.

1.3.1 The Proposed Boegoebaai Port

The proposed port precinct, an area of approximately 2 187 hectares (ha), will be developed in phases. The short-term (Phase 1A) port layout (Figure 1-2), is intended to accommodate bulk liquid items such as ammonia and diesel oil, dry bulk materials such as iron ore and manganese, and assorted break bulk cargo, which arrives in bulk and is then separated into individual components, such as lead and zinc. Consequently, TNPA needs to make provision for the infrastructure necessary to facilitate the import and export operations for all these commodities. According to the current project schedule, an estimated 5 million tonnes per annum (Mtpa) of dry bulk (manganese) and 1 Mtpa of break bulk (lead and zinc) are expected to be exported by 2033. There are also plans to export 1.4 Mtpa of GH_2 derivatives and various agricultural products (0.2 Mtpa). Diesel imports are expected to reach around 1.3 Mtpa by 2033. All exports and imports will be transported mainly through the road network in the first phase of the new port.

The port will include a two-berth jetty connected to the land via an access trestle; a sea-side berth dedicated to dry bulk and liquid cargo and a conventional multi-purpose berth (landside). The berths are sheltered from wave energy by a concrete armoured breakwater. The bulk berth will be fitted with a ship loader and a conveyor system connected to landside closed stockpiles. The bulk berth will be capable of liquid bulk import and export, and fitted with pipelines that are connected to diesel and ammonia storage tanks. The multi-purpose berth will handle containerised cargo and break bulk using two mobile cranes. Multi-purpose cargo will be stored in a dedicated multi-purpose terminal. An Admin Craft Basin will initially store equipment for breakwater construction and will be used to berth the marine fleet once the port is operational. The Admin Craft Basin will be designed as a dig-out basin within the main breakwater, protected by a secondary breakwater. The short-term port layout also involves constructing the required dry bulk terminal, multi-purpose terminal, and port administration and control buildings. Security fencing, port entrance facilities, fire station and clinic will be required. Internal port roads and rail, and truck staging facility will also be required to respond to the needs of the first phase of development.

Figure 1-2: Artist's impression of the Boegoebaai port layout. indicating the initial elements of Phase 1A development required to meet initial import and export demands (TNPA, 2024).

Detailed descriptions of the infrastructure aspects associated with the proposed short-term Boegoebaai port layout (Phase 1A) are provided in Table 1-2 below.

The longer-term vision for the Boegoebaai port (Phase 1B) is designed for flexibility to accommodate future changes in commodities and operations. This assumes that the port will continue to primarily export commodities from Phase 1A, with the potential for other GH_2 derivatives such as methanol, naphtha and e-kerosene to be added to the export mix. The projected export volumes of green ammonia, combined with methanol, naphtha and e-kerosene is expected to increase to 2.15 Mtpa from 2035 to 2050. By 2050, plans include extending the breakwater, adding multi-purpose and liquid bulk berths, a container terminal, a ship repair yard, and expanding stockpiling and enclosed warehouses for dust control. Supporting infrastructure will include rail connections, road-over-rail bridges, and tippler facilities.

Table 1-2: Detailed description of infrastructure aspects in the vicinity of the proposed Boegoebaai port (Phase 1A).

Infrastructure aspect	Description
Jetty	The jetty structure will act as a multi-use berth facility, designed to handle dry bulk, liquid bulk and multi-purpose cargo. The main jetty will consist of two berths: a 295 m long multi-purpose berth designed to accommodate Panamax vessels and a 350m long bulk berth that can accommodate Capesize vessels. The main jetty is connected to the shoreline via a 160m long access trestle. The main jetty and access trestle are founded on circular reinforced concrete piles with a sacrificial steel tubular casing. The superstructure includes reinforced concrete precast beams and slabs with in-situ concrete casts and topping to stitch the structure together. The main jetty supports ship loaders, conveyor and mobile cranes which service the bulk and multi-purpose terminal berths respectively. Vehicular access is provided via a single carriageway located beneath the ship loaders with turning circles provided at the ends of both the dry bulk and multi-purpose terminal jetty. The access trestle comprises of a single carriageway for vehicular access with the conveyor and ancillary services running adjacent.
Breakwaters	The rubble mound main and secondary breakwaters protect against wave energy at the berths and in vessel turning areas. The primary armour will require an estimated 2 785 million m^3 of rock, 63 150 m^3 of reinforced concrete, and approximately 13 150 armour units.
Admin Craft Basin (Harbour)	A dig-out admin craft basin provides additional wave protection inside the main breakwater for marine fleet. The structure comprises a concrete deck supported on vertical concrete piles cast into steel casings, with a transverse beam supported by an anchored concrete abutment on the land side.
Materials Handling Equipment	The equipment will be defined by the terminal operator based on operational requirements and contracted volumes. For the bulk berth, this includes a travelling shiploader, conveyors, and stacker/reclaimers for dry bulk cargos like manganese, lead, and similar break bulk. The multi-purpose terminal berth will use mobile cranes, trucks, and front-end loaders for break bulk and containers.
Dry Bulk Material Handling	Manganese will be stored in closed stockpiles, similarly to lead and zinc which require enclosed warehouses. Dust suppression systems, which involve water spraying the stockpile and conveyor cargo, are specified for manganese storage. A mobile stacker and bucket wheel will handle stacking and reclaiming operations.
Quayside Material Handling Equipment	Travelling ship loaders are selected for efficiency in handling large volumes of dry bulk cargo, with spatial dimensions allowing truck passage underneath during operations.
Conveyor Belts	Systems handling zinc and lead must be fully enclosed, while those handling manganese require arched coverage. Elevated belt conveyors are designed with handrailed walkways for safe access and maintenance.
Dust Control	Dust suppression and collection systems are incorporated, with all material handling equipment designed to prevent material accumulation outside the dust collection system.
Buildings	Proposed port buildings include a Port Access Gateway and Induction Centre, Port Authority Building (with a Wellness Centre and Emergency Services Building), and Terminal Operator’s Building (with workshops and satellite ablution buildings).

Infrastructure aspect	Description
Bulk Services: Water	Average daily water demand is estimated at 660 kL/day. Two options were considered: a pipeline from Alexander Bay with a water treatment plant, or an onsite desalination plant. The desalination plant (1ML/day capacity) is considered more feasible. Elevated reservoirs will provide pressure for fire suppression discharge.
Bulk Services: Sewer	The site will be divided into separate drainage areas with isolated reticulation systems, on-site treatment, and disposal. Drainage areas will use a combination of wastewater treatment plant, septic tank and soak-away systems.
Stormwater	The drainage system will separate clean and dirty water, with clean water runoff diverted around the site. High-risk dirty runoff water will flow into concrete-lined channels, and low-risk dirty runoff water will flow into block and vegetated channels. Pollution control ponds will be lined with HDPE, attenuated to the 1:50 year pre-development condition and discharged to the receiving natural environment, such as the ocean.
Electrical	The internal electrical network will include an intake substation (22kV), primary and secondary substations, distribution substations, street and area lighting, and small power and lighting for buildings.
Electronics	Security systems include fencing, CCTV coverage, access control, and coastal/railway protection systems, and will comply with the International Ship and Port Facility Security requirements. General electronic systems include fire detection, public address, evacuation systems, building management system, and security control room. Information and Communication Technology services include fibre connections, server rooms, network equipment, microwave links, and manhole and sleeve infrastructure.
Fuel storage	A liquid bulk storage facility with two 35 000 m^3 tanks and tanker loading facilities is included. Tanker vessels will discharge into storage tanks via pipeline at the multi-purpose terminal berth. This represents the first phase of the liquid bulk terminal development.
Internal Port Roads and Bridges	Port Access Interchange: Located 60 km north of Port Nolloth off the R382, designed to accommodate large volumes of heavy vehicle traffic for continuous flow. Port Access Control: Separate entrances with an access gateway and a combined weighbridge and access gateway, allowing multiple trucks to queue without causing congestion. Truck Offloading Area: Designed with three offloading terminals operating independently to prevent congestion and ensure continuous offloading.
External Roads	Development of the port in the short-term will attract mining ore transported by trucks along the R382, serving as the primary route for transporting mining commodities until rail transport viability is considered for future port expansion phases.

1.3.2 *The proposed Boegoebaai Special Economic Zone*

The Boegoebaai SEZ is envisioned as a multifaceted hub, primarily focusing on the export of GH_2/PtX products and commodities through the port. The SEZ will prioritise opportunities in manufacturing, logistics, and agro-processing to deliver a broad range of products and services (NCGHM, 2023). The Northern Cape targets include an initial 1.2 GW of electrolyser capacity to be completed by 2028, scaling up to 5 GW by 2030, and reaching 40 GW by 2050. The Boegoebaai SEZ area, encompassing approximately 33 500 ha (inclusive of the proposed conservancy area adjacent to the Boegoebaai port), will be developed in phases (as described in Table 1-3 and depicted in Figure 1-3) consisting of 10 proposed zones:

- **Zone 1**: Port Precinct (described in Section 1.3.1) – 2 187 ha
- **Zone 2**: Conservancy area – 1 170 ha
- **Zone 3:** Confirmed green ammonia facility – 4 508 ha
- **Zone 4:** SEZ Phase 1 – 499 ha
- **Zone 5:** SEZ Phase 2 – 411 ha
- **Zone 6:** SEZ Phase 3 – 833 ha
- **Zone 7:** Future green hydrogen facility – 3 713 ha
- **Zone 8:** Future expansion 01 – 3 408 ha
- **Zone 9:** Future expansion 02 – 15 067 ha
- **Zone 10:** Future tank farm – 1 704 ha

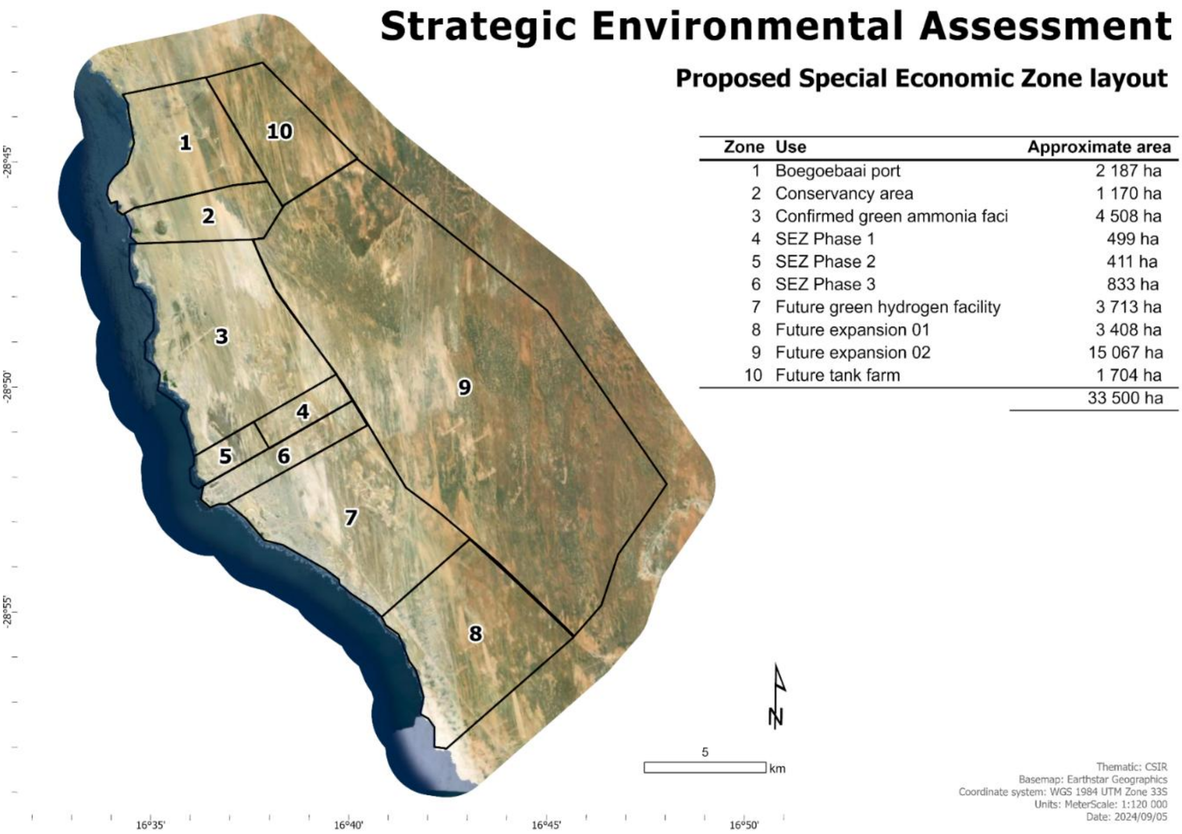

Figure 1-3: The footprint of the proposed Boegoebaai Port (Zone 1) and phases of the proposed SEZ which include a diversity of landuses across Zones 2 to 10.

The initial development of the SEZ will accommodate the green ammonia facility and the envisaged 5 GW of electrolyser capacity by 2030. This will include a sea water intake line, discharge lines to the ocean, a desalination plant, 5 GW electrolyser GH_2 production facility and green ammonia production facility, and hydrogen and ammonia storage tanks. Future SEZ activities are outlined in Table 1-3. Two entrances to the SEZ Phase 1 are proposed: a northern entrance for commercial, socio-service, and private traffic, and a southern entrance for industrial traffic. The truck staging area and the SEZ desalination plant are planned to be located near the southern entrance, facilitating road freight to and from the N14 and N7 highways.

Table 1-3: Proposed infrastructure and development activities per SEZ zone

SEZ zone	Description of infrastructure
1) TNPA port precinct	See Section 1.3.1 and Table 1-2 above.
2) Conservancy area	Conservancy area of approximately 1 170 ha that has been roughly demarcated based on initial inputs on conservation priorities such as the Boegoeberg koppies and seal colony on the Boegoebaai point. A habitat unit known as Swartvygie Heuweltjie Strandveld, located just inland of Boegoebaai, has suffered extensive damage from mining over the past century. The only intact areas are protected by the Buchuberg twins and hardened roads, which prevent sand scour. It is crucial for any port and GH_2 projects to avoid these intact portions, as they cannot be offset. There is also an interesting archaeological site at the proposed development – the Boegoebaai cave/lair.
3) Green ammonia facility	The green ammonia facility will be located near the TNPA port precinct to minimise pipeline length and enhance efficiency. The site is adjacent to the coast to facilitate desalination processes and house the 188 ML/day desalination plant. Infrastructure will include desalination plant and associated infrastructure (including seawater intake infrastructure and discharge pipeline); Water treatment unit and water reservoir; Containerised units for the electrolysers; Air separation unit; Liquid air energy system for nitrogen storage; Hydrogen and oxygen storage; Ammonia processing unit and liquid ammonia storage tank; Pipelines required for hydrogen, its' derivatives and by-products, and a control room. Seawater will be desalinated through a Reverse Osmosis (RO) process and then further processed to Demineralized water, which is needed for the production of GH_2 via water electrolysis. Cooling tower blowdown will be disposed of back to sea with the Reverse Osmosis brine and other treated wastewater streams. It is expected that the blended total dissolved solids of the cooling tower blowdown stream and the Reverse Osmosis brine and waste streams will be acceptable for seawater discharge. Firewater will be provided through firewater tanks on site. There is an opportunity to combine firewater and desalinated water storage on site. Seawater will be the backup source of firewater in case of an emergency and the stored firewater is not adequate. Lye solution purge from the GH_2 Plant will be discharged with the other return streams to the sea. Other effluents are oxygen and small quantities of off-gas which are expected to be safe to vent to atmosphere.
4-6) SEZ Industrial Park	The Industrial Park will be designated for mixed-use purposes, a manufacturing cluster, logistics and warehousing, offices. The SEZ will also include a 2.7 ML/day desalination plant, including pump station, supply pipelines, feeder pipelines etc. Seawater will be extracted and filtered, with a portion of the filtered water supplied to the SEZ Industrial Park for its use and for distribution to Port Nolloth. The SEZ Industrial Park will then desalinate this water at its own facility. The remaining filtered water will be processed through a separate desalination plant for operational use.
7) Future GH_2 facility	This will be a replication of the work that is anticipated at the initial Green Ammonia Facilities: Water treatment unit and water reservoir; Containerised units for the electrolysers; Air separation unit; Liquid air energy system for nitrogen storage; Hydrogen and oxygen storage; Ammonia processing unit and liquid ammonia storage tank; Pipelines required for hydrogen, its' derivatives and by-products, and a control room.
8) Future expansion area 01	This will be a replication of the work that is anticipated at the initial Green Ammonia Facilities: Water treatment unit and water reservoir; Containerised units for the electrolysers; Air separation unit; Liquid air energy system for nitrogen storage; Hydrogen and oxygen storage; Ammonia processing unit and liquid ammonia storage tank; Pipelines required for hydrogen, its' derivatives and by-products, and a control room.
9) Future expansion area 02	This will be a replication of the work that is anticipated at the initial Green Ammonia Facilities: Water treatment unit and water reservoir; Containerised units for the electrolysers; Air separation unit; Liquid air energy system for nitrogen storage; Hydrogen and oxygen storage; Ammonia processing unit and liquid ammonia storage tank; Pipelines required for hydrogen, its' derivatives and by-products, and a control room.
10) Future tank storage	Proposed area of approximately 1 704 ha inland of the R382 road.

1.3.3 Regional Renewable Energy and Linear Infrastructure

To power electrolysers, large scale renewable energy infrastructure (solar and wind farms) will be developed within the broader Namakwa region, covering parts of the Namakwa District of the Northern Cape Province. Some power generation infrastructure (wind and solar PV) will be located in reasonably close proximity to the SEZ, however, due to the sensitivity of the local receiving environment and potential impacts of the coastal environment on the generation facility (e.g. corrosion), in most cases, power will be generated from dispersed renewable energy projects (each requiring their own EIA processes), in some cases, several hundred kilometers away. Electricity will then be delivered to the GH_2 production plant using a combination of new and existing transmission and distribution infrastructure. In such cases the development and permitting of the generation components will be undertaken by 3rd parties, and the developer may not have control of the whole project. The project owner will purchase power from 3rd parties (or purchase the projects outright and own and operate them) and negotiate with the utility to wheel the power using the existing or new build grids. The project components are likely to be permitted separately, with the hydrogen developer permitting the electrolyser, ammonia plant, desalination plant and, in some cases, the export port facilities, and the generation (wind and solar PV) and transmission being permitted by several other 3rd party entities such as Independent Power Producers (IPPs) and Eskom. Table 1-4 Provides a brief description of the anticipated main renewable energy aspects.

Table 1-4: Brief description of the main renewable energy aspects

Renewable energy	Aspect	Description
Wind	Turbines	Rotor with blades, nacelle, tower; sizes 4-8 MW, hub height 150-180 m, blade length ~100 m.
	Other	Foundations (~32 m²), access roads, Battery Energy Storage System (BESS), on-site electrical system, substation, transmission lines, construction camp, operations & maintenance facilities, meteorological towers.
Solar PV	Solar panels	Monocrystalline/polycrystalline silicon cells; height ~6 m. Fixed or dual-axis tracking. Single or bifacial modules.
	Other	Inverters, mounting structures, BESS, foundations, access roads, electrical system, substations, transmission lines, electrical components, construction camp, operations & maintenance facilities.

The Northern Cape plans to collaborate with local stakeholders to secure land or engage IPPs. Environmental assessments will be conducted on identified land parcels for the installation of renewable energy infrastructure. The objective is to expand renewable energy capacity to enable GH_2 production, as well as to supply electricity for local needs. By 2040, the goal is to meet industrial demand and eventually meet national electricity needs.

The proposed GH_2 development at Boegoebaai also includes a comprehensive network of linear Infrastructure to connect the production site, export facilities, and regional demand hubs. This includes transmission lines, pipelines for GH_2 and derivatives, rail links and upgraded roads, all of which are considered catalytic infrastructure for the Northern Cape GH_2 economy.

Transmission lines will wheel power from solar and wind farms to electrolysis plants and, when necessary, supply surplus electricity to the national grid for load balancing. A new rail corridor is proposed to connect Boegoebaai with Kenhardt, linking into the existing Saldanha–Sishen railway route. This rail link will facilitate the transport of bulk commodities such as manganese and iron ore, as well as GH_2 derivatives like ammonia and methanol. Rail will also support the movement of renewable energy components and other industrial goods to and from the SEZ, ensuring efficient logistics for both export and local beneficiation. Dedicated hydrogen and ammonia pipelines will form the backbone of the GH_2 corridor. Proposed pipeline system routes include:

- Boegoebaai to Namibia, creating a cross-border corridor for regional integration.
- Boegoebaai to Saldanha Bay.
- A direct inland pipeline to Prieska, unlocking opportunities for local industrial use and distribution.

These pipelines aim to provide secure, cost-effective transport for high-volume flows of hydrogen and its derivatives, supporting both export markets and domestic decarbonisation initiatives.

The development of the GH2 economy will also require new roads and upgrades to existing routes as part of a broader linear infrastructure network proposed to ensure efficient movement of goods and materials.

1.4 APPROACH TO THE SEA

The SEA is being undertaken to guide strategic planning for proposed infrastructure development in and around Boegoebaai, as well as the broader Namakwa region of the Northern Cape, South Africa. Readers are reminded that the SEA is not a decision-making process, in the same way that, for example, an Environmental Impact Assessment (EIA) is. The purpose of the SEA is to, in a transparent way, guide downstream planning and decision-making processes that may, or may not, occur over many years, if not several decades into the future. Integrating a variety of best practice science-policy processes, SEAs should provide an evidence-based, cross-disciplinary perspective on the main opportunities and constraints associated with the proposed port, SEZ and network of regional renewable energy generation facilities (wind and solar PV), electrical grid infrastructure, roads, pipelines and other GH_2 support infrastructure development.

A key gap in the current knowledge and decision-making base regarding GH_2 development in the Northern Cape is the absence of an integrated, cumulative, long-term understanding of what a medium- to large-scale GH_2 economy might entail. To address this, the Work Package 2 SEA adopts an interdisciplinary, scenario-based assessment designed to explore both the scale and implications of GH_2 development in the region.

This scenarios assessment serves two main purposes:

1. To provide a concrete representation of what a large Northern Cape GH_2 economy could look like, in terms of the nature, scale, and spatial footprint of infrastructure and development.

2. To estimate the potential cumulative positive and negative impacts of GH_2 development and identify strategies to enhance benefits and mitigate adverse effects.

1.4.2.1. Figure 1-5No-Development Scenario: Scenario 0 – Dynamic Baseline (2023–2050)

The foundation of this analysis is a dynamic baseline scenario (Scenario 0), which represents a future without GH_2-related infrastructure, port development, or SEZ establishment (i.e., a “no GH_2 development” future). This baseline is important for understanding how existing trends and drivers of change will shape the region in the absence of GH_2 development and provides the reference point against which the impacts of the two GH_2 development scenarios (Scenarios 1 and 2) are assessed.

Under Scenario 0, the Boegoebaai Port and SEZ remain undeveloped, and no GH_2 production occurs in the Northern Cape. However, the region continues along its current trajectory of socio-economic and environmental change, driven by multiple interacting factors. These drivers include climate variability, land-use pressures, biodiversity loss, water scarcity, and socio-economic challenges, as summarised in Table 1-6. A trend direction explanation is also included in Table 1-5.

Table 1-5: Trend direction explanation

Trend direction	Explanation
↓	Evidence/experience suggests a substantial decrease in the driver or its quality
↘	Evidence/experience suggests a moderate decrease in the driver or its quality
→	Evidence/experience suggests no change in the driver or its quality
↗	Evidence/experience suggests a moderate increase in the driver or its quality
↑	Evidence/experience suggests a substantial increase in the driver or its quality
?	Insufficient Evidence/experience to predict the direction of the driver or its quality, or evidence/experience is conflicting

Table 1-6 Scenario 0: Drivers of macro change in the Northern Cape province (2025-2050) in absence of GH_2/PtX, SEZ and port development

Theme/Driver	Trend	Explanation
Climate change		
Temperature	↑	Climate change is causing a substantial increase in temperatures in the Northern Cape, with projections indicating a rise of ~2°C by 2040–2060 (DEA, 2018). Heatwaves and very hot days (above 36°C) are becoming more frequent, with up to 100 extremely hot days annually by 2050 (CSIR, 2019). Cold extremes are decreasing (Davis et al., 2016). These changes threaten agriculture, human health, and biodiversity (Mbokodo et al., 2020), highlighting the need for urgent climate adaptation measures. Heat-stress thresholds and heatwave mortality risks for small, ground-dwelling birds such as larks, chats, and coursers as well as bird species with poor evaporative cooling efficiency (McKechnie et al., 2021).
Rainfall	→ ↘	Historical trends in the Northern Cape show no significant change in annual rainfall totals over the past 50 years, though there are weak indications of increased wet days (CSIR, 2019). Most areas are projected to see minimal increases (up to 100 mm) by 2050, while 60% of the Namakwa district is expected to experience no change (CSIR, 2019). However, rising temperatures will likely increase evaporation, reducing groundwater availability, particularly in the western regions (DEA, 2018). Reduced winter rainfall lowers plant productivity (Milton et al., 2022) and insect prey, driving nesting failure, and lower chick survival rates and delayed or failed breeding for birds (Bourne et al., 2020).
Flooding	↗	Increased atmospheric moisture and intensified heat lows in the eastern province may lead to higher summer rainfall and extreme rainfall events, causing localized flooding and infrastructure damage (DEA, 2018). By 2050, extreme rainfall days are projected to increase by 1–2 days annually (CSIR, 2019). While flood risk remains low to medium in most areas, some regions show medium to high flood hazards, with a potential for worsening impacts due to projected rainfall decreases (CSIR, 2019).

Theme/Driver	Trend	Explanation
Wildfires	↑	Rising temperatures, prolonged droughts, and an increase in very hot days in the Northern Cape are expected to create ideal conditions for wildfires. Projections indicate that heatwave events and increased frequency of hot days, particularly in the Richtersveld, Khai-Ma, Nama Khoi, and Hantam municipalities, will elevate the likelihood of wildfires (CSIR, 2019). Drought conditions will intensify due to higher evaporation rates, further increasing wildfire risks, especially in the northern parts of the province (CSIR, 2019). This necessitates enhanced fire management strategies and proactive environmental management to protect ecosystems, human settlements, and water resources. Altered fire regimes destroy nesting/perching and foraging substrates, compounding food and water shortages (Hoffmann et al., 2009; Nunes, 2023).
Sea level	↑	Accelerated sea level rise is projected for the Northern Cape coastline, posing risks to coastal infrastructure and settlements. Rising sea levels will likely disrupt marine ecosystems and species distribution (DEA, 2018).
Storminess	↗	Increased storminess is expected to affect the province's coastline, with coastal storms becoming more frequent and intense, which will impact both coastal infrastructure and marine ecosystems (CSIR, 2019).
Ocean temperatures	↘	Expert interpretation indicates that ocean temperatures along the Namaqualand coast are likely to decrease. The increased frequency and velocity of dominant southerly winds will intensify coastal upwelling, increasing both its occurrence and strength. These changes have important implications: 1. Fog Formation As offshore ocean waters warm and evaporation increases, moist air moving over colder inshore waters will likely lead to more frequent fog events. This may reduce sunshine and provide additional moisture for plants and animals able to utilize it. Anecdotal evidence from South Africa's south and east coasts suggests that stronger easterly summer winds—comparable to Namaqualand's southerlies—are associated with more frequent and intense upwelling. 2. Fisheries and Coastal Economy Increased upwelling will affect sea fisheries and may have significant impacts on coastal ports and the fisheries economic sector. 3. Flood Risk While climate change is expected to increase thunderstorms and flooding, these events will remain largely east of the escarpment. The cold ocean will continue to prevent such weather systems from penetrating west of the escarpment, so increased flood risk is unlikely to affect the coastal plain.
Biodiversity & conservation		
Desertification	↑	Desertification in the Namakwa region is worsening due to climate change and unsustainable land use. The southward migration of the Namib Desert is decreasing rangeland productivity and negatively impacting biodiversity (Jürgens et al., 2025). The Richtersveld area is experiencing the most severe desertification, while higher-altitude areas such as Kamiesberg receive slightly more rainfall (Desmet & Venter, 2025). Loss of vegetation accelerates soil erosion, leading to reduced nesting substrates and increased dust and heat exposure, and an overall decrease in avifaunal abundance and avifaunal diversity (Hoffmann et al., 1999).
Overgrazing	↑	Farmers, particularly those in communal areas, are likely to persist in traditional grazing practices despite declining conditions, exacerbating land degradation. Land-use change, including agricultural expansion, overgrazing, is another critical driver of the ecological trends in the Namakwa region (Bourne eta al., 2015; Walker et al., 2018). These activities are reducing natural habitat, fragmenting ecosystems, and placing additional stress on species already struggling to adapt to changing climate conditions. The cumulative effects of these pressures exacerbate soil degradation and desertification, further limiting the capacity of ecosystems to recover. Grazing pressure simplifies vegetation structure, reducing foraging and nesting material for avifauna (Todd et al., 2009; Le Maitre et al., 2009). Due to the divide between commonage and private land in patterns of ownership and livestock use, the overgrazing trend is expected to follow two distinct trajectories: continued or increased overgrazing and desertification on commonages, and a static to slightly negative trend on private farms. It is important to note that land-use impacts on ecosystems occur in addition to climate change impacts, and the latter may outweigh any land-use improvements. Consequently, even with best-practice livestock management

Theme/Driver	Trend	Explanation
		aimed at improving rangeland condition, climate change effects may override these efforts, resulting in an overall negative trend.
Protected areas	↗	The distinctive biodiversity of the Succulent Karoo biome has gained global attention, prompting substantial investments from the government, non-governmental organisations, and the private sector to expand conservation areas across the biome (Hoffman et al. 2015). While conservation and protected area development are expected to expand in the Namakwa region, the rate of expansion remains slower compared to sectors like mining and energy. The transition to biodiversity-based economies is hindered by entrenched local economic behaviours, despite the greater employment potential offered by biodiversity industries (Bourne et al., 2015). A point to note is the entrenched economic behaviours in the region - characterised by strong conservatism and limited capacity to adopt/enter new or emerging economic activities due to financial and skills constraints - resulting in reluctance or inability among local communities to diversify livelihoods. Consequently, major developments in sectors such as tourism are predominantly driven by in-migrants rather than local actors. This dynamic may have implications for cultural and living heritage and could reinforce the existing social and economic status quo within the region. The Succulent Karoo is rich in endemic and range-restricted bird species, and Protected Areas expansion will help buffer against increasing threats such as climate change, habitat loss, overgrazing and invasive species (Khavhagali, 2010), and assist in the protection of microhabitats and ecological niches essential for rare bird species (Dean, 1995) contributing to an increase in avifaunal abundance and diversity. Furthermore,
Change in Habitat and species	↓	Projected biome shifts, such as the southward movement of the Desert Biome and the replacement of the Nama Karoo with the Succulent Karoo, are expected to cause habitat degradation and alter species distributions (Bourne et al., 2015). Additionally changes in temperature, rainfall levels and patterns could shift vegetation and corresponding animal distributions, with combined effects potentially being substantial. This will likely lead to local extinctions of certain species, especially those unable to adapt to the new climatic conditions (Walker et al., 2018). Loss of specialised habitat could also lead to shifts in avian species ranges, population fragmentation, community restructuring and endemism loss (Dean, 1995).
Avifauna (birds)	↓	Rising heat and reduced rainfall push arid-adapted, small ground birds beyond physiological limits (McKechnie et al., 2021), lowering survival and breeding success (Conradie et al., 2019); wildfire, desertification and overgrazing degrade nesting/foraging habitats (Hoffmann et al., 1999; Todd et al., 2009); alien invasion favours generalists (Clusella-Trullas & Garcia, 2017); drying ephemeral wetlands reduce water/food for sandgrouse, doves, waders and migrants (Smit et al., 2019). Outcome by 2050: declining abundance/diversity, with range contractions for specialists (Simmons & Barnard, 2005; Milton et al., 2022).
Bats	↘	Desertification, overgrazing, rising temperatures and declining surface water availability will reduce natural foraging habitat and insect prey availability. Drier, hotter conditions and declining groundwater recharge are expected to substantially reduce accessible open water sources required for drinking. Expansion of mining, settlements and associated infrastructure will increase artificial roosting opportunities and light pollution, favouring light-tolerant and generalist species while displacing photophobic and specialist bats, resulting in altered species composition. Renewable wind energy development is expected to increase substantially and may pose collision and barotrauma risks if not appropriately managed. Overall outcome by 2050: stable to increasing abundance of a few adaptable species, but declining diversity and increased pressure on water-dependent and specialist bat species. Overall, these interacting drivers are expected to restructure bat communities, with stable or increasing populations of a few adaptable, generalist species, and declining diversity and abundance of specialist and water-dependent bat species
Alien invasive species	↑	Climate change and human activities are facilitating the spread of invasive alien species, which outcompete native species and alter ecosystems. These invasive species further exacerbate biodiversity loss and disrupt local ecosystems (Bourne et al., 2015; Walker et al., 2018). Although invasive species lead to higher biomass and increased vegetation cover in affected areas, they pose significant risks to the Karoo's biodiversity and its limited water resources (Hoffman et al., 2018). Invasion can increase perching sites but homogenization favours generalist bird species (Clusella-Trullas & Garcia, 2017) and may cause local extinctions of specialist bird species (Simmons & Barnard, 2005).
Surface Water resources		

Theme/Driver	Trend	Explanation
Evapotranspiration	↗	Projected increase in Mean Annual Potential Evapotranspiration (MAPE) of 6 to 10% (WRC 2023). Increased vegetation uptake will impact agriculture and ecosystems. Human comfort levels will deteriorate, and water demand will increase. Stored open water bodies will experience higher losses.
Rainfall	↘	Mean Annual Precipitation (MAP) (Rainfall) has reduced from 100 years ago, but past 50 years has been stable (Benito 2011). MAP is projected to decrease between 10-20% in most places, but some locations between 0 -10% (WRC 2024). Less local water in quaternary catchments.
Mean Runoff	↓	Runoff has been dropping marginally over past 50 years in Namaqualand (Benito 2011 – check). Mean Annual Runoff (MAR) is projected to reduce by up to 50% in most quaternary catchments but may increase by up to 25% in a few places. The sporadic nature of runoff events offers very limited opportunity for useable storage. Some small farm dams are concentrated in the mountainous areas of the Buffels river and in the Salt pan areas of quaternaries D53F and D53G.
Runoff Extremes	→	Flood events are not likely to increase in intensity. (Present to Near-Future Climate change GCMs predict a 20% reduction in maximum discharge). Riparian areas will be subjected flood levels and crossings exposed to flood damage.
Dry Periods	↑	Current average duration of runoff-free periods is 350 days, with some places reporting dry periods of several years (SRK Quaternary Runoff Analysis). These dry intervals are likely to increase (Climate change GCMs predict slight increase in average duration – 1%, but large increases in the maximum dry periods up to 45%). Extended runoff-free dry periods will impact ecosystems and agriculture.
Water use	↑	Climate change projections for the Namakwa District indicate drier, hotter conditions, heightening water demand. This trend is expected to significantly increase pressure on water resources, with rising temperatures and reduced rainfall exacerbating water scarcity (Bourne et al., 2015).
Water demand	↑	Increasing MAPE, reduction in average rainfall and decrease in rainfall frequency (WRC 2023) will intensify the pressure on existing and future water resources..
Water scarcity	↑	Within quaternary catchments, higher mean annual potential evaporation (MAPE) combined with lower mean annual precipitation (MAP) will further reduce surface water availability and groundwater recharge, while extreme runoff events are unlikely to meaningfully enhance aquifer replenishment; instead, salinity levels may increase under higher evaporative demand (Benito, 2011). Although some climate models project increased flows in the Orange River due to higher future MAP in upstream catchments in Lesotho and the eastern RSA, the extent to which this may translate into additional water available for abstraction in Namakwa will depend heavily on upstream water use and allocations within the Orange–Vaal system. Overall, despite potential upstream increases, declining local recharge, high evaporation rates, and sustained water demand pressures indicate a worsening trend in water scarcity across the region.
Bulk water supply & infrastructure	↗	Increase in demand will be met from Orange river abstractions due to projected increase in Orange river MAR at points of abstraction due to predicted Climate Change increases in runoff in Lesotho and eastern RSA (WRC, 2023). However, availability for abstraction will depend on upstream water use in the Orange-Vaal systems. Increased water demand, driven by higher temperatures and population growth, will require expansion of bulk water supply infrastructure to meet growing needs, especially as current resources become more strained. It is anticipated that desalination of seawater will become the primary source of bulk water in the region. At present, regional settlements, including Pofadder, Aggeneys, Springbok/Okiep, Steinkopf, Port Nolloth, and Alexander Bay, are largely dependent on bulk water supplied from the Orange River. This supply is likely at its maximum and is expected to decline as upstream demand increases. As the unit cost of renewable energy decreases, a transition to desalination will become feasible. When this occurs, significant development of the Sandveld under renewable energy and agriculture, such as aquaculture and tunnel cropping, is likely.
Groundwater resources		
Water Use	↗	Groundwater recharge is expected to decrease over most parts of the district (CSIR, 2023) and possibly impact on households or settlements that are dependent on this source of water.

Theme/Driver	Trend	Explanation
Water Demand	↑	Increasing MAPE, reduction in average rainfall and rainfall frequency (WRC 2023) will intensify the pressure on existing and future water resources. Consequently, overutilisation of water sources like the Orange River, will likely increase surface water scarcity in the region. The depletion of surface water in the region will result in increased demand on groundwater resources (CSIR, 2023).
Water Quality	↘	Marine aerosols contribute to increased groundwater salinity through dry deposition in coastal areas. Additionally, the presence of salt-rich heuweltjies in the region, has been linked to elevated groundwater salinity (Francis et al., 2022). Projected increase in runoff extremes may result in the flushing of concentrated salts from these mounds, into the groundwater, exacerbating salinization (Van Gend et al., 2021). Increased salinity in the alluvial aquifers is likely to affect basement aquifers which are dependent for indirect recharge.
Water Availability and Recharge	↘	Reduction in groundwater availability in the alluvial aquifers due to decreased rainfall (CSIR, 2023), particularly a decrease in rainfall events that are able to sufficiently infiltrate into the aquifer systems to provide recharge. Higher extreme runoff events are not likely to improve or lessen recharge to riparian aquifers. Reduced recharge to alluvial aquifers will result in reduced recharge to dependent fractured aquifers. In many cases, aquifers are already stressed due to over-abstraction for various reasons including: high demand, poor infrastructure and improper management (Pietersen et al., 2009). Increased development and settlement will exacerbate this. Heavy reliance on groundwater in the region has already resulted in declines observed in water levels of monitoring boreholes between 1990 – 2008 (DWS, 2008).
Aquatic ecosystems: Inland and Estuarine ecosystems		
Water quality	↓	Water quality in aquatic ecosystems is expected to be on a deteriorating trajectory, with increasing salinities associated with predicted decreased rainfall (Benito 2011). Increases in populations in some local municipalities means increased loads of sewage, and associated increased risks of nutrient enrichment and possible microbial and other contamination of local watercourses, depending on wastewater treatment works efficacy.
Ephemeral pans	↘	Reduced rainfall will be compounded by increased evapotranspiration. Pan hydroperiod may decrease – if it decreases over thresholds of concern (e.g. inundation period is too short for temporary pan-adapted fauna to complete lifecycles) then aquatic biodiversity will be impacted, while terrestrial fauna dependent on pans for water for parts of the year would also be impacted. Plants in and around pans could also be impacted if conditions become hotter, drier and more saline. If plants die back, this would impact on the value of some pans for provision of grazing material.
Seasonal and temporary rivers	↘	Where extended dry periods result in loss of riparian vegetation, ephemeral and seasonal rivers will be more vulnerable to erosion when flooding occurs, particularly at road crossings, where episodic flows are concentrated. These systems are already impacted in some areas by over-grazing, focused along riverine channels, and this would be expected to be ongoing, with its impacts exacerbated by vegetation under increasingly water-stressed conditions.
Wetlands	↓	Extended dry periods and reduced MAP will impact on wetland condition, shifting permanently saturated and seasonally wetlands towards seasonal to ephemeral systems. Although such wetlands are limited in the study area they do occur (e.g. Kamiesberg mountains) where wetlands retain water and allow drinking and foraging by indigenous biota and livestock throughout the year (Samuels, 2013; Kotze et al., 2010) and provide other benefits, such as erosion control and flow regulation (Kotze et al., 2010, Black and Turpie 2016). Changes in wetland condition and type may trigger erosion and reduce crucial wetland ecosystem services in these areas. Ephemeral wetlands and seasonal streams drying impacts sandgrouse, doves, waders and migrants (Smit et al., 2019; Czenze et al., 2020).
Orange River	↓	Increased water stress may increase abstraction from the Orange River near Alexander Bay and (potentially) upstream river reaches (possibly offset by increase in MAP in upper catchment). Increased salinity in the lower estuarine salt marshes may be exacerbated by increased MAP and MAPE, in the absence of remedial measures (see DWS 2017b)
Other estuaries	↓	Estuaries already impacted by hypersalinity (e.g. the Groen River Estuary) would be further impacted. Fish recruit into the Arid Predominantly Closed estuaries in the study area during peak flow periods overtop the estuary and links it to the sea – but hypersalinity in these estuaries affects fish survival (DWS 2024). Reduced MAP and increased MAPE, leading also to increased pressure on water resources, may further threaten ground-water dependent systems (e.g. upper Spoeg and Groen

Theme/Driver	Trend	Explanation
		estuaries).
Socioeconomics		
Agricultural economy	?	Agriculture in the Namakwa District is shifting toward high-value crops such as table grapes and dates along the Orange River, benefiting from favourable climatic conditions and water availability (CSIR, 2023). However, further expansion depends on sustaining water quality. Irrigation agriculture along the river is labour-intensive, thereby attracting population to the area. The crops are largely exported, with markets expected to remain robust. Extensive grazing operations in the hinterland face challenges due to water scarcity and harsh climatic conditions. Infrastructure developments like desalination improved roads and telecommunications, and export ports could enhance agricultural competitiveness. Irrigation-based agriculture is only relevant along the Orange and Olifants rivers. Livestock numbers are likely to remain static or decline gradually as rangeland productivity. Increasing divergence within the livestock sector is anticipated: among white commercial farmers, consolidation of economic units into larger entities is anticipated as older farmers retire and sell land, either to conservation initiatives, the state (land reform), or corporate farming enterprises. However, desalination of seawater could unlock substantial agricultural expansion along the coast, potentially driving large-scale development under renewable energy and intensive production systems.
Biodiversity and Tourism economy	↗	Tourism in the region is projected to experience steady, gradual growth, supported by investments in conservation, adventure tourism, and cultural heritage tourism. Remote locations, desert landscapes, and botanical tourism (such as the wildflower season) are key attractions. Potential exists for new tourism routes, but successful development depends on leadership and policy support. The revitalisation of ports may enhance local economic prospects, particularly in the fishing industry and eco-tourism.
Mining economy	↗	New mining developments, particularly in Aggeneys and the Namakwa Special Economic Zone, the Okiep copper belt and coast mineral sands and also rare earth minerals, are expected to drive economic growth. These developments, along with infrastructure projects such as port improvements led by Infrastructure South Africa, are anticipated to shape regional settlement patterns.
Municipal service delivery	↘	Many municipalities, particularly outside Springbok, struggle with poor service delivery and inadequate governance. While Nama-Khoi Municipality has improved, others, such as Richtersveld, face financial constraints that hinder infrastructure maintenance (CSIR, 2023). However, they may follow the lead of Nama-Khoi, if new coalitions take over the reins. Namakwa District Municipality has sufficient and growing skills to assist Local Municipalities regarding planning and investment.
Municipal infrastructure	→	Infrastructure development is expected to progress through projects such as the proposed Alexander Bay to Port Nolloth water pipeline. However, financial stress and inadequate municipal revenue continue to hinder infrastructure maintenance in key settlements like Alexander Bay. For smaller municipalities, the absence of private investment in infrastructure would likely result in complete institutional collapse. Under current conditions, the status quo reflects a lack of progress.
Human settlements	↗ ↘	The population of the Namakwa area is likely to increase slowly over the next 25 years., with Kamiesberg facing a 42% decrease, while Richtersveld and Karoo Hoogland may see moderate population growth (CSIR, 2023). Settlements like Alexander Bay are declining due to reduced mining activities and financial instability. The population is urbanizing, due to the availability of services and jobs in urban areas.
Heritage		
Palaeontology	↘	Desertification and increased mining may expose new fossil sites but also risk potential fossil loss without adequate mitigation measures.
Archaeology	↓	Increasing agricultural development along the Orange River continues to pose a significant problem to archaeological sites (including graves) on the banks of the river. Renewed copper mining centred in Okiep may impact the historic Copper Mining Landscape, damaging historic infrastructure which has not been adequately recorded.

Theme/Driver	Trend	Explanation
		Artisanal mining licences and an increase in oil and gas exploration along the coast may impact archaeological and historical sites. Prospecting, and an increase in mining, for manganese and iron, as well as granite in the northern part of the study area (centred around Aggeneys and Pofadder), may impact on heritage resources in this area.
Archaeology (cumulative)	↘	Despite environmental impact assessments, the continued development of renewable energy facilities in the area, will have a cumulative negative impact on archaeological resources.
Knowledge of Palaeontology & Archaeology	↗	The increase in development will lead to an increase in environmental impact assessments, and hence our academic knowledge of the area.
Maritime Heritage	↘	Potential offshore mining and gas exploration may impact on unknown wrecks and may result in their destruction.
Built Environment	↘	Incremental increases in mining and infrastructure development, may impact on historic structures and buildings older than 60 years which may be destroyed, damaged or vandalised.
Built Environment	↗	The increase in money into the region will have a positive impact on tourist numbers, facilities and potentially also in the preservation of particularly the Built Environment which is the most tangible and threatened of heritage resources.
Graves	↘	Graves will continue to be impacted very occasionally. Given that they are generally completely unmarked, impacts are unpredictable.
Living Heritage	↘	Small stock farmers in the communal areas are likely to continue with traditional grazing practices despite poor environmental conditions and overgrazing. This may threaten certain aspects of living heritage. Infrastructure and mining development may also occur in communal grazing lands.
Cultural & Historical Heritage	↓	Population growth and infrastructure expansion will gradually alter historical and cultural landscapes. This is already happening in the Springbok/Okiep and Aggeneys areas. This is in contrast with the seasonal tourism initiatives which rely on the natural aesthetic and heritage preservation of the region.
Built Environment & Cultural Landscapes	↑	Growth in tourism may reinforce the need to protect heritage resources which are tourist attractions.
Living Heritage	↘	Small stock farmers in the communal areas are likely to continue with traditional grazing practices despite poor environmental conditions and overgrazing. This may threaten certain aspects of living heritage. Infrastructure and mining development may also occur in communal grazing lands. Therefore, development, erosion, and desertification may reduce the availability of land necessary for sustaining traditional lifestyles, thereby threatening certain aspects of living heritage.

1.4.2.2. GH2 Development Scenarios

The Work Package 2 assessment considers two GH_2 development scenarios, each compared to, and on top of, the Scenario 0 dynamic baseline where no GH_2 development occurs but other anthropogenic and climate-related changes continue. The development scenarios are summarised as follows:

- **SCENARIO 1 – "Small GH_2" (by 2030):** A 5 GW electrolyser produces 0.5 million tonnes per annum (mtpa) of GH_2 and derivatives, supported by 10 GW of renewable energy, assumed to be 60% solar and 40% wind.

- **SCENARIO 2 – "Big GH_2" (by 2050):** An upscaled GH_2 development with a 40 GW electrolyser producing 4 mtpa of GH_2 and derivatives, supported by 80 GW of renewable energy (60% solar / 40% wind).

All three scenarios are illustrated in Figure 1-4, with each GH_2 development scenario then quantified in Table 1-7, detailing approximate footprints and development scales for the port layout, electrolysers, ammonia plants, desalination facilities, renewable energy clusters, and associated linear infrastructure (pipelines, rail, roads and powerlines).

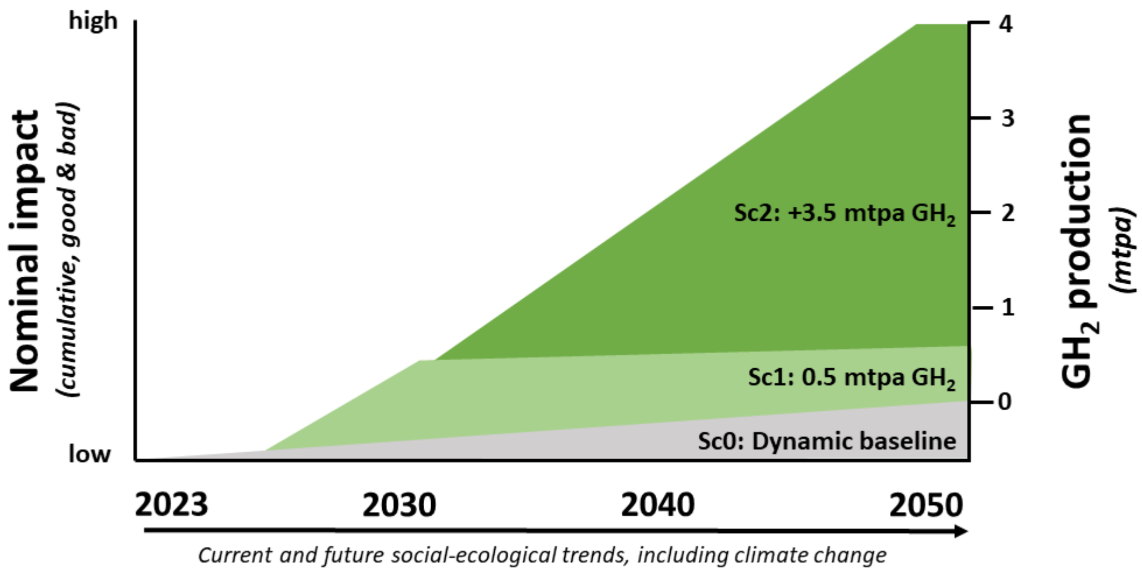

Figure 1-4: Indicative diagram of the scenarios approach for assessing cumulative impacts

Table 1-7: GH_2 development scenario quantifications (Sc1 and Sc2) for Work Package 2.

Aspect		Unit	Sc1: Small GH_2	Sc2: Big GH_2	*Assumptions*
PORT	Port layout	ha	1 280	1 280	From draft port layout
SEZ	Electrolyser capacity	GW	5	40	Northern Cape Green Hydrogen Master Plan ambition
	Electrolyser footprint	ha	75	600	Assume 15 ha per 1 GW. "Estimated footprint of 8 hectares (ha)-13 ha for a 1 GW facility using PEM, compared to 10 ha-17 ha using alkaline.
	GH_2 volume	mtpa	0,5	4,0	10 GW electrolyser = 1 mpta GH2
	GH_2 storage footprint	ha	250	2 000	Assume 10 ha per 20 000 tpa (e.g. Enertrag Hendrina) (500 ha for 1 mpta)
	Ammonia volume	mtpa	2,8	22,7	1 mt H2 for 5,67 mt NH3 (1Mt of ammonia contains 176.5 kg (just 17.65%))
	Ammonia footprint	ha	56,7	453,6	Assume 1 ha per 50 000 tpa NH3 (e.g. Enertrag Hendrina) (20 ha for 1 mtpa)
	Ammonia storage footprint	ha	28,4	226,8	Assume 0,5 ha per 50 000 tpa NH3 (e.g. Enertrag Hendrina) (10 ha for 1 mpta)
	Desalination output volume (GH_2 prod only)	Ml/day	35,7	285,7	25 kg water per 1 kg GH2 (considering electrolysis and cooling). 1Mtpa GH2 output required 25 Mtpa (=25000 MLpa) water / 350 days (Note: Assumed 350 days per year operational, to allow some maintenance time and/or shut down of intake due to unsuitable intake water quality).
	Desalination footprint (GH_2 prod only)	ha	7,1	57,1	Assume 5 Ml/day output needs 1 ha (e.g. Saldanha Desal EIA (CSIR, 2013)) where 25.5 Ml/day desal plant required fenced area of 5 ha for operational phase. This excludes marine infrastructure. Assume linear increase in area with increased Ml/day capacity.
	Desalination discharge (GH_2 prod only)	Ml/day	48,3	386,6	Assume ratio of desalinated water to brine discharge water to be 425:575. (i.e 42.5% of intake sea water is converted to desalinated water and 57.5% is discharged as brine). This is based on the CSIR Saldanha Desal EIA (2013) which assumed 40-45% desalinated water and 55-60% brine. The Namwater Desal EIA (CSIR, 2009) assumed a similar desal:brine ratio of 40:60.
	Water pipeline intake volume (GH_2 prod only)	Ml/day	84	672,3	Output + discharge
	Desal output volume (GH_2 + oversize)	Ml/day	39,3	328,6	+10% oversize for Sc1; +15 % oversize for Sc2
	Desal footprint (GH_2 + oversize)	ha	7,9	65,7	
	Desal discharge (GH_2 + oversize)	Ml/day	53,2	444,5	
	Water pipeline intake volume (GH_2 + oversize)	Ml/day	92,4	773,1	
	Water surplus	Ml/day	3,6	42,9	Assume surplus water is made available for other water users such as local municipalities, agriculture, other industrial users.
	Main infrastructure components footprint (port & SEZ)	ha	1 697,2	4 617,5	
	Main infrastructure components footprint (port & SEZ + desal oversize)	ha	1 697,9	4 626,1	

	Aspect	Unit	Sc1: Small GH_2	Sc2: Big GH_2	*Assumptions*
REGION	RE capacity total	GW	10	80	1 Mt/yr of H2 needs 10 GW electrolyser, that is powered by 20 GW
	RE capacity - solar	*GW*	6	48	60 % solar : 40 % wind
	RE footprint - solar	*ha*	*12 000*	96 000	0,5MW/ha
	RE extent - solar		*12 000*	96 000	Footprint = extent
	RE facilities - solar	*no of facilities*	6	48	Clusters of 1 GW facilities
	RE capacity - wind	*GW*	*4*	32	60 % solar : 40 % wind
	RE footprint - wind	*ha*	*4 000*	32 000	1 MW/ha
	RE extent - wind	*ha*	*40 000*	320 000	0,1 MW/ha
	RE facilities - wind	*no of facilities*	*2.7*	*21.3*	Clusters of 1,5 GW facilities
	Road length	km	300	600	New roads and upgrades same distances / routes as pipelines
	Road footprint	ha	1 200	2 400	40 m (Rural class 2 road 40-70 m. TRH26 Road Classification and Access Management)
	Rail length	km	550	550	Boegoebaai – Kenhardt. New rail direction south-east to connect to the existing Saldanha-Sishen route.
	Rail footprint	ha	1 650	1 650	30 m for rail and service track
	Pipeline length	km	300	600	Sc1: NAM<BB>SB (300km); Sc2: BB>Prieska (300km)
	Pipeline footprint	ha	600	1 200	20 m servitude
	Powerline length	km	260	1 387	Assume grid strengthening / shared infrastructure 30 km TX associated with each RE cluster.
	Powerline footprint	ha	1 300	6 933	50 m servitude (TRH 27 South African Manual for Permitting Services in Road Reserves)
	Main infrastructure components footprint (region)	**ha**	**20 750**	**140 183**	
	Main infrastructure components footprints (all)	**ha**	**22 447**	**144 801**	
	Main infrastructure components footprint (all + desal oversize)	**ha**	**22 448**	**144 809**	
Units: GW = gigawatt; mtpa = million tonne per annum; ha = hectare; Ml/day = million litres per day; km = kilometre					

1.4.2.3. Risk/Opportunity Assessment

Work Package 2 applied a structured qualitative framework to evaluate risks and opportunities associated with a regional GH_2 economy under different scenarios. Risk or opportunity was determined by combining the **likelihood of an event occurring** with the **severity of its consequence or benefit** (Figure 1-5). Consequence and benefit thresholds were defined for each theme (e.g., biodiversity, water resources, socio-economic systems) using categories ranging from Slight to Extreme, while risk and opportunity levels were classified into predefined categories from Very Low to Very High (Table 1-8).

Each impact was assessed across three scenarios [baseline (Sc0), small GH_2 development (Sc1), and large GH_2 development (Sc2)] and for different receiving environments, both before and after management interventions. Results are presented in structured outputs for risks (negative) and for opportunities (positive).

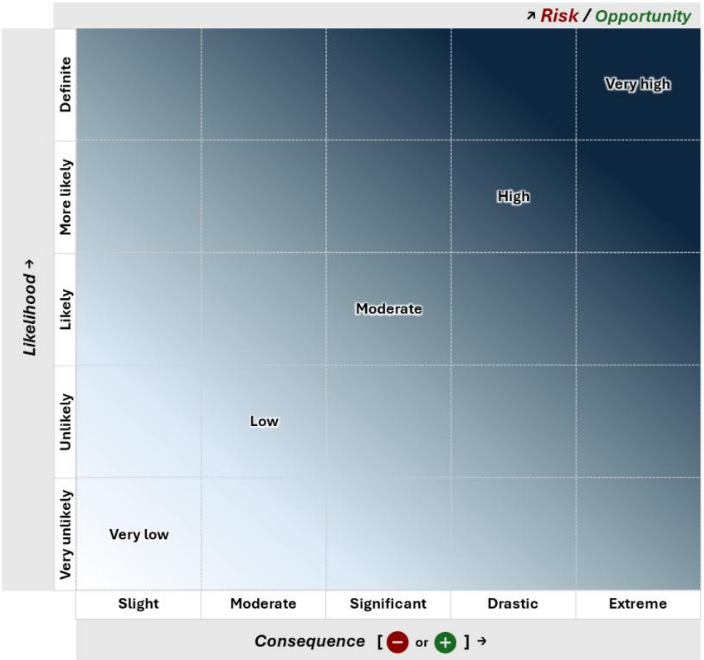

Figure 1-5: Risk and opportunity was assessed by qualitatively "multiplying" the likelihood of an impact (negative or positive) by the severity of the consequence or benefit.

Table 1-8: Predefined risk/opportunity categories.

RISK (-)		OPPORTUNITY (+)	
VERY LOW	Almost indiscernible negative impact.	Almost indiscernible positive impact.	VERY LOW
LOW	Slight negative impact, limited extent, and short duration, well within tolerance.	Slight positive impact, very localised, well below expectations.	LOW
MODERATE	Substantial impact, but less than major; within tolerance and below limits of acceptable change.	Substantial positive impact, but mostly short term, and spatially limited.	MODERATE
HIGH	Major consequence, approaching tolerance and limits of acceptable change.	Highly desirable impact, major medium to long term positive impacts across a broad range of stakeholders at local or regional scales.	HIGH
VERY HIGH	Extremely negative impact, persistent/long lasting, beyond tolerance and limits of acceptable change.	Highly desired, grandiose long term positive impacts across a broad range of stakeholders at local, regional, national, and/or international scales.	VERY HIGH

1.4.2.4. Work Package 2 Chapter Structures

A multi-author team model was adopted for both Work Packages in the SEA. A multi-author team, in the context of SEA, refers to a structured, pluralistic authorship model designed to integrate diverse perspectives and expertise across an assessment process (see Schreiner et al., 2025). For this SEA, multi-author teams were constituted through a consultative process with the Working Group (which included representatives from government, academia, NGOs, and other stakeholders) to nominate researchers who possess the required niche knowledge of this remote region, along with an understanding of strategic infrastructure impacts, academic credibility, and expertise in high-level strategic assessments. Multi-author teams were assembled for both Work Package 1 and Work Package 2 (Figure 1-6). The teams developed peer reviewed reports, with the Work Package 1 teams focusing on identifying the key sensitivities and impacts associated with the port and SEZ development, and the Work Package 2 teams undertaking a more strategic assessment of the cumulative risks and opportunities at a broader scale. Writing teams worked closely across both Work Packages for the duration of the SEA process, ensuring that all the salient issues were covered in at least one of the Work Package Chapters.

Work Package 2 represents a collaborative scientific effort, comprising of seven chapters developed by a team of thirty-four authors, peer-reviewed by thirteen independent experts. The content has also been enriched by contributions from a diversity of stakeholders engaged in the process via a formally constituted Working Group. In addition to the Summary for Policymakers (SPM) (Schreiner et al., 2025), Work Package 2 includes the following chapters (Table 1-9):

Table 1-9: Chapter numbers, titles and recommended citations for work Package 2

Chapter	Title	Citation
Chapter 1	Introduction and context (***this Chapter***)	Mqokeli et al., 2026
Chapter 2	Ecology, biodiversity and conservation planning	Desmet et al., 2026
Chapter 3	Biodiversity offset framework	Botha, 2026
Chapter 4	Water resources and aquatic ecology	Day et al., 2026
Chapter 5	Heritage resources	Orton et al., 2026
Chapter 6	Infrastructure and planning	Maritz et al., 2026
Chapter 7	Socio-economics	Atkinson et al., 2026

Work Package 2 author teams were tasked with developing the following chapter content, as far as practicable (with due recognition that some chapters had to deviate somewhat given their scope):

1. Executive Summary of 2 pages with headline findings/recommendations (including one iconic image/map to assist communication of findings to policymakers);

2. Spatial classification of receiving environments across the study area (e.g., tiered sensitivity map - LOW, MEDIUM, HIGH, VERY HIGH);

3. Description of the likely baseline receiving environment up to 2050 (Sc0) in view of current social and ecological trends e.g., mining activities, rising unemployment, decreased rainfall and water supply, other land use changes, increased tourism etc.

4. Brief description of the potential impacts, positive and negative, associated with a regional GH2 economy and other developments in the Port and SEZ.

5. Define consequence / benefit categories.

6. Description of what would constitute best-practice for effective management / mitigation / enhancement of positive and negative impacts

7. Assess the risk/opportunity of the impacts across each of the scenarios (before & after management) according to methodology provided.

8. Recommended Strategic Management Actions to guide policymakers and regional planning in, for example, Environmental Management Frameworks (EMFs), Spatial Development Frameworks (SDFs), Infrastructure Development Plans (IDPs) and future EIAs.

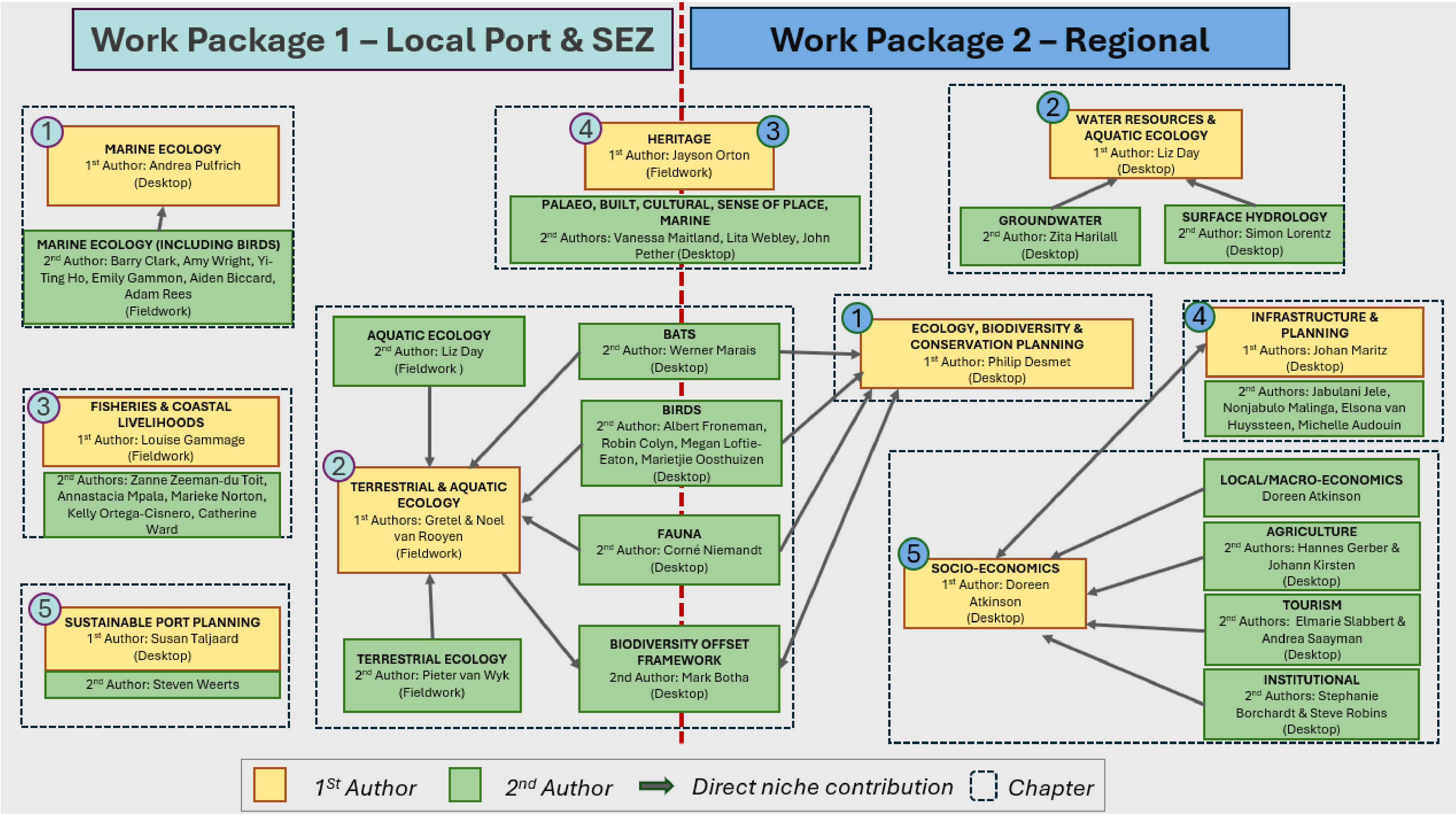

Figure 1-6: Multi-author teams and specialist chapters across the two Work Packages with notional intersections and points of collaboration and overlap indicated

1.5 REFERENCES

Atkinson, D., Gerber, H., Saayman, A., Slabbert, E., Borchardt, S., and Kirsten, J. (2026). *Chapter 7: Social and economic impacts* in Schreiner, G., Mqokeli, B., Snyman-van der Walt, L., Lochner, P & Tsedu, R. (eds.). (2026). *Work Package 2: Strategic Environmental Assessment for the proposed Boegoebaai Port, Special Economic Zone and Namakwa Region*. CSIR/SPLS/Se/ER/2025/0029/B, CSIR Pretoria: ISBN 978-0-7988-5676-8. Available at Boegoebaai Port | CSIR

Barnard P. (2017). Climate change, biodiversity early warning systems, and Africa's future. Africa Conservation Telegraph 12 (1). Published January 2017. Available at: https://conbio.org/groups/sections/africa/act/climate-change-biodiversity-early-warning-systems-and-africas-future

Benito, G., Botero, B.A., Thorndycraft, V.R., Rico, M., Sanchez-Moya, Y., Sopena, A., Machado, M.J. and Dahan, O. (2011). Rainfall-runoff modelling and palaeoflood hydrology applied to reconstruct centennial scale records of flooding and aquifer recharge in ungauged ephemeral rivers. Hydrol. Earth Syst. Sci. 15 (1185-1196).

Bourne, A.R., Cunningham, S.J., Spottiswoode, C.N. and Ridley, A.R., (2020). Hot droughts compromise interannual survival across all group sizes in a cooperatively breeding bird. Ecology Letters doi: 10.1111/ele.13604

Botha, M. (2026). *Chapter 3: Terrestrial Biodiversity Offset Framework* in Schreiner, G., Mqokeli, B., Snyman-van der Walt, L., Lochner, P & Tsedu, R. (eds.). (2026*). Work Package 2: Strategic Environmental Assessment for the proposed Boegoebaai Port, Special Economic Zone and Namakwa Region*. CSIR/SPLS/Se/ER/2025/0029/B, CSIR Pretoria: ISBN 978-0-7988-5676-8. Available at Boegoebaai Port | CSIR

Bourne, A, P. deAbreu, C. Donatti, S. Scorgie, and S. Holness. (2015). A Climate Change Vulnerability Assessment for the Namakwa District, South Africa: The 2015 revision. Conservation South Africa, Cape Town.

Clusella-Trullas, S. & Garcia, R.A. (2017). Impacts of invasive plants on animal diversity in South Africa: A synthesis. Bothalia Vol. 47 No. 2. Pretoria.

Conrad, J., Adams, S. and Titus, R. (2003). GIS based assessment of groundwater recharge in the fractured rocks of Namaqualand, South Africa. International Conference on Groundwater in Fractured Rocks. Conference Proceedings. Prague, Czech Republic.

Conradie, S.R., Woodborne, S.M., Cunningham, S.J. and McKechnie, A.E. (2019). Chronic, sublethal effects of high temperatures will cause severe declines in southern African arid-zone birds during the 21st century. Proceedings of the National Academy of Sciences 116: 14065-14070.

CSIR. (2019). Green Book: adapting South African settlements to climate change. Available at: https://greenbook.co.za/.

CSIR. (2023). Namakwa District Municipality Risk Profile Report based on the GreenBook. Available at: https://greenbook.co.za/

Czenze, Z.J., Kemp, R., van Jaarsveld, B., Freeman, M.T., Smit, B., Wolf, B.O. and McKechnie, A.E. (2020). Regularly drinking desert birds have greater evaporative cooling capacity and higher heat tolerance limits than non-drinking species. Functional Ecology 34(8), 1589-1600.

Davis, C. L., Hoffman, T.M., & Roberts, W. (2016). Recent trends in the climate of Namaqualand, a megadiverse arid region of South Africa. South African Journal of Science, 112(3-4), 1-9.

Day, L., Lorentz, S., and Harilall, Z. (2026). *Chapter 4: Water Resources and Aquatic Ecology* in Schreiner, G., Mqokeli, B., Snyman-van der Walt, L., Lochner, P & Tsedu, R. (eds.). (2026). *Work Package 2: Strategic Environmental Assessment for the proposed Boegoebaai Port, Special Economic Zone and Namakwa Region*. CSIR/SPLS/Se/ER/2025/0029/B, CSIR Pretoria: ISBN 978-0-7988-5676-8. Available at Boegoebaai Port | CSIR

DEA. (2018). South Africa's Third National Communication under the United Nations Framework Convention on Climate Change.

Dean, W. (1995). Where birds are rare or fill the air: the protection of the endemic and the nomadic avifaunas of the Karoo. University of Cape Town.

Dean, W.R.J., Barnard, P. & Anderson, M.D. (2009). When to stay, when to go: trade-offs for southern African arid-zone birds in times of drought. South African Journal of Science 105: 24–28.

Department of Science and Innovation (DSI). (2021). Hydrogen Society Roadmap for South Africa.

Department of Water and Sanitation, South Africa (DWS). (2017a). Determination of Ecological Water Requirements for Surface water (River, Estuaries and Wetlands) and Groundwater in the Lower Orange WMA. Buffels, Swartlintjies, Spoeg, Groen and Sout Estuaries Ecological Water Requirement . Authored by CSIR: L van Niekerk, J Adams, SJ Lamberth, S Taljaard for Rivers for Africa. DWS Report No: RDM/WMA06/00/ CON/COMP/0316.

Department of Water and Sanitation, South Africa (DWS). (2017b). Determination of Ecological Water Requirements for surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. Report on consequences of scenarios. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. DWS Report No: RDM/WMA06/00/CON/COMP/0117.

Department of Water and Sanitation, South Africa (DWS). (2024). Determination of water resource classes and associated resource quality objectives in the Lower Orange River Catchment. Resource Units Prioritization Report. Draft- Version 01. Report No. RDM/WMA04/00/CON/CLA/0424

Department of Water and Sanitation, South Africa (DWS). (2016). Determination of Ecological Water Requirements for surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. Wetland EWR report. Prepared by: Rivers for Africa eFlows Consulting (Pty) Ltd. Authored by J. MacKenzie. DWS Report No: RDM/WMA06/00/CON/COMP/0616.DWS 2017a

Department of Water Affairs and Forestry (DWAF). (2008). Groundwater Resources in the Northern Cape Province: 2008. Authored by Van Dyk, G. S., Makhetha, J., Potgieter, D., Zikali, T., Leeme, V., Moletsane, F., and Vonya, T. Department of Water Affairs and Forestry, Kimberley.

Desmet, P., Kellerman, L., Colyn, R., van der Merwe, C., Oosthuizen, M., Froneman, A., Niemandt, C., Marais, W., Welch, R., Venter, Z., Day, L., Lorentz, S. & Harilall, Z. (2026). *Chapter 2: Ecology, biodiversity and conservation planning* in Schreiner, G., Mqokeli, B., Snyman-van der Walt, L., Lochner, P & Tsedu, R. (eds.). (2026). *Work Package 2: Strategic Environmental Assessment for the proposed Boegoebaai Port, Special Economic Zone and Namakwa Region*. CSIR/SPLS/Se/ER/2025/0029/B, CSIR Pretoria: ISBN 978-0-7988-5676-8. Available at Boegoebaai Port | CSIR

Hoffmann, T.M., Carrick, P.J., Gillson, L and West, A.G. (2009). Drought, climate change and vegetation response in the succulent Karoo, South Africa. South African Journal of Science 105: 54–60.

Hoffmann, M.T., Cousins, B., Meyer, T., Petersen, A. and Hendricks, H. (1999). Historical and contemporary land use and the desertification of the Karoo. In: Dean, W.R.J. and Milton, S.J. (Eds.). The Karoo: Ecological Patterns 42 and Processes. Cambridge University Press, Cambridge.

Hoffman, T.M., Skowno, A., Bell, W. & Mashele, S. (2018). Long-term changes in land use, land cover and vegetation in the Karoo drylands of South Africa: implications for degradation monitoring, African Journal of Range & Forage Science, 35:3-4, 209-221, DOI: 10.2989/10220119.2018.1516237

International Energy Agency (IEA) (2022). Global Hydrogen Review 2022. Paris: IEA.

Kellerman, L., Colyn, R., van der Merwe, C., Oosthuizen, M. & Froneman, A. (2026). *Chapter 2a: Avifauna* in Schreiner, G., Mqokeli, B., Snyman-van der Walt, L., Lochner, P. & Tsedu, R. (eds.). (2026). *Work Package 2: Strategic Environmental Assessment for the Proposed Boegoebaai Port, Special Economic Zone and Namakwa Region*. CSIR/SPLS/Ems/EXP/2026/0001/A, CSIR: Pretoria: ISBN 978-0-7988-5676-8. Available at Boegoebaai Port | CSIR

Khavhagali, V.P. (2010). Importance, threats, status and conservation challenges of biodiversity in Northern Cape. The Grassland Society of Southern Africa. Vol 10 No. 4, pp 14–17.

Kotze, D., Malan, H., Ellery, W., Samuals, I. & Saul, L. (2010). Assessment of the environmental condition , Ecosystem service provision and sustainability of use of two wetlands in the Kamiesberg uplands. Report to the Water Research Commission (WRC).

Le Maitre, D., O'Farrell, P., Milton, S., Atkinson, D., De Lange, W., Egoh, B., Reyers, B., Colvin, C., Maherry, A., and Blignaut, J. (2009). Assessment and Evaluation of Ecosystem Services in the Succulent Karoo Biome. Report prepared by CSIR for the Succulent Karoo Ecosystem Programme (SKEP) Coordination Unit, SANBI.

Maritz, J., Jele, J., Malinga, N., van Huyssteen, E., and Audouin, A. (2026) *Chapter 6: Infrastructure and Planning* in Schreiner, G., Mqokeli, B., Snyman-van der Walt, L., Lochner, P & Tsedu, R. (eds.). (2026). *Work Package 2: Strategic Environmental Assessment for the proposed Boegoebaai Port, Special Economic Zone and Namakwa Region*. CSIR/SPLS/Se/ER/2025/0029/B, CSIR Pretoria: ISBN 978-0-7988-5676-8. Available at Boegoebaai Port | CSIR

Mbokodo, I., Bopape, M., Chikoore, H., Nethengwe, N., & Engelbrecht, F. (2020). Heatwaves in the future warmer climate of South Africa using CCAM output data.

McKechnie, A.E., Gerson, A.R. and Wolf, B.O. (2021). Thermoregulation in desert birds: scaling and phylogenetic variation in heat tolerance and evaporative cooling. Journal of Experimental Biology 224: jeb229211.

Milton, S.J., Petersen, H., Nampa, G., Van der Merwe, H. and Henschel, J.R. (2022). Drought as a driver of vegetation change in Succulent Karoo rangelands, South Africa. African Journal of Range & Forage Science 2022: 1–15.

Juŕgens, N., Burke, A., van Wyk, P., Grongroft, A. and Oldeland, J. (2025) A perfect storm: unprecedented expansion of the Namib Desert and cascading desertification processes in the northernmost Succulent Karoo. Journal of Arid Environments 231 (2025) 105459. https://doi.org/10.1016/j.jaridenv.2025.105459

Marais, W. & Welch, R. (2026). *Chapter 2b: Bats* in Schreiner, G., Mqokeli, B., Snyman-van der Walt, L., Lochner, P. & Tsedu, R. (eds.). (2026). *Work Package 2: Strategic Environmental Assessment for the Proposed Boegoebaai Port, Special Economic Zone and Namakwa Region*. CSIR/SPLS/Ems/EXP/2026/0001/A, CSIR: Pretoria: ISBN 978-0-7988-5676-8. Available at Boegoebaai Port | CSIR

Northern Cape Green Hydrogen (NCGH2) (2023). Northern Cape Green Hydrogen Masterplan. Available at: https://www.ncgh2.co.za

Nunes, B.B.S. (2023). Fire in Savannas and its Impact on Avifauna: Considerations for a Better Environmental Conservation. Sociedade & Natureza 35.

Orton, J., Webley, L., Pether., J. and Maitland, V. (2026). *Chapter 5: Heritage Resources* in Schreiner, G., Mqokeli, B., Snyman-van der Walt, L., Lochner, P & Tsedu, R. (eds.). (2026). *Work Package 2: Strategic Environmental Assessment for the proposed Boegoebaai Port, Special Economic Zone and Namakwa Region*. CSIR/SPLS/Se/ER/2025/0029/B, CSIR Pretoria: ISBN 978-0-7988-5676-8. Available at Boegoebaai Port | CSIR

Pietersen, K., Titus, R. and Cobbing, J. (2009). Effective Groundwater Management in Namaqualand: Sustaining Supplies. WRC Report No. TT 418/09. Water Research Commission, Pretoria.

Samuels, M.I. (2013). Pastoral mobility in a variable and spatially constrained South African environment. University of Cape Town

Schutte, S., Schulze, RE. and Clark, DJ. (2023). A National Assessment of Potential Climate Change Impacts on the Hydrological Yield of Different Hydro-Climatic Zones of South Africa: Report 1 Methodology and Results. WRC Report 2833/1/22. Water Research Commission, Pretoria.

Simmons, R. & Barnard, P. (2005). Too hot to handle? The impact of climate change on African birds. Africa – Birds & Birding: 52–60.

Smit, B., Woodborne, S.M., Wolf, B.O. and McKechnie, A.E. (2019). Differences in the use of surface water resources by desert birds is revealed using isotopic tracers. The Auk: Ornithological Advances 136 doi.org/10.1093/auk/uky005.

Schreiner, G., Mqokeli, B., Snyman-van der Walt, L., Lochner, P and Tsedu, R. (eds.). (2025). Work Package1: Strategic Environmental Assessment for the proposed Boegoebaai Port and Special Economic Zone. CSIR/SPLS/Ems/EXP/2025/1107/A, CSIR: Pretoria: ISBN 978-0-7988-5675- 1. Available at Boegoebaai Port | CSIR

Todd, S., Milton, S., Dean, R., Carrick, P. and Meyer, A. (2009). Ecological Best-Practice Livestock Production Guidelines for the Namakwa District. Botanical Society of South Africa in association with the Succulent Karoo Ecosystems Programme.Walker, C. Suzanne J Milton, Tim G O'Connor, Judy M Maguire & W Richard J Dean. (2018). Drivers and trajectories of social and ecological change in the Karoo, South Africa, African Journal of Range & Forage Science, 35:3-4, 157-177, DOI: 10.2989/10220119.2018.1518263

Van Gend, J., Francis, M. L., Watson, A. P., Palcsu, L., Horváth, A., Macey, P. H., Le Roux, P., Clarke, C. E. and Miller, J. A. (2021). Saline groundwater in the Buffels River catchment, Namaqualand, South Africa: A new look at an old problem. Science of the Total Environment, 762, p.143140.

Walker, C. Suzanne J Milton, Tim G O'Connor, Judy M Maguire & W Richard J Dean. (2018). Drivers and trajectories of social and ecological change in the Karoo, South Africa, African Journal of Range & Forage Science, 35:3-4, 157-177, DOI: 10.2989/10220119.2018.1518263