Pre-feasibility study into solar energy rollout
to Namibia – stakeholder discussion document

Africa New Energies secured funding to carry out a pre-feasibility study assessing the potential and commercial viability of widespread solar energy adoption in Namibia using a financing template that is repeatable in other African countries facing electricity shortages.

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Private and confidential

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1. Executive summary

ANE was tasked by the Namibian government, funded by the African Innovation Foundation to investigate the feasibility of large scale concentrated solar plants, utility scale PV plants and a micro-generation scheme in Namibia.

1.1. Background

Africa New Energies (ANE) was invited by the Namibian Government to assess the viability of setting up a 250 MW concentrated solar power plant (CSP) in Namibia. As Namibia currently imports over 60% of its electricity from neighbours with acute supply shortages, it is looking to secure local supply. With the world's highest levels of solar irradiation, along with one of the world's lowest population density, the government is keen to embrace solar and off-grid micro-generation.

1.2. Brief

The African Innovation Fund (AIF) tasked ANE with assessing the feasibility of:

1. A 250 MW CSP plant
2. A 250 MW utility-scale photovoltaic (PV) solar power plant
3. A national residential PV micro-generation scheme
4. A national roll-out of solar water heaters
5. Energy saving interventions that could be funded by carbon credits
6. Other carbon-saving technologies that have the potential to be financially viable

The task was to find a financing mechanism that would deliver required investor returns, while at the same time not result in increased electricity inflation, using cheaper interventions such as solar water heating (5 USc per KWh) to fund the CSP plant (30 USc per KWh). The AIF stipulated that the model was to be designed to be repeatable elsewhere in Africa, especially in Angola.

NamPower is a state owned monopoly, that currently imports electricity at 4 US cents per KWh, sells to REDs at 7 cents who in turn sell to end consumers at 15 cents. This makes residential microgeneration more competitive than utility scale solar.

1.3. Overview of the Namibian electricity market

The key market participants are the state-owned utility NamPower, the operator of the generation and transmission assets. NamPower paid an average of 4 USc per KWh for electricity imports in 2010 and less for internal generation, thanks to a historically advantageous agreement with Eskom of South Africa and a more recently one with ZESA of Zimbabwe. NamPower charges regional electricity distributors (REDs) an average of 7 USc per kWh, who in turn charge residential customers an average of 15 USc. As NamPower inherited its generation assets for $1 at Independence in 1991, it has accumulated large net cash reserves – equivalent to 18 months of revenue. Electricity inflation has averaged at 15% above inflation over the last three years and is forecast to remain at these levels for the next three. Such electricity price rises are politically unsustainable, with over half of Windhoek's residential customers in arrears. The mining sector, which uses a large minority of Namibia's electricity, indicated that they would not contribute towards renewable energy feed-in-tariffs. They will not buy directly from renewables companies, as it could harm their relationship with NamPower on whom they depend for cheap electricity.

Technology	Technical feasibility	Financial highlights	Feasibility
250 MW Concentrated Solar Power (CSP) Utility Scale Plant	Needs 6 hours of storage. Single cycle thermal efficiency 37%. Uses 3.6 litres of water per KWh, which restricts it to three areas.	CapEx US$6.00 per watt, expected production 200 GWh. Levelised electricity cost (LEC) of US$0.30 per KWh based on WACC of 12%.	**Not financially feasible,** it is not in NamPower's financial interests to agree to replace an 7 USc Eskom imported supply with 30 USc per KWh.
250 MW **Photovoltaic (PV)** Utility Scale Plant	Only technically feasible with at least three hours of storage. Round-trip losses are 30% on stored electricity.	Capital cost US$2.50 for PV only, increasing to US$5.00 with storage. Will generate 75 GWh LEC = 33 USc per kWh.	**Not financially feasible,** and also cannot hedge FX risks, as PPA will be denominated in NA$, with debt in US$.
Solar Water Heating with carbon funded insurance and maintenance	Better for farms and small businesses than residential, due to greater daytime demands. Storage possible as are hybrids where wind and solar microgeneration are integrated with batteries.	Cost of 15 USc per KWh comparable to retail electricity, but storage adds 20 USc per KWh. Off grid is more competitive than on-grid, as is diesel genset replacement – which has an average cost of 28 USc per KWh.	**Financially feasible with carbon bank:** Saves customer 2/3rd of current cost on 30% of their electricity bill. Needs microfinancing innovation.
Residential and small business on roof PV	Better for farms and small businesses than residential, due to greater daytime demands. Storage possible as are hybrids where wind and solar microgeneration are integrated with batteries.	Cost of 15 USc per KWh comparable to retail electricity, but storage adds 20 USc per KWh. Off grid is more competitive than on-grid, as is diesel genset replacement – which has an average cost of 28 USc per KWh	**Financially feasible with carbon bank:** Possible to finance as Bolton mortgage, especially with new builds. Big opportunity for carbon bank, but does need theft-proofing on PV systems.
Carbon funded energ y saving interventions	Simple technologies in households such as insulation, solar cookers and LED lighting. Insulation and lighting	Systems recover household energy costs in less than 6 months. E.g. solar cooker costs NA$500 after carbon and saves NA$8 per day for wood in peri-urban areas – payback 12 weeks.	**Financially feasible with carbon bank:** Insulation 100% carbon financed, solar cookers 60% carbon financed. LEDs can be installed through a bolt-on mortgage.
Dry cooled gasfired combined cycle power station with gradual solar conversion	*Dependent on finding local inexpensive 500 bscf natural gas deposit.* Water consumption zero. 85% capacity factor. 180 MW gas turbine, with 70 MW Rankin cycle using waste heat.	Capex including gas processing = $2.00 per watt, with 250MW plant delivering almost 2TWh per year. Investor US$ returns =35% with 5 year exit. Raises $6 billion over 40 year life for revolving carbon fund.	**Financially feasible with international financing package** – use of MIGA, debt equity ratio 70/30. FX exposures can be hedged over 5 year debt exposure period.

1.5. Key findings and recommendations

There is a major, repeatable opportunity to use unwanted, stranded natural gas in Namibia's high potential oil exploration industry to give the sub-region affordable, locally produced electricity at a low cost – just 7 cents per KWh.

1. **The key to a national solar programme lies in the building of a combined cycle natural gas-fired plant on a stranded natural gas source.** 600 billion cubic feet of feedstock will be sufficient to run a 250 MW plant for 40 years – delivering three times the volume of a 250MW CSP plant – at one-third of the capex. This new capacity will replace 80% of imports at just 7 cents per KWh – roughly the wholesale price NamPower will pay Eskom in 2012. But it would cost $885 m to build, which is too expensive for Namibia.
2. **The combined cycle gas plant can gradually be weaned off gas, with the thermal input replaced by CSP over a 20 year period.** After foreign debt has been repaid with international equity investors exiting their investment, the $6 billion of free cash generated over the remaining 35 year life of the plant will be deployed to a revolving carbon fund, which will invest profits in micro-generation and energy saving.
3. **A national solar water heating programme is vitally needed by all stakeholders** – water tends to be heated by residential customers during peak demand times in the morning and early evenings. This electricity can cost NamPower 10-20 times that of base load. More importantly, solar water heating will reduce household electricity demand by 30% at one-third of the cost of the current electricity retail price. (5 USc per KWh vs. 15 USc).
4. **The cross-subsidy model outlined in the original proposal to fund a utility-scale solar plant will not be politically possible as Namibia cannot afford to promulgate renewable energy feed-in-tariffs in the way that Europe has** – residential customers are struggling to pay bills at current levels, so will need interventions, such as carbon-funded insulation and solar water heaters to reduce the cost from current unaffordable levels. Just 80,000 of the 350,000 households in Namibia have access to electricity and almost half cannot pay for it at current prices. Forecast electricity price increases of 15% above inflation will hamper rural and peri-urban electrification.
5. **Off-grid solar will become increasing financially attractive** – especially if a low-cost storage solution can be found. Off-grid solar applications compete with higher residential rates of 15 USc per KWh vs. generation rates of 4 USc per KWh and also help the customer to avoid the large premium needed to recover grid access costs in remote areas. NamPower will welcome a large-scale roll-out of off-grid solar as they are seldom able to recover transmission investment into low population density areas.
6. **There is an urgent need to use low-carbon interventions to support the energy needs of informal settlements and the rural poor.** Namibia has 50% unemployment with half of the population subsisting in rural areas where less than 1% of the land is arable. Solar can play an important role in providing heating for these people in the form of solar cookers, largely paid for by carbon credits. Improved insulation can be funded 100% by securitisation of carbon credits.

The free cash generated from the plant will be reinvested in utilityscale solar to gradually wean the plant of gas while investing in microgeneration. Over $5 billion will be available to be invested in solar over the life of the plant, as a result of a $500 million investment.

1.6. ANE's solution – overview

The ANE development technique was applied to Namibia to produce a carbon-light, cost-effective solution, using stranded natural gas, and replacing it with solar over time by:

- **Identifying** potential stranded natural gas sites – 6 were found with potentially sufficient reserves for a 250 MW plant, close enough to transmission lines.
- **Proving** the reserve using emerging "Surface Exploration" technologies such as "Airborne Transient Pulse A-EM Surveys" "Passive Ground Tellurics," "Windowed Radiometric Surveys" and geochemical sampling as well as low-cost exploration well drilling techniques.[1]

1. As defined specifically in the Introduction to Surface Exploration Case Histories: Applications of Geochemistry, Magnetics, and Remote Sensing, published jointly by American Association of Petroleum Geologists and Society of Exploration Geophysicists, 2002.

ANE's development process involves turning low-cost stranded natural gas into electricity, while replacing the gas with solar over time.

A foreign direct investment of 4% of GDP will supply 50% of demand and give 100% basic electricity access within two years.

It is replicable in the rest of Africa – in Nigeria and Angola – using 50% of flared natural gas will result in a 450% increase in electricity generation.

- **Using** the natural gas in a combined cycle gas plant, which will produce over 50% of Namibia's needs in 2013, replacing 80% of high risk regional electricity imports.
- **Swapping** foreign ownership, by enabling a consortium of local owners to give international investors a year five exit, with a low-risk leveraged buy-out fund.
- **Extending access** to electricity using solar micro-generation – starting with a Universal Basic Electricity Access Programme (U-BEAP), giving the two-thirds of the population with no access to electricity, access to LED lighting, ability to charge a mobile phone and listen to a radio, followed by a national solar water heater roll-out, insulation and energy saving programme and finally solar PV residential roofs.
- Adding to plant capacity with concentrated solar (integrated solar thermal) and utility-scale photovoltaics with battery storage to supply peak periods.

With a foreign investment of just 4% of GDP, this strategy will achieve the following:

- Grid-wide generation cost reduction of 20% in the first year of plant operation.
- 100% of the population getting basic access to electricity within two years.
- Immediate savings of 500k tonnes of carbon emissions per year with each $1 of foreign investment will result in carbon re-investment of $5.50 – delivering in 100% electricity access within 25 years, where 70% of households derive more than 50% of their energy needs from solar.
- ANE's development strategy is replicable throughout Africa, which has a surplus of flared and stranded natural gas: For instance, converting 50% of Angolan and Nigerian flared natural gas will increase electricity production by 350% increasing each GDP by 30%.

With a foreign investment of just 4% of GDP, this strategy will achieve the following:

- Grid-wide generation cost reduction of 20% in the first year of plant operation.
- 100% of the population getting basic access to electricity within two years.
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2. Administrative information

2.1. Document management

2.1.1 Document details

Document Name:	ANE's Repeatable Namibia Solar Strategy
Document Type:	Report
Document Version:	0.07
Date:	May 2018
Readership:	The board and administrative staff of the African Innovation Fund – still internal
Document Summary:	This document assesses various strategies to bring about wide scale adoption of solar into Namibia using a finance model that does not increase electricity inflation faced by local consumers, while providing market related returns for international capital providers. No confidential data is included in this report.

2.1.2 Amendment history

Version	Date	Amended by	Approved by	Comments
0.01	2011-11-08	SL	n/a	First draft for internal comment
0.02	2011-11-15	SL	n/a	Second draft for internal comment and initial comments from the funder.
0.03	2011-12-09	SL	n/a	Third draft for internal comments – for public report
0.04	2011-12-18	BR	n/a	Fourth draft for internal comments – for public report
0.05	2011-12-31	NS	n/a	Fifth draft for internal comments – for public report
0.06	2012-01-06	SL	n/a	Sixth draft for internal comments – for public report
0.07	2012-01-08	CS	n/a	Seventh draft for internal comments – for public report – Christo Smit comments
0.08	2012-01-10	LL	n/a	Eighth draft for internal comments – for public report – Len LeShack comments
0.09	2012-02-02	BR	n/a	Ninth draft for internal comments – for public report – Brendon Raw and Thomas Roos (CSIR) comments

2.1.3 Approval

Name	Signature	Date
Completed by		
	Project Manager ANE	
Approved by		
	Project Manager African Innovation Foundation	
Accepted by		
	Board member African Innovation Foundation	

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Note that ANE was registered in November 2012 and will be used as the local vehicle should further research be commissioned into this proposed project.

3. Description of key institutional stakeholders

3.1. Key stakeholders

ECB	The Electricity Control Board of Namibia – Namibia's electricity regulator sets pricing, electricity strategy and issues generation licenses.
Eskom	South Africa's state owned electricity monopoly, which supplies about 40% of Namibia's electricity, which supplied NamPower at about 7 US cents per KWh in 2010. Eskom faces capacity shortages of 4% of capacity between 2012 and 2016 – where international industry standards suggest that 19% is required.
MME	The Ministry of Mines and Energy
Other exporters	Other state-owned exporters on the Southern African Power Pool to Namibia include ZESCO of Zambia, which could become increasingly important with the installation of a 350 KV transmission line through Caprivi, EdM of Mozambique and STEM of DRC. NamPower exports some power to BPC of Botswana. NamPower The state owned power utility that owns Namibia's generation assets and controls, owns and operates all transmission infrastructure. It also has a share in the RED's (Regional Electricity Distributors) and generates about 40% of Namibia's electricity. It is profitable and has a large cash reserve, is competently run. It is likely to resist any independent power producer initiative that could disrupt the grid, loosen its control over transmission or reduce its profitability – i.e. most intermittent renewable energy supplies.
NamPower	The state-owned power utility that owns Namibia's generation assets and controls, owns and operates all transmission infrastructure. It also has a share in the RED's (Regional Electricity Distributors) and generates about 40% of Namibia's electricity. It is profitable and has a large cash reserve, is competently run. It is likely to resist any independent power producer initiative that could disrupt the grid, loosen its control over transmission or reduce its profitability – i.e. most intermittent renewable energy supplies.
NYS	National Youth Services – a commission set up by the Namibian presidency to create youth employment. The NYS originally invited Africa New Energies (ANE) to Namibia.
REDs	Regional Electricity Distributors, who purchase electricity from NamPower and distribute it to final customers, with revenue collection usually handled by the municipalities. NamPower owns a stake in certain REDs.
ZESA	The Zimbabwe Electricity Supply Authority is a vital supplier to NamPower, which under its Whinge agreement of 2008 agreed to supply 150 MW for five years in return for $40 million of foreign exchange for vital upgrade work, at a price of less than 2USc per KWh. This agreement gave Namibia almost a quarter of its electricity (891 GWh in 2010) at one of the world's lowest prices, but it is unlikely that this award-winning agreement will be renewed.

4. Biographies of the author and model developers

The team have a mix of finance, IT, engineering and actuarial skills – and has worked together on energy saving, remote monitoring and solar PV projects in Africa for seven years.

Stephen Larkin is a chartered accountant with international solar finance, remote monitoring and micro-generation experience.

4.1.1 Project manager – Stephen Larkin

After studying economics at the University of Cape Town, Stephen started his career in 1997 with Unilever in London as a graduate trainee, becoming their media finance analyst. Studying for the Chartered Institute of Management Accountants (CIMA) examinations, he came first in Unilever in the UK. In 2001 he moved to British Airways as their energy analyst, creating BA's first exotic derivative pricing models. In 2003, he went freelance to consult for GE Capital with the change management project, moving their business intelligence division from London to Leeds. Realising the potential of GE's powerful data warehouse – containing data on 65% on UK households – he developed a statistical model predicting credit behaviour, based on GE's six sigma principles.

Stephen moved back to South Africa in 2004, where he started researching and testing his solutions for the world's mine safety problems, to develop IT accessible to mine workers in harsh working environments. During this time, his company was awarded with grant funding from the Special Programme for Industrial Innovation, attracted seed capital investment, applied for two patents and created a world first in blast optimisation for AECI. Stephen then moved to work with Brendon Raw on Pinpoint Energy (later ANE), where he wrote the tender proposals for the Turkana and Mafikeng projects. Stephen co-founded ANE in November 2012.

Brendon Raw is software developer from the energy sector.

4.1.2 Solar software development – Brendon Raw

Brendon Raw is an IT professional and investor in the IT, clean energy and property sectors.

Brendon started his career as an IT software developer in London after completing his studies in Durban, South Africa. He moved to BP Oil International, where he was tasked with developing mission critical software systems for to front office in BP's commodity trading business.

Brendon began his entrepreneurial activities with an investment into a London property portfolio. He went on to make his most successful investment – in Quirk e-Marketing. This was a start-up with less than $300,000 in revenue when he got involved and it has since grown to become the leading e-marketing service provider in Africa, with customer accounts including Hertz Car Hire, South African Airways, Southern Sun Hotels and Investec.

Neil Sheridan is an actuary with structured products experience in major UK banks.

4.1.3 Actuarial and solar modelling – Neil Sheridan

Neil Sheridan is a Fellow of the Institute of Actuaries and has an MSc in Maths of Finance from Oxford University. Currently with HSBC Middle East and North Africa Risk Department based in Dubai, he is regarded as the bank's leading authority on economic capital modelling and scenario stress testing. He has held previous roles with HSBC UK in Structured Products Development and Insurance Risk and as a quantative credit risk analyst at ABSA (part of Barclays). Neil's other insurance and actuarial experience includes working for Hansard International Life in the Isle of Man and he started his career with the Johannesburg office of Ginsburg Malan & Carson (now Alexander Forbes), the South African Actuarial Consultancy. Neil has written Raw Solar's Solar Forecasting Algorithms, Statistical Distributions for Solar resource and PV performance.

5. Assignment brief

International investment can be harnessed in co-operation with a local partner, whose mandate is to assist the local community – particularly youth

Solar can be installed without access to a national grid and can be customised in a way that fossil fuels cannot.

5.1. Background

The directors of Africa New Energies (ANE) were invited to Namibia by the Namibian Youth Services Commission in June 2011 to investigate the potential to partner Youth Services in building a Concentrated Solar Power (CSP) plant on a site near the Orange River. This site is a world class CSP location, with sufficient water rights from the Orange River and some of the highest irradiation levels in the world. Youth Services is currently funded by the Namibian Government to foster job creation amongst the youth, where there is chronic unemployment. It has been tasked with investing in projects that make it self-funded – while continuing to deliver on its mandate to create youth employment. Youth Services felt that the steady income stream from a solar power plant could help to achieve both objectives. The ownership model put forward in this proposal is one that ANE believes is sustainable elsewhere in Africa – where international investment can be harnessed in co-operation with a local partner, whose mandate is to assist the local community – particularly youth. In a highly regulated environment such as electricity generation, the greatest risks tend to be regulatory delays and investors losing the high risk, pre-bankability investment, which for projects less than $100 million can be as much as 10% of total capital expenditure using conventional project finance methods. The co-ownership with a local government partner greatly reduces this risk, while the long-term benefit to the community in the form of dividends invested in the provision of social services will ensure long-term community support for a sophisticated plant that will need to operate for decades to achieve shareholder returns.

Solar seems like an obvious solution to Africa's chronic electricity shortages. The continent has abundant sunshine, solar can be installed without access to a national grid and can be customised in a way that fossil fuels cannot – from a single panel powering a mobile phone for a subsistence farmer to a multi-billion dollar utility field supplying a small country. It is also cleaner. But the current global solar model, which relies on giant subsidies in the form of a feed-in-tariff far higher than the fossil fuel generation alternatives, will simply not work in Africa. The global industry's lobby groups are dominated by manufacturers who are adept at using Western government feed-in-tariffs to lock in higher prices for the solar equipment. They have been so successful in obtaining high subsidies that solar costs 10 times that of coal-fired generation in the UK and Spain. These subsidies have destabilised certain large Western governments: Spain now produces 4% of its electricity from solar, but this has resulted in a 30% increase in consumer electricity bills, while the government has been burdened with €125 billion in sovereign guarantees – a material contributor to Spain's sovereign default crisis.

The second risk that Africa faces is that it is particularly vulnerable to manipulation of this artificial, subsidy-driven market. Global manufacturers the world over are using soft finance to sell panels at higher-than-market prices to African countries, that are desperate for both power and investment. In Addition, some of the transactions have been tarnished by corrupt payment. This places a multi--decade burden on the continent's electricity consumers of electricity prices far higher than they needed to be – China's lobbying of South Africa to propose an initial R4.48 per KWh for Solar PV – twice what was necessary – is a case in point. The artificial feed-in-tariff market is more exposed to corruption than most as supply is limited by government policy and permitting is obtained through government relationships as supply applications is usually greater than the quota.

The third issue that solar faces is intermittency – i.e. the sun does not always shine – ANE's model does not depend on a single technology or site, but uses detailed irradiation and engineering models and an innovative consumer financing system that enables the country to afford a comprehensive programme that involves six strategic interventions:

1. The large-scale 50 MW photovoltaic plant that produces electricity during the day and is seasonal and intermittent.
2. The 50 MW concentrated solar power to further reduce peak evening and early morning power.
3. Household investment in solar water power (the cheapest form of solar energy).

4. Grant-funded off-grid micro-generation using hybrid systems to reduce peak demand.
5. Carbon-credit funded efficiency interventions.
6. The potential to add a natural gas input to the concentrated solar combined cycle strategy.

ANE's model will consolidate the impact on the grid, as well as costing the roll-out.

The combination of these six strategies enables the country to rely on a significant minority of its power from solar sources, smoothing the demand curve by reducing the dramatic residential-driven early morning and evening peaks, while extending access of electricity to rural areas, and reducing deforestation in fragile ecological environments. ANE's model will consolidate the impact on the grid, as well as costing the roll-out. This will be the first time this exercise has been done – from a technology agnostic consumer-driven standpoint within an African context.

ANE's vision is to make solar the most affordable power alternative to Africa, so the second key focus is on reducing the high-risk-pre-bankability costs of funding a utility solar strategy.

ANE has spent several years building a largely automated financial modelling process that enables the project promoter to access detailed decision support information at a low cost at the pre-feasibility stage, rather than much later as is the case with conventional project implementation. This enables unviable projects to be rejected sooner and at a lower cost, while dramatically reducing pre-bankability costs of viable projects. For this project, the funding model will be specifically tailored towards financiers and insurers with a repeatable solar finance template that can be rolled out to many sites across Africa, with each future project reducing the cost of the specific site study further.

In a financial market, where Western governments' financial viability remains stressed and Africa has yet to unlock its investment potential, this model has the potential to foster a new wave of investment into renewables from Western institutional investors looking for higher risk-adjusted returns than Western markets can currently offer.

5.2. Primary objectives of the study

The primary objectives of the services related to the pre-feasibility study are listed below where we have outlined the work needed for the development and construction of a utility-scale Photovoltaic and Concentrated Solar Plant that will deliver on the following key objectives:

- Providing an affordable and integrated national roll-out for solar energy in Namibia that includes a mix of different solar technologies to reduce peak demand in a way that enables solar to become a material part of Namibia's energy mix that is affordable to energy users in Namibia.
- Improving Namibia's security of electricity supply through the generation and dispatching of electricity.
  - at the lowest price in terms of Levelised Electricity Cost (LEC)
  - within acceptable supply intermittency constraints
  - with reasonable alternatives for ensuring successful integration into the Namibian electricity grid, taking into consideration transmission capacity, and peak demand profile
  - using technologies that are commercially proven and bankable at a low cost of capital
  - with a targeted maximum of two years construction time
- **If the pre-feasibility study finds that the strategy is financially viable, we will build a compelling investment case for the investors supporting the African Innovation Foundation, to whom ANE have offered right of first refusal to provide the capital to roll-out this project.**

5.3. Wider objectives

It is the intention of both ANE and the African Innovation Foundation that this research be used to develop a repeatable template for micro-generation adoption in Africa by:

- using the procurement budgets to foster a solar micro-generation "Green Deal" financing mechanism similar to the UK where households invest in energy saving interventions, solar water heating and on-roof solar PV as well as micro-wind generation where feasible

- Developing a carbon-credit-funded energy saving initiative for rural households to reduce the use of biomass for heating purposes
- Developing a local skill base to foster a renewables industry in Namibia
- raising foreign direct investment at the lowest cost of capital
- diversifying supply within the Southern African Power Pool (SAPP)
- using the investment in the plant to achieve other sustainability objectives and spin-off economic activity around the plant

The decision to revise the scope of the report to include a natural gas input, as well as the corporate social responsibility section for low cost lighting and cooking, are specific examples.

5.4. Summary of description of work

5.4.1 Justification

Working in co-operation with the African Innovation Foundation, Government, Utilities and Key Customers, we modelled the extent of the supply shortfall and the value proposition for the project by considering the following:

- Current supply mix and assessment of reliability of electricity imports
- Cost of electricity supply and key trends impacting future costs
- Impact on electricity demand of future economic development and economic growth within the country – particularly in the mining sector
- Impact of other generation projects within Namibia and the Southern African Power Pool
- Impact of energy saving initiatives within Namibia – particularly on with regard to residential solar water heating projects and other demand side initiatives

All the above data was collated and reduced to quantifiable inputs to an integrated demand/supply model on a calendar clock format, with the resulting gap analysis being the key deliverable.

When speaking to the Electricity Control Board (ECB) of Namibia, they made it clear that they welcome international investment into the Renewables Sector, but are concerned about the burden of higher tariffs on the consumer. **The key financial constraint on pricing was to ensure that it resulted in no increase in electricity inflation on top of the price growth curve already forecast by the ECB. As many of the alternatives did not fulfil this condition, they were rejected.**

The pricing model focused on the following constraints

- Deeper analysis of engineering procurement and construction costs
- Deeper analysis of capital structure and cost of capital
- Levelised cost of electricity from each technology as well as sensitivity analysis
- Marginal cost of generation and imports from the Southern African Power Pool
- Timing and cost of supply, for intermittent renewables, although less reliance was placed on this for the eventual technology selection in the form the combined cycle natural gas plant.

The potential to assist other stakeholders, most notably NamPower to trade peak generation of the Power Plant within the Southern African Power Pool, was investigated.

The political possibility of a Currency Levelisation Fund by using the mines natural exposure was investigated and rejected, after it became clear that the mines would not support it and there was not enough political support within the government to force minors to do so.

Tariffs were analysed by customer profile – especially those of the mines, where a calendar clock pricing mix analysis was performed.

Discussions were held on several occasions with the ECB to obtain an understanding the ECB's pricing model and its tolerance for higher priced new capacity, as well understanding the constraints resulting from its below market-rates for its allowable cost of capital on assets, to be used for revenue absorption.

Potential debt sculpting strategies to align power purchase agreement tariffs with ECB's price trajectory forecast, were investigated, but analysis was stopped when it became clear early on in the process that the cross-subsidy model proposed would not be politically possible.

5.4.2 Comparison of alternatives

5.4.2.1 Desktop renewables resource data collection exercise

Southern Namibia has some of the world's best irradiation levels for solar.

Southern Namibia has some of the world's best irradiation levels for solar, and has some potential for wind provision for off-grid systems that will be considered within the scope of this pre-feasibility study: Irradiation levels vary greatly depending on geographic location and are influenced by micro-climates – in addition certain solar technologies such as certain Concentrated Solar Power (CSP) systems are potentially heavily dependent on large volumes of local fresh water all year round, which is extremely scarce in many parts of Namibia. Wind resource varies even more dramatically than the solar resource. As the resource availability is proportional to the amount of electricity produced by the plant, the relatively inexpensive remote solar and wind resource assessment is vital to isolate a number of areas that warrant further investigation: The process involved the following:

- Collating all top level satellite data into a usable format
- Integrated SWERA (Solar Wind Energy Resource Assessment international solar study) and NASA (National Aeronautics and Space Administration, USA) into a software tool that could easily be adapted for several countries
- Augmenting the top level satellite data with locally available meteorological data

Note that as the stand alone concentrated solar power plant and the utility scale PV plant were rejected early in the process, no specific sites were investigated, so the original plan to purchase hourly current and historical satellite data that gives solar and wind performance at 3 kilometre by 3 kilometre granularity was not needed.

5.4.3 Assessment of renewable technology roll-out and performance – international experience

We include a brief section where we describe different solar technologies, do a top level costing, assess their suitability in terms of the three key objectives – cost, timing of dispatch and intermittency, as well as the extent of their international track record and their likelihood of attracting low cost development financing. The performance will be based on data collected from the Desktop renewables resource data collection exercise above.

Namibia currently receives much of its electricity from South Africa and has a network of high voltage transmission lines.

The model that evaluates performance by location is not included in this report, as it relates to commercially sensitive natural gas deposit location.

Within the scope of the pre-feasibility study, discussions with NamPower will reveal the grid connection potential for the selected site with top level cost estimates for grid integration. If the pre-feasibility study suggests further investigation, a more detailed study will be conducted by our consulting engineers – KV3 and Worley Parsons in conjunction with NamPower. This will show the existing transmission capacity, sub-station location and available capacity, as well the cost of upgrading sub-stations and step-up transformers to integrate the project to the grid.

5.5. Transmission and grid analysis

Namibia is within the Southern African Power Pool and currently receives much of its electricity from South Africa. It has a network of high voltage transmission lines, particularly in the south of the country. Grid integration is of seminal importance – as the need for transmission lines to be built to connect an otherwise optimal site can increase capital expenditure dramatically and perhaps more importantly – delay the project by anything up to a decade.

Within the scope of the pre-feasibility study, discussions with NamPower will reveal the grid connection potential for the selected site with top level cost estimates for grid integration.

If the pre-feasibility study suggests further investigation, a more detailed study will be conducted by our consulting engineers – KV3 and Worley Parsons in conjunction with NamPower. This will show the existing transmission capacity, sub-station location and available capacity, as well the cost of upgrading sub-stations and step-up transformers to integrate the project to the grid.

5.6. Top level stakeholder identification and engagement

Key stakeholders were identified and engaged with. These include but are not limited to:

- The Namibian National Youth Services Commission
- NamPower
- Government Departments at a local and national level
- Large customers, who will be encouraged to take foreign currency offtake agreements or currency offset agreements
- Local communities
- Environmental agencies
- Other generation project promoters
- Development funders and international export agencies

5.7. Internal environmental impact assessment for each alternative

While renewables provision tends to have a low impact on the environment, they need to be assessed with care: Each site will be considered for the following:

- Impact on flora and fauna
- Land ownership
- Impact on local water supply
- Aesthetics
- Need for hazardous materials handling
- Need for support infrastructure such as roads, transmission/distribution/telecoms line upgrades and security infrastructure

This internal environmental impact assessment is not to be confused with the formal external Environmental Impact Assessment within the feasibility study, which would be legally required if the development process moves forward beyond feasibility stage, and would be carried out by an independent 3rd party.

For the purposes of this public document, this information has not been included as it would reveal confidential information about the location of natural gas resources.

5.8. Legal framework analysis

The pre-feasibility study only considers advice from other stakeholders and does not formally engage our legal advisors, although they have agreed to assist at this stage. Issues that will be considered are:

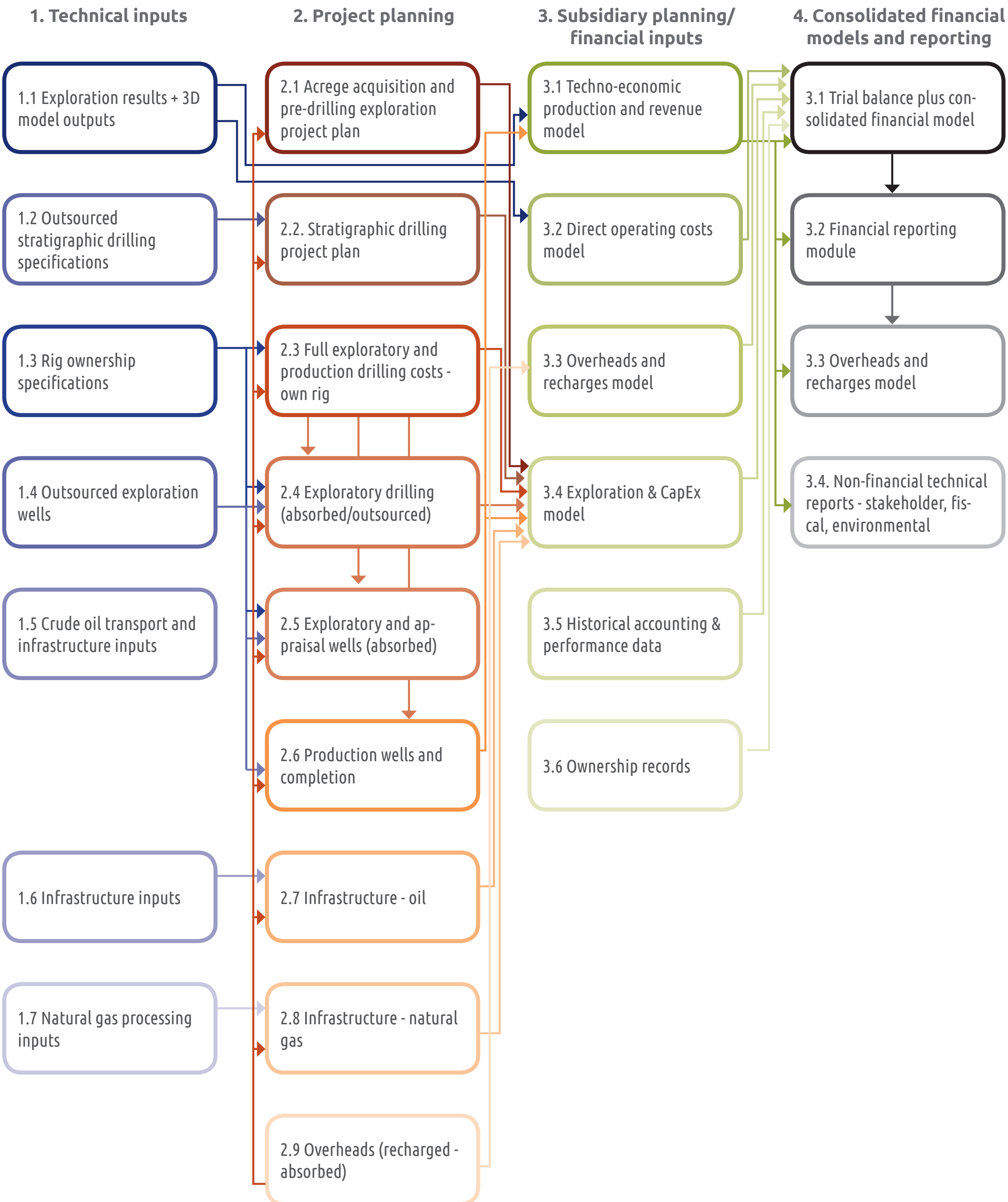
- The ECB licensing process to obtain a generation license
- Analysis of publically available power purchase agreements, land agreements and time of use (TUOS) agreements
- Issues facing currencies and pricing as well as independent power production project permissions

Note that legal issues have been excluded from the public report.

5.8.1 Pre-feasibility costing of acceptable alternatives

From our previous experience in solar projects in Africa and the UK, we have developed detailed costing models that adhere to the costing methodology. They are unique to the extent that they integrate engineering information, dynamic pricing, and project costing as well as solar resource availability to give more thorough analysis of alternatives than is possible with other pre-feasibility models. See below for our methodology:

Figure 1 – The ANE Process Financial Planning Methodology called the ANE Process



5.8.2 Financing alternatives

Our key objective for the client to deliver the lowest LEC within the supply constraints and our two key competitive advantages lie in our ability to:

1. Reduce procurement costs through detailed activity-based costing analysis and creating supplier competition by turning this project into a strategic must-win for competing technology providers
2. Reduce the cost of renewables financing through the use of export credit agency financing, innovative insurance products and operational risk management techniques
3. Investigate the potential to use Multilateral Investment Guarantee Agency (MIGA) to reduce insurance costs

Note that the analysis of financing alternatives is not included in this report due to confidentiality issues around natural gas, shareholder returns and required pricing.

5.9. Recommendations

Based on the analysis above, we will collate all information into a set of recommendations to take the project to the next level.

Recommendations will include:

- Technology selection
- Assessment of site and potential alternatives
- Top level financing strategy
- Project sponsor – which will depend heavily on technology selected
- Engineering Procurement and Construction partners

The report was originally to be communicated in the following manner:

- First draft of comprehensive report – six weeks after receipt of funds
- Final draft of comprehensive report – two weeks after submission of first draft of the comprehensive report
- A summary report - two weeks after submission of first draft of the report
- In both electronic and printed format
- A PowerPoint presentation summarising findings

Workshops with interested parties delivered in Switzerland after submission of the final draft of the comprehensive report were offered, to gain stakeholder support to implement recommendations.

6. Overview of the Namibian electricity market

6.1. Demand and supply for electricity in Namibia

6.1.1 Background

Namibia is an ideal candidate to use off-grid solar to give the poor electricity for the first time.

Namibia has a population of 2.5 million people, and a stable multi-party parliamentary democracy. Agriculture, herding, tourism and the mining industry – including mining for gem diamonds, uranium, gold, silver, and base metals form the backbone of Namibia's economy. After Mongolia it is the second least densely populated country in the world, which along with hosting the world's highest irradiation levels, makes it an ideal candidate to use off-grid solar to give the poor electricity for the first time.[2] A GDP of $14.6 billion (ppp) shows a GDP per capita of $7,000, the third highest in sub-Saharan Africa, masking one of the world's most unequal income distributions with a gini-co-efficient of 0.7 – approximately half the population live below the international poverty line[3] – and the nation has suffered heavily from the effects of HIV/AIDS, with 15% of the adult population infected with HIV in 2007.

Despite these challenges, Namibia is regarded as a well-run economy and as one of the most investor friendly in Africa – albeit one with high taxes. The prospect of hydrocarbon riches and a hydrocarbon fiscal regime that will generate handsome government revenues could transform the lives of the country's poor. They need help – half of the population subsists in rural areas where less than 1% of the country is arable.

6.1.1.1 The importance of electricity provision within the broader economy – Namibia from a global perspective

While most Namibians the author spoke to do not share these sentiments, Namibia has one of the best electricity infrastructures in Africa, where energy provision was 1,800 KWh per capita.[4] Africa's average is 555 KWh per year, while India's is 444 KWh per year.[5] There is a strong correlation between GDP and electricity provision, where a Ugandan study suggested $1 of economic growth was generated by every extra KWh of electricity generated.[6] A separate study suggested that the economic impact of providing one KWh of electricity in Kenya contributed US$0.83 to the economy.[7] This suggests that even investing in the most expensive alternative – utility-scale photovoltaic with battery storage at a levelised electricity cost of 33 US cents per KWh would bring with it economic growth, if the decision were to be made on purely economic grounds and the electricity could be dispatched to those who do not have it.

2. Summarised from Wikipedia - http://en.wikipedia.org/wiki/Namibia

3. Source – CIA World Factbook – ppp stands for Purchasing Power Parity, meaning that goods purchased locally are adjusted for their true cost, rather than the GDP in local currency divided by the official exchange rate, which results in a lower GDP - $12.6 billion from the same source. The international poverty line is $1.25 per day. A gini co-efficient is a measure of income inequality – perfectly equal share of income would result in a Gini co-efficient of 0, while the Gini coefficient would be 1, if one person earned all the money in the economy. Note that *Global Finance magazine* estimate for GDP was $14.6 billion in 2009, about 5% higher than the CIA world fact book. http://www.gfmag.com/gdp-data-country-reports/213 – namibia-gdp-country-report.html#axzz1di5DaFOC.

4. Source – Electricity consumption in Namibia – NamPower Annual Financial Statement, divided by the population estimate from note 1.

5. Analysis performed by the author based on electricity consumption and population data provided by the CIA World Factbook.

6. Source – Michael Dynes of African Investor in conversation with the author.

7. Source – Kenyan Ministry of Energy – *Update of the Least Cost Power Development Plan* – 2009-2029 published in March 2008.

Figure 2 – The relationship between global electricity consumption and GDP per capita – All countries

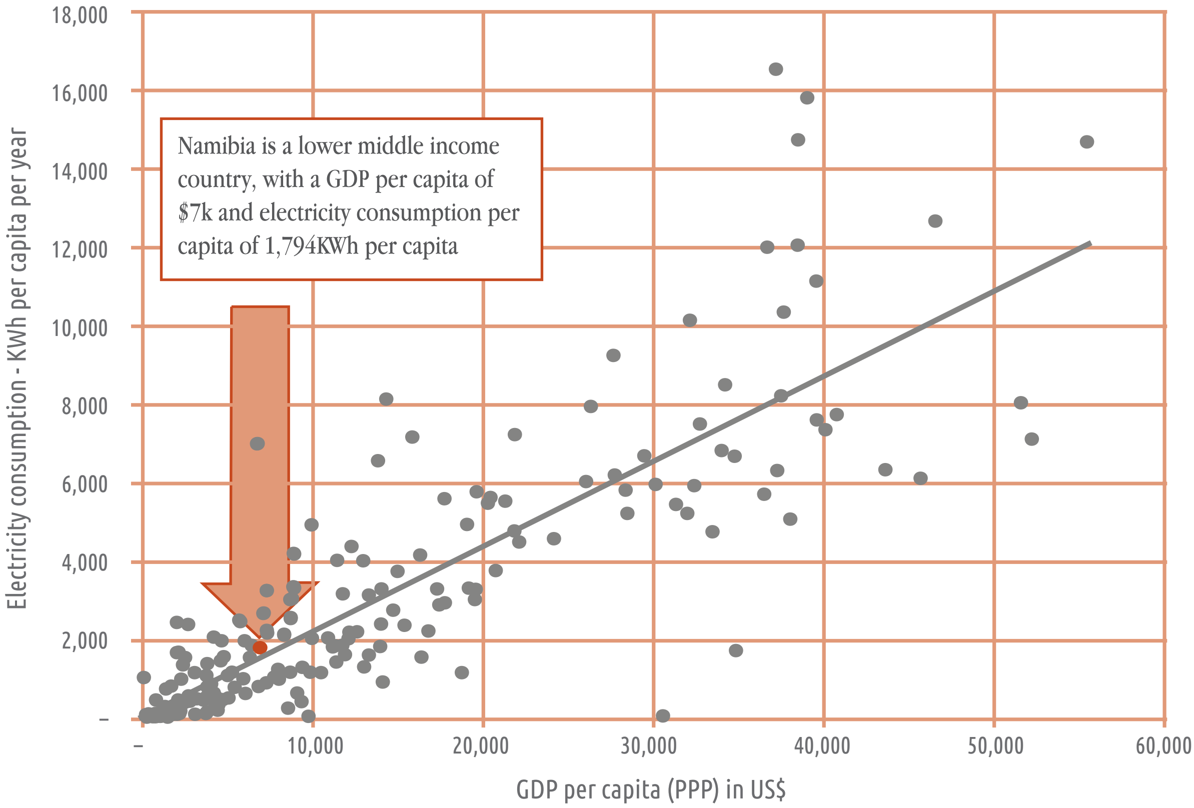


Figure 3 – KWh electricity consumption vs.GDP per capita

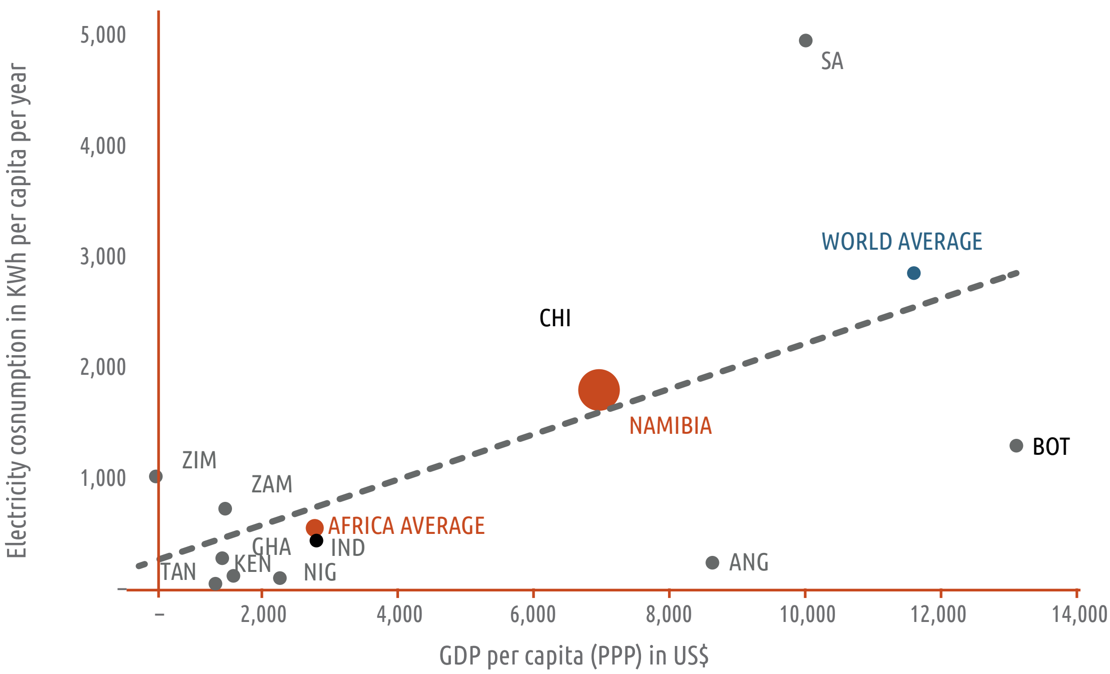


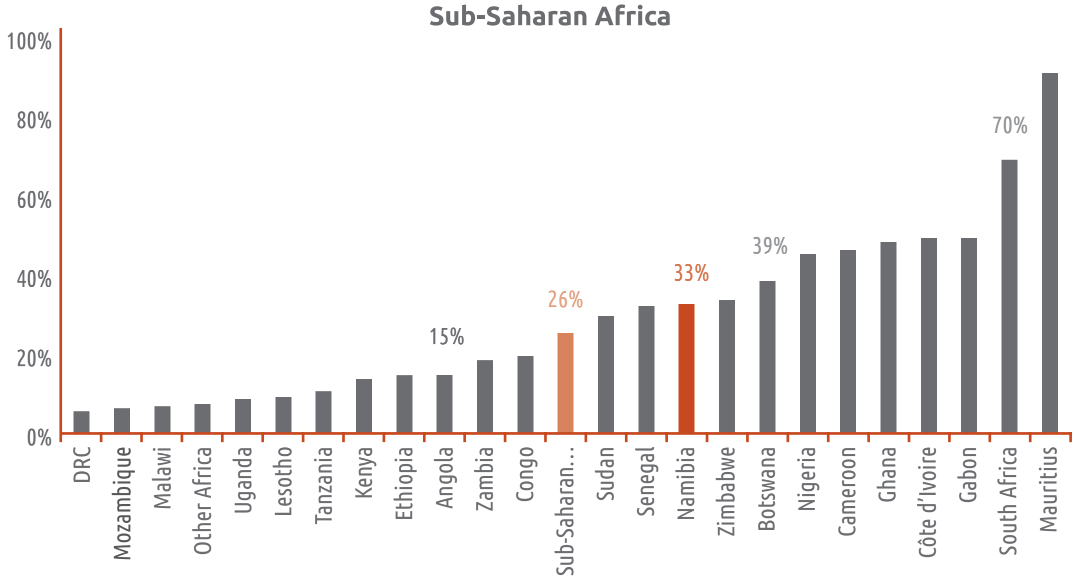
Figure 3 shows the relationship between GDP and electricity consumption per capita for selected developing economies – including her neighbours. Namibia receives more electricity than Botswana, which has a GDP per capita of almost twice that of Namibia, but is in a much better position than other neighbours such as Zambia, Zimbabwe (more analysis on in later sections) and Angola. South Africa is particularly well endowed with electricity, because of the demand of its mining and beneficiation which consumes 52% of its electricity.

6.1.1.2 The demographics of electricity access

Figure 3 KWh electricity consumption vs.GDP per capita – Namibia vs. her regional peers – seems to indicate that Namibia is in a better position than all of her SADC peers bar South Africa when it comes to electricity provision – and is more than triple the African average of 555 KWh per capita. Just as the GDP per capita numbers mask the highest level of income inequality, this seemingly rosy picture masks the inequality of electricity access – just 80,000 of the Namibia's estimated 350,000 households have access to both electricity and running water with a further 40,000 having access to electricity without running water.[8]

This has and will continue to be a vexing problem – providing electricity to the poor is currently financially unaffordable for the government due to the remoteness and the thin population density of rural communities, and the impermanence of peri-urban informal settlement dwellings.

Figure 4 – Percentage of population with access to electricity Sub-Saharan Africa



The graph above benchmarks Namibia's electricity access to that of its sub-Saharan peers. Some 33% of the Namibia population have access to electricity in their homes in 2005, against the sub-Saharan average of 26%, while Botswana, which has a similar economy and less electricity consumption – does mildly better with 39% access. One of South Africa's less trumpeted successes is its aggressive electrification programme. In 1994, the year of the country's first democratic elections, less than 35% of the population had access to electricity in their own homes. By 2005, it had doubled to 70%, and by 2010 had increased to almost 80%. The rise of pre-paid mobile payment services have played an important role in this success, and offers important insights to Namibia, which has the same level of electricity access as South Africa had in 1994.

This graph is also important in the way that it shows how few sub-Saharan Africans are connected to the grids. According to the International Energy Agency (IEA), some 625m people in sub-Saharan Africa were without access to electricity in 2014. The problem is usually threefold – a lack of generation generally, and where there is generation infrastructure, it tends to be old and overly dependent on hydroelectric power – which is susceptible to erratic rainfall. Furthermore, there is a lack of transmission lines and distribution infrastructure – where it exists it is crumbling. For example, one interviewee indicated that in Brazzaville, in the Democratic Republic of Congo, the distribution infrastructure was in such a poor state, that 50% of generated electricity was lost.[9]

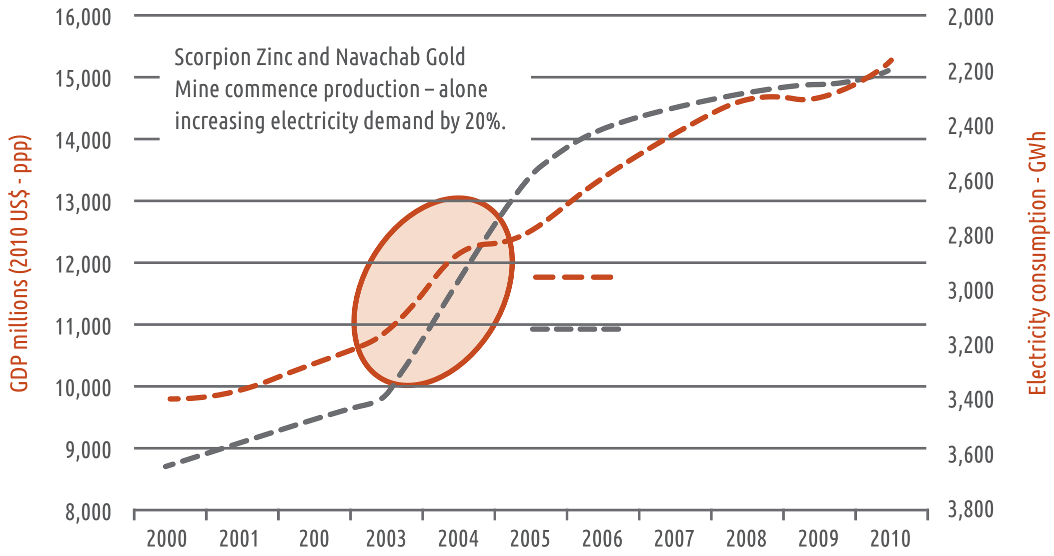
8. Based on data from the 2001 Census, the last census for which data are available. Compared to the *World Energy Outlook 2006 Table B2 Electricity Access in 2005: Africa* – page 568, which also provides the data for Figure 4

9. Discussions in Windhoek, June 2011 with various engineering firms involved in tenders in Africa outside Namibia.

6.1.2 Demand forecast

6.1.2.1 The energy density of historic GDP growth

Figure 5 – Namibian real GDP vs electricity demand 2000 – 2010



The graph above shows that in Namibia energy demand is intimately linked with real GDP growth. In fact so much so, that is reasonable to say that a lack of electricity will profoundly restrict economic growth.

Table 1 – Relationship between electricity demand increases and real GDP growth

	Growth between 2000 and 2010	Compound average growth rate (CAGR)
Electricity demand growth	72%	5.6%
GDP growth	55%	4.5%
Energy intensity of GDP growth 2000 – 2010	130%	
Correlation co-efficient	98%	

The electricity density is more than double that of South Africa, which is where each 1% of GDP growth results in 0.6% increase in electricity consumption.

6.1.2.2 The impact of mining and hydrocarbon sector expansion on electricity demand

The mining sector contributes 10% to GDP, 50% of foreign exchange earnings and consumes a large minority of Namibia's electricity. Scorpion, the world's 8th largest Zinc mine, increased electricity demand by as much as 15% when it started production in 2004. It is estimated that the mines use over 1,500 GWh of the 3,767 GWh supplied by NamPower in 2010.[10]

Moving energy consumption from diesel to electricity – Namibian mines are following the South African mining trend of using electricity to transport ores wherever possible, as the price of electricity to large mining customers in Namibia has increased by just 300% in the last twelve years against an increase in US$ of 10 fold in the diesel price.

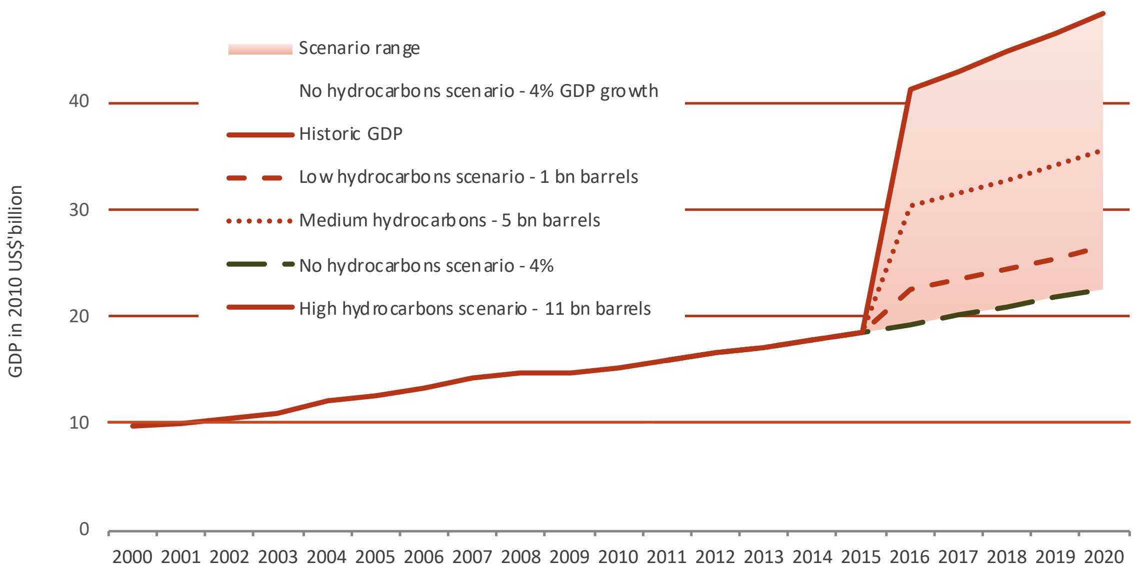
10. Sources – various – the 1998 Ministry of Mining and Energy Affairs estimated that mine electricity demand was 630 GWh confirmed in a later NamPower set of annual financial statements. Key mining companies include NAMDEB (diamonds), Rossing Uranium and Rosh Pinah. As Navachab Gold Mine has opened in 2003, and Ongopolo Mining has reopened the old copper mine in Tsumeb, it is estimated that mining demand has increased by a compound annual growth rate of 3% since, increasing the demand of these main mining assets to 900 GWh. Skorpion Zinc Mine's electricity consumption is disclosed in the country's financial statements as it is so significant – increasing electricity demand by over 20% in 2004 when the mine ramped up to full production. Demand in 2010 according to NamPower's Annual Financial Statements was 673GWh. NamPower does not publish detailed information about user profiles, so information has been collated and extrapolated from several sources to give this estimate.

Water shortages – Water is in extremely short supply for Namibia and to cater for the mines in the Walvis Bay area, a reverse osmosis desalination plant was built. This plant processes 20 million cubic meters per year and uses an estimated 4KWh per cubic meter of desalinated water. New mines will require desalination and ground water which will increase electricity demand.

Future trends – Namibia has an investor friendly environment and a plethora of mineral resources–key prospects lie with uranium, rare earths and copper:

1. **Uranium** – Namibia already produces 7% of the world's uranium and has four new mines in various stages of development. Swakob Uranium, owned by Areva, will increase demand by 60MVA or between 300GWh and 6% of 2010 demand.
2. **Copper** – Tsumeb Mine produced over 1.5 million tonnes at world-leading grades over its 100 year life. There has been a dramatic increase in prospecting in the North that is largely unexplored – Northern Namibia has the potential to become the second to Zambia in African copper production – along with precious metals as bi-products.
3. **Rare earths** – Much to the West's dismay, rare earths, which are vital to the renewable energy industry, as well as many high tech electronics industries are dominated by China, which started a far-sighted production policy in the 1960's. China currently produces 95% of the world's rare earths and the West is falling over itself to find alternative sources. Namibia has a world-class resource.
4. **Hydrocarbons in the medium-term:** The Kudu off-shore gas field finally looks like it will be developed, four decades after it was discovered, and with it comes the prospect of an off-shore hydrocarbon boom. Eco Oil and Gas has raised $300 million for Namibian exploration – their reserve off-shore from Kunene is estimated to have 1 billion barrels of extractable oil. HRT – part owned by Petrobas of Brazil – which has successfully exploited similar offshore lithology off the Brazilian Coast. The Energy Minister estimated that Namibia could have as much as 11 billion barrels.[11] 1 billion barrels output is worth 8 years of current GDP, of which half will go to the government, which has a historic opportunity to use old revenues to provide social services to all. This alone will triple residential demand. If half of the 11 billion barrels are recovered over a 40 year period, an average of 500 thousand barrels per day will result in an increase of Namibia's GDP by $11 billion at current oil prices, causing a sustained, one-off increase in the size of the economy by almost 100% On-shore natural gas and oil prospects are also very promising, which will increase the demand for support services and boost the services sector. The use of on-shore natural gas is the key focus of this proposal.

Figure 6 – Hydrocarbon impact on Namibia's GDP

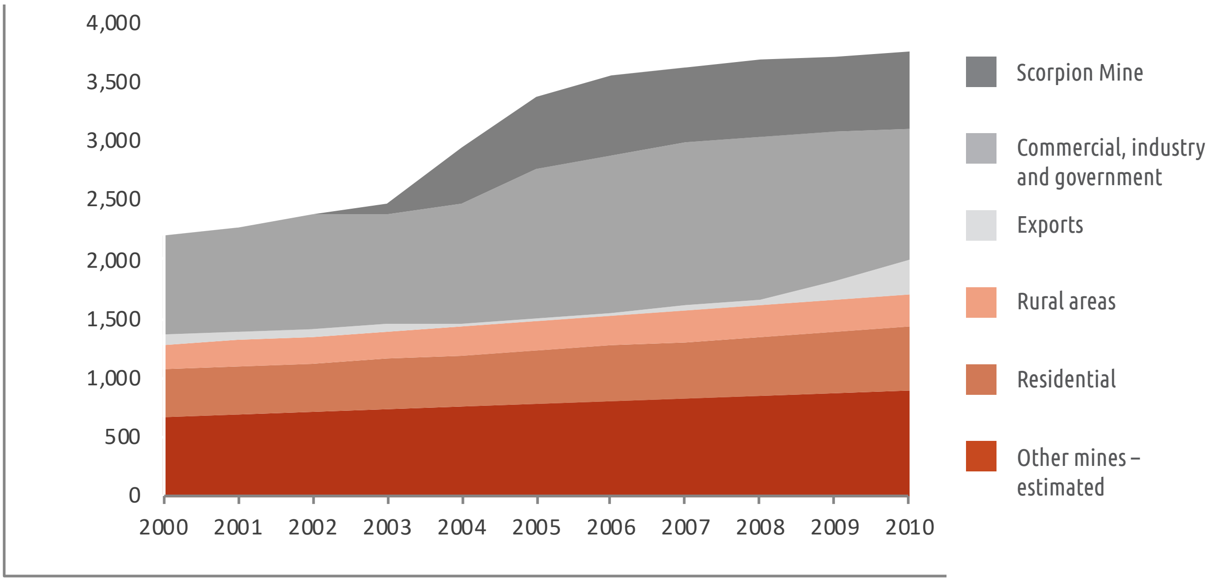


11. Speech made by Mines and Energy Affairs Minister Isak Kitali on 7 July 2011 http://www.iol.co.za/business/international/namibia-sees-11-bln-barrels-in-oil-reserves-1.1094806

An interesting point to notice is that Namibia will avoid the economic curse of Dutch Disease where hydrocarbon discoveries fundamentally change the country's balance of payments – causing the country's exchange rate to increase. As the Namibian Dollar is linked on a 1:1 relationship with the much larger South African Rand, even at the most optimistic $11 billion scenario, such an injection into what is in effect a wider currency union will only increase the combined GDP of South Africa and Namibia by 3%. It will help offset currency outflows as a result of South Africa's $400 billion infrastructure programme.

6.1.2.3 Historical demand by user type

Figure 7 – Namibia's key electricity user-groups
Estimated demand – 2000 – 2010



There is little information available of energy consumption by user-group, but it is vital to gain an understanding as different user-groups offer different opportunities – especially for renewables, where residential and small business customers pay three times what NamPower pays for its imports. This graph makes the following assumptions:

1. **Skorpion** – actuals based on NamPower AFS
2. **Other mines** – estimated based on 1998 report, increasing by 3% per year
3. **Exports** – actuals based on NamPower AFS
4. **Rural areas** – estimated based on 1998 report, increasing by 3% per year
5. **Residential** – split into three user-groups:
   - **a.** 50,000 prepaid households, who use 100 KWh per month
   - **b.** 50,000 households, who use 200 KWh per month
   - **c.** 40,000 households, who use 600 KWh per month (this constitutes about 12% of households. This was cross-referenced against the 2005 household electricity connection ratio of 33% and the South African residential usage of 17% of total.

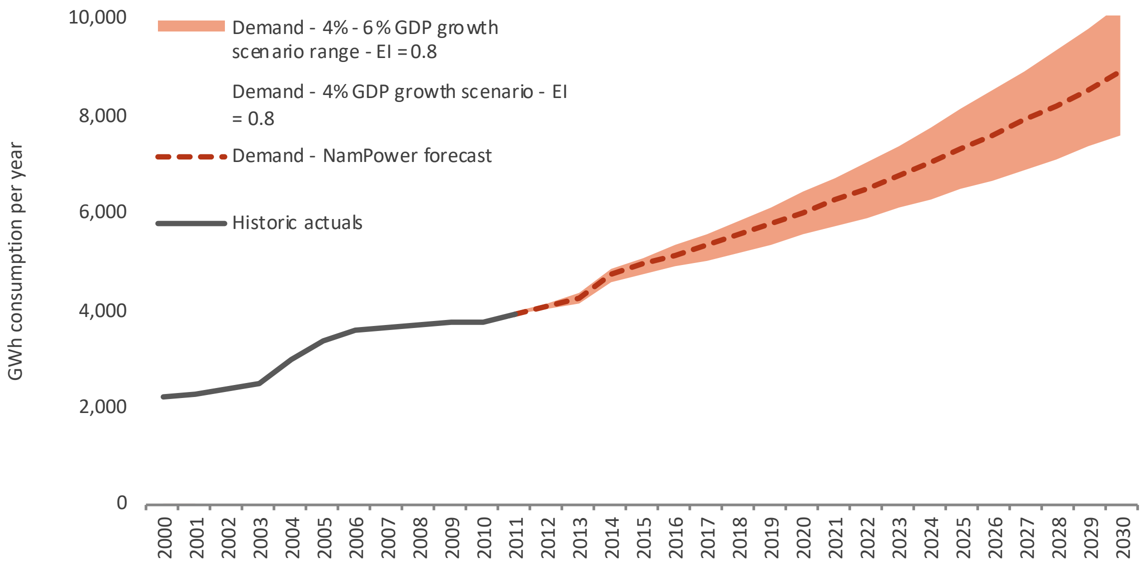
This model estimates that residential users come 14% of the total.

6. Commercial and government users – the difference between the total supplied by NamPower and the sum of user-groups 1-5. It estimates that this group, made up of manufacturing, heavy industry, food processing, farming, government and retail space, uses 29% of the electricity provided to the grid.

6.1.2.4 Demand forecast scenarios

The electricity intensity of GDP growth will put pressure on all power infrastructure. Based on the last ten years of mine-induced growth, every 1% of GDP growth will result in 1.3% growth in electricity demand. It is assumed that an aggressive energy saving programme will be implemented, particularly with residential customers struggling to pay bills, reducing electricity intensity to 0.8.

Figure 8 – Namibian demand forecast/growth scenarios



For the purposes of this document, NamPower's estimate of 4% annual electricity demand growth is used to forecast after 2014, with a cumulative 25% demand growth between 2010 reported figures and 2014, meaning that demand will double by 2030, and increase by five-fold by 2050. As can be seen from the GDP impact of the hydrocarbons and mining prospects, this has the potential to increase dramatically higher. If demand is greater, there is scope to both repeat ANE's proposed solution and to increase the size of a single plant by up to eight fold.

6.1.3 Electricity supply in Namibia

6.1.3.1 NamPower's existing generation capacity and future plans

6.1.3.1.1 Background and financial position

NamPower is a state-owned utility that owns and operates generation and transmission capacity that it inherited at Independence in 1991. The company also owns shares in regional electricity distributors, and regards the management of transmission and integration into the Southern African Power Pool, the regional power grid, as key competencies. As it did not pay for the infrastructure it inherited from Eskom in 1991, it is profitable and has large and accumulating cash reserves – after tax profits were NA$273 million (US$34 million) on a turnover of NA$1 804 million (US$225 million) – an after tax profit margin of over 15%. With its short-term cash deposits of NA$2,885 million (US$360 million – equivalent to 19 months of 2010 revenue), and debt of NA$1,200 million (US$150 million), NamPower has a strong balance that generated healthy net finance income in 2010 – NA$148 million (US$19 million).

6.1.3.1.2 Generation

NamPower reports 993 MW of capacity of which one-third is located within Namibia, there is no independent power production of more than 0.25MW, so it is ignored.

Table 2 – Namibian sources of electricity

Plant/source	Energy source	Installed capacity in MW	Generation – 2010 GWh	Load factor
Ruacana	Hydro	249	1,257	58%
Van Eck	Coal	120	46	4%
Walvis Bay (Paratus)	Diesel	24	3	4%
Interconnector	Mainly coal – imports from SA and Zimbabwe	600	2,462	47%
Total		993	3,767	43%

The majority of Namibia's local electricity generation is from hydroelectric power on the Kunene River at the Ruacana Plant, which is has three 82 MW turbines, with a fourth being available in 2012. Van Eck is a small coal-fired power station near Windhoek that tends to be used for hours at a time during winter peaks, while Paratus near Walvis Bay and the soon to be built Anixas are diesel peaking plants, with extremely high levelised electricity costs due to high diesel feedstock costs as well as low capacity utilisation.

Figure 9 – The Ruacana hydro electric scheme on the Kunene River in Northern Namibia, supplied 96% of Namibia's locally generated electricity in 2010. It is being expanded by 92MW or one third.

6.1.3.1.3 Local generation expansion projects

With the Hwange contract expiring in 2013, NamPower is considering a number of expansion plans into baseload and mid-merit: Some have been considered for decades – such as Kudu, while others – such as renewables have only recently been mooted. Due to the imminent shortages, plans are in a state of flux. A summary of the key base load projects listed by the NamPower financial statements are listed below:

Kudu Natural Gas project – Kudu has been proven since 1974, but remains technically daunting:

The capital expenditure will cost $1.2 billion and the natural gas will be processed offshore, which gives NamPower little pricing power for feedstock. Other challenges include:

1. Over-capacity for current Namibian needs – an 800 MW plant has been proposed, where Namibia will use less than half on current usage trends. It is therefore dependent on Eskom for an off-take agreement, which it has failed to negotiate since 2005. Due to the imminent shortage, NamPower has desperately been negotiating with the international consortium (comprising Tullow Oil and Gazprom) for an off-take agreement.
2. Foreign currency exposure – a key sticking point on negotiations has been denomination of feedstock contracts. NamPower is reluctant to be exposed to the US$, while the development partners require repatriation of the $1.2 billion of foreign capital.
3. Development risk – only in the last ten years was the extraction of this gas technically feasible. It remains a daunting technical challenge extracting the gas 170 kilometres off the coast. The proposed subsea tie back which would potentially make it one of the world's longest, while the Kudu-8 exploration well was abandoned in 2007.

Walvis Bay Coal Power Station – a 250 MW – 500 MW power station has been proposed, but has fallen foul of environmental concerns, after NamPower failed to get its original site approved. The power station will take at least five years to plan and build, and the capital budget of $1.2 million per MW seems optimistic – this is half the cost of building in the US and ¼ of the cost per MW of South Africa's much larger projects. NamPower admits that it will be impossible to have this project ready before 2016. It is also exposed to foreign currency fluctuations as the coal needs to be imported. The expected coal price is US$80 per tonne less than half of the cost NamPower is paying for van Eck's coal.

Hydroelectric projects – these include the Baynes Hydro Power Plant (500 MW) on the Kunene River and LOHEPS – a proposed hydroelectricity scheme on the Orange River. Both have been considered for several years and face political challenges. In the view of the author, both are viable projects that will help deal with Namibia's power shortages in the future at the lowest absorbed electricity cost – when compared to all alternatives. It is unlikely these plants will be commissioned before 2018 according to NamPower.

6.1.3.2 Other Utility scale renewables projects in Namibia

The study draws on a paper by Dr Detlof von Oertzen, who has advised the author on many issues relating the Namibian grid. In theory Namibia should be an ideal location for renewables:

Solar irradiation – It is the highest solar irradiation in the world – with solar panels able to generate up to 2,000 KWh per kilowatt capacity (the UK generates 800). The largest project so far is the 200KW Tsumkwe Solar hybrid mini-grid system installed by Juwi on EU grant funding in the north of the country. NamPower partnered with the European Commission, Desert Research, Foundation of Namibia and Otjozondjupa Regional Council to implement the Tsumkwe Solar hybrid mini-grid system.

Low population density – Namibia has the second lowest population density in the world, so centralised electricity transmission systems are not financially viable in rural areas. This boosts the need for off-grid community and micro-generation systems.

Wind and wave power – It has over 1,000 kilometres of coastline which gives excellent potential to harness coastal winds. The Luderitz Wind Farm has fallen foul of NamPower on technical grounds and the Japanese funders have pulled out of the transaction. Vestas are in discussion with NamPower to use the wind project to cover 25% of the 2013 shortfall. Wave power is still in its infancy.

Geothermal – the author has come across much anecdotal evidence of warm springs and thermal seepages. The tectonic plate movements explained by experts suggests that there are a number of rift formations that will give rise to close-to-surface level geothermal resources. Unfortunately, these have never been surveyed. It is ANE's intention to use some of the corporate social responsibility funding to commission academic studies into using geothermal as a means of boosting tourism and local energy generation in several parts of Namibia.

Biomass – perhaps the most advanced, where NamPower has signed a power purchase agreement for a 250 KW generation system – C-BEND. In the view of the author, biomass has a limited role to play, due to the fact that 99% of the country is not arable. That said, there are areas in the North of the country, which have uncontrolled and damaging bio-mass growth, that could be processed in a sustainable way. Both the local consultants that ANE engaged believe in the potential for biomass to play an important role in solving the country's electricity crisis.

Waste heat – a project involving turning the methane from the waste dump in Windhoek into heat to replace the electricity a local brewery uses, is potentially an excellent small-scale project that could be repeatable. Based on an estimate by the African Development Bank, Cape Town produces about 0.7 tonnes of waste per person per year that could be turned into 500 KWh. This in theory could potentially replace 25% of Namibia's existing supply. If heat is generated and it is used directly to replace heat, 250% of the electricity originally used for the heating process can be saved. The combination of carbon credits (each tonne of methane saved is equivalent to 21 tonnes of CO_2, generating a US$300 per tonne, five times the price of electricity).

6.1.3.2.1 Government policy on renewables

The government policy around renewables needs input – something the government openly acknowledges.[12]

Areas that need addressing include:

- There is no national renewables target
- There is no renewable energy legislation
- Independent Power Producer's allowance return on capital is below the required returns of investors
- There is no feed-in-tariff for micro-generation, where renewables are cheaper than fossil fuelled grid connection costs
- Where net metering is available, it pays 40% less than the retail electricity price
- Financing of micro-generation is limited and only available to credit-worthy customers – less than 10% of the population
- There are no accelerated tax allowances outside the farming sector – in South Africa renewables can be written off over three years. Strangely, mining equipment can be written off over three years, so there is potential for mines to exploit renewables.

6.1.3.3 Electricity imports

6.1.3.3.1 Overview of the Southern African Power Pool

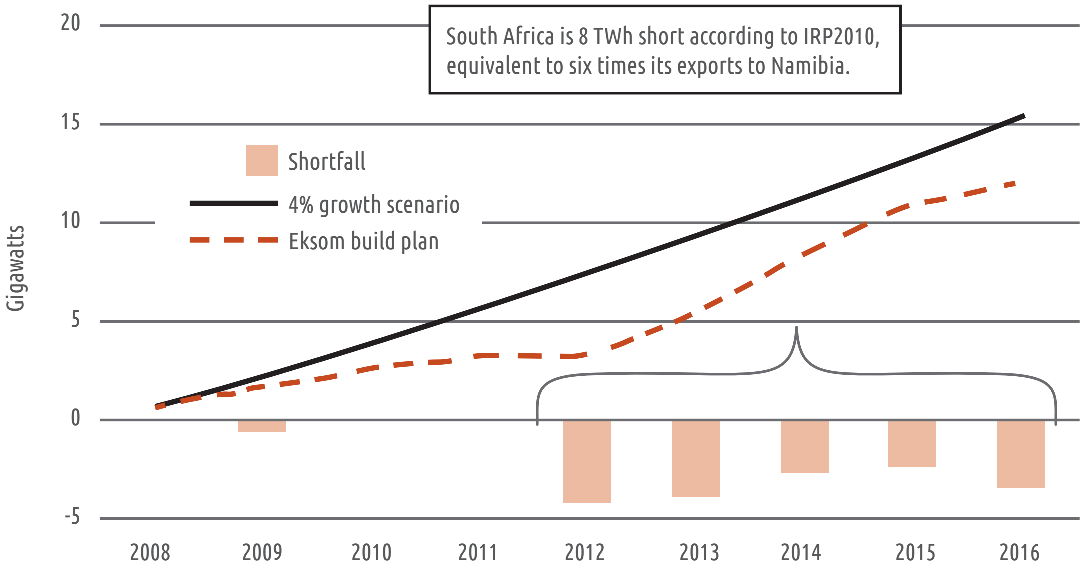
The 15 member Southern African Power Pool (SAPP) was created with the primary aim to provide reliable and economical electricity supply to the consumers of each of the SAPP members, consistent with the reasonable utilisation of natural resources and the effect on the environment. Dominated by Eskom, which produces 50% of sub-Saharan Africa's electricity, the Power Pool can claim to be successful. Perhaps the best examples of co-operation are the 1.3GW Mozal Smelter deal between South Africa and Mozambique and the Hwange deal (see below).

12. Meeting between ANE and the ECB on 16 June 2011, where ECB asked ANE to add policy suggestions to improve the investment climate for renewables

6.1.3.3.2 South Africa

A discussion on South Africa's electricity situation is a paper in its own right. As NamPower's 2014 projection involves Eskom supplying more electricity than NamPower itself, it is important to understand the South African power situation – where the prognosis is poor.

Figure 10 – Eskom's short term supply shortage – 2012 - 2016



6.1.3.3.3 Zimbabwe

Recent events suggest that NamPower has shown world-class skill in diversifying its reliance from Eskom. The award-winning Hwange deal with ZESA (Zimbabwe Electricity Supply Authority) enabled Namibia to reduce its reliance on Eskom imports 40%. Zimbabwe's economic implosion meant that it was unable to raise US$40 million urgently needed for maintenance on its Hwange Power Station. Namibia raised the capital in the form of a loan to ZESA, which repaid in kind in the form of 150 MW of capacity with no variable cost per kilowatt hour, at capacity provision price of $5.14 per kw per month. Amortising the loan against cost of sales, where 891 GWh were sold for a loan repayment of US$8.8 million means that NamPower was able to replace of 40% of its imports at an effective cost of 0.9 US cent per KWh.[13] The 150 MW delivered 891 GWh, which assuming transmission losses of 6% means that Hwange has been operating at a load factor of 73% – effectively full technical capacity. The deal started in 2008 and Zimbabwe, which is facing acute electricity shortages as its economy recovers, has indicated that this contract will not be renewed.[14] ZESA estimates that the country requires 2,000 MW of power a day but the country currently produces only 1,300 MW and imports 300 MW, leaving a shortfall of 400 MW.[15] Recent indications are that NamPower has offered 36% more to keep ZESA in the deal until its expiry in 2013.[16]

6.1.3.3.4 Other potential import sources

NamPower hopes to increase imports from Zambia and to participate in the Southern African Power Pool. ANE estimates that they can potentially source 400 GWh by 2014, as all countries face immediate capacity constraints. The Power Pool has great long-term potential – particularly on hydro-power from the proposed Inga project in the DRC, but these projects take over a decade to plan and build, so will not cover the country in its 2013 supply shortfall.

13. NamPower Annual Financial Statements 30 June 2010 – Note 9 *Loans and Other Receivables* page 94

14. Confirmed publically by the CEO of NamPower, Mr P.I. Shilamba in a presentation on the future of the wind sector on 7 November 2011

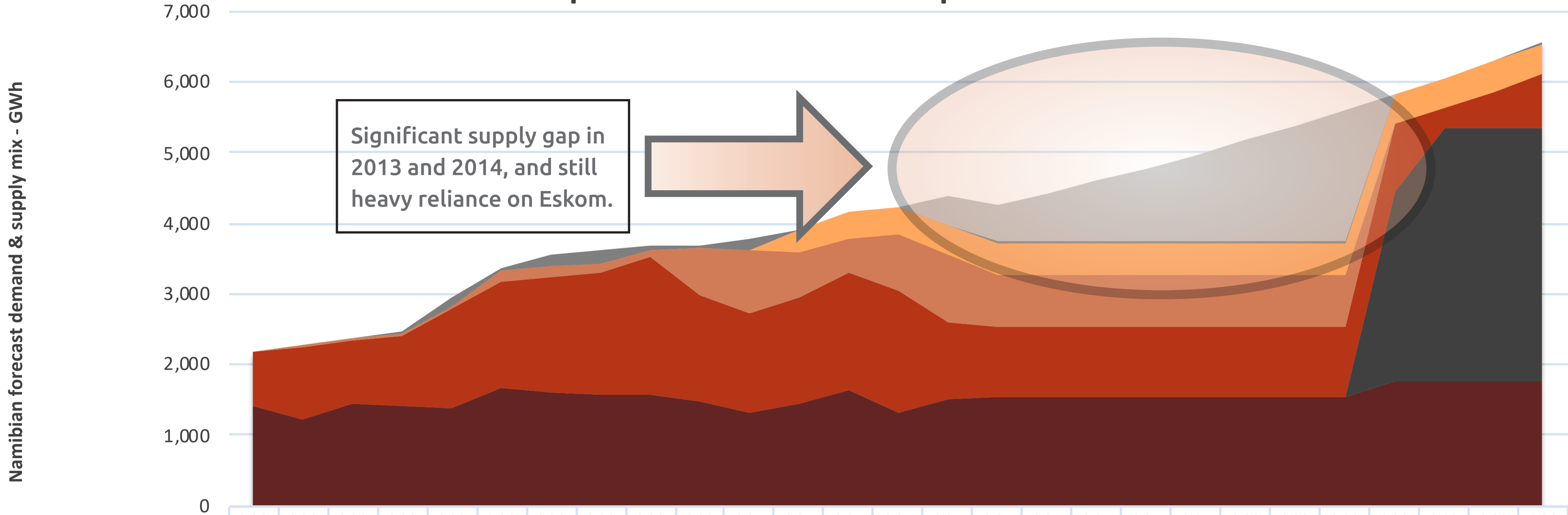
15. Source *Afrique Avenir Zimbabwe, Namibia reviewing electricity barter deal* 11 February 2011 http://www.afriqueavenir.org/en/2011/02/09/zimbabwe-namibia-reviewing-electricity-barter-deal/

16. Jo-Mare Duddy –Zim puts spark in power tariffspublished in *The Namibian* – 16 November 2011 http://www.namibian.com.na/news/full-story/archive/2011/november/article/zim-puts-spark-in-power-tariffs/

Key assumptions are:

1. The Anixas Diesel Generator Power Station will be commissioned in 2011 and will operate the same load factor as the Paratus Power Station. This gives 5% of Namibia's peaking power.
2. Van Eck Coal Fired Power Station generates 200 MWh per year – about a 15% load factor.
3. Eskom supplies at the same level as 2008 – 1,400 GWh, an optimistic assumption considering the Integrated Resource Plan of South Africa assumes a shortfall of 8,000 GWh between 2012 and 2016.
4. The Hwange deal ends in 2013 and Zimbabwe uses the 150MW currently being dispatched to Namibia to replace its own 400MW shortage.
5. The Caprivi Interconnector will enable Namibia to import 400 GWh on a 5MW capacity. The 951km 350KV HVDC lines and converter stations linking the far north-east with central Namibia was commissioned in 2010.

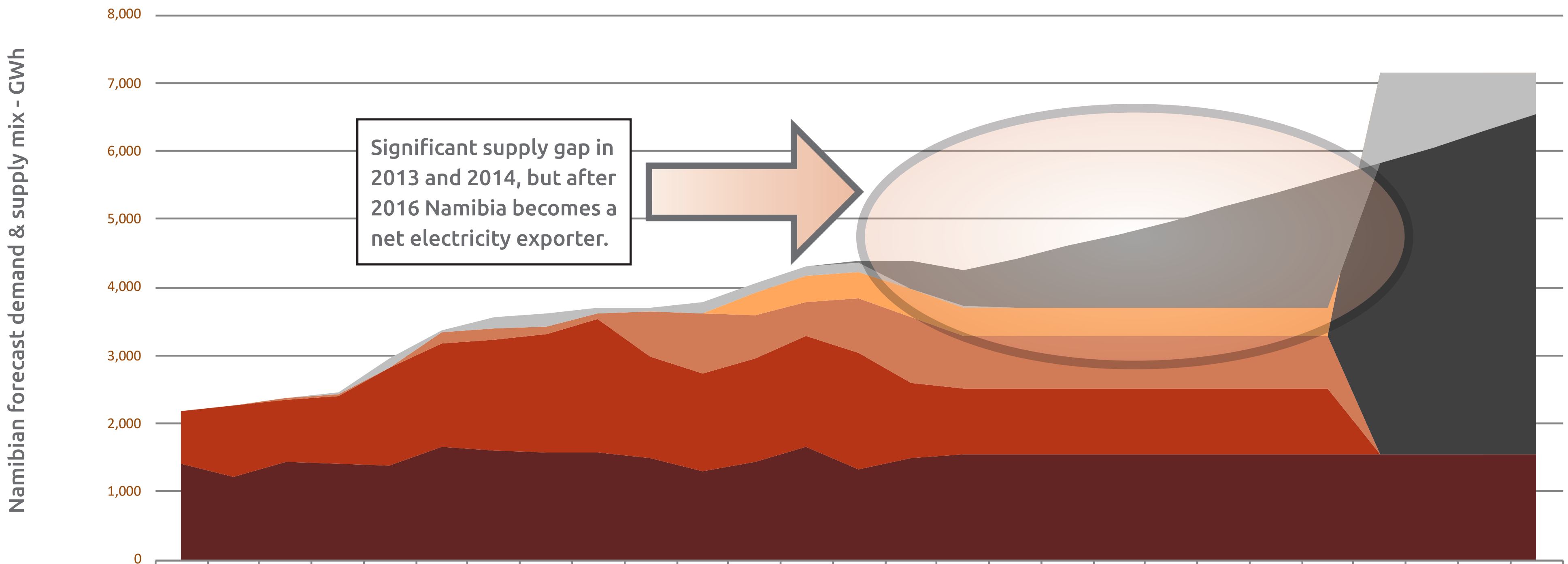
NamPower Coal-fired Scenario 2000 - 2026
700 MW coal plant with Eskom and imports



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Shortfall/Agrekko														19	413	517	687	864	1,04	1,24	1,43	1,64	1,86				
Other imports net of exports			0	36	134	31	166	208	74	53	142	2	0	0	0	35	35	35	35	35	35	35	35	(0)	(0)	(0)	(0)
Zambia												319	378	389	420	422	422	422	422	422	422	422	422	422	422	422	422
Zimbabwe	19	21	21	21	9	158	162	104	85	648	891	637	496	781	962	761	761	761	761	761	761	761	761				
South Africa	766	1,04	921	988	1,42	1,51	1,62	1,73	1,96	1,50	1,42	1,52	1,64	1,71	1,09	982	982	982	982	982	982	982	982	950	283	525	777
NamPower new build coal plant																								2,70	3,60	3,60	3,60
NamPower existing plants	1,40	1,21	1,42	1,42	1,37	1,66	1,60	1,57	1,57	1,49	1,30	1,43	1,64	1,33	1,49	1,53	1,53	1,53	1,53	1,53	1,53	1,53	1,53	1,75	1,75	1,75	1,75

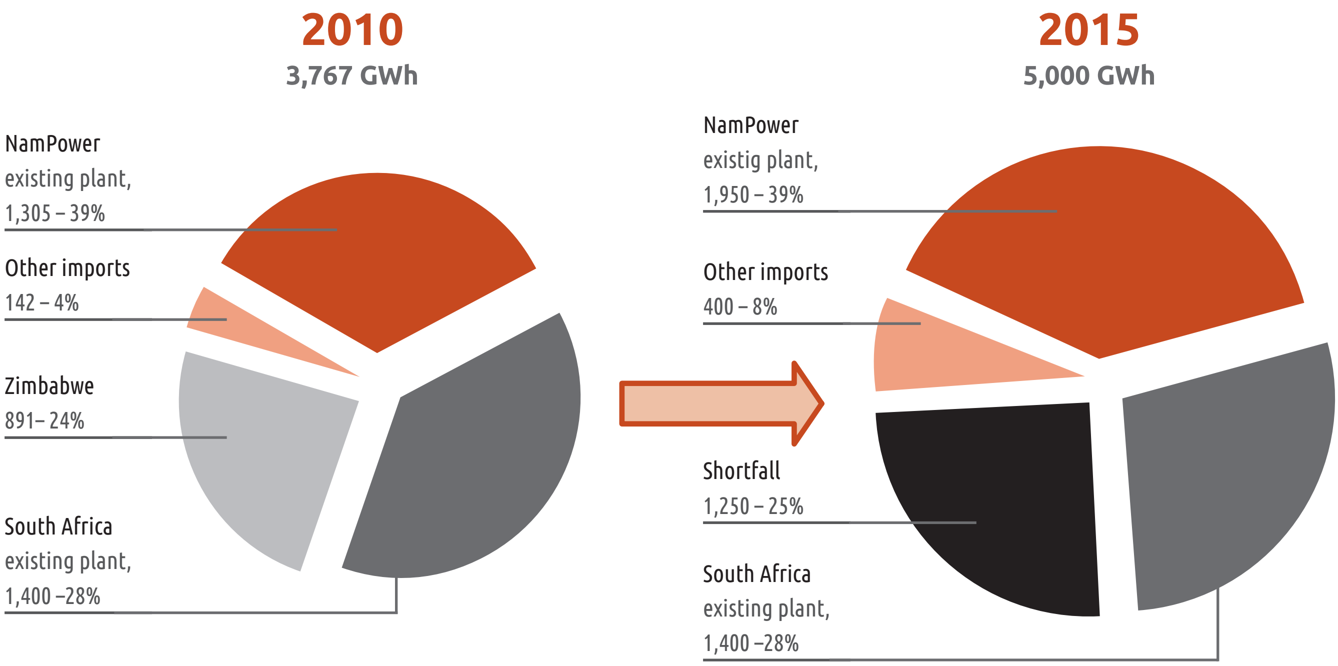
NamPower Kudu Gas Scenario 2000 - 2026

300 MW coal plant with Eskom and imports



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Agrekko												0	0	19	413	517	722	899	1,083	1,275	1,474	1,681	1,896				
Other imports net of exports			0	36	134	31	166	208	74	53	142	150	150	150	0	35	0	0	0	0	0	0	0	(1,322	(1,089	(846)	(595)
Zambia												319	378	389	420	422	422	422	422	422	422	422	422				
Kudu gas																								5,606	5,606	5,606	5,606
Zimbabwe	19	21	21	21	9	158	162	104	85	648	891	637	496	781	962	761	761	761	761	761	761	761	761				
South Africa	766	1,045	921	988	1,423	1,514	1,620	1,733	1,961	1,501	1,429	1,522	1,645	1,718	1,091	982	982	982	982	982	982	982	982	0	0	0	0
NamPower existing plants	1,407	1,211	1,429	1,421	1,379	1,660	1,606	1,576	1,572	1,490	1,305	1,430	1,643	1,331	1,498	1,537	1,537	1,537	1,537	1,537	1,537	1,537	1,537	1,537	1,537	1,537	1,537

Figure 13 – electricity supply shortages - 2010 - 2015

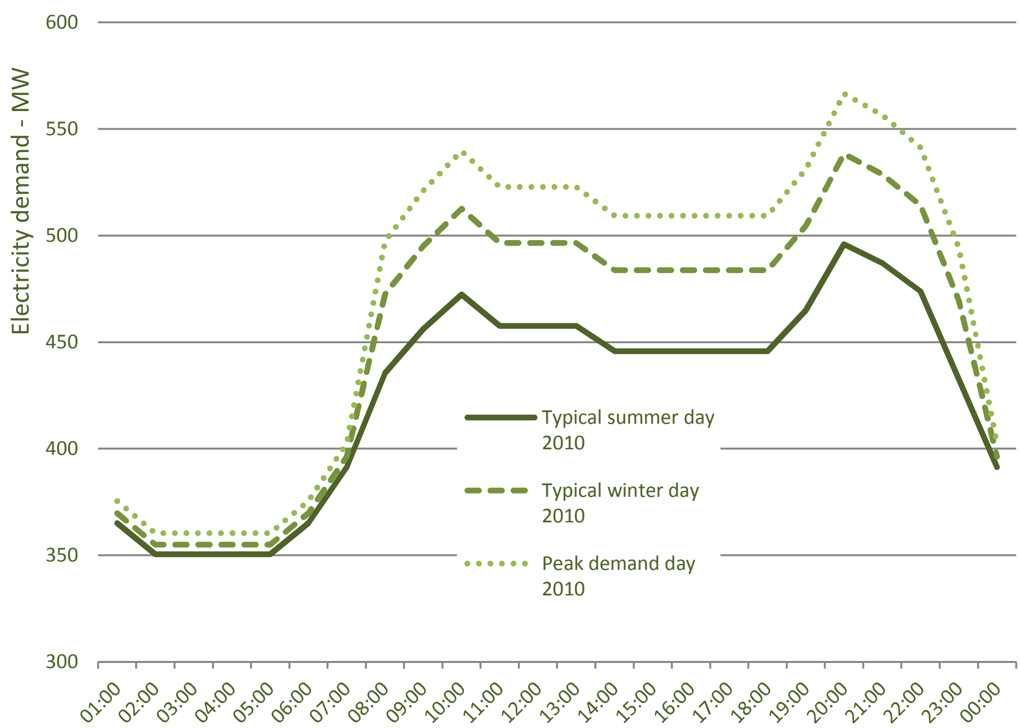


6.1.5 Time of Use[17]

Electricity pricing varies greatly depending on when it is used, with residential customers causing morning and evening peaks. Namibia's residential market does not have access to natural gas, so uses electricity for heating of water and environment, greatly increasing winter demand. Indeed the peak winter demand of 568 MW in 2010 was 20% higher than that of a typical summer's day.

6.1.5.1Time of Use model

Figure 14 – Namibian Electricity Demand – Daily Time of Use



17. The Namibian Time of Use Model is not based on actual numbers, which are not publically available, but an extrapolation based on other countries' seasonal patterns. The model is explained in detail in Addendum B

Figure 15 – Weekly peak to average demand ratio, Nambia 2010
Smoothed model - Namibian grid - 2010

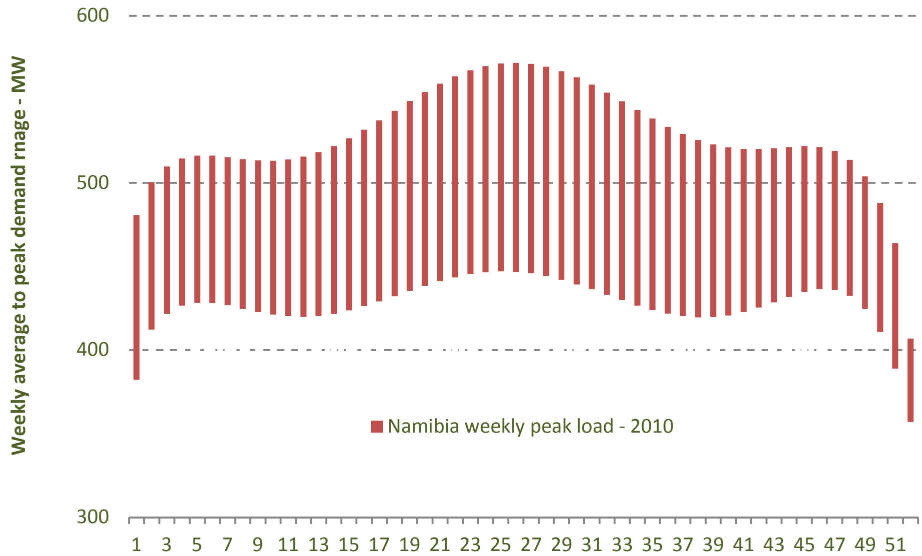


Figure 15 shows that there is significant seasonal variation with peak demand in winter (May – August), as household and commercial heating demand increases.

Important for electricity cost analysis is what is called "8760 Analysis", where the hourly demand for each hour in the year is sorted from highest to lowest. The name 8760 is derived from the fact that there are 8,760 hours in a year based on 24 hours per day 365 days per year. The hour of peak demand is likely to be in a cold winter evening, when baths are running, food is being cooked and heating is on in houses. The time of lowest demand is Christmas Day, when mining activity has largely stopped, no commercial businesses are open and there is no need for heating. As Namibia gets wealthier, this profile will change – in hot, high-income regions such as Spain and Atlanta, the peak demand is driven by air-conditioning to keep homes and buildings cool in the middle of hot, summer days. It is no accident that Solar PV has been adopted in these countries.

The graph below shows Namibia's 8,760 Analysis for 2010, based on ANE's model.

Figure 16 – Namibia, "8760" Grid Load Factor Analysis
South Africa – 2010 vs. Namibia – 2010

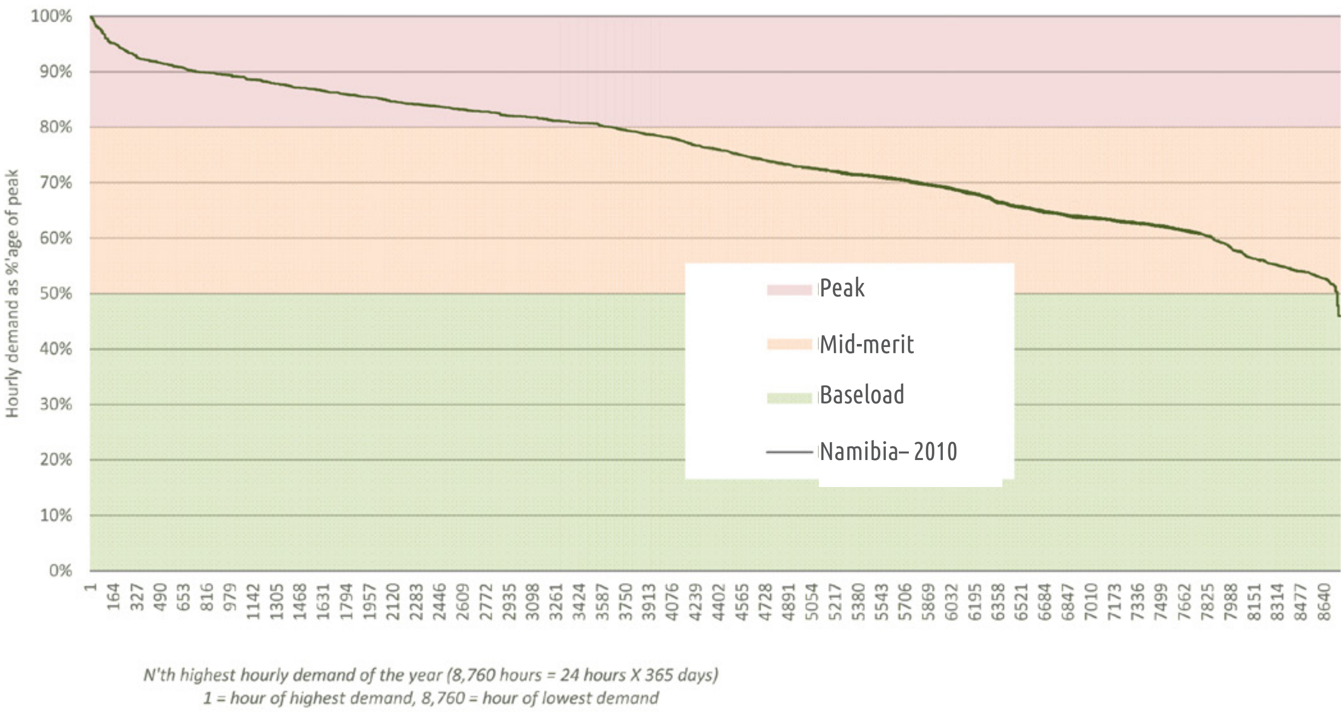


Figure 17 – Namibian demand distribution by hour – 10 MW increments

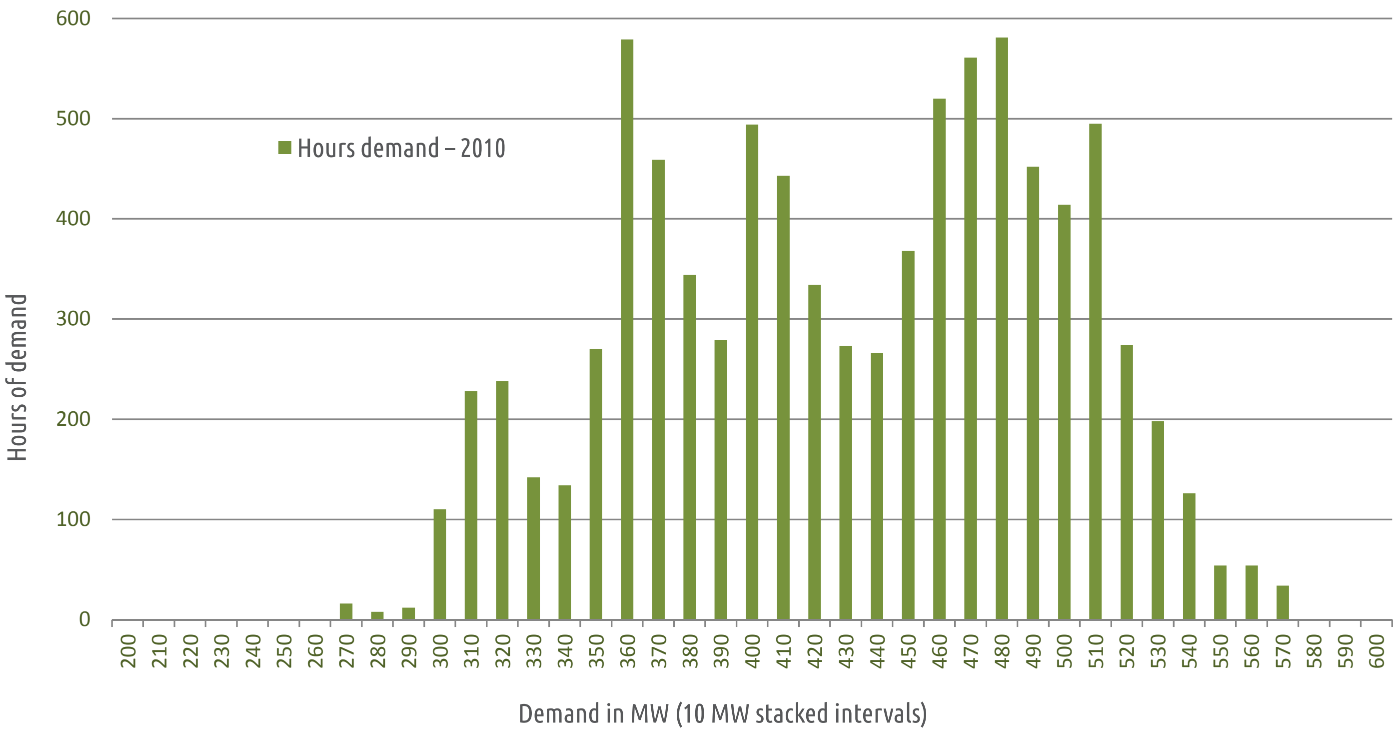


Figure 18 – Weekly mid-merit and peak demand range

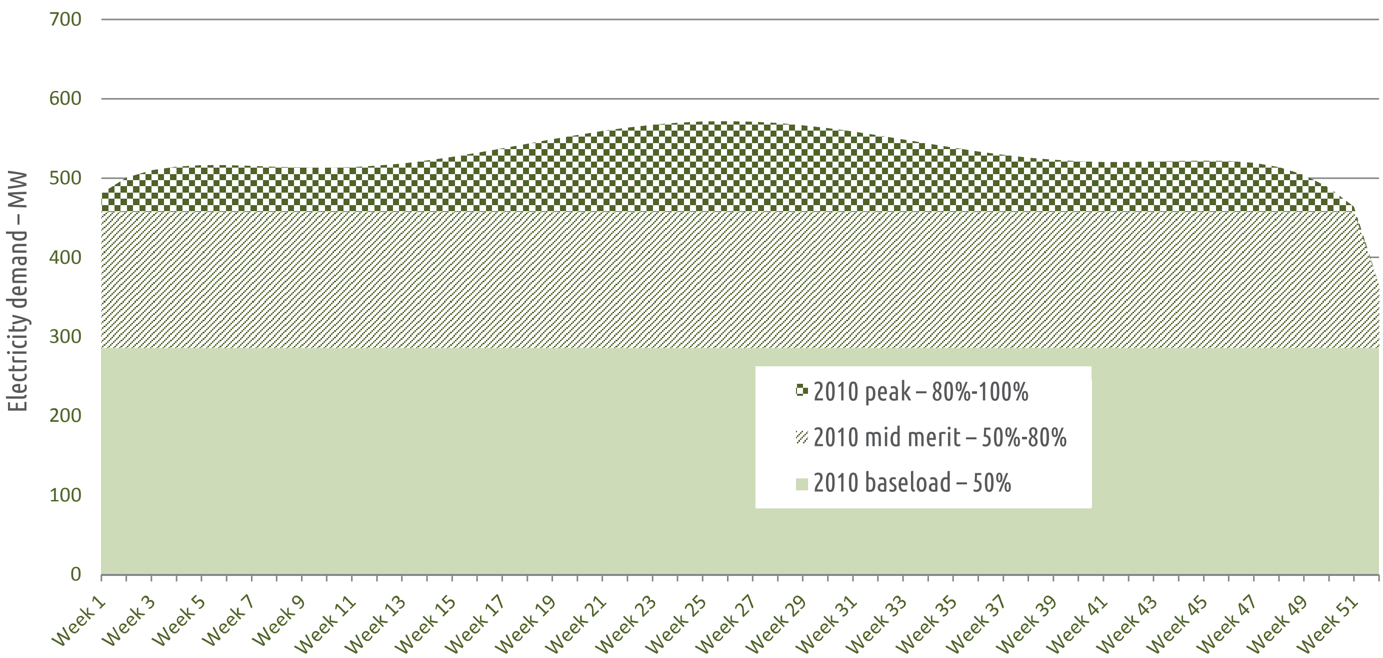


Figure 19 – Namibian grid demand calendar clock 2010
Smoothed estimate based on 2010 actuals

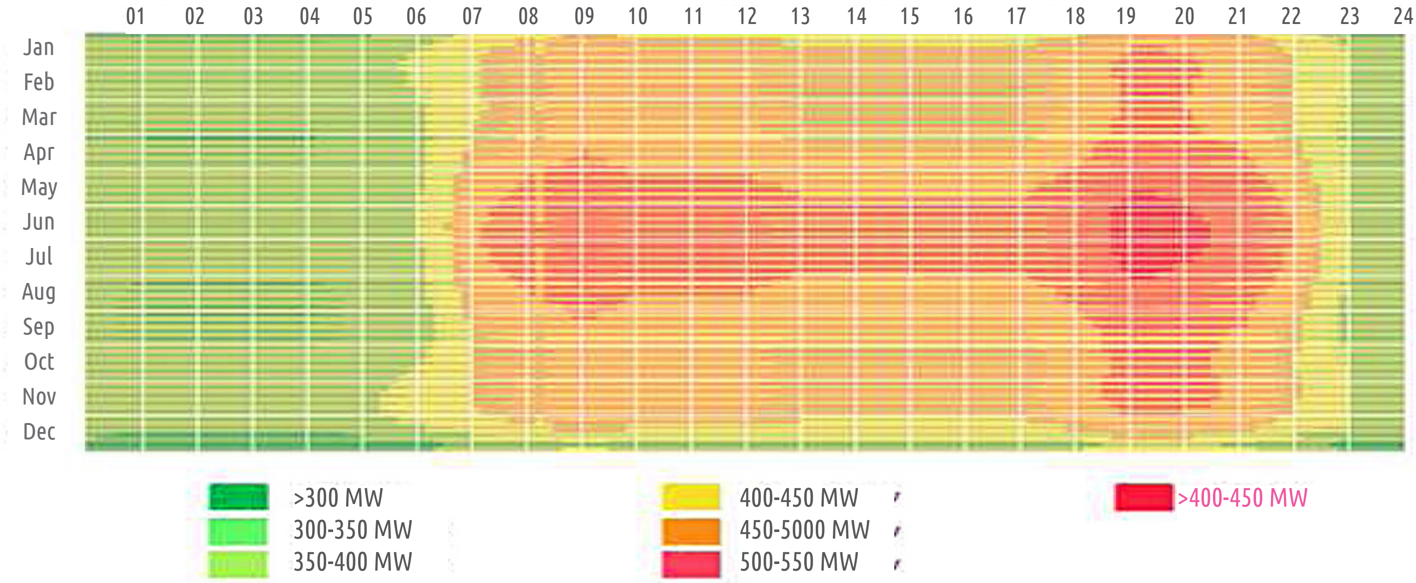
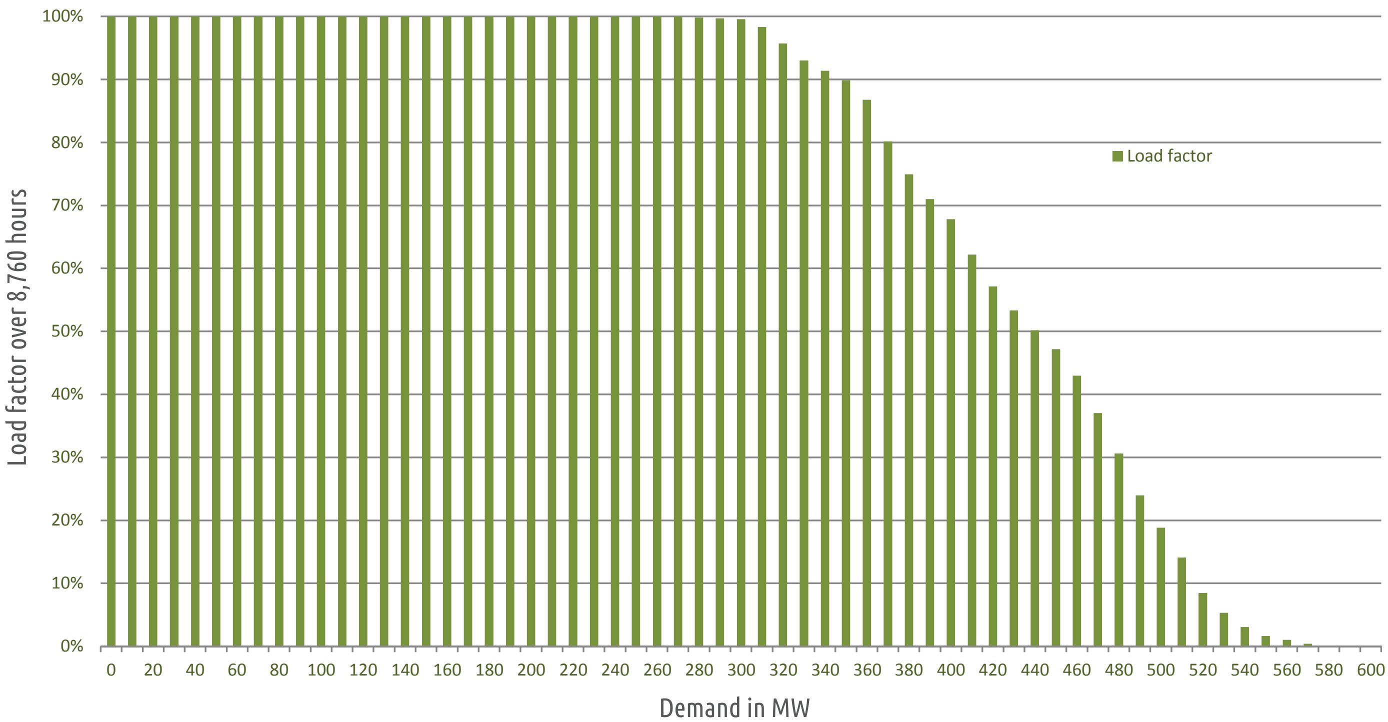


Figure 20 Namibia incremental load utilisation



6.1.5.2 The effect of utilisation on cost of supply

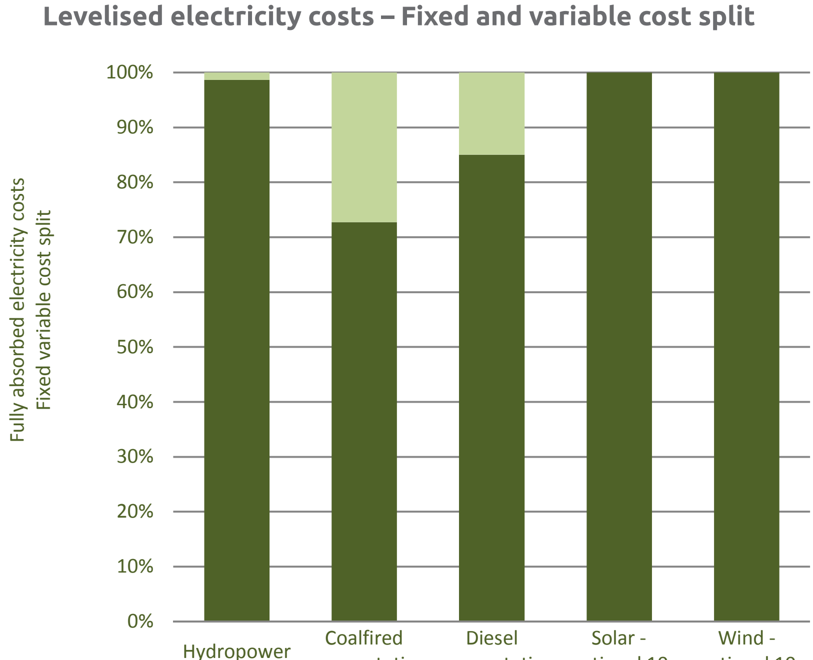
Figure 21 – Load capacity of different feedstocks in Namibia

Technology	Capacity in MW – 2010	Volume in GWh – 2010	Utilisation
Hydropower - Ruacana	249	1,247	57%
Coalfired powerstation – Van Eck	120	55	5%
Diesel powerstation – Paratus	24	3	1%
Solar - notional 10 MW	10	16	18%
Wind - notional 10 MW	10	28	32%

Winter peak demand is particularly expensive, as capacity needs to be available for the whole year, but can be used as few as a few hours per year as is the case with the Paratus power station, which is in full use equivalent – effectively less than 80 hours per year.

The reason for this is that the much of electricity costs are fixed overheads, see below:

Figure 22 – Load capacity of different feedstocks in Namibia



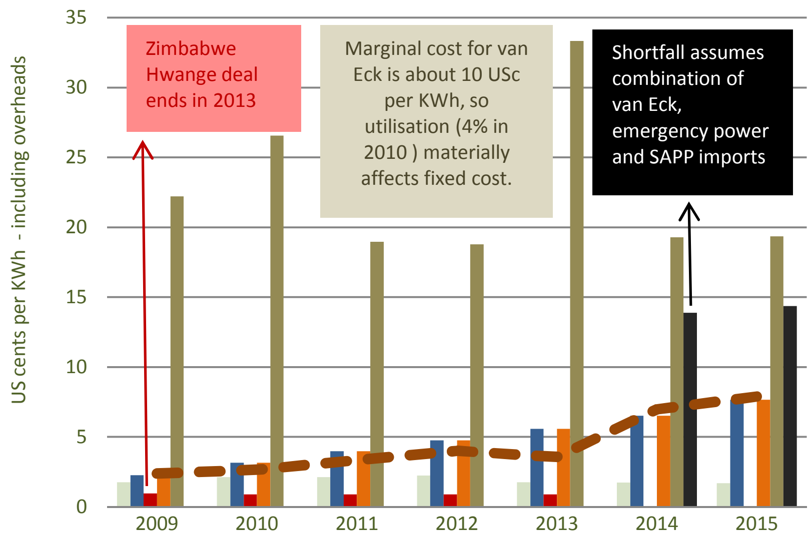
	Hydropower - Ruacana	Coalfired powerstation - Van Eck	Diesel powerstation - Paratus	Solar - notional 10 MW	Wind - notional 10 MW
Variable cost - Usc per KWh	0.0	13.9	22.9	0.0	0.0
Fixed cost - Usc per KWh	2.1	37.2	130.4	18.7	11.8

6.2. Pricing

6.2.1 Modelling generation cost recovery – nature of commercial contracts

NamPower faces significant inflation – 25% per year in its purchases from Eskom and this will continue for the next two years. Establishing pricing information is not an exact exercise as much pricing data is not published, and in the pricing model certain assumptions have been made and dated information in some cases has been used. The model has been cross referenced with totals, Eskom pricing models and input from the local consultants ANE has engaged for the project. Generally, ANE estimates lower prices than NamPower has indicated to the consultants, and has exercised prudence in deriving its target price from its own model:

Figure 23 – NamPower cost of electricity from key sources, estimated for years ended 30 June 2009 – 2015



	2009	2010	2011	2012	2013	2014	2015
Ruacana - hydro	1.8	2.1	2.1	2.3	1.8	1.7	1.7
South Africa - Eskom	2.3	3.1	4.0	4.8	5.6	6.5	7.7
Zimbabwe - ZESA	1.0	0.9	0.9	0.9	0.9		
Other imports	2.3	3.1	4.0	4.8	5.6	6.5	7.7
Van Eck - coal	22.2	26.6	19.0	18.8	33.3	19.3	19.4
Shortfall						13.9	14.4
Weighted average	2.4	2.6	3.3	4.0	3.6	7.0	7.9

As it is assumed that NamPower will be the only viable off-taker at a utility-scale, the unit price acceptable to NamPower is the most important input to the entire model.

A more detailed explanation of the workings within the model is described in addendum A3.

6.2.2 The role of the Electricity Control Board in pricing

Namibian electricity prices are regulated by the Electricity Control Board and they indicated in several meetings with ANE that their first concern was to ensure that no proposal increased inflation for the end consumer, who already faces electricity increases of 25% per year in line with the Eskom increases that NamPower faces. The ECB has faced increasingly hostile audiences in explaining electricity price rises, as regional electricity distributors struggle to pay electricity prices. In Erongo, according to the Namibian newspaper, essential services are being trimmed due to the high levels of arrear payments on electricity bills – estimated in the article at 55%.

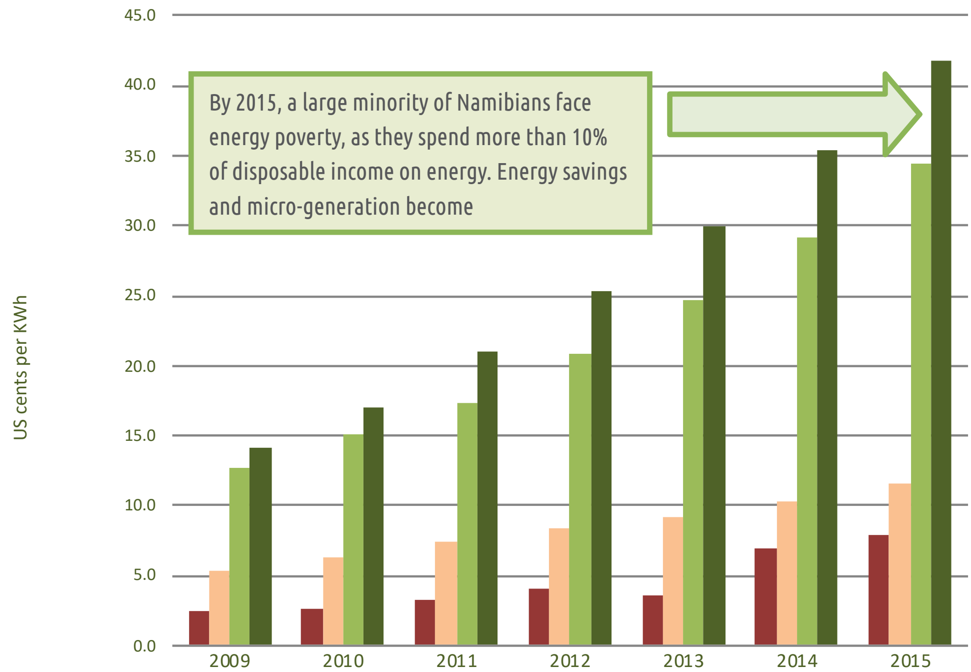
These tensions highlight the acutely political nature of any independent power purchase agreement in the current Namibian energy climate.

6.2.3 Wholesale electricity pricing distribution

6.2.3.1 Regional electricity distributor pricing

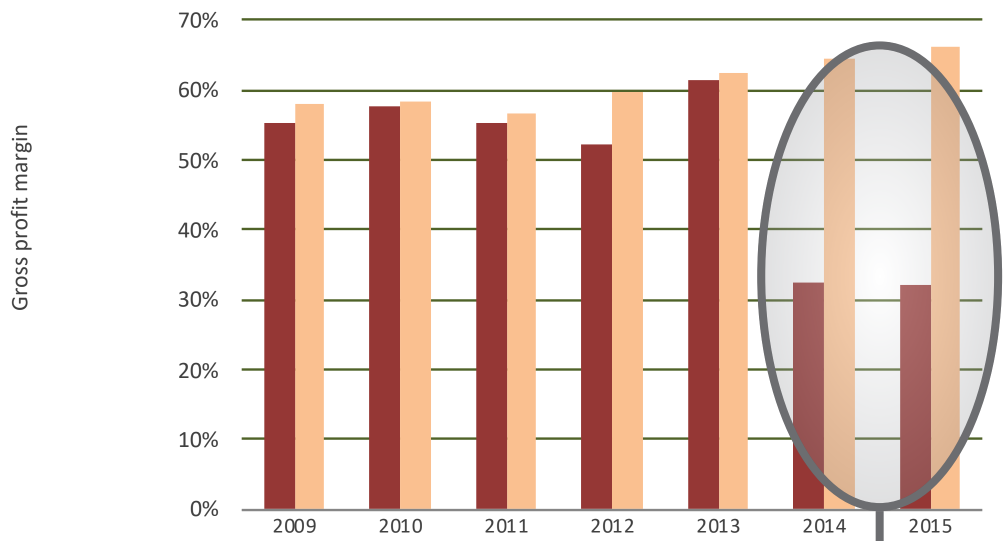
NamPower distributes power to regional electricity distributors (REDs), who in turn distribute electricity to end users. The REDs are facing cashflow pressures from arrears payments and are increasingly concerned about increased prices, as they are sandwiched between NamPower and customers who cannot afford to pay.

Table 3 – Difference in value between generation, wholesale and retail accounts



	2009	2010	2011	2012	2013	2014	2015
Generation - Nampower	2.4	2.6	3.3	4.0	3.6	7.0	7.9
Wholesale - REDs	5.3	6.3	7.5	8.4	9.2	10.3	11.6
Retail - account	12.7	15.0	17.3	20.9	24.7	29.1	34.4
Retail - prepayment	14.2	17.0	21.0	25.4	30.0	35.4	41.8

Table 4 NamPower and RED gross profit margins



	2009	2010	2011	2012	2013	2014	2015
NamPower gross profit margin	55%	58%	55%	52%	61%	33%	32%
RED retail gross profit margin	58%	58%	57%	60%	63%	65%	66%

By 2014, the annual 25% electricity increases will not be enough to cover NamPower's cost increases and its gross profit margin will halve. The REDs will need to maintain high gross profit margins to cover bad debts.

The electricity inflation numbers look like the regional electricity distributors will be the largest beneficiary of the electricity inflation, but they are not. Bad debts are becoming rampant, and the RED's are depending on a smaller core of wealthier property owners to pay for electricity. Increasing numbers are being forced onto pre-paid electricity, which is more expensive than electricity on account.

6.2.4 Extending access to rural and peri-urban areas

Rural off-grid economics represent an impossible challenge for conventional grid transmission. Just 2.5 million people live in a country that has an area of 825,000 square kilometres. As about 50% live in urban or peri-urban areas, off-grid solutions that involve micro-generation renewables are the only practical way of solving this problem, but the cost is currently prohibitive and the beneficiaries cannot afford to pay. Some 40% of Namibians live on less than $1.25 per day.[18] These people will need to be assisted on a carbon funded or grant basis as they are generally not involved in the cash economy.

Peri-urban dwellers represent a different challenge, they are also poor, but are generally involved to some extent with the formal economy. However their informal dwellings are not permanent and will never be suitable for on-grid electrification. Only formal housing will get them onto the grid – and formal housing is outside the scope of this report.

6.2.5 Constraints faced by a utility-scale independent power producer in Namibia

NamPower indicated to the author that they welcomed independent power producers (APPs), especially in the area of renewables, but did indicate that any power purchase agreement was to be signed with them, rather than directly with a RED or large mine. Any SAPP trading would also involve NamPower, as all transmission lines connecting to neighbouring countries are owned by the utility.

NamPower's solid financial position and track record of conservative, technical competence will have an important bearing on the solution ANE proposes:

- State-owned utilities are conservative by nature – they are only noticed when things go wrong, so tend to be careful. In NamPower's case, the legacy of a profitable, cash-rich business means that management have a number of alternatives and are not desperate.
- Its strong balance sheet means that it is able to finance – at a lower cost of capital than independent power producers – generation infrastructure.
- NamPower is extremely concerned about independent power producers' intermittent renewable energy supply disrupting the grid, so will demand storage and intermittency management.
- Its skill at trading on the Southern African Power Pool, gives it confidence to seek to repeat the Hwange deal – especially with the transmission investment connecting Namibia to Zambia via the Caprivi Strip, meaning that a local power producer will need to offer better value, predictable supply and speed of deployment to beat the alternatives.

6.2.5.1 Pricing and financial constraints

6.2.5.1.1 Pricing constraints likely to be imposed by NamPower

NamPower will not pay an independent producer more than it is currently paying for its highest price imports. Its local production from fossil fuels is also inexpensive, while the costs of its hydro-electric power are marginal, as there are no ownership costs to recover. ANE estimates from the pricing analysis above that price maximum NamPower can afford is 7.5 US cents per KWh in 2014, the same price that they are estimated to pay for Kudu.

6.2.5.1.2 Returns on capital constraints set by the ECB

The ECB made it clear as did the Department of Mineral and Energy Affairs that they were concerned about energy security and strongly welcomed the investment that ANE proposes. From the two meetings with the board of the ECB it seemed that applying for a provision generation license would be straightforward and the costs of the application immaterial – US$100. However, their rule that capital recovery should enable a maximum return of 11% is higher than NamPower's which is backed by a sovereign guarantee, but lower than that of an independent power producer. The rate of return in local currency is estimated at over 25%. ANE uses a subsidy system to subsidise solar to overcome this problem.

6.2.5.1.3 Foreign exchange risks

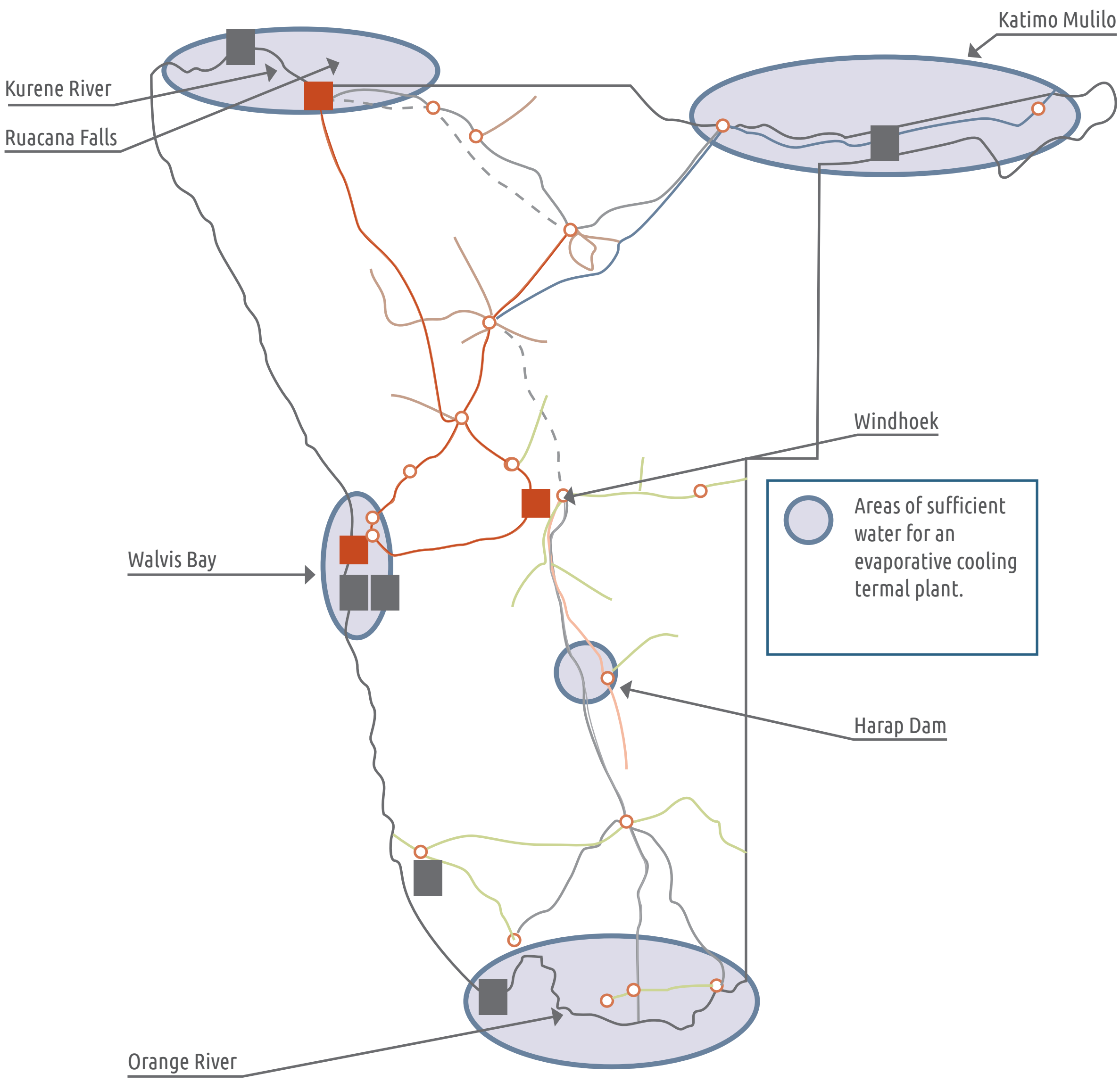
18 Source CIA Factbook – reinforcing the high Gini co-efficient

Foreign exchange risks have made the Kudu Gas deal impossible for international capital providers to back. The Namibian Dollar is linked to the South African Rand, so a forward market will be able to be accessed. Discussions with local banks suggest that they will only offer forward cover for five years, which is not enough time to recover debt or equity in most cases.

- Kunene River in the far North
- Orange River in the far South
- Hardap Dam near Mariental

6.2.5.2 Transmission and water constraints

Figure 24 – Transmission infrastructure



Namibia is mainly desert, where water is scarce. Certain technologies use water – for instance Concentrated Solar Power Parabolic Trough systems uses 3.6 litres per kilowatt hour – three times that of coal. A 300 MW plant will use 6,000 cubic meters of water per day – the same as a medium-sized mining operation. This restricts the location of a CSP plant to the Kunene River, Orange River and Hardap Dam. Sea water cooling could be a possible solution, while evaporative cooling systems reduce performance by up to 20%.

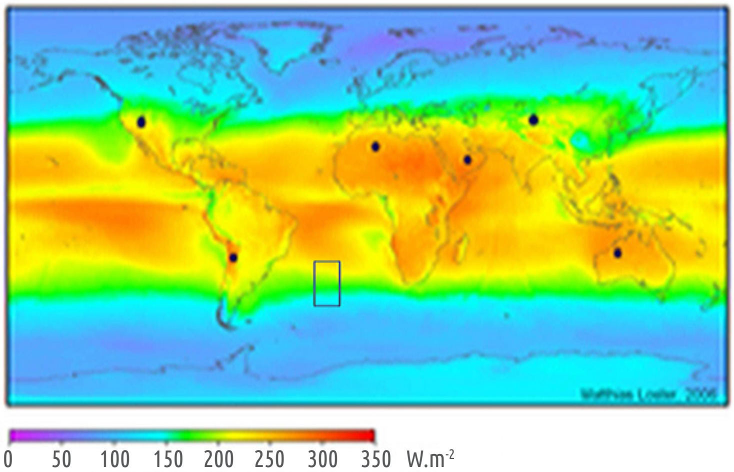
7. Potential for solar in Namibia

Namibia has the highest levels of solar irradiation in the world and unusually a dry winter, with excellent irradiation during peak demand months.

7.1.1 Namibia's solar resource

The world has more than enough solar energy to replace all energy industries with a fraction of the sunlight that reaches the earth. Nowhere is this more the case than in Namibia, see below:

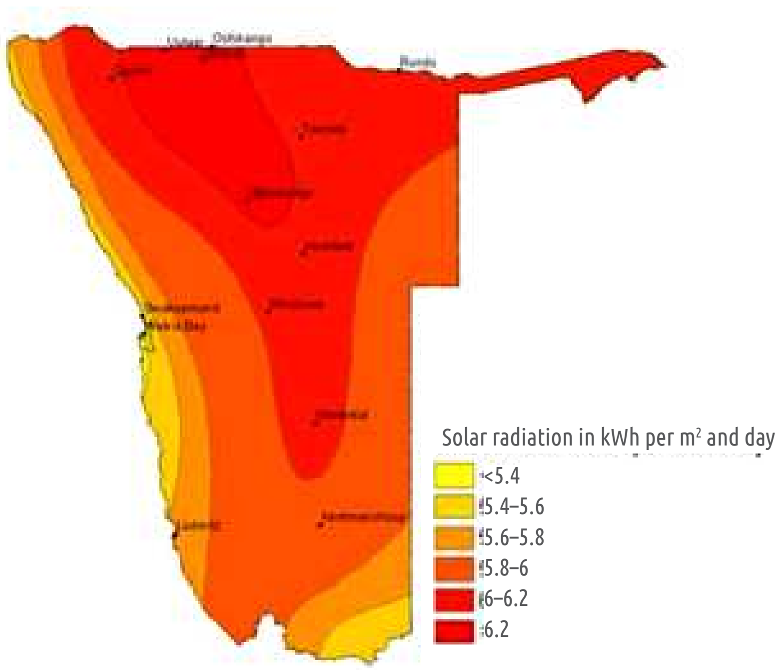
Figure 25 – Global horizontal irradiation levels



The small black circles above show the area it would take to replace all the world's energy sources and substitute them with solar. It represents a circle with a diameter of about 1,000 kilometres.

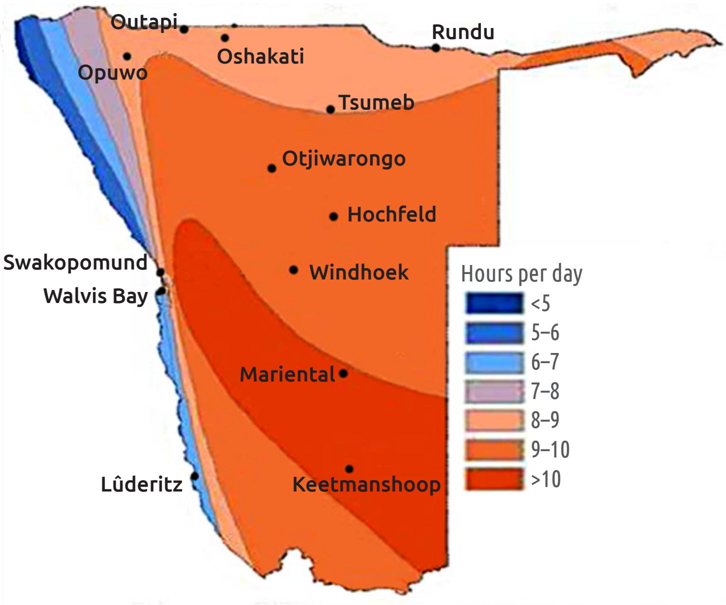
The map below shows the amount of sunshine that reaches a flat surface in various areas in Namibia. Due to fog, coastal areas perform slightly worse than the rest of the country. This type of sunshine is called global horizontal irradiation (GHI) and is measured in KWh per square meter per day. This includes diffuse irradiation – i.e. light that has been dissipated by the clouds as well as sunshine that reaches the ground without any interference through the atmosphere. This is the measurement needed for photovoltaic panels, which can convert all forms of sunlight into electricity.

Figure 26 – Namibian global horizontal Irradiation per day



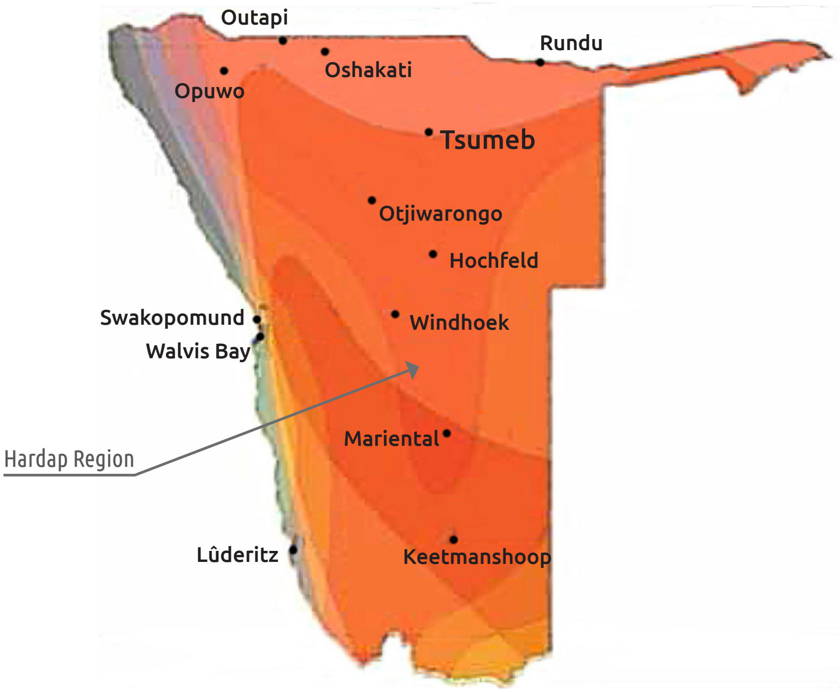
Concentrated solar power (see section below for technology description) on the other hand can only access beam irradiation, which is perpendicular to the surface of the solar collector. This type of sunlight is called direct normal irradiation and is much more sensitive to cloud cover, hence the dramatically lower readings towards the coast. The levels in Southern Namibia are the highest out of over 40,000 readings in Africa, according to the SWERA report.

Figure 27 – Direct normal irradiation isolevels in Namibia



Superimposing both images gives the following map which shows that all non-coastal areas are good and the best are in the centre of the country in the Hardap region.

Figure 28 – Superimposed global horizontal irradiation and direct normal irradiation isolevels in Namibia



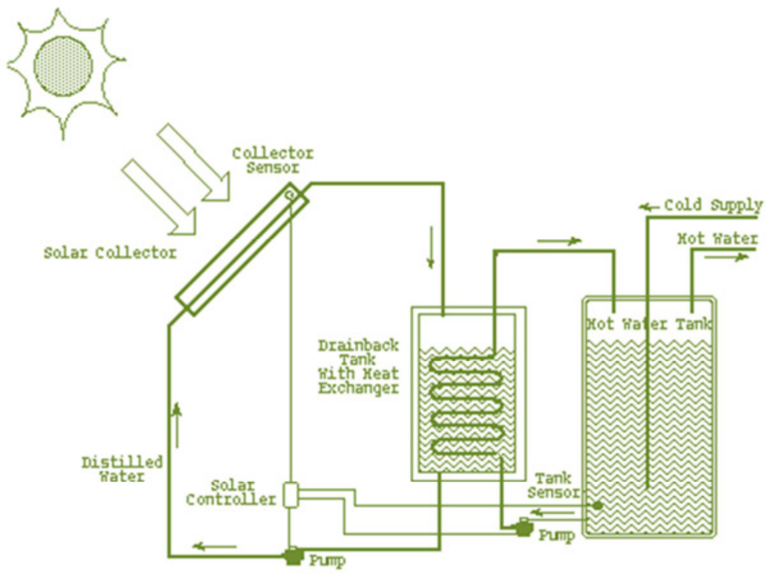
7.1.2 Different technology options evaluated to harness the solar resource

Solar energy can be converted into electricity – photovoltaic process or into heat for industrial processes, desalination, heating of domestic water or as thermal input for a solar plant – solar thermal, and can be as small as a few watts on an informal settlement or household to a multi-billion dollar solar plant supplying the national grid – utility-scale power. The section below describes the key technologies ANE evaluated in this study:

7.1.2.1 Micro-generation technologies

7.1.2.1.1 Solar water heating and low cost residential energy saving

Figure 29 – Diagram of a domestic solar water heater



Solar Water heating has the potential to replace one-third of residential consumption and at key times during the morning and evening demand peaks. Because Namibia faces a dry winter, the country is usually lucky with respect to this technology's ability to deal with the winter high demand season, where solar water heating if specified with sufficient capacity can provide electricity all year round. When combined with obvious and low-cost energy saving interventions such as better insulation, light emitting diodes and voltage management, most households will reduce their electricity demand by over 50%, without any behaviour changes – all at a levelised cost of less than 1/3rd of the current retail price of electricity.

Currently the government has a small revolving fund that has strict credit criteria to finance installation of solar water heaters, and it is estimated that less than 1,000 have been installed out of 80,000 houses with electricity and municipal water.

Criterion	Description	Significance
Able to supply during peak demand times	Yes, with heating of water acts as lowest cost solar storage available	Extremely valuable to utility and grid operator
Can manage intermittency	Yes, energy stored in the form of higher water temperature	High
Build time	1 day	High
Sensitive to high outside temperatures	No	Medium, but depends on location
System complexity	Low	High
Roof area needed	4 square meters for middle income house (200 litre) and 2 square meters for small house.	High. Smaller houses lack roof space and this is the most efficient use of roof space available
Local employment opportunities	Good, requires 4 man-days of semi-skilled, easily trainable employment	Medium importance – is an excellent project for Youth Services Commission, which has a plumbing programme.
Solar conversion	>50%	See comment on roof area needed
Levelised cost per watt – current – based on large order	5 USc per KWh	Less than one third of the current retail cost of electricity
Estimated levelised cost in 2020	Similar to current price – no real deflation forecast	Already inexpensive, so will increase competitiveness
Insurance risks	Low risk of theft, maintenance can be covered by carbon credits	Important if a private financing solution is to be put in place

Figure 30 – Solar Water Heater

Figure 31 – Solar Panels installed on a roof of a house

7.1.2.1.2 On-grid residential photovoltaic panels

Solar PV is the most high-profile solar technology and should be considered only once solar water heating and energy saving interventions has been installed, as it is considerably more expensive and less efficient. There is also not yet a suitable battery storage solution. However as solar PV costs are decreasing fast, within ten years it will become the cheapest alternative available, if low-cost finance is available, so will form a vital part of any national long term micro-generation strategy.

Criterion	Description	Significance
Able to supply during peak demand times	Not unless battery is included, which is expensive and/or inefficient	Household use is small during the day relative to morning and evening peaks, and net-metering tariffs are lower than retail prices, where they exist in Namibia.
Can manage intermittency	No – see above	Grid will be able to cope with smaller volumes, but as volumes growth,
Build time	2-3 days on residential system	High
Sensitive to high outside temperatures	Yes, performance will reduce by 12% at 40 degrees on a typical polysilicon panel	Medium, but depends on location
System complexity	Low	High
Roof area needed	4 square meters for middle income house (200 litre) and 2 square meters for small house.	High. Smaller houses lack roof space and this is the most efficient use of roof space available
Local employment opportunities	Good, requires 4 man-days of semi-skilled, easily trainable employment	Medium importance – is an excellent project for Youth Services Commission, which has a plumbing programme.
Solar conversion	20%	Port conversion compared to solar water heating, so needs relatively more roof space.
Levelised cost per watt – current – based on large order	20 USc per KWh without storage and 40 cents with storage	About double the cost of retail electricity, will catch up in five years based on 8% deflation in the industry and 15% retail inflation of electricity prices.
Estimated levelised cost in 2020	Deflation has been 50% since 2008	Will be cheaper than retail within five years – including storage
Insurance risks	High risk of theft without technology intervention.	Can only be installed in residences with heavy security, as not yet suitable as a low-income electricity access strategy, until anti-theft proofing.

Issues with batteries

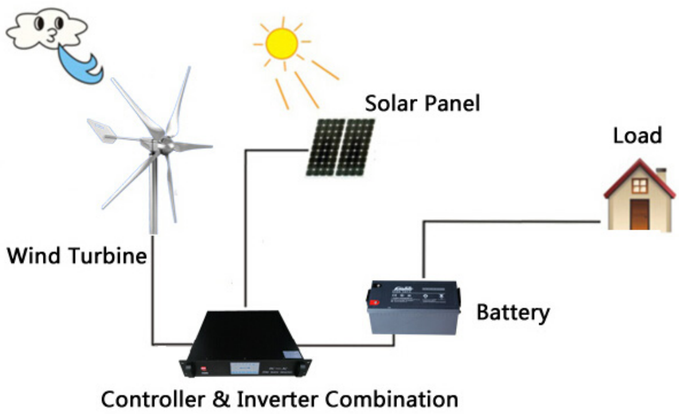
It is often said that two things matter in batteries – cost and life – but the user can only have one. Traditional lead-acid batteries have changed little since the 19th century, are cheap, do not have long lives – about 1,000 cycles, if they are run down to 75%. The round-trip losses are significant and can be as high as 1/3rd of electricity generated. This means that the cost of electricity from a small battery is 20 USc on top of the cost of producing it, or obtaining it from the grid.

Battery technology will be changed fundamentally by the car industry which requires a light, low-cost 100% drawdown battery that can survive 5,000 cycles. The Nissan Leaf has a battery life of 24 KWh hours – enough to run a medium-sized household for two days – while Tesla's lithium ion battery has a 70 KWh battery, easily enough electricity to run a small house for a week.

Once car batteries become commonplace, the solar storage problem will be solved and will in the view of the author make solar PV the dominant source of electricity. This is unlikely to happen in the next ten years, but is likely to happen within the next twenty. Other smaller battery technologies are receiving venture capital and academic resources, where nanotechnology holds particular promise. It is quite possible that a disruptive battery storage technology will emerge, fundamentally rewriting the economics of microgeneration and storage. Outside the scope of this document, ANE is creating a UK tax-funded investment plan to overcome the financial constraints of smaller batteries.

As stated earlier, Namibia has the second lowest population density in the world – after Mongolia – with just 2.5 million people living on 825,000 square kilometres. This means that extending grid access to the remaining two-thirds of the population will be financially prohibitive, as multi-million dollar grid investment to connect clusters of rural dwellings cannot be recovered by fully absorbed tariffs. To give access to this section of the population, off-grid hybrid systems will become important.

Figure 32 – Off-grid hybrid system that includes solar panels, 5KW wind turbines as well as a battery system and back-up diesel generator. The second picture is of a mobile phone tower: Mobile phone towers have boosted the market for off-grid power solutions as operators attempt to reduce the $4 billion they pay for diesel to generate the electricity needed to run the towers



These systems already make economic sense in remote social infrastructure such as schools and clinics, which need electricity and have no prospect of getting grid access. Currently many of these remote installations are running on diesel, which is more expensive than running on solar and wind, even with the battery storage. Diesel can cost up to $1.00 per litre in remote rural areas, and smaller diesel pumps can consume 400 ml per KWh (as opposed to utility-scale thermal power plants, where 200 ml per KWh is expected), which makes the diesel cost alone 40 US cents, excluding maintenance and capital costs. The solution is made more attractive by the fact that wind often blows more at night than in the day, while solar is only generated during the day, reducing storage needs and losses – and avoiding expensive battery drawdowns. When combined with energy efficiency and solar water heating, solar hybrid systems are the cheapest available solution, but remain very expensive relative to on-grid electricity. In Namibia, the use of biomass has potential and in the C-Bend project the country has a pilot showing the potential of biomass. This has a lower capital cost and potentially higher load factor than solar PV – where it is available.

The market for hybrid systems has received a significant boost in Africa from mobile phone companies, who spend a staggering $4 billion per year on diesel to generate electricity to run their towers.[19]

19 Palm Telecom – conversation with management team – June 2011

Criterion	Description	Significance
Able to supply during peak demand times	Yes, storage is vital	High, must provide energy to critical infrastructure such as telecoms, schools and hospitals
Can manage intermittency	Yes, battery storage	High
Build time	Depending on size, usually a number of weeks	Low
Sensitive to high outside temperatures	Solar PV and certain batteries are	Built into specification, so managed in design phase
System complexity	Intermediate	High, as maintenance is challenging, due to remoteness
Land needed	Insignificant compared to availability, as the system is ground-mounted	Low – as land tends to be readily available
Local employment opportunities	Small, requires external experts, although some potential for basic maintenance.	Medium importance – is an excellent project for Youth Services Commission, for Youth development as well as service contracts for the energy shops.
Conversion	Combination of wind and solar, so about 30%	Not relevant, added for completeness
Levelised cost per watt – current – based on large order	230-40 USc per KWh, depending on solar and wind resources	Less than cost of diesel, but still high, with very high upfront costs, usually for poor communities with little income or credit access.
Estimated levelised cost in 2020	Much lower, battery and solar PV costs will reduce by 2/3rds, with total system prices halving	Will still be expensive in 2020 – at 20 US cents per KWh, but will remain the only option for providing electricity to remote, isolated rural communities, so will depend on subsidies and grant funding, such as the solution ANE proposes.
Insurance risks	Intermediate risk of theft, need community involvement to protect infrastructure	Need technology intervention to theft-proof panels, turbines and batteries.

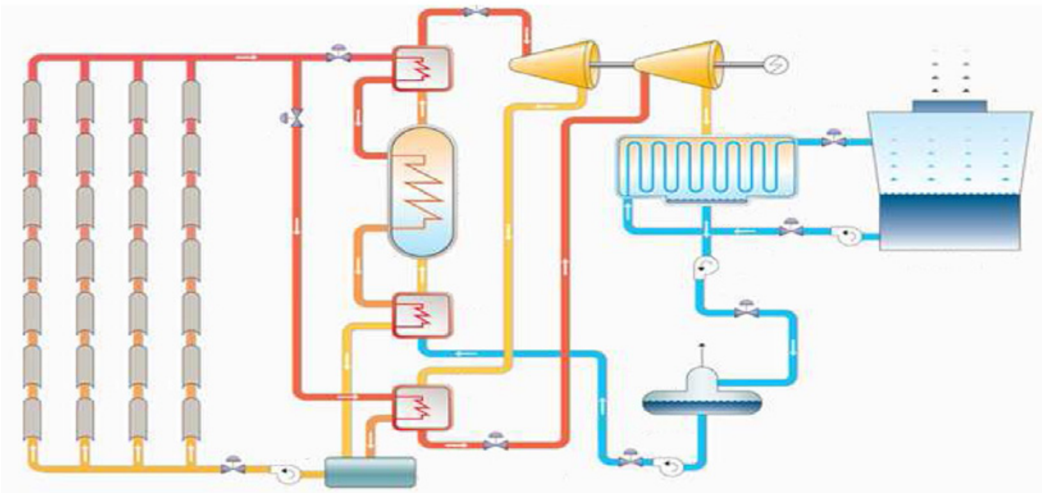
7.1.2.2 Utility-scale solar technologies

7.1.2.2.1 Concentrated solar power plant

Figure 33 – Abengoa's Power Tower near Seville, Spain. Abengoa has been selected to build a similar plant close to the Namibian border, where they will be paid R2.70 (USc 33 cents) per KWh

A concentrated solar power (CSP) plant uses mirrors to shine the sun onto a tower (Power Tower) or an absorber tube (Parabolic Trough). This heats up a fluid whose thermal energy is transferred into a storage tank containing salt that is pumped into a conventional thermal (Rankin) Plant, which heats up water, driving turbines and generating electricity in the same way a fossil fuel thermal plant does.

Figure 34 – Parabolic trough process diagram



Until recently, parabolic troughs have attracted more finance, but now Power Towers are more popular, as they operate at higher temperatures, track the sun on two axes, increasing solar efficiency and use less expensive mirror technologies, which proponents claim combine to deliver a 40% levelised electricity cost advantage over parabolic troughs. The world's leading promoter of parabolic troughs and builder of the iconic Andersol project in Spain, Millennium Solar, has recently filed for bankruptcy, raising questions about the future of parabolic troughs. Once large-scale storage becomes widely available, it is difficult to see a future for concentrated solar power outside co-generation applications, as the one proposed in this study.

Criterion	Description	Significance
Able to supply during peak demand times	Yes, with storage which only loses 6% round-trip losses	Technically critical
Can manage intermittency	Yes	High
Build time	2-3 years	High
Sensitive to high outside temperatures	No	Medium, but depends on location
System complexity	High	High, deploying highly skilled engineers for the life of the plant is high.
Land needs per MW	5 hectares (6 hours storage)	Low, land is usually free for these plants in emerging economies
Water needed per KWh	3.6 litres	High, assume water is reasonably available as plant is part of integrated industrial development.
Local Jobs per MW	1	Medium importance to the host country, but should not be included as short term job creation can distort appreciation of downstream energy costs.
Solar-to-electric efficiency	16%	Irrelevant as land assumed to be free
Cost per watt – current – based on large order	$3.00 (no storage) $6.00 (with six hours storage)	Vital for project returns. Could be higher in challenging construction environment
Estimated cost in 2020	$2.50 (no storage) $5.00 (no storage)	Concentrated Solar Power is going out of fashion in Europe and the United States, as their demand profile is more suited to solar PV than CSP. Namibia is well suited to CSP, with its low-cost storage option, giving 6 hours of energy in the evening and early morning. The low forecast internal demand means that prices will stay high.

7.1.2.2.2 Solar Photovoltaic Utility-Scale Power Plants

Figure 35 – A 4.6 megawatt solar farm in Springville USA occpuying some 10 hectares.

A solar panel absorbs a photon (light) and converts the light into direct current electricity. The panels are installed in groups (arrays). They are wired to an inverter, which converts the direct current to alternating current, the most common form in which electricity is used and transported on high voltage transmission lines.

The photovoltaic industry receives vast subsidies at every level of the value chain. Enormous resources are being invested into innovation, where the progress can be dizzying. Many countries, not least Germany, China and the United States regard market leadership in solar as a national imperative and have boosted their manufacturers and consumers with subsidies, tax credits and loan guarantees as well as generous feed-in-tariffs.

Global competition is brutal, with production in 2011 forecast to be 30 GW, and sales of just 13-17 GW. Already there is 12 months of stock in the supply chain, and high-profile bankruptcies have resulted. These include Q-Cells, the world leader in 2007, and Solyndra in the US, which consumed $468 million in US government guarantees before collapsing, causing a Washington scandal. This over-production has come at a time when all major economies are reducing feed-in-tariff subsidies and banks are reluctant to finance. These factors have combined to reduce prices by 50% since the financial crisis in 2008.

These factors, along with dramatic economies of scale bode well for Namibia. Prices are expected to reduce by 8% per year for the foreseeable future, while different technologies such as Copper Indium Gallium Selenium with ultra-efficient manufacturing processes and development in nano-technologies will transform both costs and performance.

Solar PV is attractive because it is the most scaleable of all electricity generation technologies. Its prices are reducing dramatically, but the same concerns about storage persist at a utility-scale, where storage doubles the levelised electricity cost.

Criterion	Solar PV	Importance
Able to supply during peak demand times	No, unless set up with NaS batteries, which double the levelised cost of electricity. 30% losses on storage. NaS batteries weigh 80 tonnes per MWh	Technically critical
Can manage intermittency	Yes, at a cost – see above	High
Build time	6m months – 1 year	High
Sensitive to high outside temperatures	Yes, loses 0.5% of effectiveness for each degree above 25 degrees Celsius.	Medium, but depends on location
System complexity	Medium/Low	High, deploying highly skilled engineers for the life of the plant is high.
Land needs per MW	2.5 hectares	Low, land is usually free for these plants in emerging economies
Water needed per KWh	None	High, assume water is reasonably available as plant is part of integrated industrial development.
Local Jobs per MW	0.3	Medium
Solar-to-electric efficiency	17% for Silicon, 12% for thin film	Irrelevant as land assumed to be free
Cost per watt – current – based on large order	$2.00 without storage and $4.00 with storage.	Vital for project returns. Could be higher in challenging construction environment
Estimated cost in 2020	$1.00 for thin film, which will be the dominant technology	Will be key, and $1.00 will enable solar to compete on a utility scale with all fossil fuel new builds.

8. ANE's solution – overview

Namibia faces a shortage of electricity of 40% of peak demand by 2013.

ANE's development strategy involves turning low-cost stranded natural gas into electricity, while replacing the gas with solar over time.

A foreign direct investment of 4% of GDP will supply 50% of demand and give 100% basic electricity access within two years.

It is replicable in the rest of Africa – in Nigeria and Angola – using 50% of flared natural gas will result in a 450% increase in electricity generation.

Namibia's power sector is similar to the rest of Africa in that it faces three key problems:

- electricity shortages - 40% of peak demand in 2013
- limited population access – just one third of the population has access to electricity against a sub-Saharan African average of 26%, and
- affordability – three years of 20%+ increases in electricity prices has resulted in over half of the certain municipalities being in arrears with electricity payments.

The ANE development strategy was applied to Namibia to produce in a carbon-light, cost effective solution, using stranded natural gas,[20] and replacing it with solar over time by:

- **Identifying** potential stranded natural gas sites – 6 were found with potentially sufficient reserves for a 300 MW plant, close enough to transmission lines.
- **Proving** the reserve using emerging technologies such as proven "Surface Exploration"[21] technologies e.g., "Airborne Transient Pulse A-EM Surveys" "Passive Ground Tellurics," "Windowed Radiometric Surveys" and geochemical sampling as well as low-cost exploration well drilling techniques.
- **Using** the natural gas in a combined cycle gas plant, which will produce over 50% of Namibia's needs in 2013, replacing 80% of high risk regional electricity imports.
- **Swapping** foreign ownership, by enabling a consortium of local owners to give international investors a year five exit, with a low-risk leveraged buy-out fund.
- **Extending** access to electricity using solar micro-generation – starting with a Universal Basic Electricity Access Programme (U-BEAP), giving the two thirds of the population with no access to electricity access to LED lighting, ability to charge a mobile phone and listen to a radio, followed by a national solar water heater rollout, insulation and energy saving programme and finally solar PV residential roofs.
- **Adding** to plant capacity with concentrated solar (integrated solar thermal) and utility-scale photovoltaics with battery storage to supply peak periods.

With a foreign investment of just 4% of GDP, this strategy will achieve the following:

- Grid-wide generation cost reduction of 20% in the first year of plant operation.
- 100% of the population getting basic access to electricity within two years.
- Immediate savings of 500,000 tonnes of carbon emissions per year with each $1 of foreign investment will result in carbon re-investment of $5.50 – delivering in 100% electricity access within 25 years, where 70% of households derive more than 50% of their energy needs from solar.

ANE's development strategy is replicable throughout Africa, which has a surplus of flared and other known, undeveloped, on-shore stranded natural gas deposits. For instance, converting 50% of Angolan and Nigerian flared natural gas will increase electricity production by 350% increasing GDP by 30% in each country.

8.1. The Stranded Gas to Solar Concept

Stranded natural gas is defined as natural gas that has no access to a market, and therefore no resale value. This is a common phenomenon as natural gas infrastructure required for processing is extensive. A gas-to-liquid processing plant (GTL) costs $2.5 billion and it is generally accepted that a GTL plant will need at least 1 trillion cubic feet (180 million barrels oil equivalent) to recover the investment. Natural gas also needs access to a pipeline network, which Africa does not have. Gas pipelines

20 Stranded Natural gas is defined as natural gas that has no access to a market – it could be undeveloped – i.e. left in the ground or if a by-product of oil production, flared or re-pumped in the well to increase well pressure.

21 See definition in footnote 1

cost \$0.75 to \$2 million per kilometre, and can face years of planning delays and even geo-political intrigue. Extracting oil has much lower barriers to entry and is more lucrative, so more energy companies focus on oil and leaving many natural gas deposits in situ, known and undeveloped.

Converting natural gas into electricity makes sense on a continent with chronic shortages of electricity and little natural gas infrastructure. The table below compares natural gas to coal and nuclear as a feedstock:

Figure 36 – Battle of the baseloads – Coal vs. Nuclear and Natural Gas

Technology	Nuclear	Coal	Combined cycle natural gas
Build time in years	10	8	2
CapEx – US$ per watt	$7.50	$1.2 -$5.00	$0.60-$1.20
Life in years	40	>40	20
Levelised electricity cost – US cents per KWh	20-30 cents	7-15 cents	7-10 cents
Thermal efficiency	38%	37%	60%
Carbon emissions – tonnes per MWh	0	0.7-1.40	0.3
Externalities	Safety perception, government guarantees needed, spent fuel	Water, pollution, long term scarring of countryside	Water

8.2. The ANE development process

ANE investigated several clean energy alternatives and found that the cheapest and most technically feasible solution lays in accessing stranded natural gas and turning it into cheap electricity and gradually investing plant profits into utility-scale solar and microgeneration:

ANE's development process works as follows:

Figure 37 – ANE's development process

Identify	Identify natural gas/thermal source.
Prove	Prove reserve adequate for life of plant.
Use	Use natural gas to fire combined cycle gas power station funded international investors.
Swap	Swap international equity on exit with local buyout and carbon fund.
Extend	Extend by giving electricity access to off-grid applications, residential solar water heating and genset replacement.
Add	Add to the utility solar capacity, plant by gradually building solar capacity that fully replaces natural gas at the end of the natural gas plant's 20 year life.

8.3. Identifying potential natural gas resources

There is currently no natural gas production in Namibia, so no prospect of using flared natural gas – see more detailed discussion in Addendum A about flared natural gas. But it has a large proven reserve. The Kudu gas field is an offshore field approximately 170 kilometres (115 miles) north-west from the city of Oranjemund. It is located in the Orange Sub-basin in 170 metres (557ft.) of water. Discovered in 1974, the license has been held by a number of companies including Royal Dutch Shell, Chevron Texaco and Energy Africa and lately Tullow Oil and Gazprom. The field is estimated to contain 1.3 trillion cubic feet.

The Namibian government remains committed to developing Kudu, and building an 800 MW natural gas power station but the challenges the owners face are significant:

- Feedstock pricing – there is no known oil in Kudu, so it will only be viable if the natural gas is processed. As processed natural gas is worth more on the international markets than NamPower can afford to pay, the partners will be reluctant to sell the gas to NamPower. The 800MW power station will use an estimated 120 Mmscf per day – over the twenty year life – about 900 bscf – some 70% of proven reserves, crowding out more lucrative revenue opportunities.
- Development risk – to transport the natural gas, a 170 km undersea cable will need to be built, breaking the world record for the longest undersea natural gas cable.
- Foreign exchange risk – the international developers of Kudu will require payment in US$ to recover the estimated $1.2 billion capex from NamPower, while NamPower receives income in NA$. This exposure to the volatile rand requires a hedge to be in place – and it is difficult to see how one can be created. Power purchase agreement sharing – Namibia's planned 800 MW power station requires co-operation from Eskom to offtake 300 MW for a five to ten year period. Since attempts in 2005, no agreement has been reached with Eskom.

In short, Kudu is not stranded gas – and is technically challenging to develop so it is not an ideal solution.

Namibia has many instances of natural gas seepage and evidence of on-shore oil. There is much local knowledge that can be harnessed, and cross referenced with traditional top level geological evaluation techniques. Using techniques described in addendum A, ANE has used non-mainstream techniques to find other potential sources of natural gas.

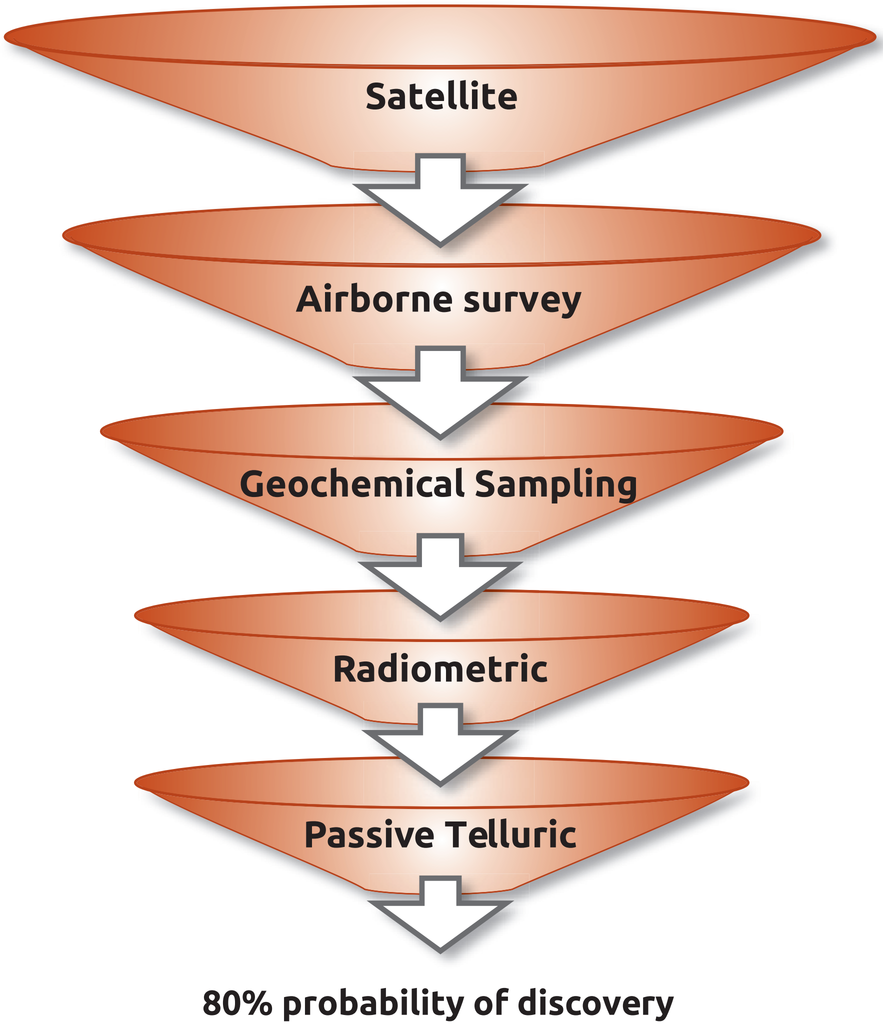
Figure 38 – Natural gas leads identified by ANE and its exploration partners

Name	Years of production for 300 MW plant	Probability score Pnn	Proximity to transmission lines	Water availability	Access to mineral rights	Solar irradiation	Priority
Block 7a	Greater than 20	P80	<10 km	Yes	Not yet	World leading	1
Block 7b	Greater than 20	n/a	10-20 km	Yes	Not yet	World leading	2
Block 7c	Greater than 20	n/a	10-20 km	Yes	Not yet	World leading	3
Block 7d	Greater than 20	n/a	20-30 km	Yes	Not yet	World leading	4
Block 4	Greater than 20	n/a	10 km + upgrade needed	No	Yes	Good	5
Block 5	Greater than 20	n/a	10 km	Yes	Yes, share	Good	6
Block 1	15-20	n/a	70 km	No	Yes	Excellent	Reject
Block 2	15-20	n/a	100 km	No	Yes	Good	Reject
Block 3	15-20	n/a	80 km + upgrade needed	No	Yes	Good	Reject

8.4. Proving reserves

Hydrocarbon companies find exploration risky and difficult. It is estimated that discovery costs are $12 per barrel. The decade from 2000 has shown that companies that embrace new technologies have built significant competitive advantage – for instance Tullow Oil has an 85% success rate in drilling – while BP's is only 50%. HRT – a major player in Namibia – has a market capitalisation of $4 billion without any production, due to the respect the management team accords for its holistic technology approach to prospecting.

Figure 39 – ANE's adopted stranded gas discovery process



ANE and its exploration partners based their exploration philosophy on the old Chinese proverb – "When you want to know the truth – ask the same question of many people". There are many independent technology methods that can be used to find hydrocarbons, that use physical evidence of seepages, satellite data, geological, geophysical, geochemical and hydrocarbon microseepage–based Surface Exploration technologies, which is not suitable for finding the smaller, more subtle formations that ANE is looking for:

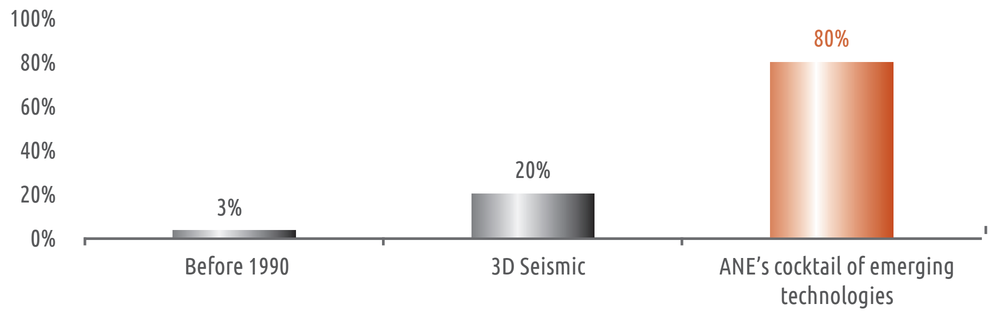
Seismic is not suitable for this environment as it:

- struggles to differentiate between brine (salty water) and hydrocarbons
- has difficulty in penetrating volcanic basalts above the hydrocarbon sediments, which are common in Namibia
- is more effective in finding the structural traps that are likely to contain hydrocarbons, and struggles to isolate more subtle fluvial-dominated deltaic stratigraphic traps, that ANE and its partners have identified in Namibia

The manner in which ANE has been able to identify so many sites with so few resources, is proprietary information. But once it has identified a lead – as it has done as per Figure 38 – natural gas leads identified by ANE and its exploration partners, it proposes to prove the reserve, using the following techniques, which are cheaper and simpler than seismic. Exhaustive peer reviewed academic studies have proven these techniques to achieve 80% success rates when used in concert with each other.[22] The paper sited, collected data on over 2,700 wells across the world from every type of hydrocarbon setting.

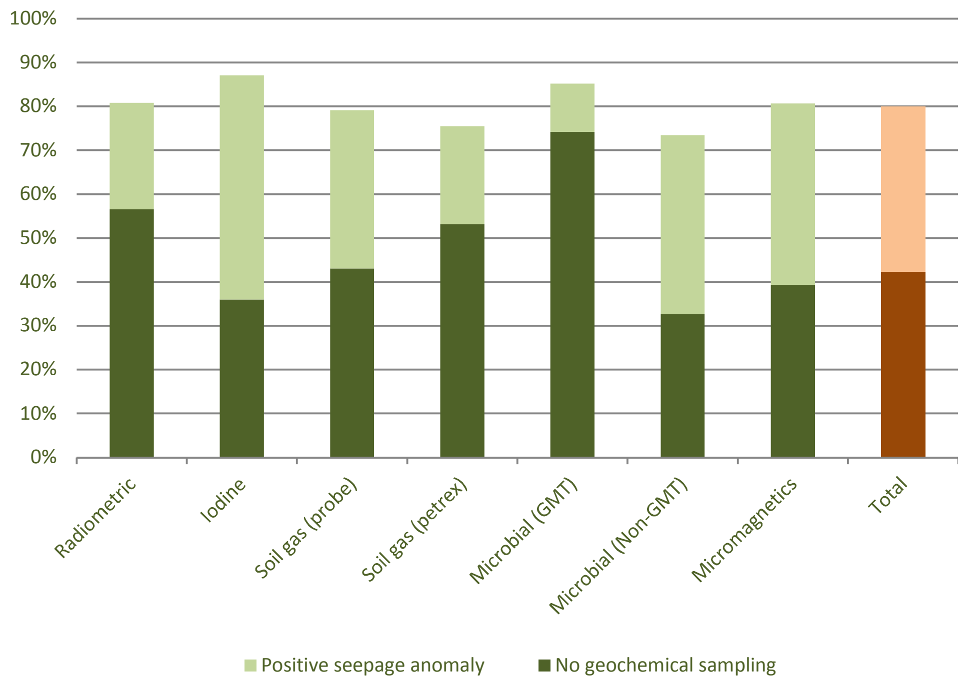
Discovery rates are improving, as the industry embraces new technology. See below:

Figure 40 – Success rate when drilling wildcat exploratory wells



The following graph shows the Chinese proverb at work cross-checking positive anomalies from independent technology evaluations dramatically improves discovery rates – whatever technology is cross-referenced against geo-chemical sampling.

Figure 41 – Effect of geochemical sampling on discovery rate of hydrocarbons, when used in conjunction with other technologies



22 Schumacher, D, 2010, *Integrating hydrocarbon microseepage data with seismic data doubles exploration success*, PROCEEDINGS, INDONESIAN PETROLEUM ASSOCIATION Thirty Fourth Annual Conference and Exhibition, May 2010.

8.5. Using the gas - the combined cycle plant

8.5.1 Engineering overview

8.5.1.1 Natural gas processing plant

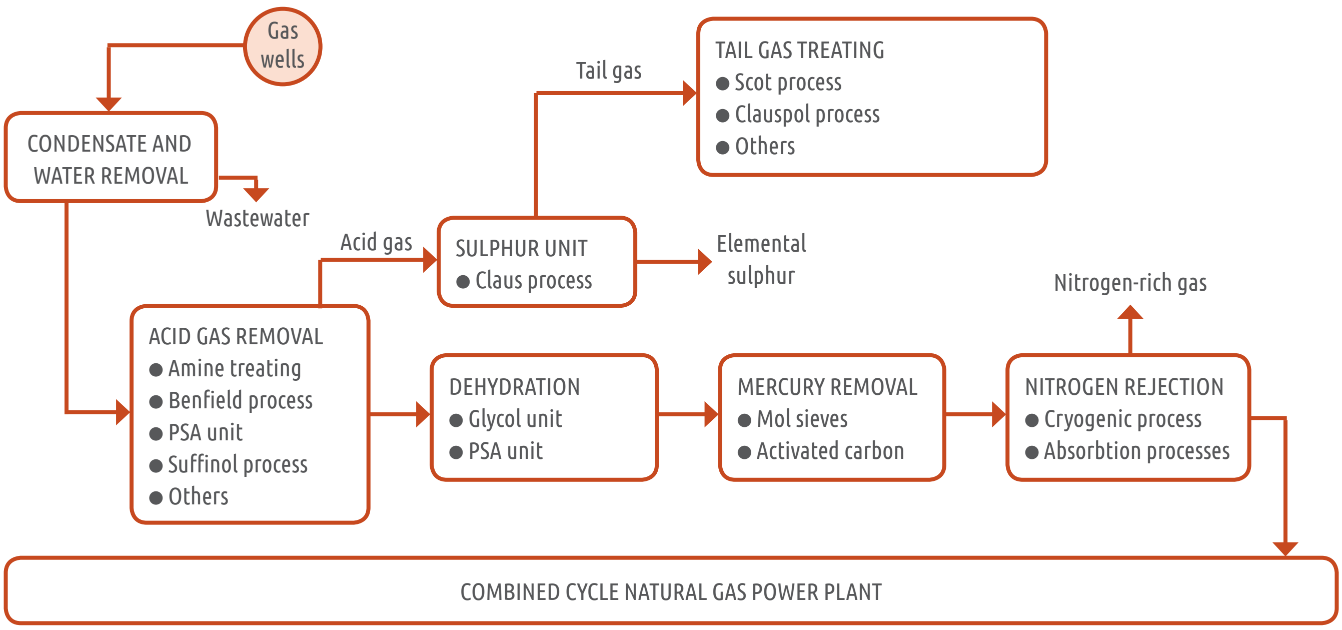
An onsite plant that will process the natural gas will cost a minimum of $60 million, while a full LNG processing facility will cost $120 million.

The natural gas extracted from production wells needs processing before it is "pipeline specification" – i.e. ready for use in the power plant, after the removal of unwanted byproducts such as:

- Sulphur
- CO^2
- Water vapour
- Nitrogen
- Trace elements such as lead, zinc and copper, which have high concentrations in one of the local areas.

The process of extracting natural gas is illustrated below:

Figure 42 – Typical natural gas processing plant[23]



Note that PSA stands for Pressure Swing Absorber and Acid gasses include hydrogen sulphide and carbon dioxide.

The engineering "rule of thumb" is that a natural gas processing plant costs approximately US$1 million per million standard cubic feet per day (Mmscfd) processing capacity – and US$1.5 million per Mmscfd for full conversion to Liquid Natural Gas.[24] As this plant will need about 45 Mmscfd, the input feedstock to the processing plant, plus contingency should be specified to 60 Mmscfd, so capital expenditure has been estimated at $100 million for the non-GTL plant alone – excluding pipelines, storage and loading facilities.

8.5.1.2 300 MW Natural gas combined cycle plant

A 300 MW combined cycle plant will produce 2.2 TWh at an 85% capacity, enough to cater for 50% of Namibia's current electricity needs. It will replace 80% of imports including the Zimbabwean deal, which supplies 40% of imports. The plant will require 50 MMscfd of natural – a 20 year reserve of

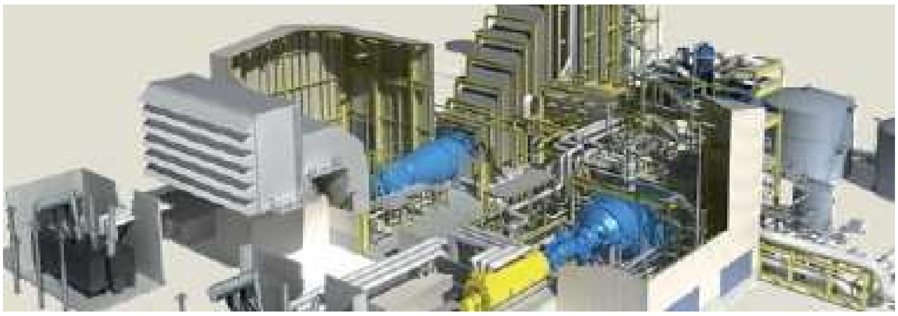
23 Adapted for diagram – http://en.wikipedia.org/wiki/Natural-gas_processing

24 Yukon Department of Energy, Mines and Resources,Oil & Gas Resources Branch, 2010, *ENERGY FOR YUKON: THE NATURAL GAS OPTION – Eagle Plain Case Study – http://www.emr.gov.yk.ca/oilandgas/pdf/eagleplain_.pdf*

A 300 MW gas plant will cost $300 million with 1 year planning and a 2 year construction period. It will replace 80% of Namibian imports saving 24 million tonnes of CO^2 over its useful life

0.35 trillion scf – too small to justify a traditional investment in pipelines or a gas-to-liquids plant. The plant will take two years to build, with capex estimated at 4% of GDP, comprising wells, pipelines, natural gas processing, generation and grid integration. Substantial geological work has been done to confirm the presence of hydrocarbons. Currently ANE targets a price lower than the forecast Eskom supply price in 2015 and the replacement of imported or interim supplies will reduce NamPower's generation and cost of electricity by 20%. The plant will also generate 600,000 tonnes of saleable carbon credits, which will contribute to foreign exchange. As the natural gas source will be owned by the buyer, input cost is expected to be at marginal cost – or a significant discount to the US & UK prices respectively.

Figure 43 – Alstom's K132 combined cycle plant – the waste heat cycle increases thermal efficiency by 50%



8.6. Adding capacity

8.6.1 Integrating concentrated solar power

Solar replacement – After year 6, when the international capital providers have exited their investment, the carbon fund will invest 25% of its annual cashflows into concentrated solar power and 25% into solar photovoltaics – both with 6 hours of storage. This stored electricity will be supplied to the grid and by the time the natural gas combined cycle plant comes to the end of its 20 year life, these will continue for another 20 years.

Figure 44 – e-Solar's revolutionary new modularised concentrated solar plants

The engineering solution takes advantage of the fact that the most expensive components of a concentrated solar power plant are the collector fields (mirrors that reflect light onto an absorbed tube or power tower) – 60% of total costs, and the storage systems at 25% of total costs. As on a traditional concentrated solar power plant, the thermal efficiency is just 30%, a natural gas input increases the solar efficiency to over 60%, meaning that the natural gas input doubles the amount of electricity that is generated from the concentrated solar power field. The e-Solar system, which has recently been bought by GE, enables small 5 MW modules to be purchased and uses simple production processes and non-specialised materials for the mirrors, so is cheaper than competing technologies such as parabolic troughs.

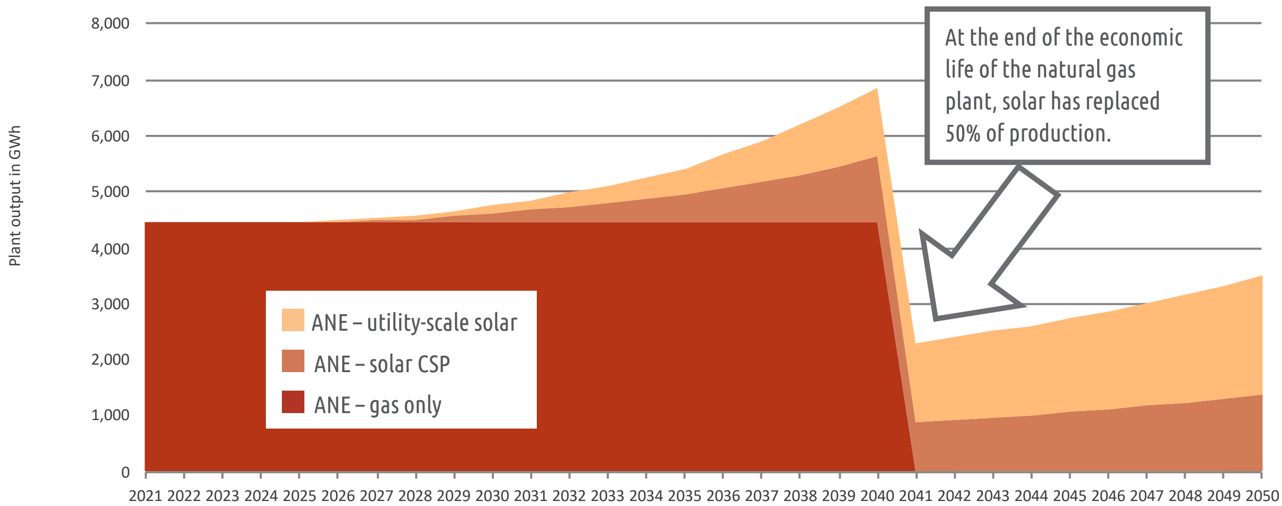
8.6.2 Large-scale photovoltaics with 6 hours of storage

Figure 45 – Utility-scale photovoltaics with NGK's battery giving 6 hours of storage and supply at peak times.

ANE plans to augment the gas and CSP with utility-scale photovoltaics, along with NGK's 6 hour Sodium Sulphur battery storage system – the world's only bankable large-scale battery for wind and solar. The advantage of photovoltaics is that they are technically simple to install and capacity can be grown 1 MW per planned annual installation.

As the capital costs for the utility-scale solar roll-out are paid from retained earnings, foreign exchange risks and high required returns on capital are avoided for 85% of the solar roll-out.

Figure 46 – Output by technology at ANE's proposed plant, 2015-2050



8.6.3 Commercial overview

Revenue – ANE's primary goal is to minimize the price it has to charge for electricity. It is estimated that the price charged will be slightly less than the forecast Eskom prices in 2015, and the lower feed-stock costs (expected to be 75% less than international market value) mean that the levelised cost of electricity will be lower than any internal alternative – except for hydro-electric power. EBITDA are forecast to be high as much as 70% of revenues.

Debt funding – once the natural gas reserve has been proven, the project proposes a debt/equity ratio of 60:40, with debt protected by MIGA (Multilateral Investment Guarantee Agency) insurance at a cost of 1.75%. It is estimated that with the completion of an insured front-end-engineering and design (FEED) study, and the gas supply, local, owned and proven that debt can be raised at 200 basis points above the sovereign rate – about 10% in US$ and 14% in NA$ with 4% FX hedging cost. The loan will be repayable from cash generated from the first five years of production and the FX risk will be hedged – the Namibian dollar is linked to the rand, which has a deep enough FX market, while the MIGA insurance will cover currency repatriation, customer default and expropriation risks.

Equity returns – the project was designed to attract international equity investors, and as the natural gas will be supplied at marginal cost, makes it possible for the project to generate healthy returns, while selling the electricity at cheaper prices than alternatives at the state-owned utility faces. ANE targets returns of at least 30% with a five year exit for international equity investors.

Local ownership – fostering indigenous ownership is a cherished policy of most African countries, which all use state procurement budgets to encourage local entrepreneurship. The ANE model enables 100% local ownership from year 6, with a local buy-out fund, which will be 100% leveraged secured by the revenues of the plant, by which time the foreign debt is repaid. 20% of free cash will be distributed as a dividend, while 80% will be reinvested in the carbon fund.

Figure 47 – Project timelines

Years 0-2

- Planning
- Construction

Years 2-6

- Plant operates 100% natural gas
- EBITDA pays off foreign debt (60%)
- Foreign equity investors (40%)
- Rollout of universal minimum electricity access programme

Years 7-16

- Local leveraged buy-out structure, based by 100% local debt buys out foreign equity
- 20% of free cash distributed to equity owners
- 80% of cash invested in Carbon Fund
- 50% in concentrated solar power collector capacity and in utility scale solar photovoltaics with 6 hours of storage – split equally between CSP and PV
- 25% in solar water heating, pre-paid solar photovoltaics and off-grid and on-grid solar photovoltaics
- Carbon fund invests 12.5% in corporate social responsibility projects (10% of total free cash)

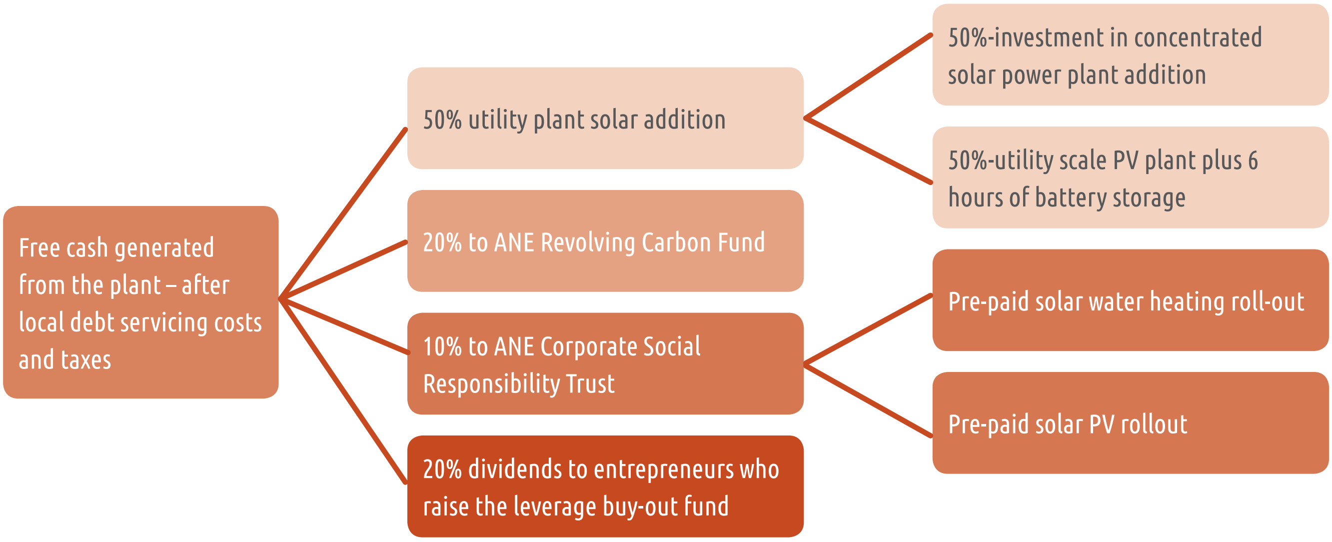
Years 16-42

- Natural gas plant useful life ends at year 20, by which time plant solar output is 85% of original gas output
- Carbon fund continues to invest in solar and energy saving until the end of the useful life of the concentrated solar power plant

8.7. Extending access - the ANE Revolving Carbon Fund

Free cash generated by the plant from year 6 will be distributed in the following way:

Figure 48 – Distribution of free cash generated by the plant from year 6



The investment in the concentrated solar plant and the utility-scale photovoltaic plant has been discussed already. Below the micro-generation investment programme is discussed:

8.7.1 Reasons for a micro-generation programme

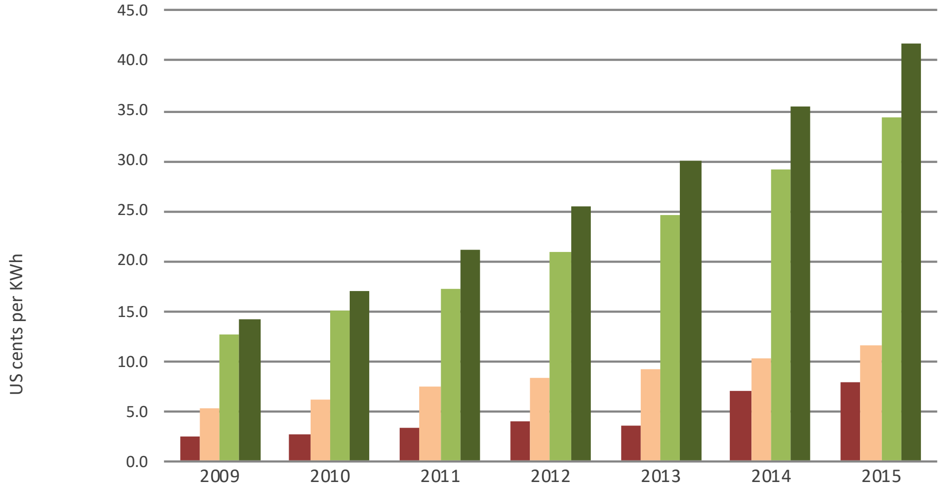
There are three key reasons for the need for a clean energy micro-generation revolving investment fund making low interest loans, accessing carbon credits and grants.

1. Affordability – the average Namibian has a low disposable income: the recent and forecast consumer energy price increases are causing social disquiet – prepaid electricity customers are the worst off with price rises and increases are preventing increased electricity access. Namibia's electricity prices have traditionally been some of the lowest in the world, where it has combined inexpensive hydro power with an advantageous legacy power purchase agreement from South Africa. The power cuts of 2008 in South Africa shocked the entire subcontinent into the realization that expensive new capacity was needed and South Africa has more than doubled energy prices in the last three years. In addition, South Africa's drive towards renewables will result in a carbon tax that will increase energy costs by 30%. This energy inflation has rippled over to Namibia, and is expected to continue for the foreseeable future – with the Electricity Control Board forecasting energy inflation of at least 20% per year for the next five years.[25] This electricity inflation is already causing tensions with angry exchanges in the Karas province between councillors and RED's, and 55% of Windhoek's rate payers being in arrears.[26]

25 Helena Vosloo, Head of Economics – Electricity Control Board in meeting with ANE on 15 June 2011 at ECB offices in Windhoek

26 Harald Schütt – independent consultant and former director of the Renewable Energy & Energy Efficiency Institute – in conversation with the author in meeting on Wednesday, 5 October 2011. Both incidents were reported in the daily news.

Figure 49 Generation vs wholesale vs retail pricing Namibia - 2009 - 2015



	2009	2010	2011	2012	2013	2014	2015
Generation - Nampower	2.4	2.6	3.3	4.0	3.6	7.0	7.9
Wholesale - REDs	5.3	6.3	7.5	8.4	9.2	10.3	11.6
Retail - account	12.7	15.0	17.3	20.9	24.7	29.1	34.4
Retail - prepayment	14.2	17.0	21.0	25.4	30.0	35.4	41.8

2. **Off-grid access** – Off-grid solar will become increasing financially viable especially as low-cost storage solutions reach the market over the next five years. Off-grid solar applications compete with higher residential rates of 15 USc per KWh vs. generation rates of 4 USc per KWh and also help the customer to avoid the large premium needed to recover grid access costs in remote areas. The state utility will welcome a large scale roll-out of off-grid solar, as it is seldom able to recover transmission investment into low population density areas.

8.7.2 Sub-programmes with the micro-generation programme

8.7.2.1 Solar water heating roll-out

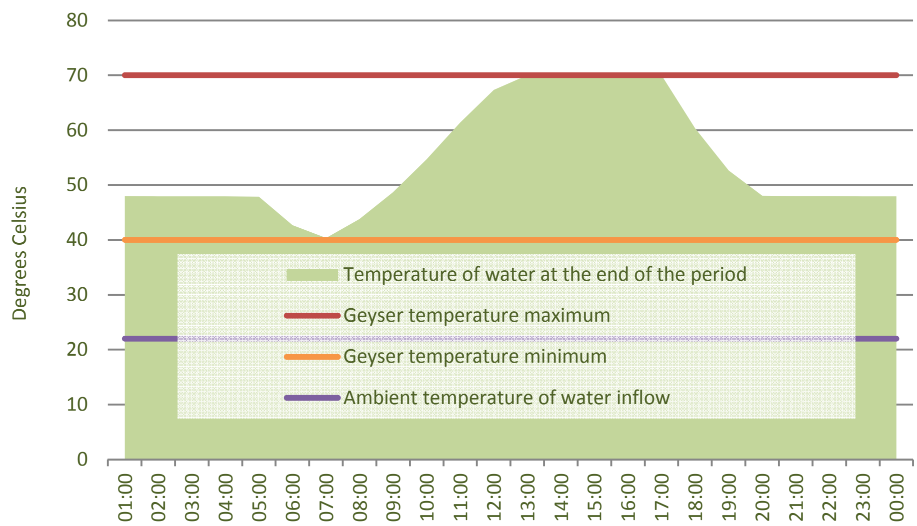
The benefits of solar water heaters within middle and lower-income homes in Namibia

Households are the most expensive type of customer for electricity providers to supply to as they demand electricity during the morning and evenings, when demand is at its highest. Electricity provision during peak periods can cost 10-20 times as much as baseload costs.[27] As the heating of water makes up about one-third of electricity demand of households and most water heating is done during these peak periods, solar water heating is one of the cheapest energy-saving interventions available. Secondly, solar water heating is four times as space efficient as solar PV, as up to 70% of the solar energy is converted into thermal energy, unlike solar PV panels where 17% is converted.

Solar water heating can cover all household heating needs – especially in winter, as Namibia is a summer rainfall region, so direct normal irradiation is relatively higher in winter. On a typical autumn day – modelled below, there is a significant amount of surplus irradiation to achieve maximum temperature:

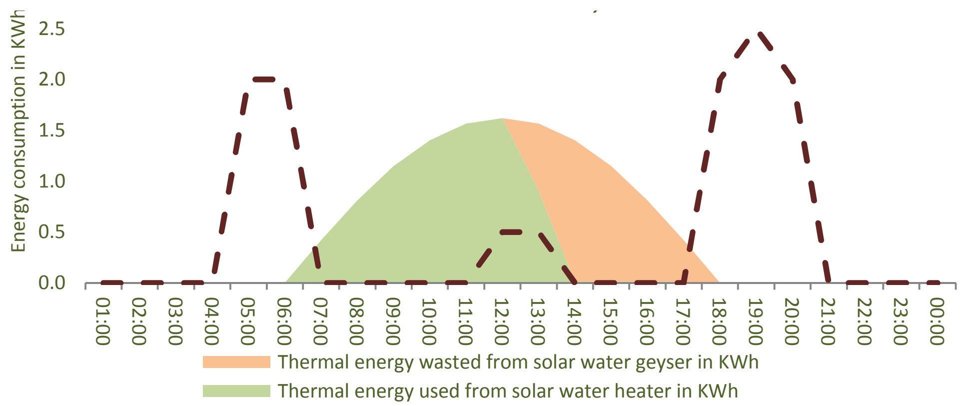
27 Harald Schütt – independent consultant and former director of the Renewable Energy & Energy Efficiency Institute – presentation

Figure 50 Solar water heater boiler temperature on typical autumn day – based on 200 litre SWH and 0% electricity input



This means that houses with smaller roofs have enough space for a solar water heater, but will usually not have the space of solar PV panels. Thirdly, solar water heating is the cheapest way of storing the sun's energy, as water is heated up in well insulated tanks, and available for use in the expensive evening and morning peaks.

Figure 51 – Peak time energy savings of a solar water heater on a typical autumn day
Based on 200 litre SWH and DSM electricity available but not used



It is vital that all stakeholders work towards a national solar water heating programme, where currently an estimated 80,000 households can benefit, halving their exposure to energy inflation in the next three years.

ANE's solar water heating proposal has the following unique selling points:

1. **Economies of scale** – ANE is not pushing any technology or manufacturer, seeking only to create a large volume competitive tender situation where the most suitable solar water heater within the Namibia context is made as affordable as is financially feasible. We target a 100 litre solar water heater to be fully installed for NA$7,000 with the potential market of 80,000 units, with scope for rolling this solution out to other countries.
2. **Measurement and timers** – solar energy is derived during the day and stored in the form of hot water – and consumed in the early morning and evening. The timers will ensure that where there are on-grid backups, the grid is never tapped during these peak demand times. The measurement systems will also alert in the case of problems and lay the foundation for a pre-paid solar water heater.

3. **Carbon funded maintenance programme** – as water heating consumes more energy than heating any other substance – 4.2 KJ.kg-1.k-1 – the carbon savings are substantial. As the energy saved will be measured, these carbon savings will be valuable enough to pay for the on-going maintenance and monitoring for 10 years. It is expected that each 100 litre system will save about 0.5 tonnes of carbon in Namibia, worth about NA$100 per year. This will pay for basic monitoring and the average number of call-outs over the ten year period the maintenance contract will cover.
4. **Innovative financing structures which enable it to access the prepaid market** – the measurement and maintenance systems mean that the risk on repayment is lower than for other solar water heating proposals. This will reduce required interest rates and enable a low cost addition to a mortgage – a 4% addition to the average mortgage balance of NA$180k.

Impact of the scheme on a household's finances – with mortgage:

Figure 52 – Typical cashflows on a 100 litre solar water heater in Namibia – to be used in a lower middle-income household

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
KWh saved pa	800	800	800	800	800	800	800	800	800	800	800
Elec. price - NA$.KWh-1	1.42	1.67	1.97	2.33	2.75	3.24	3.50	3.78	4.08	4.41	4.76
Savings per year - NA$	1,133	1,337	1,577	1,861	2,196	2,592	2,799	3,023	3,265	3,526	3,808
Repayment	(997)	(997)	(997)	(997)	(997)	(997)	(997)	(997)	(997)	(997)	(997)
Saving per year - NA$	136	340	581	865	1,200	1,595	1,802	2,026	2,268	2,529	2,811

The average 100 litre system target price – fully installed plus first year of maintenance and insurance is NA$7,000. Based on the interest rates that the National Housing Enterprise (NHE) is current obtaining, a bolt-on mortgage can be repaid at about NA$1,000 per year, while 800 KWh are expected to be saved each year. On a ten-year repayment, the deal is cashflow positive for the mortgage holder from day one, and by 2022 will save almost NA$3,000 per year. This will shield the mortgage payer from energy inflation on one-third of their energy consumption.

The impact on peak demand will be noticeable. Assuming the average electric element uses 1.5KWh in peak times, the total impact of the 11,200 houses currently on the portfolio will be to reduce peak evening and morning consumption by 17 MW out of the total, and the total carbon saving per year will be about 5,000 tonnes. The revenue derived from this carbon sale could be used to help fund a 10 year maintenance contract.

1. Pilot

ANE will carry out a pilot on 50 houses in the NHE Portfolio. The pilot will test the effectiveness of the scheme as well as covering the consulting costs of registering the scheme for carbon purposes.

2. Retrospective fit to all houses on the NHE portfolio

The NHE provides an important volume driver for a large-scale roll-out of solar water heaters and the finance via its access to low-cost funds, so at this stage will not require capital from ANE, apart from the pilot costs and management time.

ANE has already received a letter of support from the NHE, saying that on completion of the pilot, they will retrofit the 11,200 houses on their portfolio and will do so over a five year roll-out, completed by the time the carbon fund is launched.

3. Roll-out to other creditworthy customers

Other low-credit risk customers in Namibia include:

- houses that have mortgages with high street banks
- the hospitality industry
- social infrastructure and government buildings, of which all new builds are required by law to use solar water heating

ANE will use its revolving carbon fund to finance these at low interest rates – 6%. It is estimated that about 8% of households and most commercial enterprises will fall into this category, so the demand will be about 20,000, 200-litre-units, rolled-out over 3 years from year six of the project. Total loans underwritten will be NA$200 million or US$20 million. The carbon fund in its first three years will have sufficient funds to underwrite this with commercial banks or extend loans itself. It is expected that bad debt ratios will be lower than 10% and that 50% of the carbon fund's micro-generation budget will be used towards this sector of the solar water heater market in year six – continuing to year eight.

4. Roll-out of energy saving devices and solar water heaters to pre-paid electricity customers

Most households in Namibia pay for electricity via mobile pre-payment systems, rather than on account. Without accurate figures, the author estimates that 50,000 of the 80,000 household electricity users use prepayment. To extend access to this market, solar water heater financing will not be viable. Experience in South Africa suggests that there is not a sufficient credit culture to bank on repayment, and unlike certain consumer goods such as cars, TVs and furniture, it is not practical for a solar water heater to be repossessed on non-payment.[28]

This sector of the population is most vulnerable to electricity inflation, so this market is ignored at the country's peril. However servicing it will require the 4 C's:

- C**oncessionary finance**, which ANE will be able to provide in the form of the Corporate Social Responsibility Trust, which will receive 25% of the free cash allocated to the Carbon Fund
- **Carbon credits** to finance maintenance and monitoring programmes for the solar water heaters and 100% financing for insulation and low-energy lighting
- **Community** peer-pressure credit management techniques as pioneered by the Grameen Bank, where communities will be given credit targets, which if they fail to achieve, will result in no new installations, until repayment levels resume
- **Change** in the technology, to enable customers to buy a pre-paid hot water service in the same way they buy electricity, using mobile micro-payment systems over their mobile phone. The technology is available and a suitable partner found. The solar water heaters will need to be modified to cater for cut-off after pre-paid solar water heating has been dispensed. The electronics will have to be made tamper-proof – and customers will have a financial incentive to use the solar water heater to heat their water rather than pre-paid electricity, as the pre-paid cost of solar water heating will be 50% of the cost of using pre-paid electricity to heat the water, with regular use resulting in ownership after 5 years

Even with these interventions, it is expected that bad debts on the pre-paid solar water heating and solar PV will be at least 50% – they would be close to 100% without them so only concessionary funds are suitable. The social benefits are worth it. ANE estimates that the market will have grown to 70,000 by the time the scheme is launched, and that it will take five years to implement. Energy savings from the solar water heater (100 litre) are estimated at 500 KWh per year from the solar water heating, while the carbon funded insulation and the LED lighting will add another 300 KWh per household, so the savings to the grid are a significant at 560 GWh or 8% of the 6.5TWh forecast demand in 2022. The costs of $14 million per year will be funded by the Corporate Social Responsibility Trust from year 7, with pre-payment proceeds re-invested in other social projects within the community whose residents pay for the pre-paid solar water heating.

28 In conversation with Mercantile Bank in South Africa, this worked with Teljoy on a failed solar water heater roll-out programme. Teljoy is best known as a television rental company in South Africa.

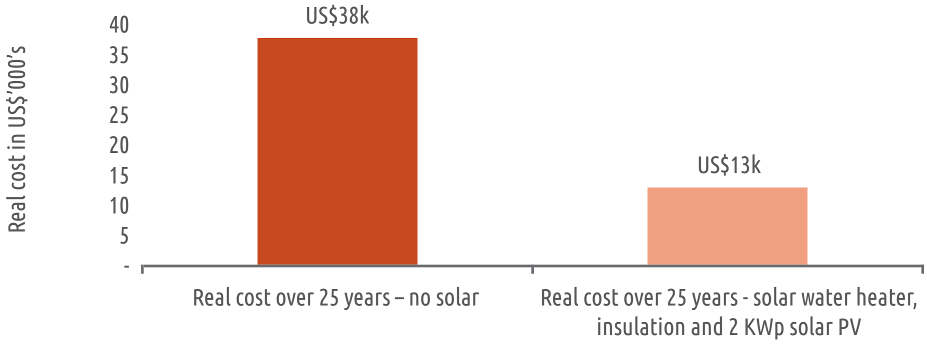
The total potential for solar to provide the energy to heat water in Namibia can save the country up to 10% of current demand – most of it at the most expensive peak demand times. It is the cheapest, most space efficient form of solar energy provision and has storage built in. It has a role to play in Namibia's goal of achieving carbon neutral energy security in an affordable way.

8.7.2.2 Adding Solar PV with battery storage

ANE will to use the revolving carbon fund to offer low-cost loans to farmers, tourist facilities, social service providers and credit-worthy residential customers the ability to buy solar PV and battery storage. This will form a key part of the solar PV roll-out.

The economic attractiveness is simple enough. A three-way package that includes, Solar PV, solar water heating and better insulation will be two-thirds cheaper even with the most optimistic grid inflation forecast (2% real increase per year).

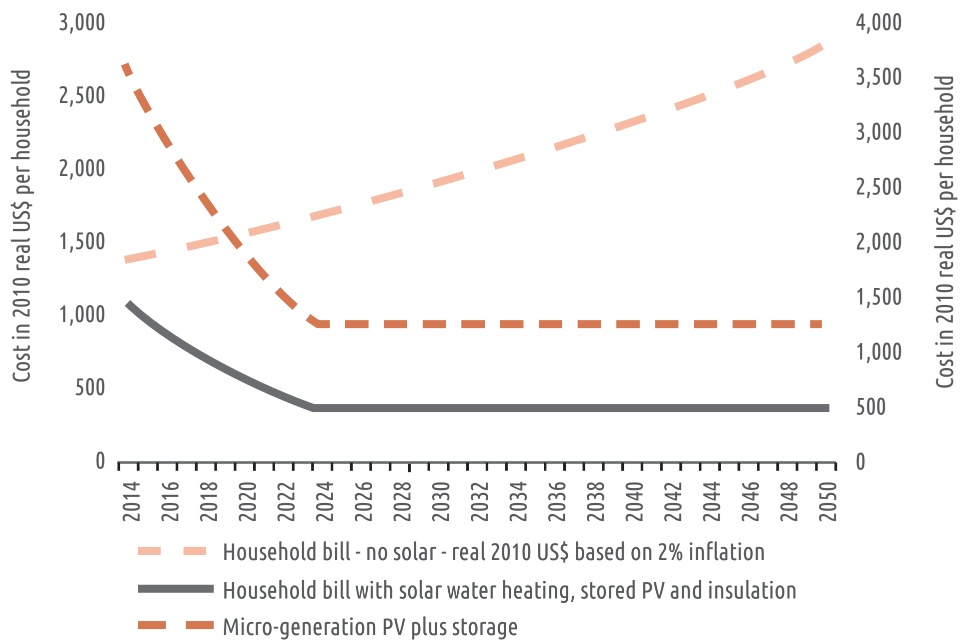
Figure 53 – Savings over the life of a combined solar water heating, solar PV and insulation upgrade on a top 20% consumption house in Namibia



Key assumptions – apart from real inflation include:

- 300 KWh demand per month – 20th percentile demand in Namibia
- 2KWh PV system with 12.5 KWh of battery, replaceable every five years
- House has suitable roof space – where 13 m^2
- Finance is in the form of a 10 year loan for NA $8,200 in 2014 at 6% interest rate – equivalent to the local currency government borrowing rate – resulting in repayment of about US$1,200 per month in 2014, the planned start date and after ten years; this debt will be paid off.
- The solar panels will be guaranteed to perform for 25 years.
- Maintenance, insurance and remote monitoring will be paid for carbon credits on voluntary carbon markets at $10 per tonne
- Solar production of 1,500 KWh per KWp based on global horizontal irradiation of 5.5 KWh per square meter per day.

Figure 54 – Decrease in costs per KWh of solar PV vs. forecast capital costs



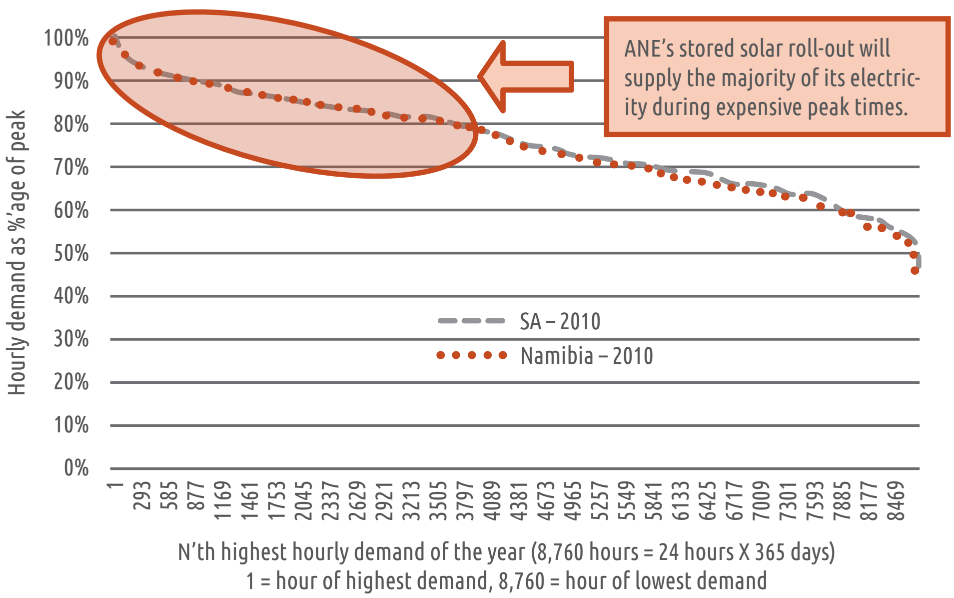
The graph above shows the increasing attractiveness of solar and the key reason for delaying this roll-out. By 2020, solar will deliver electricity at half the current residential rate in Namibia.

Cost of systems are decreasing by 8% per year and will eventually flatten out at $1.00 per watt (2010 US$) in about 15 years' time. The fact that a loan depreciates by 6% per year in real terms from the effects of inflation and the author has assumed that the on-grid retail electricity price will only increase by 2% in real dollar terms from 2014 – currently it is increasing by 18%.

8.7.3 ANE's 4-step technology development roadmap for the micro-generation programme

On-grid micro-generation can play an important role in providing power when the grid most needs it. This is especially the case with solar water heaters, where the cost per KWh over the 15 year life of the system is 5 USc per KWh, 1/3rd of the currency electricity price and one sixth of the forecast electricity price in 2015.

Figure 55 – Namibian and South African electricity demand levels over the 8,760 hours in 2010



To achieve this strategy, the following technology interventions are being designed:

Figure 56 – ANE's 4-step technology development road map for micro-generation integration

Step 1	Step 2	Step 3	Step 4
Solar remote monitoring unit developed Insurance tie in (completed)	Theft proofing Add wind, and hybrids Solar water heating Battery storage monitoring	Theft proof integration for solar PV Prepayment integration with mobile payments platform	Integration with grid for peak shaving with SMS notification Vertical spinning capacity (ultrashort term supply to grid to smooth demand)

Step 1 – Remote monitoring and insurance add-on

ANE's micro-generation partner has developed a remote monitoring system that currently monitors performance and irradiation levels, enabling an insurer to ensure performance. This greatly reduces financing costs. The system works as follows:

Figure 57 The Prophecy Solar Remote Monitoring System

Step 2 – Theft proofing, adding wind, solar water heating and battery storage monitoring

Solar panels are valuable – a single on-roof solar panel is worth more than a years' earnings of 40% of the population. Experience of solar installers in Africa (mainly for the mobile telecoms industry) is that theft is a major problem. It is an even bigger problem when the panel is being financed, so needs to be insured.

ANE has developed the Solar Remote Monitoring System (SMRU) with C2I2 an innovation company in South Africa, which will integrate wiring within the panel itself to a remote code and a local access code. If a panel is stolen, it will be of no use except in the installation where the embedded IT allows for activation of use remotely.

The circuit board is exceptionally versatile and can take up to 200 data inputs, so wind data, solar water heating monitoring and battery storage and dispatching will be included. The battery dispatching will also assist with dealing with shading – solar PV is sensitive to shade as a small amount of shade affects the whole array due to panels being connected in series. The innovative configuration of the battery enables the panels to feed the battery individually.

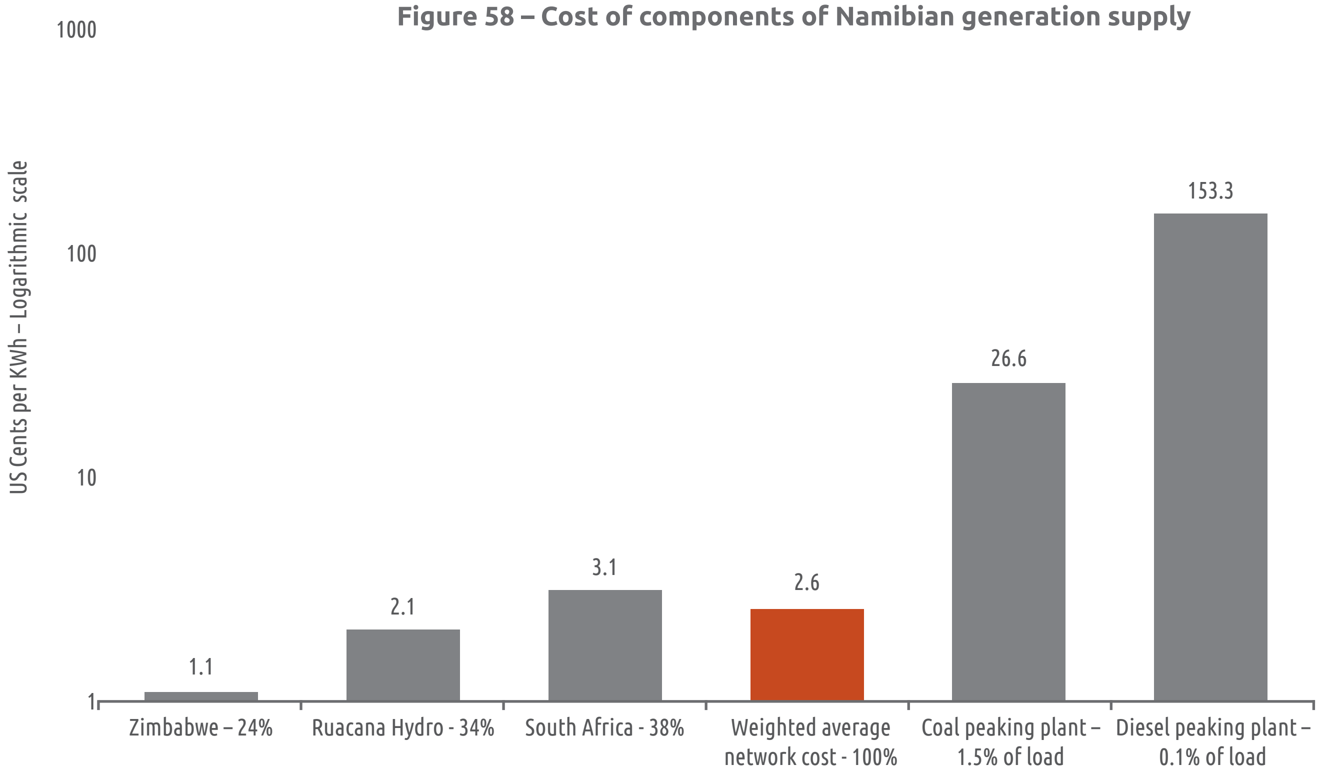
Step 3 – adding pre-payment capability

Only 50% of Namibia's population has access to a bank account, and 20% of households would be credit worthy enough for a loan from ANE's Revolving Carbon Fund. As a fundamental aim of the programme is universal affordable access, ANE will use the CSR Trust to offer pre-paid solar panels and solar water heating, where the service is paid for on a mobile phone and topped up – at a price of half of the cost of electricity from the grid. Pre-payments will be re-invested in community development, so the local peer pressure will help to foster a sense of community, as people "invest" in their own communal social development, at the same time they develop a banking history and credit worthiness.

Step 4 – SMS dispatching – virtual spinning reserve

Residential customers are difficult for the grid to cater for as their usage tends to be in the morning and evening peaks, which are the most expensive times for generators to provide electricity. See below:

Figure 58 – Cost of components of Namibian generation supply



The SMRU system will ensure that houses with micro-generation will use their storage at the most expensive times for the grid, avoiding the need for hugely expensive peaking plants, such as Paratus which costs $1.53 per hour – 60 times the average cost to generation on the grid.

The SMS approach offers other advantages

1. **Speed** – SMSs can be dispatched within one minute, so the system can be used to smooth demand onto the grid – and replaces expensive "spinning capacity" i.e. expensive grid capacity that can be bought online in less than ten minutes.
2. Avoided transmission losses – the battery storage will reduce loads on the grid at high demand times by using the on-site battery, so transmission losses from the grid on this electricity will be zero. In extreme cases, where supply is obtained from far-off grids such DRC, losses can be 20% or 3 times average.
3. Awareness and time of use tariffs – this technology paves the way for time of use tariffs, where customers are charged based on when they use electricity, encouraging energy saving through a market mechanism.

8.8. Corporate social responsibility trust

A corporate social responsibility trust will be an important to marketing ANE to the government: The CSR budget will evolve over the following timeline:

Figure 59 – Corporate social responsibility budget raising and spending

Years 2-3	Years 4-6	Years 7-42
● 2% of capex injection from project funds ● Rollout of U-BEAP	● 1% of annual revenue funds ● Social carbon-funded projects such as solar cookers and carbon funded insulation	SCSR Trust receives 25% of free cash from the plant investing in: ● Pre-paid solar PV and solar water heating ● Repayments from the pre-paid solar will be invested directly into the community into: ● Education and use of IT in education ● Entrepreurship development ● Energy provision for social services ● Research into lowcost clean energy solutions for the poor such as waste heat and geothermal ● Clean water provision and desalination ● Tourism development

8.8.1 Universal Basic Electricity Access Programme (U-BEAP)

Portable solar packs –- Non-profit access to off-grid solar power – where every household that does not have electricity access is given a pack which comprises:

- A 20 watt portable solar panel, which can be taken down at night
- A small battery and charge controller
- A plug socket for a mobile phone to be recharged
- A socket for a small radio, which is to be included
- 100% carbon-funded insulation programme – funded by the voluntary carbon market

Figure 60 – The U-BEAP kit

The cost of 200,000 units at $50 each is $10 million, where it is estimated that a bulk discount of 50% from current unit purchase retail price will be achieved. This project comprises about 2% of the project capital value. It is proposed that this project be rolled out in the two year period on commissioning of the power station and is designed as an industrial offset commitment.

8.8.2 Pre-paid solar

Alluded to in the technology section, the majority of the population do not have a bank account, credit history or electricity. Some have electricity but no credit history so are on pre-paid. A solar PV roll-out and solar water heating roll-out is vital for these markets, so a pre-paid system will be created using a mobile banking platform, where the costs of using solar will be half of the cost of using on-grid electricity.

As the forecast credit recovery will be less than 50% of the revolving carbon fund, where bad debt ratios are estimated to be less than 5%, this cannot be funded on a commercial basis, so is funded on a grant basis through the community trust.

As with the solar water heating, electricity pre-payment proceeds will be re-invested into the community and will face community targets, so that there is peer-pressure to make payments. These pre-payments will fund the programmes mentioned in Figure 61 Corporate social responsibility disbursement plan below:

8.8.3 Reinvested corporate social responsibility funding

Figure 61 – Corporate social responsibility disbursement plan

U-BEAP	Pre-paid solar	Proceeds from pre-payments reinvested in community development
Industrial offset credit Universal access to basic electricity)	Solar PV – prepaid Pre-paid – solar water heating	Solar cookers Carbon funded insulation One laptop per child Water purification Permaculture Educational IT - school.net Entrepreneurship development Social media tourism strategy

After the U-BEAP project has been rolled-out in years 3 & 4 of the project – i.e. in the first two years after the plant has been commissioned, the CSR fund will invest in the following projects:

- Carbon funded insulation of building
- 60% funded solar cookers will also be offered, along with a solar cooker breadmaking entrepreneurship programme, which is estimated to create 1,000 jobs.
- A One-Laptop-per-Child roll-out, based on the $35 iPad-like device developed in India
- Water purification kits and solar water pumps to access underground water
- Permaculture and micro-climate development
- Entrepreneurship development programmes
- Social media tourism strategy

This programme offers vast social returns, over a two year period two-thirds of the population goes from having no electricity to having access to light at night, the ability to charge a cell phone, listen to the radio and be able to cook their food without wood – which costs over $1 per meal. It is also designed to cater for both peri-urban areas, where informal dwellings are not suitable for electricity access as well as traditional development strategy that focus more on sparsely populated rural areas.

A more detailed discussion and budgeting of this proposed programme is available to interested parties.

9. Rejected and delayed alternatives
Cross-subsidised multi-technology solar strategy

The initial hypothesis was to use inexpensive technology interventions such as solar water heating, better insulation, LED lighting to reduce residential and small business demand by 50%, to negate the inflationary effects of much more expensive utility-scale solar. In later years, solar PV on houses would make financial sense and could if credit risks could be managed, be a profitable private sector initiative, if the cost of debt was kept low.

On a top level, the following table gives an indication of forecast costs:

Technology	Timing of supply	Cost (levelised)	Volume
Nation-wide solar water heating strategy	Takes pressure off grid at key morning and evening slots.	US$0.05 per KWh, about 1/3rd of residential costs.	If 100,000 houses were installed with solar water heaters, with a 50:50 mix between 100 litre and 200 litres, peak demand could be reduced by as much as 100 MW, with 7%-6% reduction in electricity demand.
Energy savings such as LED lighting, better insulation, voltage control and boiler blankets	Residential consumption for heating and lighting tends to be in the morning and evening peaks – especially in the high demand winter season.	Less than the cost of solar water heaters, can largely be funded by voluntary carbon credits.	Can reduce household consumption by 1/6th, so together with SWH will halve electricity consumption in households, in theory enabling household electricity unit prices to double before absolute cost of electricity goes up.
Micro-generation in the form of on-grid solar PV with storage	Can store electricity to relieve the grid in peak times. Works well in the winter due to the low diffuse irradiation and summer rainfall climate.	Currently 40 USc per kilowatt hour for stored PV at low interest rates – assuming a lead acid battery with 1,000 cycles is depleted to 80%. The economics of higher quality batteries has similar effect on levelised cost of electricity.	Could eventually eliminate the 20% peak demand, so be a potent demand side management tool, especially if combined with GSM mobile phone technology, enabling this tool to manage short term fluctuations in demand.

Technology	Timing of supply	Cost (levelised)	Volume
Micro-generation in the form of off-grid solar PV with storage	Irrelevant to grid, but storage is vital especially if supporting critical social infrastructure such as health-care and clinics.	Same as above, except that it can be reduced by ground mounted wind and biomass. As it is competing with diesel generation, this is currently the cheapest supply option where it is affordable. The problem is that communities lack credit and income, so this solution is currently financially inaccessible to all but wealthy farmers, tourist facilities and grantfunded social infrastructure.	2/3rds of Namibian lack access to electricity, so the demand for this solution will be dependent on supply of capital.
Utility-scale PV plant without storage working in conjunction with a CSP plant with storage	PV will supply mainly during the day, but much during the critical morning peak demand period. The CSP will supply almost entirely during peak periods with 6 hours of storage – delivering 3 hours at peak capacity in the evening and 3 hours peak capacity during the day.	Very high – as this technology is not competing with retail, but wholesale rates, it is sadly hopelessly uncompetitive if financed conventionally – even with the generous subsidies it could attract – 30% of capital cost has been assumed in the model. The PV will cost about 15USc per KWh and the CSP over 33 USc per KWh – which is almost five times the limit of 8USc per KWh hour that we estimate NamPower can afford, even if it is being produced during peak periods.	90 GWh for the PV plant, excluding storage, 75 GWh with storage. The CSP plant will produce about 160 GWh. These will produce the majority of output during peak periods, so will comprise about 6% of total demand and at times as much as 15% of peak demand (in the mornings in winter).

Reasons for rejection – In theory this model would not result in any new energy inflation for consumers, the original constraint set by the electricity control board, as the solar water heating and energy savings initiative would halve household volumes, enabling the prices to double before impacting on electricity monthly bills. But in practice, this is politically unworkable for the following reasons:

1. Current electricity costs are unacceptably high to most households and needs to be reduced in absolute terms. The interventions suggested are needed to reduce electricity bills from current levels to half rather than doubling then reducing to current levels.
2. The proposals require low-cost finance that is not available to the levels required. The solar water heating initiative requires US$100 million and would not be suitable unless interest rates were set at 6% in local currency terms
3. Credit risk on most customers is not acceptable for a private financing initiative – only 10% of customers are likely to pass credit tests, so the proposal would leave the most vulnerable with higher energy costs, while only the richer households benefited from the subsidy – which is inequitable and politically unsustainable

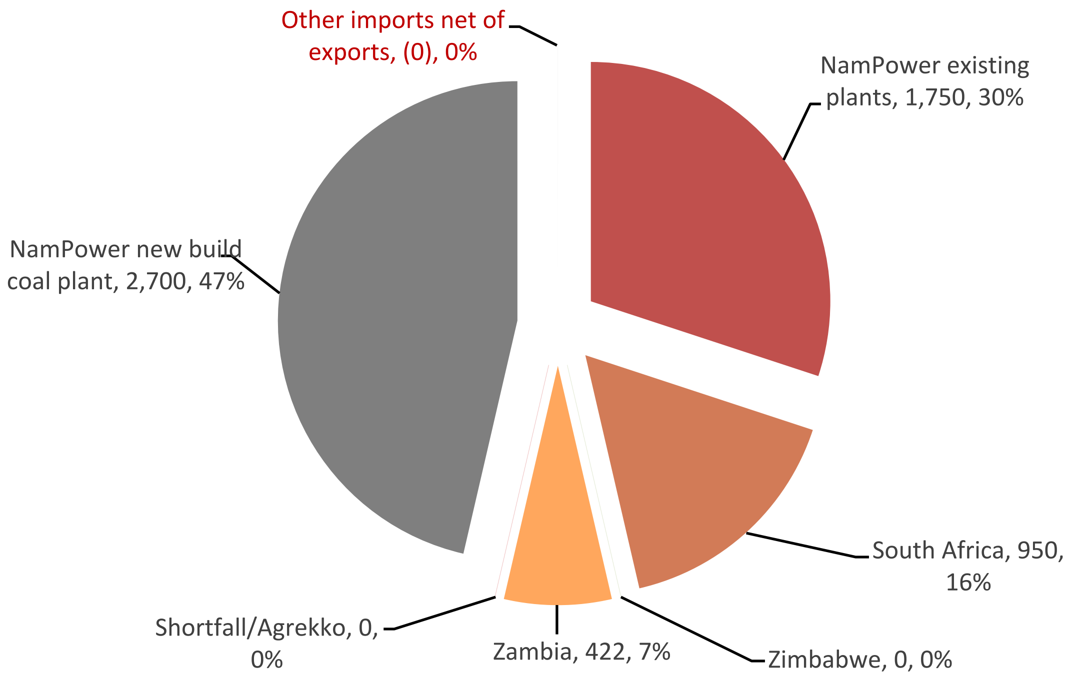
4. A capital asset should only be financed if the risk of destruction or theft can be transferred with low-cost insurance. The risk of theft of expensive solar infrastructure – particularly in remote rural areas is very real, and can only be addressed with the technology intervention mentioned in the previous section. This technology is not currently available.
5. The utility-scale subsidies required would be vast – about 75% of revenue. It is possible that a 30% grant could reduce levelised electricity costs by a quarter, but the micro-generation scheme would need to be water-tight enough to generate the cash to subsidise the remaining 50% of the "internal feed-in-tariff". In light of the low level of income, banking penetration and credit culture, this is not a reasonable assumption. NamPower and the Namibian government could not be expected to shoulder this burden, which is in excess of 0.5% of GDP for a 25 year period.
6. Utility-scale solar PV without storage would not be technical feasible without solar PV storage. Integration of utility-scale renewable plants onto the grid, is extremely technically challenging, vexing utilities all over the world. Wind and many solar applications do not currently have cost effective storage and also cause a host of technical problems that are listed below:
    - Communication – control and monitoring the performance of solar and wind farms
    - Protection of the transmission connection – unitised protection throughout
    - Voltage / reactive power control by the solar and wind farms
    - Low Voltage ride through capability
    - Fault level contribution
    - Ramp up / ramp down gradient
    - Tripping frequencies during island mode
    - Harmonics – filter requirements

These technical integration issues effectively make storage compulsory – tripling the cost of wind and doubling the cost of solar. The source of this list is the Shilimba presentation mentioned previously.

10. Impact of proposed solution

Without the ANE plant, Namibia faces sustained electricity shortages. As the entire sub-region faces electricity shortages, they need to build capacity in their own country. If they use Kudu gas (where they will need to use 70% of proven reserves over the life of the proposed plant) or a more expensive coal-fired power station – which is estimated to cost 50% more per KWh than Kudu, based on ANE's models – neither will be able to be built before 2016, so they face shortages of 25% of demand by 2015.

Figure 62 – Namibian electricity supply sources – 2021
Local coal-fired power station scenario

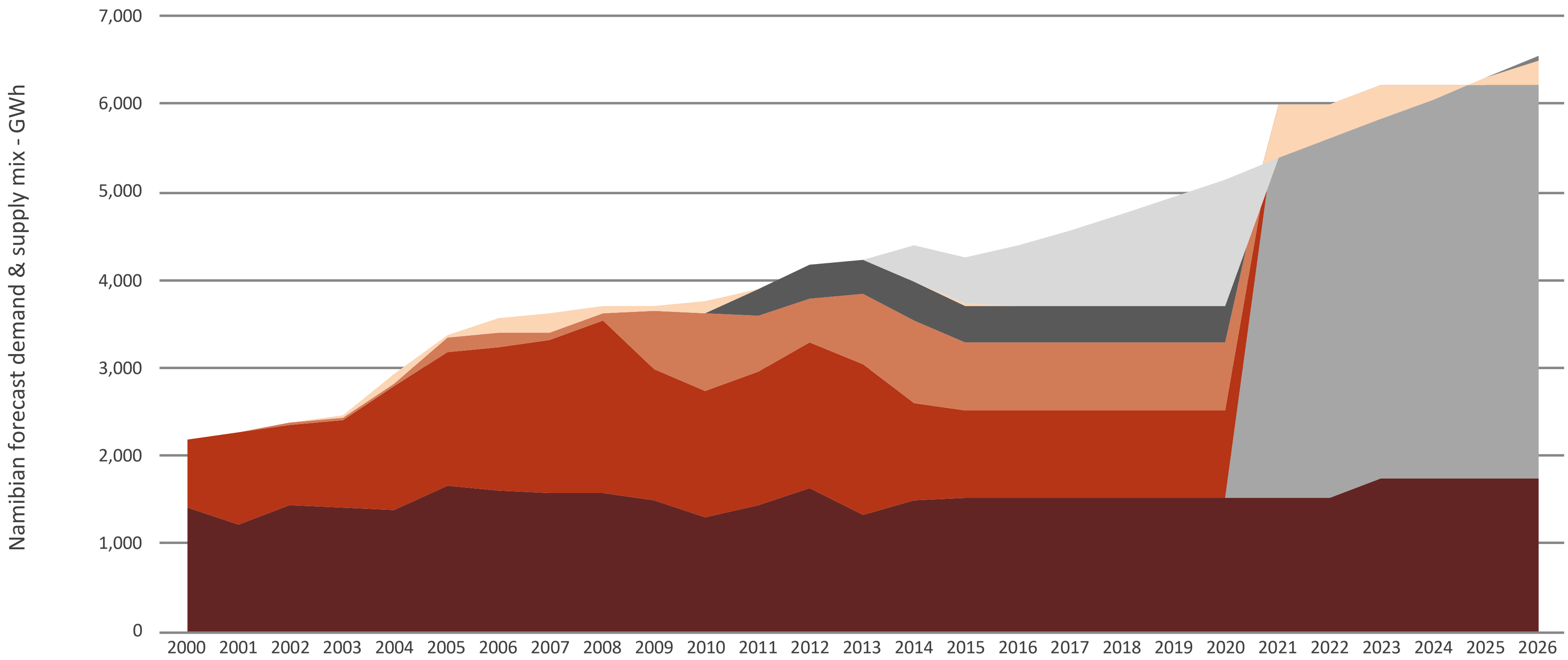


Short-term supply options for this shortfall are not appealing:

1. **Load-shedding** – which will have a negative impact on economic growth – based on the unserved cost of electricity in Uganda and Kenya, 25% load-shedding will reduce growth from +4% to – 7%, a net 11% contraction of the economy
2. **Delays in mining investment** until sufficient local power capacity is built – delaying the opening of the four major mining projects in the next three years will also have a disastrous impact on the benign country rating for mining investment and tourism, on which it is pinning its national development strategy.
3. **Emergency supply options:**
   a. Running the van Eck Power station at full capacity for the 120 MW needed which is so expensive it will wipe out NamPower's healthy cash balance in 2010 – marginal costs, due to the low efficiency are over 5 times the average generation cost of NamPower's baseload supply.
   b. Diesel power from Aggreko – this is extremely expensive and will require NamPower to be bailed out by the government. Costs are 20USc per KWh, double the marginal cost of van Eck.

10.1. Short-term Namibian electricity security

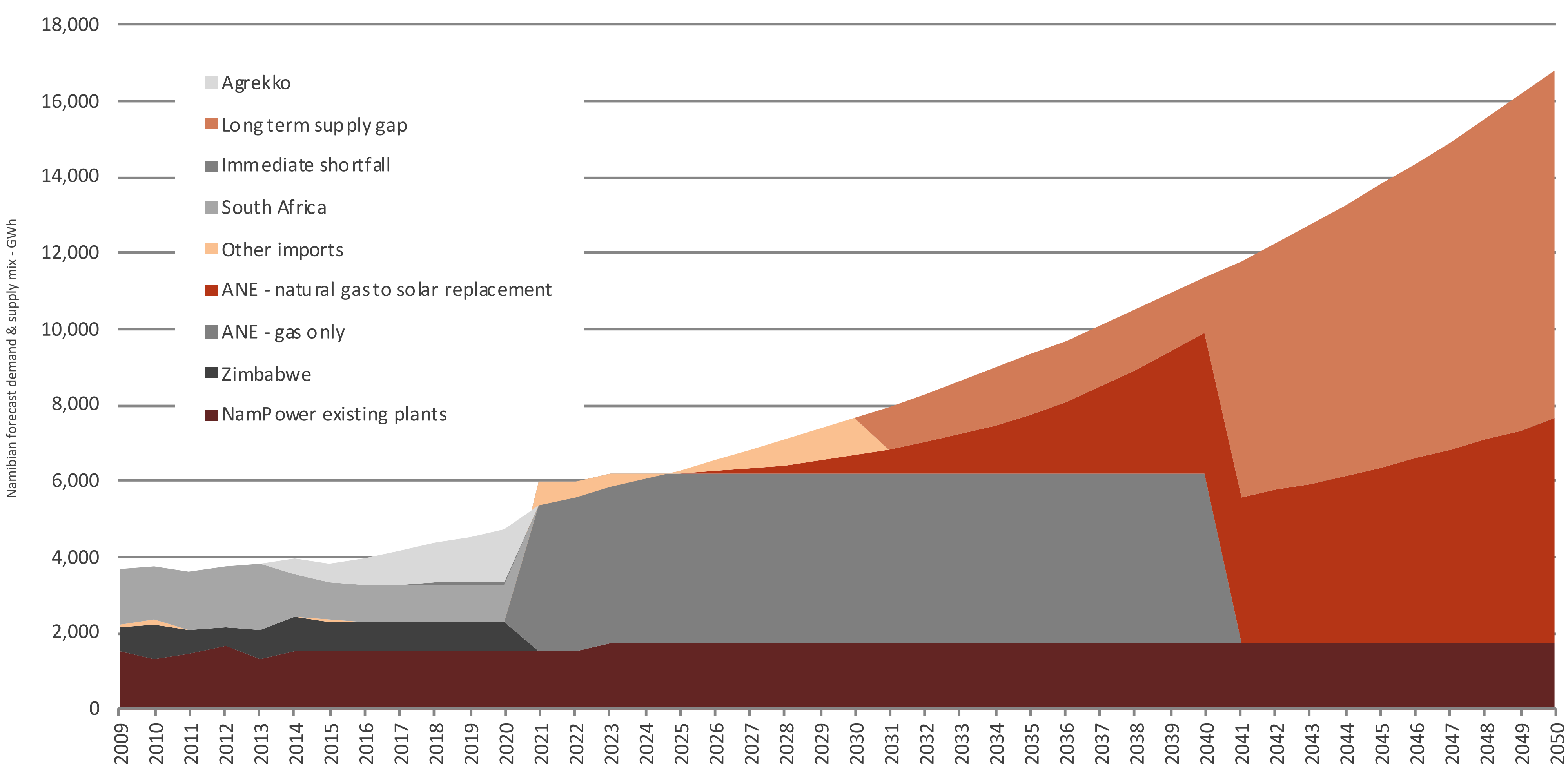
**Figure 63 – ANE Namibia Scenario – 2000-2026
300 MW natural gas combined cycle plant with CSP replacement**



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
ANE 1 - natural gas to solar replacement																						0	0	0	0	0	44
Agrekko												0	0	19	413	517	687	864	1,048	1,240	1,439						
Other imports	0	0	0	36	134	31	166	208	74	53	142	2	0	0	0	35	0	0	0	0	0	(622)	(407)	(396)	(163)	79	287
Zambia												319	378	389	420	422	422	422	422	422	422						
Zimbabwe	19	21	21	21	9	158	162	104	85	648	891	637	496	781	962	761	761	761	761	761	761	0	0	0	0	0	0
South Africa	766	1,045	921	988	1,423	1,514	1,620	1,733	1,961	1,501	1,429	1,522	1,645	1,718	1,091	982	982	982	982	982	982						
ANE - gas only	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4,468	4,468	4,468	4,468	4,468	4,468
NamPower existing plants	1,407	1,211	1,429	1,421	1,379	1,660	1,606	1,576	1,572	1,490	1,305	1,430	1,643	1,331	1,498	1,537	1,537	1,537	1,537	1,537	1,537	1,537	1,537	1,750	1,750	1,750	1,750

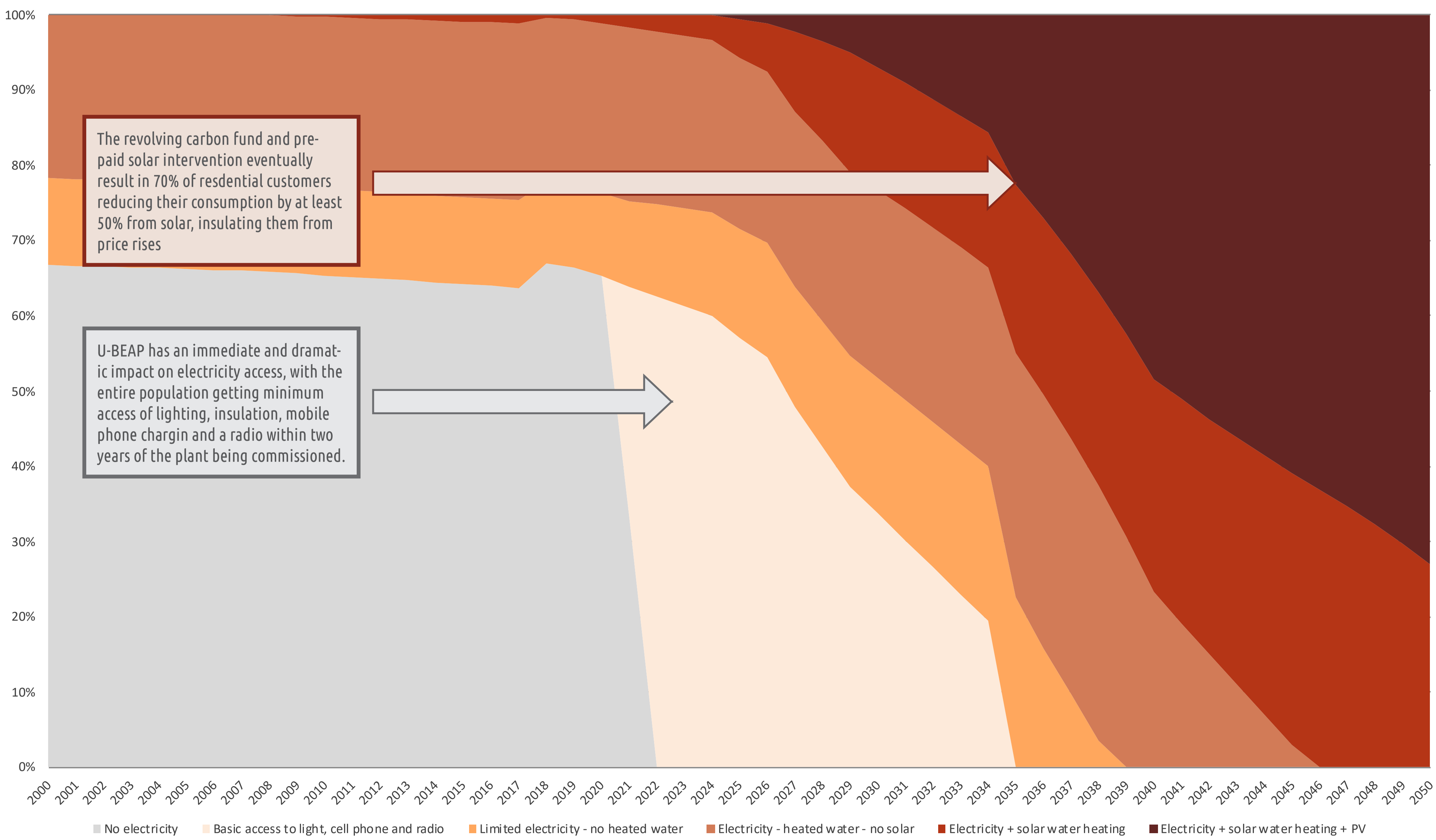
10.2. Long-term Namibian electricity security – 2000 - 2050

Figure 64 – ANE Namibia Scenario – 2009-2050
300 MW natural gas combined cycle plant with solar replacement



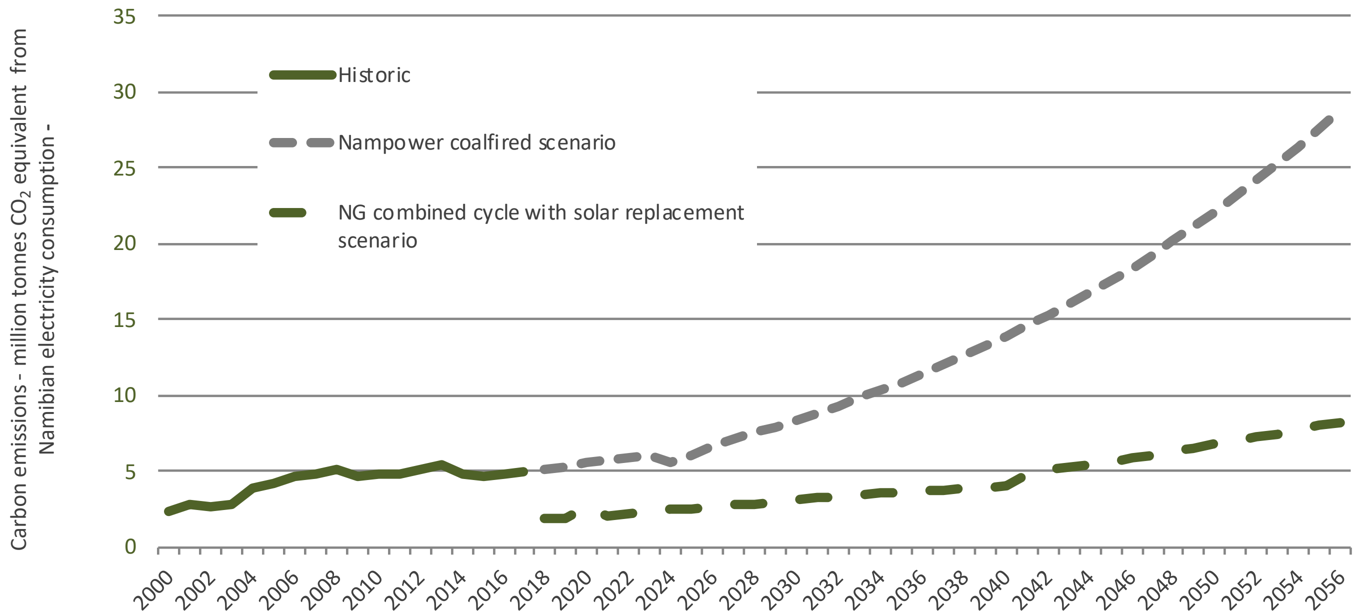
10.3. Universal electricity access

Figure 65 – ANE Carbon Trust – universal electricity access roll-out Namibia – 2000 – 2050



10.4. Carbon impact

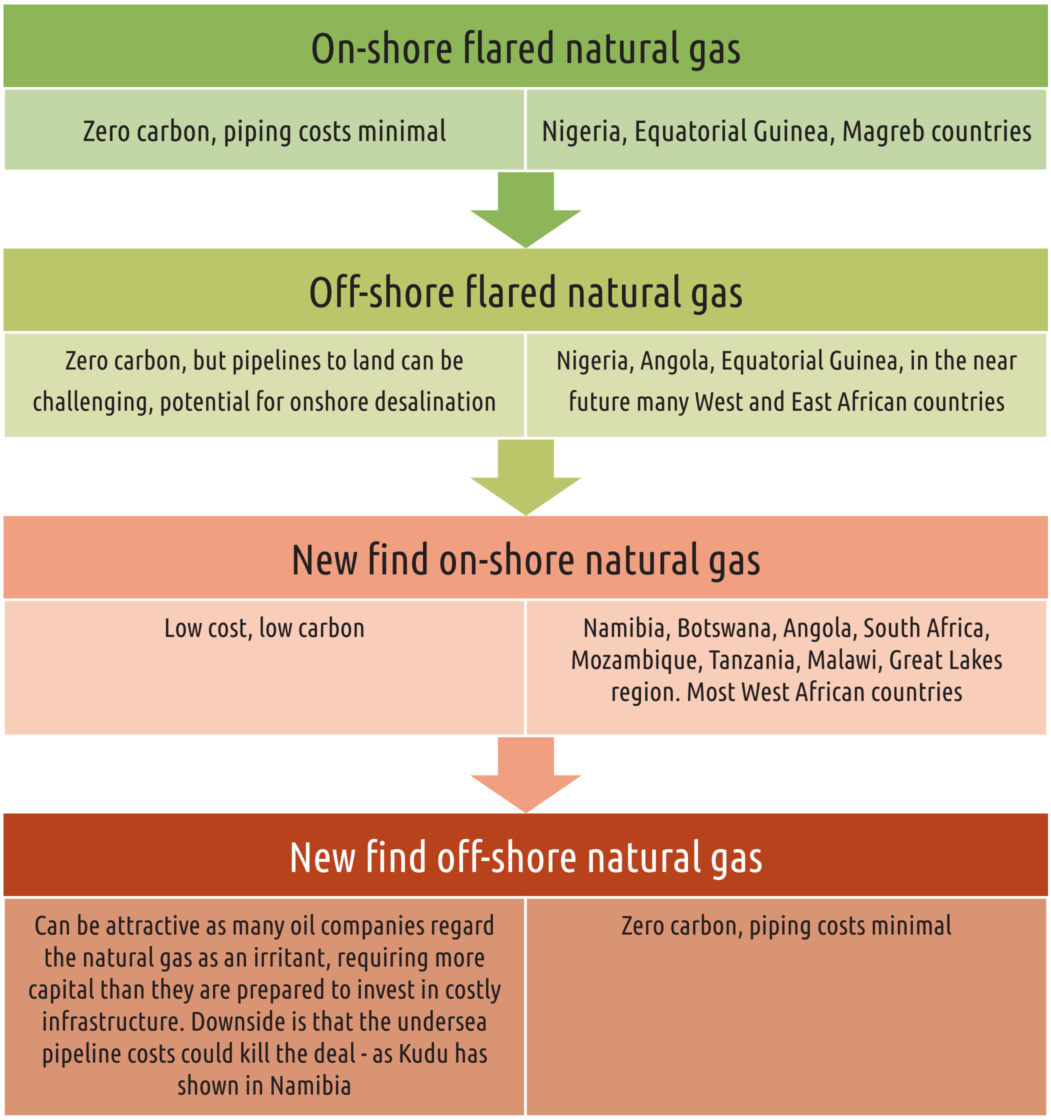
Figure 66 – Namibian electricity sector carbon emissions – 2000-2050
Coal-fired + imports vs Natural Gas scenario – worst case



11. Replicating the ANE development strategy into other African countries

This project depends entirely on the accessibility of "stranded natural gas" or some other thermal input, which has a lower price than if it could access the markets. So finding the natural gas or another thermal input is seminal to the successful roll-out of this project.

Figure 68 – Thermal inputs decision tree

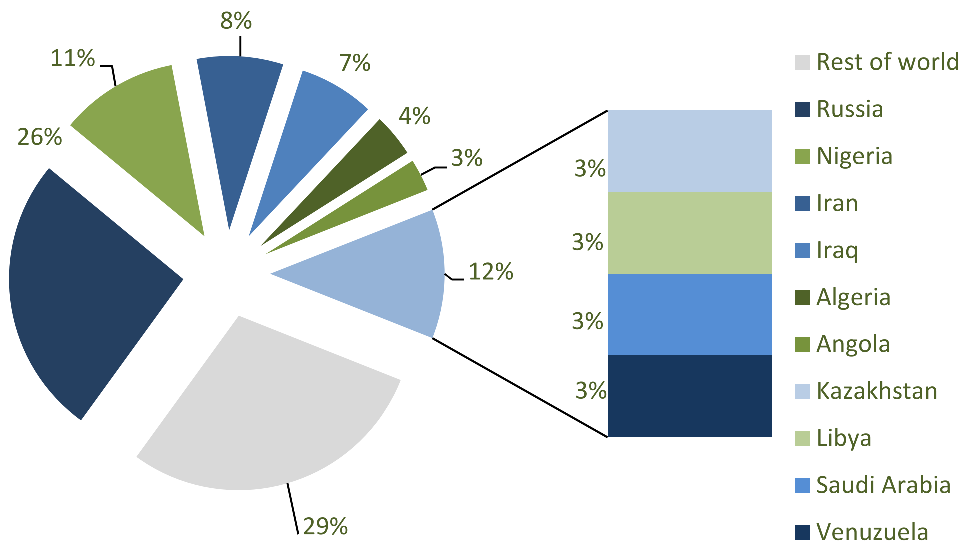


11.1. Flared natural gas

The opportunity lies in turning natural gas into market-ready gas-to-liquid (GTL) products, which requires a vast investment as well as substantial access to natural gas. Generally GTL plants cost about $2.5 billion dollars and require a minimum of 1 trillion standard cubic feet, while pipelines cost from $1-$2 million per kilometre on shore, and many times that offshore, so the investment required for the sale of natural gas is many times greater than that of oil. As a result, the vast majority of natural gas produced with oil is either flared or pumped back into the reserve to increase oil extraction rates. The World Bank estimated that over 7 trillion cubic feet of natural gas are flared each year. See below.[29]

29 The Global Gas Flaring Reduction Public Private Partnership - Estimated Flared Volumes from Satellite Data, 2006-2010 http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTOGMC/EXTGGFR/0,,contentMDK:22137498~pagePK:64168445~piPK:64168309~theSitePK:578069,00.html

Figure 69 – Top 10 countries where natural gas flaring is most prevalent
Africa is responsible for flaring 25% of the world's flared natural gas



Total flaring in Africa is over 7 trillion cubic feet per year. Nigeria flares about 800 billion cubic feet, while Angola flares over 200 million – about 70% of all natural gas extracted in the case of Angola. If these countries used 50% of the flared gas to generate electricity, they could dramatically increase their electricity production to both economies whose economies are severely hampered by their lack of infrastructure:

Figure 70 – Effect on electricity production if 50% of flared natural gasis converted – Nigeria and Angola

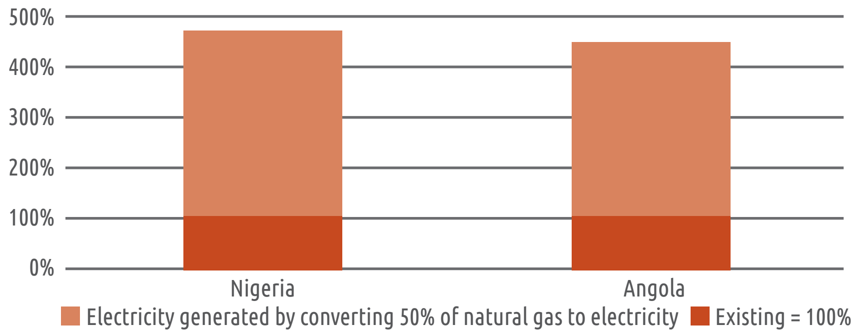


Figure 71 – Flared natural gas model inputs – Nigeria and Angola

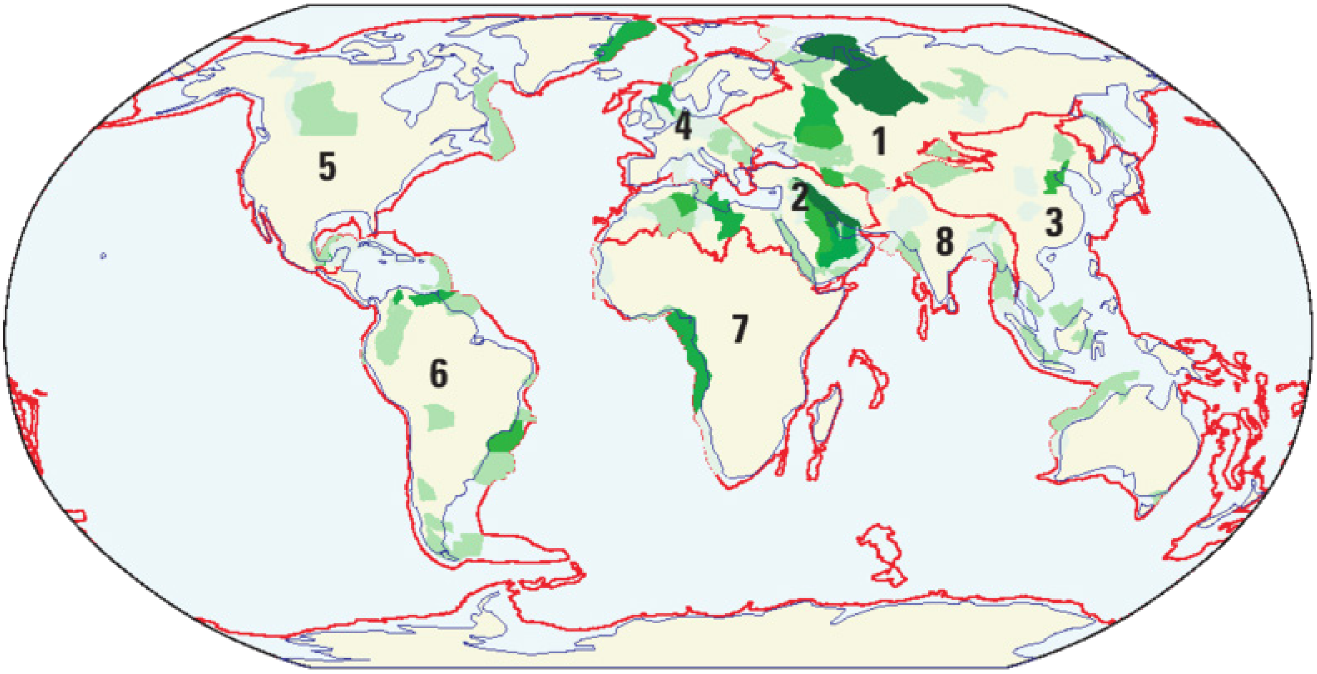
Model input	Nigeria	Angola
Natural gas volume currently being flared in billions of standard cubic feet (bscf)	Greater than 800 bscf	Greater than 200 bscf
50% of volume being flared – bscf	400 bscf	100 bscf
Potential electricity output – based on 60% thermal efficiency	52 TWh	14 TWh
Existing electricity generation	15 TWh	4 TWh
Percentage of existing generation the 50% of flared natural gas will add		

The capital cost of converting this natural gas into electricity is about $15 billion in Nigeria (assuming $2.00 per watt capital cost, which is three times the cost of Europe). This is less than ninety days of government oil revenues. Assuming each KWh of electricity increases $1 of GDP, this will grow Nigeria's economy by over $50 billion, from its $405 billion in 2016, increasing the size of the economy by 30%. This means that the payback in economic growth is less than 60 days, showing how starved the Nigerian economy is for electricity. Economic paybacks of electricity plants are usually counted in years, not days.

11.2. The potential to find smaller natural gas deposits in other African countries

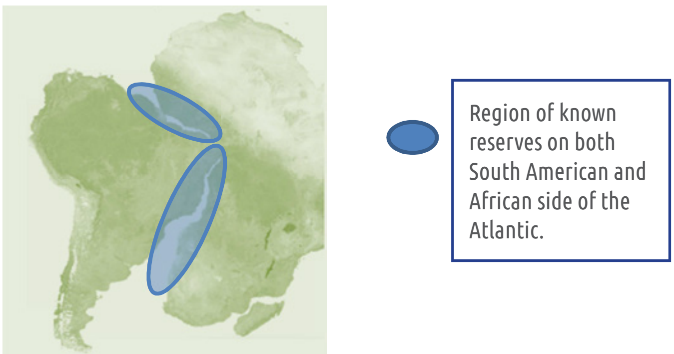
The graph below shows where the world's ***known*** giant oil and natural gas fields are:

Figure 72 – Oil endowment (cumulative production plus remaining reserves and undiscovered resources) for provinces assessed. Darker green indicates more resources.[30] United States areas are not included.



The shifting of continental plates explains the location of most of the world's giant oil fields. Indeed, much of Africa's production and known reserves lies off West Africa, and originated with the split of Gondwanaland from the Lower Jurassic to the Upper Cretaceous periods (200 million years ago until 40 million years ago). The vast new finds off Brazil are also explained by this phenomenon, as is interest in Namibia.

Figure 73 – The Gondwanaland split – 200 million years ago



30 Source US Geological Survey – Department of Interior published by Wikipedia – http://en.wikipedia.org/wiki/File:USGS_world_oil_endowment.png

Most exploration and production interest lies offshore. However there is every reason to believe that the tectonic plate movements within the African continent create the right conditions for the formation of large oil reserves.

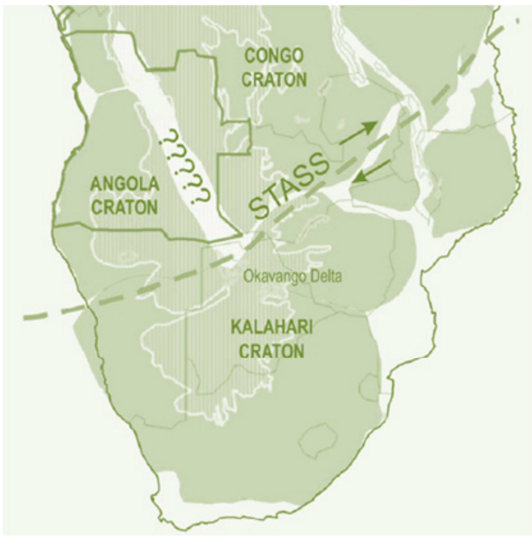
The following paper was produced by Dr Colin Reeves, a pioneering geophysicist, who was instrumental in collecting the first aeromagnetic survey of Botswana in 1974, and has worked on developing access to geological data in Africa for over four decades. His research leads him to believe that the movement between cratons – across Southern African, have significant potential for hydrocarbons, in the same way that reserves have been proved in Sudan and Chad.[31]

Hidden resources in Angola **– by Dr Colin Reeve**

"Almost all of Africa is underlain at depth by the Precambrian rocks that made up the supercontinent of Gondwana (Africa, South America, India, Australia and Antarctica) for about 350 million years from its formation at the end of the Precambrian to its eventual fragmentation about 180 million years ago (180 Ma). At times, several episodes of rifting – akin to what is currently happening in East Africa – spread through Gondwana. The Karoo rifting episode (300 to 200 Ma) was evident in southern Africa in many different ways."

"A major trans-Gondwana rift (STASS) stretched all the way from Namibia through Botswana, Zambia, Tanzania and into Somalia and was active in this period. Then, from about 180 Ma, the older parts of Gondwanaland began 'unwrapping' themselves clockwise from around what was to become Africa, starting in East Africa with Madagascar leaving Somalia in the Jurassic and ending with the opening of the South Atlantic Ocean in the Early Cretaceous. The development of the offshore petroleum resources that are now well-known on the South Atlantic margins was a consequence of this process."

Figure 74 – Tectonic fault lines in Southern Africa – STASS stands for Southern Trans-Africa Shear System



"There are good reasons to suppose that products of both the Karoo and the Cretaceous rifting episodes lie hidden below the Kalahari sand cover of eastern Angola. Clearly these rifts did not develop into oceans like the South Atlantic but they could still host resources in the way the currently active rift does in Uganda, for example."

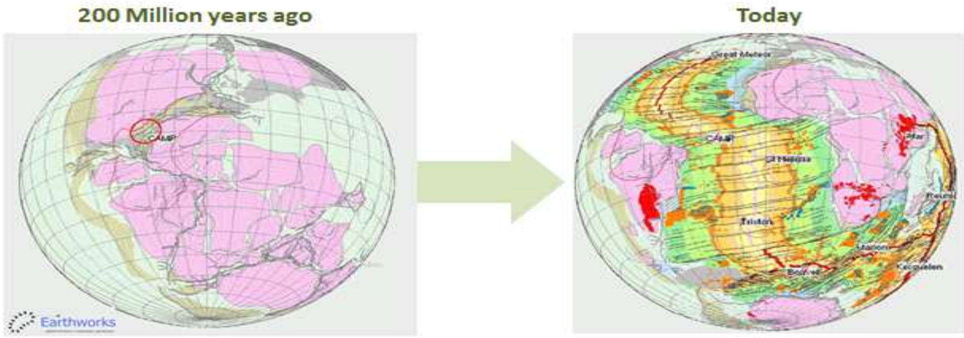
"A simple tectonic model divides the continental crust of Africa into strong 'cratons' that have defied fracturing and deformation and weaker zones between them where rifting has always tended to concentrate. The exposed Precambrian geology of west and central Angola forms one such craton and the possibility exists that a weak zone of rifting exists east of it, striking NNW from approximately the present-day Okavango delta to east of Luanda in Angola.

Tectonic activity on this feature could have occurred during the Karoo movements of the STASS, making the supposed eastern Angola rift an analogue of the Muglad rift in southern Sudan. Its orientation is also perfectly suited to reactivation during the earliest phases of rifting along the line of the South Atlantic Ocean itself. Both events hold potential for development of rift basins that could host hydrocarbon accumulations in eastern Angola. Any such rifts would now be hidden below the sand cover. In this way the structure would also be analogous to the oil-prone rift system that extends from Chad through CAR into Sudan and Kenya."

This is one of many potential lines of investigation that suggest that these fault lines across Africa will yield pockets of stranded natural gas in the same way that this investigation has shown in Namibia. The map below, also created by Dr Reeves shows the major cratons that form Africa, along which most have potential for natural gas.

31 *Hidden Resources of Eastern Angola* – Dr Colin Reeves – November 2011

Figure 75 – Tectonic fault lines in Africa



In conclusion, most countries in Africa have the potential to follow ANE's development strategy and where there is no gas to be found, the Southern African, East African, West African and Central African power pools and emerging gas pipelines – such as the West Africa Gas Pipeline – are making it possible for gas-less countries to benefit from that of their neighbours, fostering a climate of pan-continental economic co-operation.

12. Conclusion and recommendations

The African Innovation Foundation awarded ANE a grant to create a solar strategy for Namibia. In this study, a number of technologies and financing strategies were evaluated to arrive at the findings presented. The key finding was the a cross-subsidisation model, where cheaper solar water heating, household energy saving initiatives and micro-generation of PV subsidising a utility-scale roll-out of Concentrated Solar power and Solar PV Utility-Scale Farms, was not feasible. The use of Natural Gas to reduce initial capital costs and gradually replacing the natural gas with solar over a two-decade time period, was found to achieve foreign equity required returns, while saving NamPower on their cost of electricity. The structure also enabled a locally owned buy-out fund and a carbon trust to be created to finance the solar replacement and a nation-wide solar generation program.

Technology	Technical feasibility	Financial highlights	Feasibility
50 MW Concentrated Solar Power (CSP) Utility Scale Plant	Needs 6 hours of storage. Single cycle thermal efficiency only 37%. Uses 3.6 litres of water per KWh, which restricts it to just three areas	CapEx US$6.00 per watt, expected production 200 GWh. Levelised electricity cost (LEC) of US$0.30 per KWh based on WACC of 12%.	**Not financially feasible**. It is not in NamPower's financial interests to agree to replace an 7 USc Eskom imported supply with 30 USc per KWh.
50 MW Photovoltaic Utility Scale Plant	Only technically feasible with at least three hours of storage. Round-trip losses are 30% on stored electricity.	Capital cost US$2.50 for PV only, increasing to US$5.00 with storage. Will generate 75 GWh LEC = 33 USc per kWh.	**Not financially feasible**, and also cannot hedge FX risks, as PPA will be denominated in NA$, with debt in US$.
Solar Water Heating with carbon funded insurance and maintenance	Already 2,000 homes have it in Namibia. Excellent local installer base. Stores energy to save during morning and evening peaks.	A 100 litre system's target price is US$1,000, which will save 1,000 KWh per year costing 5 USc per KWh – 1/3rd of current residential rate.	**Financially feasible with carbon bank.** Saves customer 2/3rd of current cost on 30% of their electricity bill. Needs microfinancing innovation.
Residential and small business on-roof PV	Better for farms and small businesses than residential, due to greater daytime demands. Storage possible as are hybrids where wind and solar micro-generation are integrated with batteries.	Cost of 15 USc per KWh comparable to retail electricity, but storage adds 20 USc per KWh. Off grid is more competitive than ongrid, as is diesel genset replacement – which has an average cost of 28 USc per KWh.	**Financially feasible with carbon bank.** Possible to finance as bolt-on mortgage, especially with new builds. Big opportunity for carbon bank, but does need theft-proofing on PV systems.
Carbon funded energy saving interventions	Simple technologies in households such as insulation, solar cookers and LED lighting. Insulation and lighting require not changes in customer behaviour, while cookers do.	Most systems recover household energy costs in less than 6 months. E.g. solar cooker costs NA$500 after carbon and saves NA$8 per day for wood in peri-urban areas – payback 12 weeks.	**Financially feasible with carbon bank.** Insulation 100% carbon financed, solar cookers 60% carbon financed. LEDs can installed through a bolt-on mortgage.
Dry cooled gas-fired combined cycle power station with gradual solar conversion	Dependent on finding local inexpensive 500 bscf natural gas deposit. Water consumption zero. 85% capacity factor. 200 MW gas turbine, with 100 MW Rankin cycle using waste heat.	Capex including gas processing = $2.00 per watt, with 250MW plant delivering almost 2TWh per year. Investor US$ returns =35% with 5 year exit. Raises $6 billion over 40 year life for revolving carbon fund.	**Financially feasible with international financing package.** Use of MIGA, debt equity ratio 70/30. FX exposures can be hedged over 5 year debt exposure period.

There is a major, repeatable opportunity to use unwanted, stranded natural gas in Namibia's high potential oil exploration industry to give the sub-region affordable, locally produced electricity at a low cost – just 7 cents per KWh.

The free cash generated from the plant will be reinvested in utility-scale solar to gradually wean the plant of gas while investing in microgeneration. Over $5 billion will be available to be invested in solar over the life of the plant, as a result of a $500 million investment.

12.1. Key findings and recommendations

7. **The key to a national solar programme lies in the building of a combined cycle natural fired plant on a stranded natural gas source.** 600 billion cubic feet of feedstock will be sufficient to run a 300 MW plant for 40 years – delivering three times the volume of a 250 MW CSP plant – at one third of the capex. This new capacity will replace 80% of imports at just 7 cents per KWh – roughly the wholesale price NamPower will pay Eskom in 2012.
8. **The combined cycle gas plant can gradually be weaned off gas, with the thermal input replaced by CSP over a 20 year period.** After foreign debt has been repaid with international equity investors exiting their investment, the $6 billion of free cash generated over the remaining 35-year life of the plant, will be deployed to a revolving carbon fund, which will invest profits in micro-generation and energy saving.
9. **A national solar water heating programme is vitally needed by all stakeholders** – water tends to be heated by residential customers during peak demand times in the morning and early evenings. This electricity can cost NamPower 10-20 times that of baseload. More importantly, solar water heating will reduce household electricity demand by 30% at one third of the cost of the current electricity retail price. (5 USc per KWh vs. 15 USc).
10. **The cross-subsidy model proposed in the original proposal to fund utility-scale solar will not be politically possible as Namibia cannot afford to promulgate renewable energ y feed-in-tariffs in the way that Europe and South Africa have** – residential customers are struggling to pay bills at current levels, so will need interventions, such as carbon-funded insulation and solar water heaters to reduce the cost from current unaffordable levels. Just 80,000 of the 350,000 households in Namibia have access to electricity and almost half cannot pay for it at current prices. Forecast electricity price increases of 15% above inflation will hamper rural and peri-urban electrification.
11. **Off-grid solar will become increasing financially attractive** – especially if a low-cost storage solution can be found. Off-grid solar applications compete with higher residential rates of 15 USc per KWh vs generation rates of 4 USc per KWh and also help the customer to avoid the large premium needed to recover grid access costs in remote areas. NamPower will welcome a large-scale roll-out of off-grid solar, as they are seldom able to recover transmission investment into low population density areas.
12. There is an urgent need to use low-carbon interventions to support the energy needs of informal settlements and the rural poor. Namibia has 50% unemployment with half of the population subsisting in rural areas where less than 1% of the land is arable. Solar can play an important role in providing heating for these people in the form of solar cookers, largely paid for by carbon credits. Improved insulation can be funded 100% by securitisation of carbon credits.

12.2. Long-term benefits to Namibia

Local electricity security – the proposed 300 MW provision with 85% load factor, more than half of Namibia's current electricity needs and the extent of the supply gap in 2013. The cost of this natural gas to solar is estimated to be less than Eskom tariffs and 20% less than alternatives.

Foreign direct investment – over US$500 million will be invested in Namibia, with a crosscommodity subsidy package to assist the country with balance of payments challenges that may result from this investment – ANE is proposing that the power purchase agreement be an inflation-linked Namibian-dollar based contract.

An export opportunity for the Namibian Power Services Sector – This use of stranded natural gas, with a carbon-fund is readily replicable – and needed throughout Africa, and Namibians, who participate in the supply of this project, will be well placed to export their skills to other African countries, virtually all of whom face supply challenges in the short and medium-term.

Universal electricity access – the first corporate social responsibility project will ensure that within two years of the plant being operational, that every Namibian household, especially those in peri-urban and rural areas, get access to light, the ability to charge a mobile phone and a radio within two years.

Local ownership of a vital asset will boost local financial institutions as they get the opportunity to finance a large-scale asset with stable, profitable cashflows, while the local ownership model will give rise to local entrepreneurs with capital to re-invest locally.

Corporate social responsibility – the carbon trust will provide finance for universal access to electricity, raising and investing over $6 billion (in 2010 US$) over the combined 40-year life of the project.

13. References and source data

13.1. Interviews, telephone conversations, and meetings

The authors would like to thank, in no particular order, the following for their time and advice on many telephone calls, emails and meetings, without which this research paper would never have happened.

The entire Board of the Electricity Control Board of Namibia

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Mr Conrad Roedern, the founder and CEO of Solar Age, one of Namibia's most respected solar energy companies

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14. Glossary of terms

14.1. Abbreviations

bscf	Billion Standard Cubic Feet of Natural Gas
bscfd	Billion Standard Cubic Feet of Natural Gas per day
C&I	Control and instrumentation
CDM	Clean development mechanism
CFL	Compact fluorescent lamps
CO_2	Carbon dioxide
CPI	Consumer price index
CSI	Corporate social investment
CSP	Concentrating solar power plant
CV	Calorific value
DSLI	Distribution supply loss index
EAF	Energy Availability Factor . the ratio of the available energy generation over a given time period to the reference energy generation over the same time period
EAP	Economically active population
EBITDA	Earnings before interest, tax, depreciation and amortisation
EIA	Environmental impact assessment
EMPs	Environmental management plans
EMS	Environmental management system
FBE	Free basic electricity of 50kWh/month to assist low-income households (RSA)
FGD	Flue gas desulphurisation
FPM	Fine particulate matter
GDP	Gross domestic product
GHG	Greenhouse gas
GPS	Global positioning system
GWh	Gigawatt hour (1 000MWh)
HVAC	Heating, ventilation and air conditioning optimisation
HVDC	High-voltage direct current
IFRS	International Financial Reporting Standards
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent power producer
IRM	Integrated risk management
KPI	Key performance indicator
kt	kilotons (1 000 tons)
kWh	kilowatt-hour
kWh	SO kilowatt-hour sent out
LEC	Levelised cost of electricity also LCOE
LME	London Metals Exchange
LTIR	Lost-time incidence rate

LED	Light emitting diode lighting
LNG	Liquefied Natural Gas
m3	Cubic metres
MMI	Monthly moving index
MMBTu	Million British thermal units - equivalent to the energy of 100 cubic feet of natural gas
Mscf	One thousand standard cubic feet of natural gas
Mscfd	One thousand standard cubic feet of natural gas per day
MMscf	One million standard cubic feet of natural gas
MMscfd	One million standard cubic feet of natural gas per day
MW	Megawatt
MWh	Megawatt-hour (1 000kWh)
ML	Megalitre (1 000 000 litres) or 1 cubic meter of water
mSv	Millisievert - measurement of radioactivity
MVA	Mega volt ampere
MYPD	Multi-year price determination
NG	Natural gas - comprised mainly of methane
NGO	Non-governmental organisation
NO_2	Nitrogen dioxide
Nox	Nitrogen oxide
N_2O	Nitrous oxide
OCGT	Open cycle gas turbine
OCLF	Other capability loss factor. Unplanned losses not under management control, i.e. weather
OEM	Original equipment manufacturer
OMS	Outage management system
PBMR	Pebble bed modular reactor
PCP	Power conservation programme
PCLF	Planned capability loss factor. Ratio of the energy not produced over a given time period, due to planned shutdowns, to the maximum amount of energy which could be produced over the same time
PV	Photovoltaic
RED	Regional electricity distributor
RSLI	Reticulation supply loss index
SADC	Southern African Development Community
SAIDI	System average interruption duration index
SAIFI	System average interruption frequency index
Sapp	Southern African Power Pool
SHEQ	Safety, health, environment and quality
SMME	Small, medium and micro enterprises
SME	Small and medium enterprises
SOE	State-owned enterprise
SO_2	Sulphur dioxide
SO_3	Sulphur trioxide

SWH	Solar Water Heating
Tcf	Trillion cubic feet of natural gas – also called a quad
TOU	Time-of-use (tariff)
UCF	Unit capability factor
UCLF	Unplanned capability loss factor. Ratio of the unplanned energy losses over a given time period to the maximum amount of energy which could be produced over the same time period
ULM	Utility load manager
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
VAT	Value added tax
ZLED	Zero liquid effluent discharge

14.2. Key power generation terms

AC Power (Alternating Current)	An electrical current whose magnitude and direction varies continuously and sinusoidally. AC is the form in which electricity is delivered to businesses and residences. It can be thought of as "standard" electrical power.
Ampere (Amp)	A unit of measure that indicates how much electricity, or electrical current, is flowing through the system's wires.
Anticline	An anticline is an area of the earth's crust where folding has made a dome like shape in the once flat rock layers. Anticlines often provide an environment where natural gas can become trapped beneath the earth's surface, and extracted. See also Traps, Faults, Permeability, and Porosity.
Arrear debts as a percentage of revenue	total arrear debts/total revenue multiplied by 100.
Base-load plant	Base-load power stations, largely coal-fired and nuclear, are designed to operate continuously
Bcf - Billion Cubic Feet	Gas measurement approximately equal to one trillion (1,000,000,000,000) Btu's. See also Mcf, Tcf, Quad.
Black start	A black start is the process of restoring a power station to operation without relying on the external electric power transmission network.
Block	A lease or a number of leases of adjoining tracts of land that constitute a unit of acreage sufficient to justify the expense of drilling a wildcat. In Namibia, blocks are divided into 1 degree latitude by 1 degree longitude blocks, with an area of approximately 10,000 square kilometres.
Bright spot	On a seismic section, coda that have high amplitudes due to a formation containing hydrocarbons.
Brine	Brine is a kind of sedimentary rock found near shores. It is composed of the shells of many sea creatures that have formed a layer of sediment, which then formed a layer of rock. It often contains a large amount of salty water.
Btu - British Thermal Unit	The Btu is a unit of measurement for energy. It represents the amount of heat that is necessary to raise the temperature of one pound of water by 1 degree, Fahrenheit. There are approximately 1000 BTU of energy in a standard cubic foot of gas - see conversion table.
Bundled Service	Gas sales service and transportation service packaged together in a single transaction in which the pipeline, on behalf of the utility, buys gas from producers and then delivers it to the utility. See also, Unbundled Services.
Capacity payment	Capacity payments ensures that the generator covers all its fixed costs and makes a regulated profit even if it does not get dispatched. Normally, the capacity payment is made to the generator for every kW it has declared available for use (either to generate electricity or to provide ancillary services) over a certain time period.

Carbonate Rock	A rock consisting primarily of a carbonate mineral such as calcite or dolomite, the chief minerals in limestone and dolostone, respectively.
Casing	A casing is used to line the walls of a gas well to prevent collapse of the well, and also to protect the surrounding earth and rock layers from being contaminated by petroleum, or the drilling fluids.
Cathodic Protection	Cathodic protection refers to the method of preventing corrosion in metal structures that involves using electric voltage to slow or prevent corrosion. It is used along natural gas pipelines, as well as in certain bridges or other large metal structures that need to resist corrosion over an extended period of time.
CFC's Chlorofluorocarbons	Chlorofluorocarbons - often abbreviated to CFC's. These gaseous compounds are used for cooling, but are being rapidly replaced by new materials because their release into the atmosphere has produced ozone depletion. See also HCFC's.
Chance of success	An estimate of the chance of all the elements (see above) within a prospect being present to make it commercially viable, described as a probability. High risk prospects have a less than 10% chance of working (P10), medium risk prospects 10-20% (P10-P20), low risk prospects over 20% (>P20). Typically about 40% of wells recently drilled find commercial hydrocarbons, however firms such as Tullow oil have a success rate of 85%, through the use of seismic technology in conjunction with other more recent exploration innovations such as using satellite, magnetic and gravity survey data.
Christmas Tree	A Christmas Tree, when referring to gas production, is the term given to the series of pipes and valves that sits on top of a producing gas well. Since some gas wells have natural lift because of the high pressures underground, they don't require an artificial pumping mechanism to produce the gas. In these cases, a Christmas Tree is used in place of a pump to extract the gas from the well.
Citygate	A location at which custody of gas passes from a gas pipeline company to an LDC.
Clawback	The actual over-recovery against that allowed by regulator in the multiyear price determination or even under-recovery whereby the power producer will claw back.
Coal Bed Methane	Prior to the mid-1980's, methane from coal seams was classified as an uneconomic resource - one of vast potential, but low value due to poor recovery rates and high associated water production. By applying new production technologies to this resource, coal bed methane has become the single largest new source of gas supply in the past decade. Current estimates show approximately 100 Tcf of coal bed methane that appears to be economically recoverable in the lower 48 states alone. Coal bed methane provided the USA with 8% of its natural gas production in 2009, up from zero in 2005. There are two companies applying for coal bed methane licenses in Namibia
Combined cycle gas turbine	A technology for producing electricity from otherwise lost waste heat as it exits from one or more gas (combustion) turbines, increasing thermal efficiency from 42% to up to 60%. I.e. of every unit of thermal energy input to the process in the form of natural gas, 60% is converted to electrical energy.
Compression	Natural gas is compressed during transportation and storage. The standard pressure that gas volumes are measured at is 14.7 Pounds per Square inch (psi). When being transported through pipelines, and when being stored, gas is compressed to save space. Pipelines have compressing stations installed along the line (one about every 100 miles) to ensure that the gas pressure is held high while the gas is being transported. Current pipelines can compress natural gas to nearly 1500 psi, but most tend to operate at closer to 1000psi.
Concentrated solar power	Converting solar irradiation (or sunlight) into thermal energy using mirrors that then concentrate the heat onto an absorber tower (Power Tower) or using parabolic troughs to project onto an absorber tube. The thermal energy is transferred via an anabolic hydrocarbon or water vapour to run a Rankin Turbine, which converts the water vapour into kinetic energy to drive the turbine, which turns this kinetic energy into electrical energy. Most concentrated solar power plants are utility scale, which means they are generally more than 5MW. They can be attractive, as they include an efficient mechanism to store thermal energy with just 6% round trip losses.
CSST	Corrugated Stainless-Steel Tubing - Flexible piping used to install gas service in residential and commercial areas.

Cubic Foot	A unit of measurement for volume. It represents an area one foot long, by one foot wide, by one foot deep at air pressure at sea level at a benign ambient temperature (between 15 degrees and 20 degrees Celsius). Natural gas is measured in cubic feet, but the measurements are usually expressed in terms of Bcf, Tcf, Mcf, or Quads. The energy contained in a cubic foot of natural gas is approximately 1,000 BTu.
Cutting	A cutting is a piece of rock or dirt that is brought to the surface of a drilling site as debris from the bottom of well. Cuttings are often used to obtain data for logging.
Daily peak	The maximum amount of energy demanded in one day by electricity consumers.
DC Power (Direct Current)	An electrical current whose magnitude and direction stay constant. The photovoltaic cells on solar panels capture energy from sunlight in the form of DC. In order to power a home or business, this current must be converted to AC by an inverter.
Debt service cover ratio:	Cash generated from operations/(net interest paid plus debt repaid (both capital and interest payments).
Debt: equity including long-term provisions:	net financial assets and liabilities plus non-current retirement benefit obligations and noncurrent provisions divided by total equity.
Decommissioning	Removing a facility (e.g. a reactor) from service, and subsequent actions of safe storage, dismantling and making the site available for unrestricted use.
Delivery or Receipt Point	Designates the point where natural gas is transferred from one party to another. The city gate is the delivery point for a pipeline or transportation company because this is where the gas is transferred to the LDC.
Demand-side management (DSM)	Planning, implementing and monitoring activities to encourage consumers to use electricity more efficiently, including both the timing and level of electricity demand.
Development phase	The phase of petroleum operations that occurs after exploration has proven successful, and before full-scale production. The newly discovered oil or gas field is assessed during an appraisal phase, a plan to fully and efficiently exploit it is created, and additional wells are usually drilled.
Dip	A layer's dip refers to the angle at which it lies in relation to a flat line at the surface. Most layers of rock do not lie flat because they have been folded one or more times throughout their history. The dip of a rock layer can tell a geologist important information that could help locate possible petroleum traps.
Dry hole	An exploratory well that is sunk and where there are not sufficient, easily reachable hydrocarbons to justify further investment. Sometimes the term is used to describe a formation that contains brine instead of oil, one of the most common causes of dry wells being drilled, as seismic data has a poor track record of differentiating between brine and hydrocarbons. Other technologies such as magnetic telluric are able to avoid this, reducing the probability of sinking a dry well by 60%, when both sets of tests are done.
Dynamic reactive capacity	Reactive power exists in an AC circuit when the current and voltage are not changing at the same time and is measured in volt ampere reactive – var. The integration of renewables, along with large customers such as mines, who can have low power factors, makes frequency synchronisation more challenging and therefore causes more losses. Dynamic reactive capacity, increases the power factor on the grid and therefore reduces losses. This is a potential revenue source of renewables, as modern inverters usually come with dynamic reactive capacity.
Dutch Disease	In economics, Dutch disease is a concept that purportedly explains the apparent relationship between the increase in exploitation of natural resources and a decline in the manufacturing sector. The claimed mechanism is that an increase in revenues from natural resources (or inflows of foreign aid) will make a given nation's currency stronger compared to that of other nations (manifest in an exchange rate), resulting in the nation's other exports becoming more expensive for other countries to buy, making the manufacturing sector less competitive. As the Namibian Dollar is linked to the South African Rand, with the South African economy 30 times the size of Namibia, it is argued in this paper that Namibia will not be affected by Dutch Disease.
EBIT	Earnings before interest and tax (before profit/loss on embedded derivatives).

EBITDA	Earnings before interest, tax, depreciation and amortisation.
Electric Panel	An electrical distribution board that houses electrical circuit breakers. It is the main point at which electricity is distributed throughout a building. It is otherwise known as a breaker box or electrical cabinet.
Electrical Current	The flow of charged electrons through a circuit. Depending upon its behaviour, an electrical current can be alternating or direct (AC or DC).
Electricity operating costs per kWh	Primary energy costs, net transfer pricing, employee benefit cost, depreciation and amortisation plus impairment loss and other operating expenses)/external sales in kWh.
Electricity revenue per kWh	Electricity revenue including environmental levy/kWh sales total.
Electronic Bulletin Board (EBB)	An electronic bulletin board (in the context of the natural gas industry) is an electronic service that provides information about pipeline company rates, available capacity on lines, confirmation of delivery and so forth.
Embedded derivative	A financial instrument that causes some or all cash flows that would otherwise be required by a contract to be modified according to a specified variable such as a currency.
Energy availability factor (EAF)	A measure of power station availability taking account of energy losses not under the control of plant management and internal non-engineering constraints.
Energy efficiency	Programmes to reduce energy used by specific end-use devices and systems, typically without affecting the services provided.
Exploration	The search for reservoirs of oil and gas, including aerial and geophysical surveys, geological studies, core testing, and drilling of wildcats.
Exploration well	A well drilled in an area where no oil or gas production exists. See also test well or Wildcat.
Fault	A fault occurs when a part of the earth's crust fractures due to forces exerted on it by movement of plates on the earth's crust. Faults often occur along with earthquakes that result from the rapid movement of the plates against one another. Faults can have movement that is horizontal or vertical, and they can be classified as normal or reverse. With regard to natural gas, faults are of interest because they often form traps.
Firm Service Contract	A type of contracted service where the distributor agrees to provide the buyer with uninterrupted supply of gas. This type of contract is usually more expensive, and is used primarily by those firms who cannot afford to risk loss of fuel for any period of time. See also Interruptible Service.
Flashover	Electrical insulation breakdown.
Flat spot	An oil-water contact on a seismic section; flat due to gravity.
Forced outage	Shutdown of a generating unit, transmission line or other facility for emergency reasons or a condition in which generating equipment is unavailable for load due to unanticipated breakdown.
Formation	A formation refers to either a certain layer of the earth's crust, or a certain area of a layer. It often refers to the area of rock where a petroleum reservoir is located.
Fossil Fuel	Fuels that are derived from natural resources, usually in the form of coal, oil, or natural gas. There is a limited supply of these resources, and they are only located in certain parts of the world, making them subject to political and international manoeuvring, and causing energy prices to be unstable.
Fracturing or fracking	Fracturing - sometimes called "fracking" - refers to a method used by producers to extract more natural gas from a well by opening up rock formations using hydraulic or explosive force. Advanced fracturing techniques are enhancing producers' ability to find and recover natural gas, as well as extending the longevity of older wells. However the fracking process is regarded as environmentally dangerous, as the chemicals are extremely toxic, which could result in ground water supplies being contaminated, methane escaping and while the high pressure jets of water increase seismic activity within fracking vicinity.
Free basic electricity (FBE)	Amount of electricity deemed sufficient to provide basic electricity services to a poor household

Fuel Cell	Fuel cell technology is one of the most exciting and environmentally sound advances in Natural Gas technology. These cells were first used by NASA in the 1960's for power generation in space capsules. The high price of fuel cell technology has limited the growth of their implementation, but now cells are being used to generate power in hospitals, and soon vehicles may employ this technology. Fuel cells rely on the chemical interaction of natural gas and certain other metals, such as platinum, gold and other electrolytes to produce electricity. The only by product of a fuel cell's operation is water, which is pure enough to drink.
Funds from operations (FFO) as a percentage of gross debt:	Funds from operations/gross debt multiplied by 100.
Funds from operations (FFO):	Cash generated from operations adjusted for working capital (excluding provisions) and net interest paid/received, dividends received and non-current assets held for risk management.
FVF	Formation volume factor - oil shrinks and gas expands when brought to the surface. The FVF converts volumes at reservoir conditions (high pressure and high temperature) to storage and sale conditions.
Gini Co-efficient	The Gini coefficient is a measure of the inequality of a distribution, a value of 0 expressing total equality and a value of 1 maximum inequality.
Greenhouse Gases	Gaseous components in the atmosphere that contribute to a gradual warming of the planet. The most prevalent of these gases is carbon dioxide, which is released in large quantities when fossil fuels are burned. Nothing is burned to convert sunlight into power. Since solar energy does not have any gaseous by-products, it is considered "clean."
Grid Connected System	A solar system connected in parallel with the electric utility grid.
Gross debt/EBITDA	gross debt/earnings before interest, tax, depreciation and amortisation.
Gross debt:	debt securities issued, borrowings, finance lease liabilities and financial trading liabilities plus the after-tax effect of: retirement benefit obligations and provisions for power station-related environmental restoration and mine-related closures.
Gross Domestic Product	The value of economic output of an economy – calculated by the expenditure method as private consumption PLUS gross investment PLUS government spending PLUS (exports MINUS imports)
Ground Mounted Systems	A solar system that is not attached directly to a building, but is supported by a structure that is built low to the ground. Ground mounts are ideal for sites with limited roof space and a lot of open land.
GRV	Gross rock volume - amount of rock in the trap above the hydrocarbon water contact.
HCFC's – Hydrochlorofluorocarbons	Hydrochlorofluorocarbons, or HCFC's to most, are gaseous compounds that meet current envi ronmental standards for minimizing stratospheric ozone depletion. See also CFC's.
Horizontal Drilling	Horizontal Drilling, heralded today as "causing the greatest change in the industry since the invention of the rotary bit," is the most rapidly growing movement in the petroleum industry. Essentially, in addition to the vertical shaft in an oil or gas well, special equipment allows producers to extend horizontal shafts into areas that could not otherwise be reached. This technique is especially useful in off shore drilling, where one platform may service many horizontal shafts, thus increasing efficiency. Horizontal wells can be categorized as short (extending only 20-40ft from vertical), medium (300-700ft from vertical) or long (1000-4500ft from vertical) radius. The larger radius wells are typically found off-shore.
Hydrocarbon	An organic compound containing only carbon and hydrogen. Hydrocarbons often occur in petroleum products, natural gas, and coals.
Hydrocarbon in place	Amount of hydrocarbon likely to be contained in the prospect. This is calculated using the volumetric equation - Gross Rock Volume (GRV) x Net Gross ratio (N/G) x Porosity x Hydrocarbon saturation (Sh) x Formation Volume Factor (FVF).
Independent power producer (IPP)	Any entity, other than a state owned utility, that owns or operates, in whole or in part, one or more independent power production facilities

Independent Producer	The basic definition of an Independent Producer is a non-integrated company which receives nearly all of its revenues from production at the wellhead. They are exclusively in the exploration and production segment of the industry, with no marketing or refining within their operations. The tax definition, published by the IRS, states that a firm is an Independent if its refining capacity is less than 50,000 barrels per day in any given day or their retail sales are less than $5 million for the year.
Interconnection	The link between the utility company and a building that enables power to move seamlessly in either direction.
Interest cover	operating profit before net finance cost/(net finance cost but before unwinding of discount on provisions, change in discount rate and borrowing cost capitalised).
International financial reporting standards (IFRS)	Global accounting standards that require transparent and comparable information in general purpose financial statements issued by the International Accounting Standards Board.
Interruptible load	Load that can be interrupted in the event of capacity or energy deficiencies on the supply system.
Interruptible power	Power whose delivery can be curtailed by the supplier, usually in agreement between the state owned utility or independent power producer and the customer.
Interruptible Service	Interruptible service contracts allow a distributing party to temporarily suspend delivery of gas to a buyer in order to meet the demands of customers who purchased firm service. Interruptible service is less expensive than firm service, and is used by customers who can either accommodate interruption, or switch to alternative fuels temporarily.
Inverter	A device that converts DC power captured by the photovoltaic cells on solar panels into AC power that can be used to power a home or business. This device is an integral part of a solar system. Large solar systems may have more than one inverter.
Kilowatt-hour (kWh)	Basic unit of electric energy equal to one kilowatt of power supplied to or taken from an electric circuit steadily for one hour; one kilowatt-hour equals 1 000 watt hours.
Knot or Nautical Mile	The Knot is the unit of measurement for water speed. It is nearly equivalent to miles per hour for land. It is also used to measure wind speeds over water. One nautical mile is approximately 1.85 kilometres.
kWp (Kilowatt peak)	A measurement of power. A kilowatt is one thousand watts. The size of a solar system is often measured in kW. A typical size solar system for a home is 5 kW; for a medium sized business is 100 kW.
Lead	A structure which may contain hydrocarbons.
Levelised electricity cost	Levelised energy cost (LEC, also commonly abbreviated as LCOE) is the price at which electricity must be generated from a specific source to break even. It is an economic assessment of the cost of the energygenerating system including all the costs over its lifetime: initial investment, operations and maintenance, cost of fuel, cost of capital, and is very useful in calculating the costs of generation from different sources.
Liquefied Natural Gas	Liquefied natural gas or LNG is natural gas (predominantly methane, CH4) that has been converted temporarily to liquid form for ease of storage or transport. Liquefied natural gas takes up about 1/600th the volume of natural gas in the gaseous state. It is odourless, colourless, non-toxic and non-corrosive.
Lithology	Lithology is the study of rocks. It is important for exploration and drilling crews to have an understanding of lithology as it relates to the production of gas and oil. Often, cuttings have to beanalysed to make important decisions about a well. See also logging.
Load	Amount of electric power delivered or required at any specific point on a system.
Load factor	Proportion of name plate capacity that is used during a year. For instance if a coal fired power station with a name plate capacity of 1 GW produces 6,132 GWh per year, it is said to have a load factor of 70% based in the following calculation - 6,132 GWh produced /(1 GW of capacity X 24 hours X 365 days). Solar PV tends to have a load factor of 10% - 20%, CSP 25% - 35%, Coal 60% - 75%, nuclear 80% - 95%, natural gas combined cycle 85% - 90% and geothermal 90% - 98%.

Load management Activities to influence the level and shape of demand for electrical energy so demand conforms to the present supply situation, long-term objectives and constraints Load profile Information on a customer's electricity use over time, sometimes shown as a graph.

Load shedding Scheduled and controlled power cuts by rotating available capacity between all customers when demand is greater than supply to avoid total blackouts in the supply area.

Load shifting The transfer of loads from peak to off-peak periods; e.g. in situations where a utility does not expect to meet demand during peak periods but has excess capacity in off-peak periods.

Local Distribution Company A retail gas distribution company that delivers natural gas to end users.

Logging Logging or data logging refers to the lowering of different types of measuring instruments into the wellbore and gathering and recording data on porosity, permeability and types of fluids present near the current well. This data is then used to construct subsurface maps of a region to aid in further exploration.

LORAN LORAN is a satellite navigation system commonly used by ships and naval vessels to precisely locate their position while at sea.

Lost-time incident rate A proportional representation of the occurrence of lost-time injuries over 12 months.

Magnetometer This device is able to measure small changes in the earth's magnetic field at the surface, which indicates what kind of rock formations might be present underground. Originally, this technology was only mildly useful because the magnetometers were bulky and only small areas could be surveyed. However, with increasing technology, magnetometers can now be placed in helicopters, airplanes, and in 1981 NASA launched a magnetometer satellite, named Magsat.

MAGSAT In 1981, NASA developed sufficient technology to launch a magnometer satellite. This satellite serves as a useful tool for structural geologists to use when studying formations of rock within the earth's surface. See also Magnetometer.

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Magsat Satellite The Magsat is a satellite launched by NASA in 1981 that is used as a magnetomoter to study magnetic fluctuations in the earth's crust.

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Maximum demand Highest demand of load within a specified period.

Mcf - Thousand Cubic Feet Mcf stands for one thousand cubic feet. It's a unit of measure that is more commonly used in the low volume sectors of the gas industry, such as stripper well production. See also Btu, Bcf, Tcf, Quad.

Megawatt One million watts.

Megawatt-hour (MWh) One thousand kilowatt-hours or one million watt-hours.

MER or Most Efficient Recovery The MER, or most efficient recovery rate, is based on the most oil and gas that can be extracted for a sustained period of time without harming the formation. Generally, most wells cannot produce oil and gas for 24 hours a day, 7 days a week, or the rock formation could be damaged, which would result in less oil and gas being produced in the long run.

Methane Methane, commonly known as natural gas (or CH4 to a scientist), is the most common hydrocarbon gas. It is colourless and naturally odourless, and burns efficiently without many by products. Natural gas only has an odour when it enters your home because the local distributor who sells it to you adds it as a safety measure.

Mid-merit power generation Installations that generate electricity when electricity demand is higher than average. Rough guide is that when demand is greater than average, but less than 80% of annual peak demand, the supply would be classified as mid-merit.

MMscf - Thousand Cubic Feet	Mcf stands for one thousand cubic feet. It's a unit of measure that is more commonly used in the daily production volume calculations in gas industry. See also Btu, Bcf, Tcf, Quad.
Mothballed Plant	(i.e. power stations) placed in long-term storage.
Muds	Muds are used in drilling to lubricate the drilling bit in rotary drilling rigs. These fluids cool the bit, remove cuttings and debris, and coat the wellbore with a cake. Most fluids have a clay base, and are customized for the specific formations that are encountered at a given site. The cake that forms from the fluids serves to coat the walls of the wellbore until a steel casting can be put in place to prevent collapse.
Multiple Completions	Sometimes, in order to take full advantage of all the gas and oil present in a reserve, it is beneficial to drill to several different depths from a single well to increase the rate of production or the amount of recoverable petroleum. See also casing.
N/G	Net/gross ratio - proportion of the GRV formed by the reservoir rock (range is 0 to 1).
Natural Gas Co-Firing	Co-Firing refers to the injection of natural gas with pulverized coal or oil into the primary combustion zone of a boiler. Co-firing is not new technology, but efforts to determine optimal natural gas injection levels for both environmental and operational benefits are relatively recent. Cofiring only produces a mild increase in production costs, but benefits plants by offering cleaner overall operation. Slag that builds up inside boilers is reduced, and precipitators, which capture soot and ash from coal or oil firing, foul up less frequently.
Natural Gas Resource Base	An estimate of the amount of natural gas available, based on the combination of proved reserves, and those additional volumes that have not yet been discovered, but are estimated to be "discoverable" given current technology and economics. Current estimates for the resource base in the lower 48 states range from 900 to 1,300 Tcf.
Natural Gas Vehicle (NGV)	A natural gas vehicle is a new breed of car, bus or truck that is powered by a natural gas, either in compressed or liquefied form, rather than the traditional gasoline or diesel fuel. These vehicles offer an extremely clean, safe and efficient alternative to traditional transportation. With the passage of the Clean Air Act Amendments and the Energy Policy Act of 1992, these alternative fuel vehicles are expected to proliferate in the later 1990's. Already, major car manufacturers are offering natural gas vehicles, and there are over 700 fuelling stations nationwide.
Net Metering	An agreement between a solar system owner and the local electric utility that allows the system owner to buy and sell energy in the form of electric credits. When the solar system produces excess energy, it is sold back to the electric utility at peak prices, literally causing the electric meter to spin backwards. When the system is not producing energy, the system owner can use the credits to buy back energy at off-peak prices.
Non-technical losses	The difference between total losses and technical losses is referred to as non-technical losses.
NOx - Nitrogen Oxides	Acid deposition, commonly called acid rain, occurs when sulphur dioxide (SO2) and, to a lesser extent, NOx emissions are transformed in the atmosphere and return to the earth as dry deposition or in rain, fog or snow. Highway vehicles - autos, trucks and buses - account for nearly 30 percent of all NOx and non-methane hydrocarbons emitted annually in the United States. Burning any fossil fuel produces NOx, and it is difficult to generalize with respect to the relative NOx emissions of the various fuel types for different applications. However, the substitution of new high-efficiency gas equipment can offer significant NOx reductions, relative to older and less efficient equipment. For example, replacing a coal-fired electricity generating unit with a new gas-fired combined-cycle unit can reduce NOx by some 95 percent. See also SO2, CFC, HCFC.
Off Peak Period	The period of time during a day, week, month or year when gas use on a particular system is not at its maximum.
Off-peak	Period of relatively low system demand.
On/Off Grid System	A solar energy system that is interconnected with the utility grid is said to be an on-grid or grid-tied system, while a system with battery storage is not interconnected and is described as an off-grid system.

Outage	The period in which a generating unit, transmission line, or other facility is out of service.
P.I.G.s	Pipeline information gathering (systems) - these robotic agents roam the pipeline collecting data. Intelligent PIGS are used to inspect pipeline interior walls for corrosion and defects, measure pipeline interior diameters, remove accumulated debris and for other specialty tasks. As the PIG travels through the pipeline, it takes thousands of sensor measurements for later computer analysis and comparison with other historical data. Advances in these technologies are improving pipeline reliability and reducing the need for excavating long sections of pipe for inspection.
Peak demand	Maximum power used in a given period, traditionally from 07:00 to 12:00 in the morning and 17:00 and 20:00 in the evening on weekdays. Rough guide is that when demand is greater than 80% of the high recorded demand for the year, it is defined as peak demand. See also base-load and mid-merit.
Peak Shaving	Using sources of energy, such as natural gas from storage, to supplement the normal amounts delivered to customers during peak-use periods. Using these supplemental sources prevents pipelines from having to expand their delivery facilities just to accommodate short periods of extremely high demand (see Peak Use Periods).
Peak Use Period	The period of time when gas use on a particular system is at its maximum. This is the period when gas supply is most likely to be suspended for interruptible service customers. Distributors also employ techniques such as peak shaving to soften the impacts of high demand on the pipelines.
Peaking capacity	Generating equipment normally operated only during hours of highest daily, weekly or seasonal loads.
Peak-load plant	Usually gas turbines or a pumped-storage scheme used during peak-load periods.
Permeability	Permeability is the measure of how easily a fluid can pass through a section of rock. If fluid can pass relatively easily through a given layer, then the permeability is said to be high. However, if a layer effectively blocks fluids, or no fluids can flow through the layer at all, then the layer is said to be impermeable. Such layers are known as layersin traps. See also Porosity.
Photovoltaic (PV) System	PV systems convert sunlight and ultra violet light directly into electricity. Solar thermal systems use a different technology that uses sunlight to heat water or air, often used to heat swimming pools.
Play	A particular combination of reservoir, seal, source and trap associated with proven hydrocarbon accumulations.
Porosity	Percentage of the net reservoir rock occupied by pores (typically 5-35%) Porosity Pores are spaces between grains of sediment in sedimentary rock. A sedimentary rock with larger grain size will generally be more porous, allowing more fluid or air to flow through it. Very porous rock acts somewhat like a sponge, soaking up water, air and petroleum. Generally, porosity, or the degree to which a formation can hold fluid, decreases with depth because increased pressures press grains together, thus decreasing the space between grains. See also Permeability.
Pounds Per Square Inch Gauge (psig)	Pressure measured with respect to that of the atmosphere. This is a pressure gauge reading in which the gauge is adjusted to read zero at the surrounding atmospheric pressure. It is commonly called gauge pressure.
Power pool	An association of two or more interconnected electricity supply systems that agree to co-ordinate operations and seek improved reliability and efficiencies.
Power Purchase Agreement (PPA)	A Power Purchase Agreement (PPA) is an agreement between buyer and a seller of electricity. It is usually of a 25 year period for solar PV, due to the life of the panels and the agreement usually forces the buyer to buy whatever energy the system generates.
Primary energy	Energy embodied in natural resources (e.g. coal, liquid fuels, sunlight, wind, uranium).
Producer	A natural gas producer is generally involved in exploration, drilling, and refinement of natural gas. There are independent producers, as well as integrated producers, which are generally larger companies that produce, transport and distribute natural gas.

Prospect	A lead which has been fully evaluated and is ready to drill.
Proved Resources	The part of the Natural Gas Resource Base that includes the working inventory of natural gas - volumes that have already been discovered and are readily available for production and delivery. For instance in the USA, of an estimated 900 to 1300 Tcf of gas in the resource base in the lower 48 states, about 155 Tcf are proved resources. Namibia has proven reserves of 1 Tcf and no working inventory of natural gas.
Pumped-storage scheme	A pumped-storage scheme consists of a lower and an upper reservoir with a power station/ pumping plant between the two. During off-peak periods the reversible pump/turbines use electricity to pump water from the lower to the upper reservoir. During peak demand, water is allowed to run back into the lower reservoir through the turbines thereby generating electricity.
Purchasing Power Parity (ppp)	purchasing power parity (PPP) is a condition between countries where an amount of money has the same purchasing power in different countries. The prices of the goods between the countries would only reflect the exchange rates.
Quad	An abbreviation for a quadrillion (1,000,000,000,000,000) Btu. For natural gas, roughly equivalent to one trillion (1,000,000,000,000) cubic feet, or 1 Tcf. See also Bcf, Mcf.
Reburning	Natural gas reburning is an effective and economic means of reducing NOx emissions from all types of industrial and electric utility boilers. Gas reburn may be used in coal or oil boilers, and it is even effective in cyclone and wet-bottom boilers, for which other forms of NOx control are either not available or very expensive. A reburn application which entails the injection of natural gas into a coal-fired boiler above the primary combustion zone- representing 15 to 20 percent of the total fuel mix- can produce NOx reductions in the 50 to 70 percent range and SO2 reductions in the 20 to 25 percent range.
Recoverable hydrocarbons	Amount of hydrocarbon likely to be recovered during production. This is typically 10-50% in an oil field and 50-80% in a gas field.
Reserve Additions	Volumes of the Natural Gas Resource Base that are continuously moved from the resource category to the proved resources category. Reserve additions represent the volumes that become part of the gas industry's working inventory as producers replace volumes that are sold and used.
Reserve margin	Difference between net system capability and the system's maximum load requirements (peak load or peak demand).
Return on average equity:	Profit/loss for the year after tax/average total equity.
Return on average total assets:	Profit/loss for the year after tax/ average total assets.
Roof Mounted System	A solar system in which solar panels are mounted directly on the roof of a building or adjacent structure. The majority of solar systems are mounted on a roof.
SCADA	Supervisory Control and Data Acquisition - Remote controlled equipment used by pipelines and LDCs to operate their gas systems. These computerized networks can acquire immediate data concerning flow, pressure or volumes of gas, as well as control different aspects of gas transmission throughout a pipeline system. See also EBBs, Compression.
Separator Tank	These tanks are usually located at the well site. They are used to separate oil, gas and water before sending each off to be processed at different locations.
Sh	Hydrocarbon saturation – some of the pore space is filled with water – this must be discounted.
Single Buyer	An office which is set up to buy electricity from all generators whether publically owned or not. A vital set in the liberalising of electricity markets, where traditionally a state owned entity owns and operates all transmission, generation and distribution infrastructure.
SO2 - Sulphur Dioxides	Acid deposition, commonly called acid rain, occurs when sulphur dioxide and, to a lesser extent, nitrogen oxides (NOx) emissions are transformed in the atmosphere and return to the earth as dry deposition or in rain, fog or snow. Roughly 23 million tons of SO2 is emitted annually in the United States, according to the U.S. Environmental Protection Agency (EPA). The combustion of natural gas produces virtually no SO2 and, with proper design, far less NOx than combustion of coal or fuel

	oil. The Clean Air Act Amendments of 1990 will have major impacts on electric utility power plants. Together, these plants must reduce their SO2 emissions by roughly 10 million tons annually, by the year 2000. In addition, an absolute cap of 8.9 million tons will be placed on the electric utility sector in 2000. See also NOx, CFC, HCFC.
Solar Array	A group of solar panels collectively makes up a solar array.
Solar Energy	Electromagnetic energy transmitted from the sun. In order to power buildings, this energy must be captured and converted to AC electrical power.
Solar Lease	A financing arrangement whereby homeowners or businesses pay a fixed monthly payment for their solar system, and can get started with no money down. Solar Lease can make it possible to switch to clean, solar power for less money than homeowners currently pay for electricity. Solar Lease is not available in all areas.
Solar Panel	A group of solar cells arranged into a panel that can be installed onto a flat surface. Also can be called solar modules. The panel captures sunlight and converts it into DC power.
Solar remote monitoring unit	A service that constantly measures and displays how electricity is used throughout a building. Understanding energy usage patterns can help save money by informing smarter choices on how and when electricity is used. For instance, shifting energy intensive activities to off-peak hours when utility prices are lower, so they could offer these savings to residential and business owners.
Spent fuel	Nuclear fuel that has been irradiated in, and permanently removed from, a nuclear reactor. At Koeberg power station approximately 52 fuel assemblies (one third of the fuel assemblies) are removed from each of the two reactors on average every 16 months, and stored on site in the spent fuel pools in the respective fuel buildings next to the respective reactors.
Spinning reserve	The unused capacity which can be activated on decision of the system operator. Spinning reserve is provided by devices that are synchronized to the network and able to affect its active power. Correspondingly, negative spinning reserve is that energy that can quickly be switched off in the case of a short term dip in demand. "Spinning refers to the turbines that spin up to 3,600 revolutions per minute, in the case of the plant specified in this document and spinning reserve normally is defined being able to activate within 10 minutes of warning.
Spot Market	A product of deregulation, the spot market is a method of contract purchasing whereby commitments by the buyer and seller are of a short duration at a single volume price. The duration of these contracts is typically less than a month, and the complexity of the contracts is significantly less than their traditional market counterparts.
Spot Purchase (also called off-grid system)	Natural gas purchased on the spot market, which involves short-term contracts for specified amount of gas, at a one-time purchase price.
Stand-Alone System Also called an off-grid system.	A solar energy system that is not connected to the utility grid. To provide continuous power, these systems must be connected to storage units that can store excess power produced during daylight hours for use at night.
Stripper Wells	Stripper wells are natural gas wells that produce less than 60,000 cubic feet of gas per day. Ohio, West Virginia, Texas, Kentucky and New Mexico all have significant numbers of stripper wells. In 1994 there were 159,369 stripper wells in the United States, and they produced 940,420,777 Mcf.
Supply-side management	Planning, implementing and monitoring supply-side activities to (SSM) create opportunities for costeffective purchase, management, generation, transmission and distribution of electricity and all other associated activities.
Surface Exploration Methods	Exploration for hydrocarbons by measurement of surface or near-surface effects of microseeping hydrocarbons from underground reservoirs System minutes The international benchmark for measuring the severity of interruptions to customers. One system minute is equivalent to the loss of the entire system for one minute at annual peak.
Technical losses	Technical losses are the naturally occurring losses that depend on the power systems used.

Test well	A well drilled in an area where no oil or gas production exists. See also exploration well or wildcat.
Three Dimensional (3-D)	Seismic Possibly the single most important advancement in exploration technology in years, the three dimensional seismic allows producers to see into the earth's crust to find promising formations for retrieval of fossil fuel. Taking advantage of highly advanced supercomputers, geologists process millions of pieces of data to generate a detailed, three dimensional image of underground structures. They can rotate and slice these models for closer examination, searching for evidence of hydrocarbons. Using 3-D seismic, drilling has become more precise and the risk of costly dry holes has diminished. 3D seismic has helped natural gas and oil companies to reduce the risks of drilling a dry well from 80% to 50%, i.e. increased the success of a Wildcat well being commercially viable from 20% to 50%.
Tilt Angle	The angle at which a solar array is tilted towards the sun. Depending on the geographic location of a building, a solar array might be installed flat or tilted.
Time-of-Use (TOU)	Rates A utility billing system in which the price of electricity depends upon the hour of day at which it is used. Rates are higher during the afternoon when electric demand is at its peak. Rates are lower during the night when electric demand is off peak.
Traps	A trap is a generic term for an area of the earth's crust that has developed in such a way as to trap petroleum beneath the surface. When exploring for natural gas and oil, geologists look for evidence of traps. For a full description of the exploration process. See also Faults, Permeability, and Porosity.
Trillion Cubic Feet	A volume measurement of natural gas. Approximately equivalent to one Quad. See also Btu's, Bcf, Mcf.
Unbundled Services	Unbundling, or separating, pipeline transmission, sales and storage services, along with guaranteeing 'open access' to space on the pipelines for all gas shippers.
Underground Gas Storage	The use of sub-surface facilities for storing gas that has been transferred from its original location for the primary purpose of load balancing. The facilities are usually natural geological reservoirs, such as depleted oil or gas fields or water-bearing sands on the top by and impermeable cap rock. There are currently more than 400 underground storage facilities spread across 27 states and Canada, which together can hold more than 3 quads of gas.
Unit capability factor (UCF)	A measure of power station availability indicating how well plant is operated and maintained.
Unplanned automatic grid separations (UAGS)	A measure of the reliability of the service provided to the electrical grid that logs the number of supply interruptions per operating period.
Unplanned capability loss factor (UCLF)	All occasions when a power station unit has to be shut down and taken out of service. Energy losses due to outages are considered unplanned if they are not scheduled at least four weeks in advance Utility frequency The utility frequency, (power) line frequency (American English) or mains frequency (British English) is the frequency at which alternating current (ac, also AC) is transmitted from a power plant to the end-user. In most parts of the world this is 50 Hz, although in the Americas it is typically 60 Hz. Namibia and indeed all participants in the Southern African Power Pool operate at 50 Hz. Frequency control involves controlling the generation towards the frequency target. Renewables integration with intermittent supply can make this extremely challenging.
Utility Grid	The infrastructure of power lines, transformers and substations that delivers electric power to homes and businesses. The utility grid is owned and managed by electric utility companies.
Utility Meter	A device that measures the flow of electricity between a site that uses electricity and the electric utility company. When a solar system produces excess power, the meter spins backwards – if net metering is allowed.
Utility scale solar photovoltaics	A stand-alone solar farm, using solar photovoltaic panels, which is large enough to connect to the transmission infrastructure on the grid. Usually more than 5MW of capacity.
Value created per employee:	Value created divided by number of employees.

Viscosity	Viscosity is the measure of a fluid's thickness, or how well it flows. Water would have a very low viscosity since it flows very easily, while maple syrup or molasses would have a very higher viscosity since they flow slowly.
Volt (V)	The amount of force required to drive a steady current. Electrical systems of most homes use 220 volts in Namibia, South Africa and Europe, but 120 volts in the United States.
Voltage control	Similar in principle to frequency control, a voltage control system ensures that voltages are regulated within acceptable parameters. Transmission lines transport electricity at 765, 400, 330 and 133 KV AC, while consumers use the electricity for home use at 220V, while 3 phase customers use electricity at 380 V.
Watt (W)	The Watt is the standard unit of measure for power, either by capacity or demand. For example, light bulbs are classified by wattage.
Wildcat	A well drilled in an area where no oil or gas production exists. See also test well or exploration well.
Working capital ratio	(Total current assets, less financial instruments with group companies, less investments in securities, less embedded derivative assets, less derivatives held for risk management, less financial trading assets, less cash and cash equivalents)/(total current liabilities, less financial instruments with group companies, less debt securities issued, less borrowings, less embedded derivative liabilities, less derivatives held for risk management, less financial trading liabilities).

15. Grid factors and conversion tables[32]

15.1. Crude oil[33]

	Tonnes (metric)	Kilolitres	Barrels	US gallons	Tonnes/year
From			Multiply by		
Tonnes (metric)	1	1.165	7.33	307.86	–
Kilolitres	0.8581	1	6.2898	264.17	–
Barrels	0.1364	0.159	1	42	–
US gallons	0.00325	0.0038	0.0238	1	–
Barrels/day	–	–	–	–	49.8

15.2. Oil derivative products

	Barrels to tonnes	Tonnes to barrels	Kilolitres to tonnes	Tonnes to kilolitres	Barrels to tonnes
From		Multiply by			
LPG	0.086	11.6	0.542	1.844	0.086
Gasoline	0.118	8.5	0.740	1.351	0.118
Kerosene	0.128	7.8	0.806	1.24	0.128
Gas oil/ diesel	0.133	7.5	0.839	1.192	0.133
Residual fuel oil	0.149	6.7	0.939	1.065	0.149

15.3. Natural gas and liquefied natural gas (LNG) conversion factors

			Barrels to tonnes	Tonnes to barrels	Kilolitres to tonnes	Tonnes to kilolitres	Barrels to tonnes
From				Multiply by			
1 billion cubic metres NG	1	35.3	0.90	0.74	35.7	6.60	1
1 billion cubic feet NG	0.028	1	0.025	0.021	1.01	0.19	0.028
1 million tonnes oil equivalent	1.11	39.2	1	0.82	39.7	7.33	1.11
1 million tonnes LNG	1.36	48.0	1.22	1	48.6	8.97	1.36
1 trillion British thermal units	0.028	0.99	0.025	0.021	1	0.18	0.028
1 million barrels oil equivalent	0.15	5.35	0.14	0.11	5.41	1	0.15

32 Source –adapted from BP statistical review of energy – 2010

33 Based on worldwide average gravity.

15.4. Metric unit conversions and carbon grid factors

Units
1 metric tonne = 2204.62 lb.
= 1.1023 short tons
1 kilolitre = 6.2898 barrels
1 kilolitre = 1 cubic metre
1 kilocalorie (kcal) = 4.187 kJ = 3.968 Btu
1 kilojoule (kJ) = 0.239 kcal = 0.948 Btu
1 British thermal unit (Btu) = 0.252 kcal = 1.055 kJ
1 kilowatt-hour (kWh) = 860 kcal = 3600 kJ = 3412 Btu

Carbon grid factor	Tonnes CO_2e per MWh
Namibia existing local sources	0.55
South Africa	1.02
Zimbabwe	1.00
NamPower new build coal plant	1.00
Pinpoint gas only	0.34
Pinpoint solar + gas combined cycle	0.20
Pinpoint utility scale PV	0.00
Pinpoint micro-generation	0.00
Pinpoint solar water heating	0.00
Solar water heating/off-grid	0.00
Other	0.50
Shortfall	1.00

15.5. Tonne of oil equivalent

One tonne of oil equivalent equals approximately:

Heat units	10 million kilocalories
	42 gigajoules
	40 million Btu
Solid fuels	1.5 tonnes of hard coal
	3 tonnes of lignite
Electricity	12 megawatt-hours

Biodiesel

1 barrel of ethanol = 0.57 barrel of oil

1 barrel of biodisel = 0.88 barrel of oil

1 tonne of ethanol = .57 ton of oil

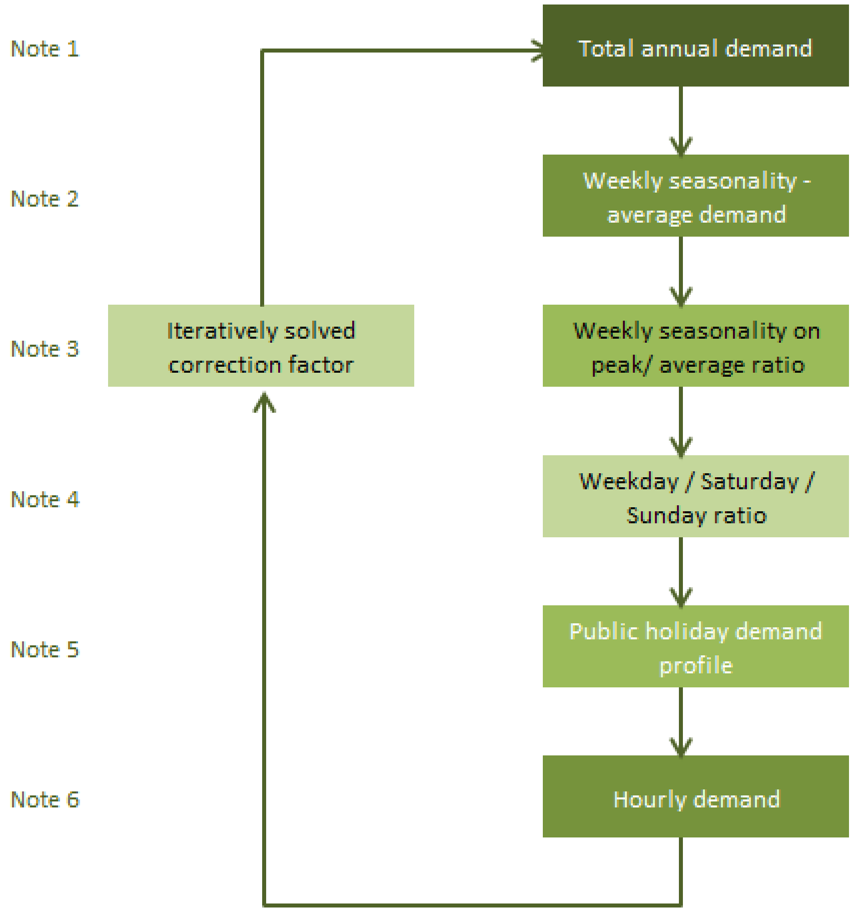
1 tonne of biodiesel = .88 ton of oil

One million tonnes of oil produces about 4400 gigawatt-hours (=4.4 terawatt hours) of electricity in a modern power station

16. How the Time of Use forecast model was calculated

Namibia does not publish detailed weekly data in the way that Eskom does – nor the even more detailed UK national grid, which publishes half-hourly demand. The model was derived from both sets of data based on the process listed below:

Figure 76 – Time of Use calculation process



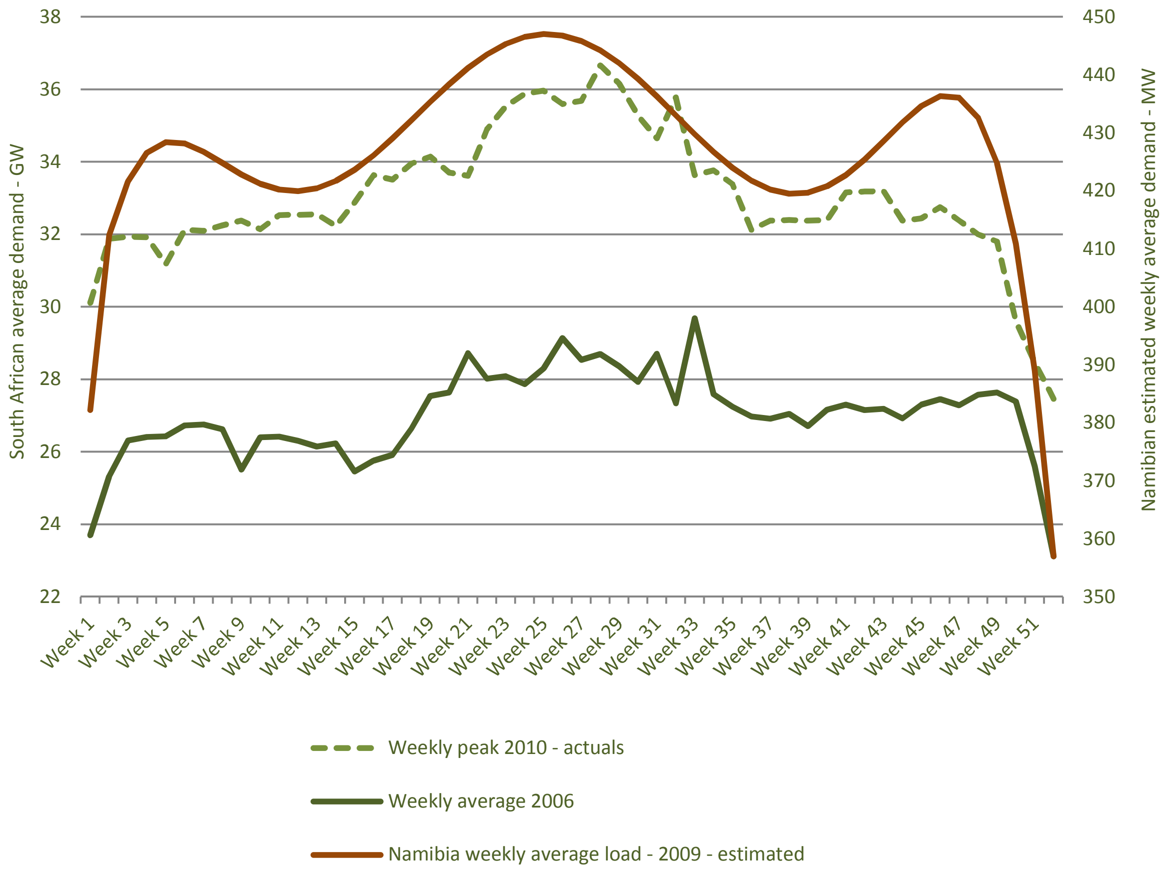
Note 1 – Total Annual Demand

Annual demand is published in the NamPower financial statements and was 3,767 GWh for the year ended 30 June 2010 and for the year ended 30 June 2009 was 3,692 GWh. For the sake of simplicity the two were averaged and divided by 8,760 (24 hours X 365 days) to give the average demand of 426 MW for the 2009 calendar year, the most recent year for which published these top level data are available in Namibia.

Note 2 – Weekly average seasonality

Namibia does not publish weekly demand data, as Eskom of South Africa does. So South Africa's demand weekly data are used too. This is a reasonable assumption as South Africa and Namibia are likely to have similar time of use profiles as they have similar shares of electricity users – heavy but smooth demand from mines with high residential driven demand in the winter. Therefore the weekly peak and average demand data provided by Eskom over the same period will indicate similar ratios in Namibia.

Figure 77 – South African vs. Namibian weekly demand patterns



The Namibian estimated demand curve for 2009 was iteratively solved and resulted in the following equation:

Equation 1 – the smoothed weekly peak to average demand ratio for Namibia

$$D_{wa} = -1.76.10^{-6}w_n^6 + 2.70.10^{-4}w_n^5 + 1.58.10^{-4}w_n^4 + 4.344.10^{-1}w_n^3 + 5.73w_n^2 - 33.36w_n + 359.78$$

$$D_{wa} = weekly\ average\ demand\text{-}\ MW$$

$$w_n \ = the\ n^{th}\ week\ of\ the\ calender\ year$$

Note 3 – Weekly peak to average seasonality

Namibia's peak demand of 568 MW is published, so the graphs were fitted between a published average of 426 MW and the published maximum, based on the weekly average seasonal adjustment. This data was smoothed and could be compared with Namibia, where the annual average and peak demand is published.

Figure 78 – Smoothed weekly to average peak demand

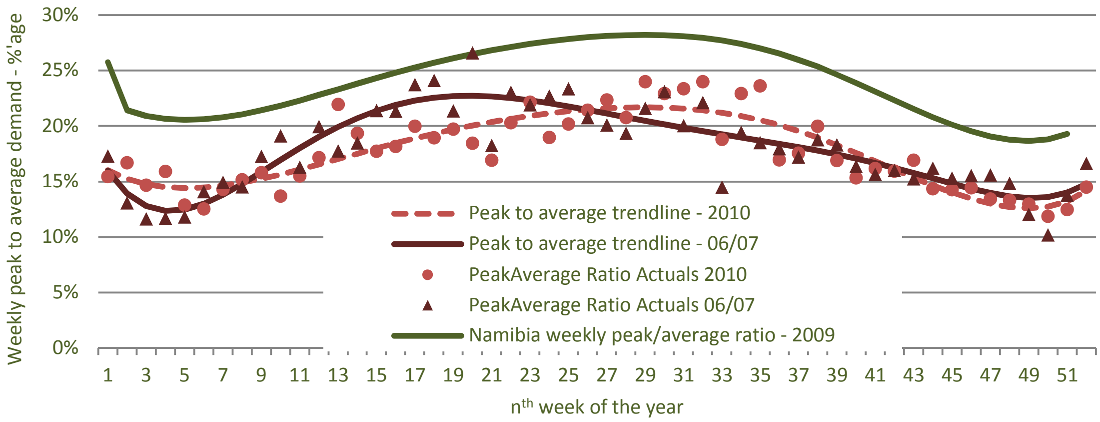
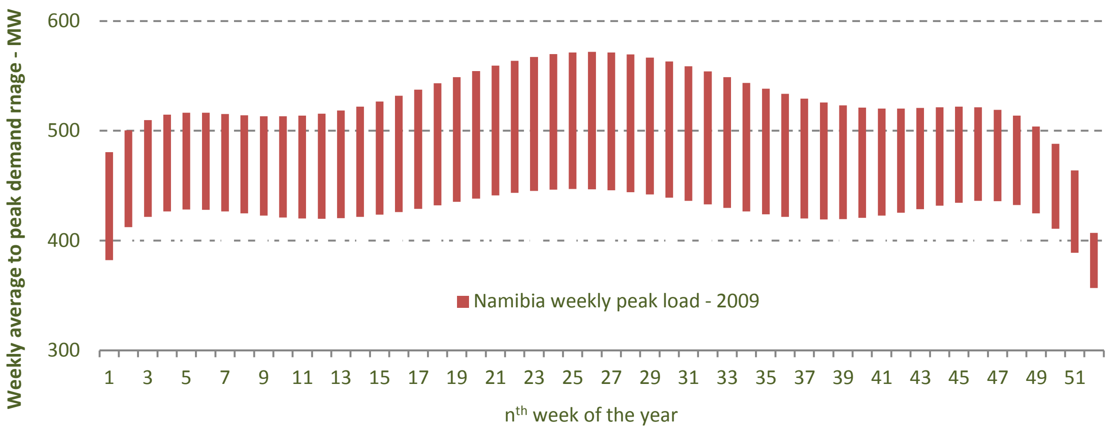


Figure 79 – Weekly peak to average demand ratio – Namibia 2009



Equation 2 – the smoothed weekly peak to average demand ratio for Namibia

$$D_{wp} = 2.03.10^{-10}w_n^6 - 3.70.10^{-8}w_n^5 - 2.87.10^{-6}w_n^4 - 1.21.10^{-4}w_n^3 - 2.57.10^{-3}w_n^2 - 2.04.10^{-2}w_n + 0.258811$$

$$D_{wp} = weekly\ peak\ demand\text{-}\ MW$$

$$w_n = the\ n^{th}\ week\ of\ the\ calender\ year$$

Note 4 Weekday/Saturday and Sunday ratios

Neither Namibia nor South Africa publish daily demand data, so the differences between weekday and weekend demand are estimated based on the UK grid ratios. As South Africa, Namibia and the UK have similar contribution to GDP of services – all between 65% and 72%, it is reasonable to assume that the ratio between weekdays, Saturdays and Sundays will be similar.

Figure 80 – Weekday vs. weekend daily demand.
UK daily averages 2009 – on which Namibia model is based

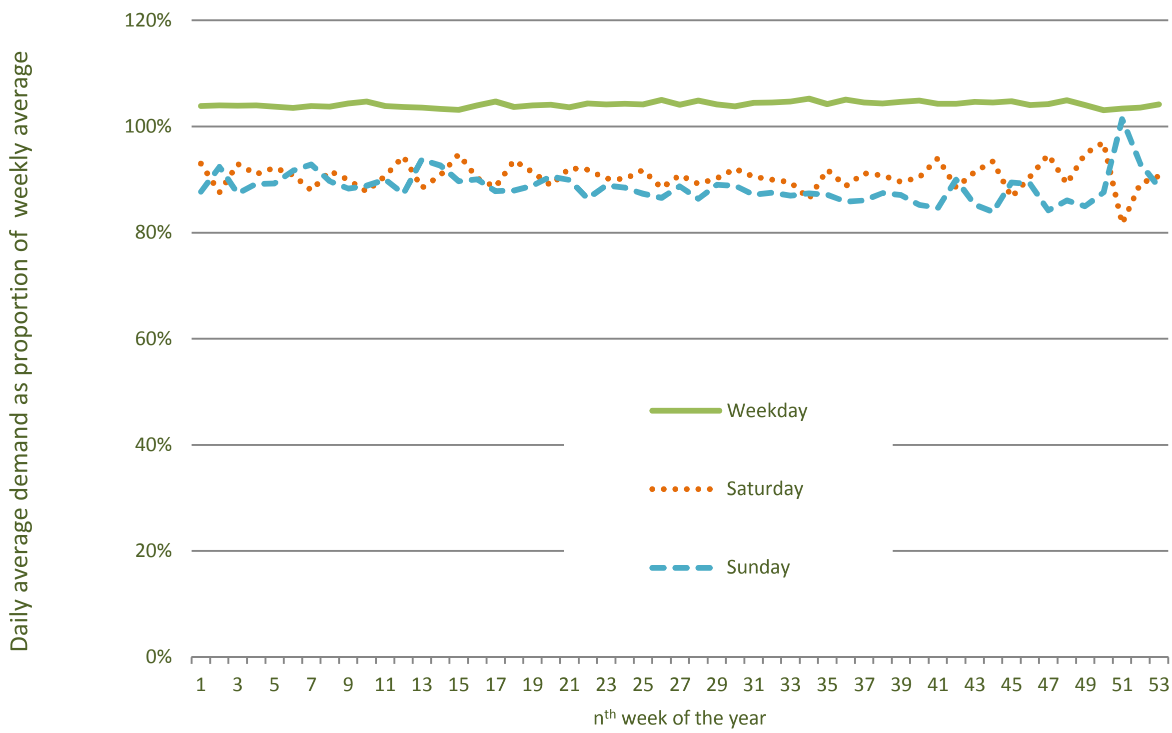


Figure 80 shows that the ratios are constant throughout the year, except where there are public holidays, such as at the end of the year: Based on these assumptions the model is weighted as the table below:

Table 5 – weekday vs. Saturday and Sunday demand profiles

Day usage profile	Percentage of weekly average
Weekday	104.2%
Saturday	90.6%
Sunday 88.5%	88.5%

Note 5 Public Holidays

Demand is lower on public holidays than normal days of the week, so adjustment needs to be made to the demand profile. This table is based on the Eskom prescribed pricing to municipalities in South Africa, so this profile is likely to affect Namibian demand in a similar way.

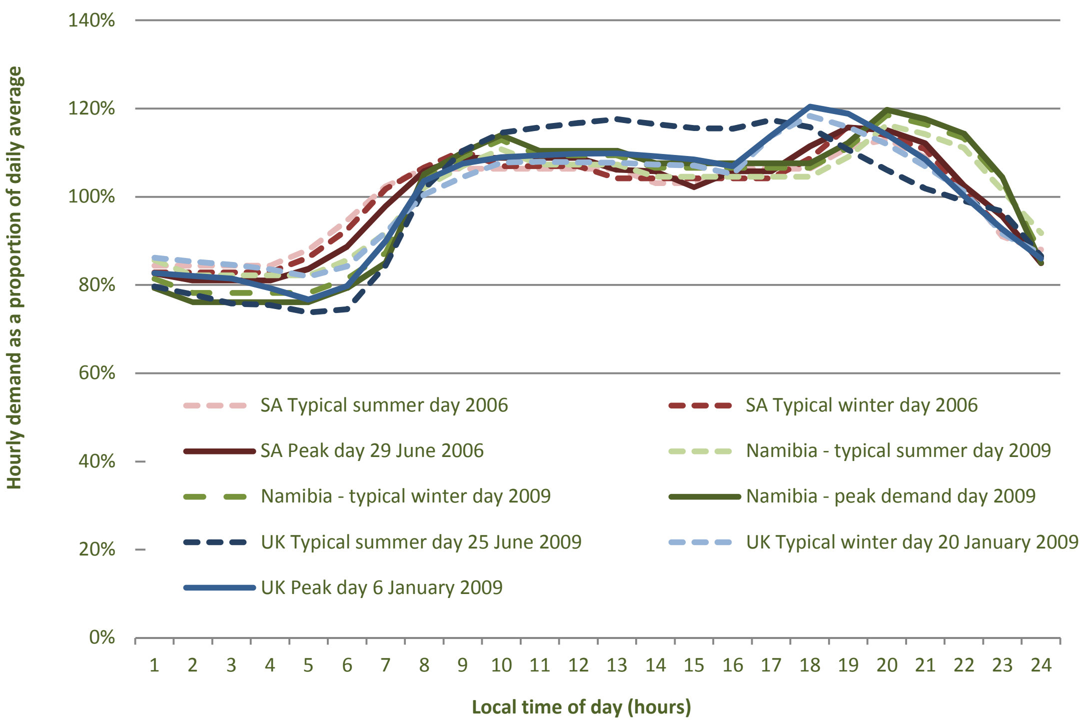
Table 6 – Namibian public holidays in 2010

Date	Public Holiday Name	Actual day of week	Demand profile
01-Jan-11	New Year's Day	Friday	Sunday
21-Mar-11	Independence Day	Sunday	Sunday
22-Mar-11	Public Holiday	Monday	Saturday
2 April	Good Friday	Friday	Sunday
5 April	Easter Monday	Monday	Sunday
01-May-11	Workers Day	Saturday	Saturday
04-May-11	Kasinga Day	Tuesday	Saturday
13-May-11	Ascension Day	Thursday	Saturday
25-May-11	Africa Day	Monday	Saturday
26-Aug-11	Heroes Day	Thursday	Saturday
10-Dec-11	Day of the Namibian Women and International Human Rights Day	Friday	Saturday
25-Dec-11	Christmas Day	Saturday	Sunday
26-Dec-11	Family Day	Sunday	Sunday
27-Dec-11	Public Holiday	Monday	Sunday

Note 6 – hourly demand

Both South Africa and the UK publish hourly demand and both economies show similar demand patterns, with a morning and a larger evening peak. Namibia will behave similarly to South Africa – day-light saving has been taking into account, showing that Namibia has a slightly later evening demand profile than South Africa, which is further east, so the sun sets earlier. The UK's day-light savings has a more dramatic impact on demand profiles, where the evening peak happens earlier in the day.

Figure 81 – Hourly demand as a proportion of daily averag SA vs Namibia typical winter and summer days

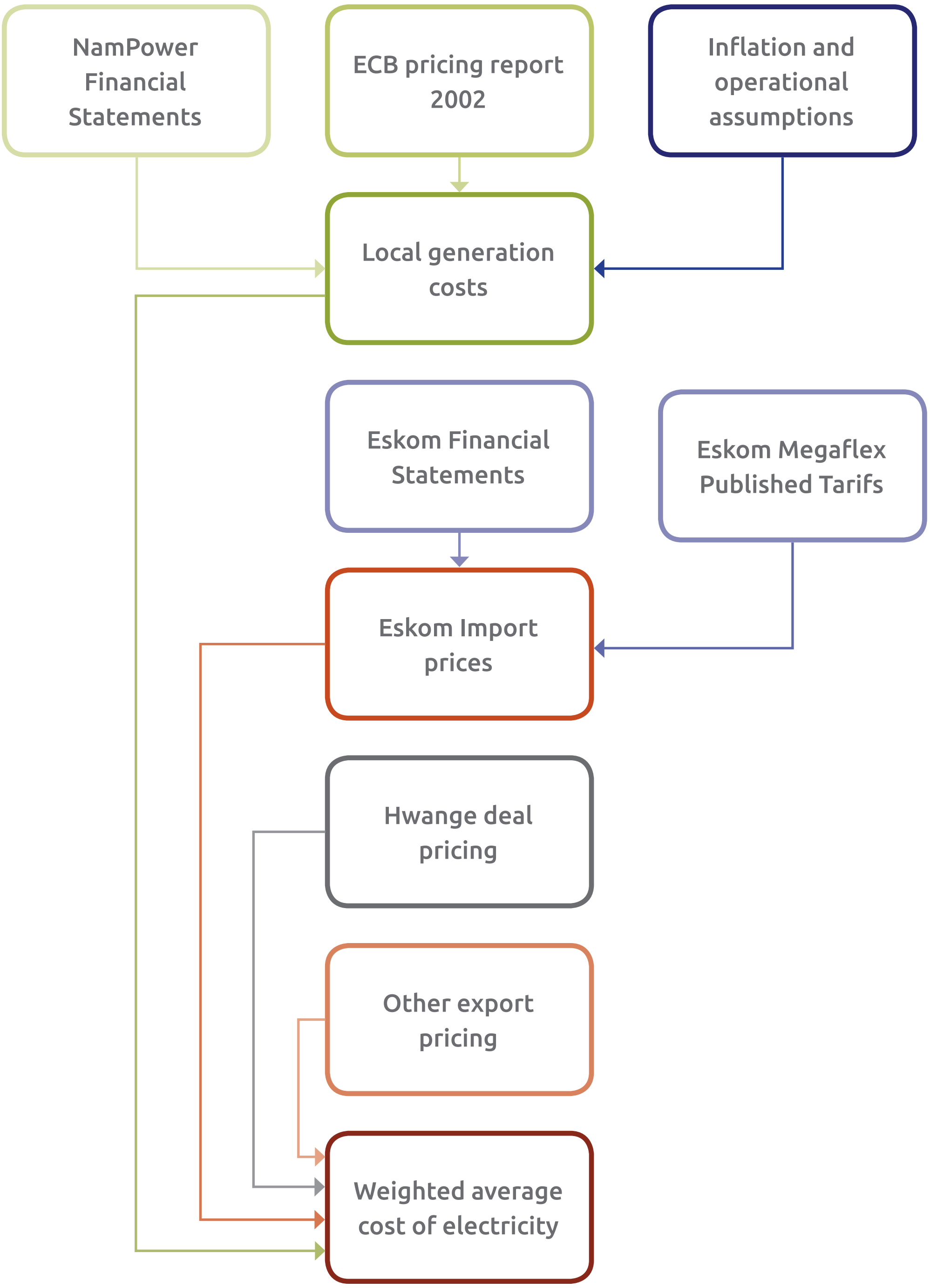


17. NamPower pricing model

17.1.1 Model description

ANE's model is based on inputs from published pricing listing such as Eskom Megaflex, Annual Financial Statements of NamPower, the ECB Pricing Study Report of 2002 and estimated inflation numbers over the last ten years:

Figure 82 – ANE NamPower pricing model



17.1.1.1 NamPower input costs without ANE's project

NamPower fully absorbed generation/purchase cost	Note	2009 NA$'mil	2010 NA$'mil	2011 NA$'mil	2012 NA$'mil	2013 NA$'mil	2014 NA$'mil	2015 NA$'mil
Namibia - Nampower estimated generation costs	1	362	350	467	596	446	673	731
Hydropower - Ruacana		193	203	213	234	260	273	281
Coalfired peaking plant - Van Eck		134	112	215	292	124	336	356
Diesel fired peaking plants - Paratus & Anixas		35	35	38	71	62	64	93
South Africa - Eskom import charges	2.1	264	345	430	533	661	819	1,017
Zimbabwe - Barter payment from ZESA - Hwange deal	2.2	48	61	62	64	68	0	0
Other imports	2.3	9	34	46	152	189	234	291
Time of use and other differences		0	(26)					
ANE								
Shortfall	1.4			0	0	0	1,245	1,705
Cost of electricity purchases		***683***	***764***	***1,004***	***1,346***	***1,363***	***2,972***	***3,744***
Change YOY		*31%*	*12%*	*31%*	*34%*	*1%*	*118%*	*26%*

Volumes - GWh	Note	2009 GWh	2010 GWh	2011 GWh	2012 GWh	2013 GWh	2014 GWh	2015 GWh
Namibia - NamPower		1,490	1,305	1,450	1,500	1,800	1,950	1,950
Hydropower - Ruacana		1,409	1,247	1,300	1,300	1,750	1,750	1,750
Coalfired peaking plant - Van Eck		78	55	147	194	44	194	194
Diesel fired peaking plants - Paratus & Anixas		3	3	3	6	6	6	6
South Africa - Eskom		1,501	1,429	1,400	1,400	1,400	1,400	1,400
Zimbabwe - ZESA		648	891	900	900	900	0	0
Other imports		53	142	150	400	400	400	400
ANE		0						
Shortfall		0	0	0	0	0	1,000	1,250
Volume needed to satisfy demand		***3,692***	***3,767***	***3,900***	***4,200***	***4,500***	***4,750***	***5,000***

Ruacana 92MW turbine benefits local production, reducing inflation.

Average cost per unit – NA$ cents per KWh

	Note	2009 NA$c per KWh	2010 NA$c per KWh	2011 NA$c per KWh	2012 NA$c per KWh	2013 NA$c per KWh	2014 NA$c per KWh	2015 NA$c per KWh
Namibia - Nampower		24.3	26.8	32.2	39.8	24.8	34.5	37.5
Hydropower - Ruacana		13.7	16.3	16.4	18.0	14.9	15.6	16.1
Coalfired peaking plant - Van Eck		172.3	203.5	146.5	150.3	282.3	173.0	183.8
Diesel fired peaking plants - Paratus & Anixas		1,155.7	1,174.1	1,281.1	1,179.8	1,026.4	1,068.0	1,545.9
South Africa - Eskom		17.6	24.1	30.7	38.1	47.2	58.5	72.7
Zimbabwe - ZESA		7.4	6.9	6.9	7.1	7.5	n/a	n/a
Other imports		17.6	24.1	30.7	38.1	47.2	58.5	72.7
ANE								
Shortfall		n/a	n/a	n/a	n/a	n/a	124.5	136.4
Weighted average cost per unit - NA$ cents per KWh		***18.5***	***20.3***	***25.7***	***32.1***	***30.3***	***62.6***	***74.9***

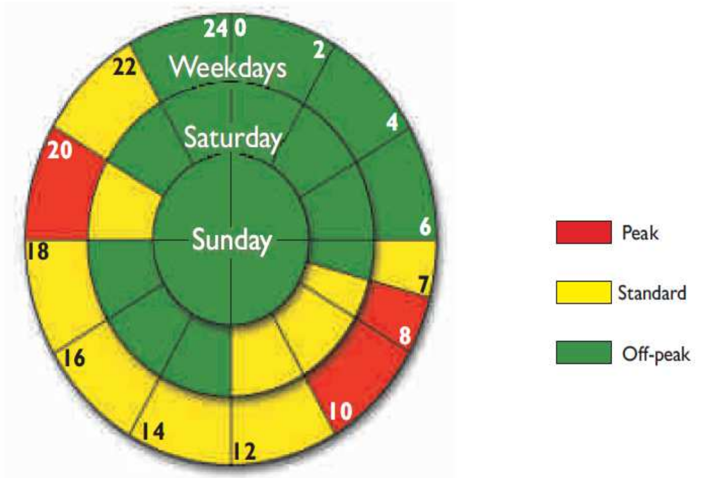
Average cost per unit - US$ cents per KWh	Note	2009 US$c per KWh	2010 US$c per KWh	2011 US$c per KWh	2012 US$c per KWh	2013 US$c per KWh	2014 US$c per KWh	2015 US$c per KWh
Namibia - Nampower		3.1	3.5	4.2	5.0	2.9	3.8	3.9
Ruacana		1.8	2.1	2.1	2.3	1.8	1.7	1.7
Van Eck		22.2	26.6	19.0	18.8	33.3	19.3	19.4
Paratus		148.9	153.3	165.9	147.5	121.2	119.1	162.8
South Africa - Eskom		2.3	3.1	4.0	4.8	5.6	6.5	7.7
Zimbabwe - ZESA		1.0	0.9	0.9	0.9	0.9	n/a	n/a
Other imports		2.3	3.1	4.0	4.8	5.6	6.5	7.7
ANE								
Shortfall	4.4	n/a	n/a	n/a	n/a	n/a	13.9	14.4
Weighted average cost per unit - US$ cents per KWh		***2.4***	***2.6***	***3.3***	***4.0***	***3.6***	***7.0***	***7.9***
Exchange rate - USD:NAD		*7.76*	*7.66*	*7.72*	*8.00*	*8.47*	*8.97*	*9.50*

Note that year co-oncide with NamPower yearend - e.g. 2012 refers to the period of 1 July 2011 - 30 June 2012

17.1.1.1.1 Eskom's time of use pricing

Eksom summary

	2009	2010	2011	2012	2013	2014	2015
Volume of Eskom purchases in GWh - "As-is Scenario"	1501	1419	1400	1400	1400	1400	1400
Eskom transmission network charges NA$/kVA/m	3.46	4.25	4.46	4.82	5.20	5.62	6.07
Capacity on which transmission costs are based - MW	600	600	600	600	600	600	600
Transmission charge in NA$'millions	**25**	**31**	**32**	**35**	**37**	**40**	**44**
Eskom charges per unit - NA$ cents per KWh	15.9	22.1	28.4	35.6	44.5	55.6	69.6
Eskom unit charges in NA$'millions	**239**	**314**	**398**	**499**	**623**	**779**	**974**
Total Eskom charges in NA$'millions	**264**	**345**	**430**	**533**	**661**	**819**	**1,017**
Eskom sales per KWh - "As is Scenario"							
Cost of electricity in NA$	264	345	430	533	661	819	1,017
Volumes in GWh	1,501	1,419	1,400	1,400	1,400	1,400	1,400
Eskom cost of sales price - NA$ cents per KWh	17.6	24.3	30.7	38.1	47.2	58.5	72.7



2.1 Workings – Eksom Time of Use (ToU) Tariff analasys – actuals based onzone 4 Megaflex municipale rates

Table 4 – Eksom Time of Use prices

Financial year	**2008**			**2009**			**2010**			**2011**		
Beginning of high demand season	01/06/2008			01/06/2009			01/06/2010			01/06/2011		
End of high demand season	31/08/2008			31/08/2009			31/08/2010			31/08/2011		
Days of high season	91			91			91			91		
Start date 1	01/04/2008			01/07/2008			01/07/2009			01/07/2010		
End date 1	30/06/2008			30/06/2009			30/06/2010			30/06/2011		
	Weekdays	Saturday	Sunday	Weekdays	Saturday	Sunday	Weekdays	Saturday	Sunday	Weekdays	Saturday	Sunday
P	5	0	0	5	0	0	5	0	0	5	0	0
S	11	7	0	11	7	0	11	7	0	11	7	0
O	8	17	24	8	17	24	8	17	24	8	17	24
Total hours per day - check	**24**	**24**	**24**	**24**	**24**	**24**	**24**	**24**	**24**	**24**	**24**	**24**
HD_Peak	325	0	0	325	0	0	325	0	0	325	0	0
HD_Standard	715	91	0	715	91	0	715	91	0	715	91	0
HD_Off-peak	520	221	312	520	221	312	520	221	312	520	221	312
LD_Peak	917	0	0	917	0	0	917	0	0	917	0	0
LD_Standard	2,016	355	0	2,016	355	0	2,016	355	0	2,016	355	0
LD_Off-peak	1,466	862	960	1,466	862	960	1,466	862	960	1,466	862	960
Total hours	**5,959**	**1,529**	**1,272**	**5,959**	**1,529**	**1,272**	**5,959**	**1,529**	**1,272**	**5,959**	**1,529**	**1,272**
	8,760			**8,760**			**8,760**			**8,760**		
	Annual hours	Proportions	Pricing	Annual hours	Proportions	Pricing	Annual hours	Proportions	Pricing	Annual hours	Proportions	Pricing
HD_Peak	325	3.7%	58.1	325	3.7%	78.5	325	3.7%	111.0	325	3.7%	143.1
HD_Standard	806	9.2%	15.4	806	9.2%	20.8	806	9.2%	29.9	806	9.2%	37.2
HD_Off-peak	1,053	12.0%	8.4	1,053	12.0%	11.3	1,053	12.0%	15.5	1,053	12.0%	19.9
LD_Peak	917	10.5%	16.5	917	10.5%	22.3	917	10.5%	31.0	917	10.5%	40.0
LD_Standard	2,371	27.1%	10.2	2,371	27.1%	13.8	2,371	27.1%	19.0	2,371	27.1%	24.5
LD_Off-peak	3,288	37.5%	7.2	3,288	37.5%	9.8	3,288	37.5%	13.3	3,288	37.5%	17.2
Total hours/100%/weighted average price	**8,760**	**100.0%**	**11.8**	**8,760**	**100.0%**	**15.9**	**8,760**	**100.0%**	**22.1**	**8,760**	**100.0%**	**28.4**

17.1.1.2 Cost recovery on NamPower's local generation

Nampower charges	Notes	Ruacana	Van Eck	Paratus & Anixas	Total
Primary energy costs - 2009	1.1	0	83	5	88
Wages and salaries - 2009	1.2	30	18	12	61
Repairs and maintenance - 2009	1.3	5	3	2	10
Other operating costs - 2009	1.3	4	3	2	9
Company overheads - 2009	1.3	24	15	10	49
Transmission charges charged to generation - 2009	1.3	98			98
Depreciation - 2009		31	13	4	48
Total - 2009		**193**	**134**	**35**	**362**
Primary energy costs - 2010	1.1	0	57	4	61
Wages and salaries - 2010	1.2	33	20	13	65
Repairs and maintenance - 2010	1.3	5	3	2	11
Other operating costs - 2010	1.3	5	3	2	10
Company overheads - 2010	1.3	26	15	10	51
Transmission charges charged to generation - 2010	1.3	104			104
Depreciation - 2010		31	14	4	48
Total - 2010		**203**	**112**	**35**	**350**
Primary energy costs - 2011	1.1		158	6	164
Wages and salaries - 2011	1.2	35	21	14	69
Repairs and maintenance - 2011	1.3	5	3	2	10
Other operating costs - 2011	1.3	5	3	2	10
Company overheads - 2011	1.3	27	16	11	55
Transmission charges charged to generation - 2011	1.3	110			110
Depreciation - 2011		31	14	4	48
Total - 2011		**213**	**215**	**38**	**467**
Primary energy costs - 2012	1.1		226	6	232
Wages and salaries - 2012	1.2	47	28	19	93
Repairs and maintenance - 2012	1.3	6	4	5	14
Other operating costs - 2012	1.3	5	3	4	13
Company overheads - 2012	1.3	29	17	23	69
Transmission charges charged to generation - 2012	1.3	117			117
Depreciation - 2012		31	14	14	59
Total - 2012		**234**	**292**	**71**	**596**
Primary energy costs - 2013	1.1		55	6	61
Wages and salaries - 2013	1.2	49	30	20	99
Repairs and maintenance - 2013	1.3	8	4	5	17
Other operating costs - 2013	1.3	8	3	5	16
Company overheads - 2013	1.3	31	18	12	61
Transmission charges charged to generation - 2013	1.3	124			124
Depreciation - 2013		41	14	14	69
Total - 2013		**260**	**124**	**62**	**446**

Primary energy costs - 2014	1.1		263	6	269
Wages and salaries - 2014	1.2	52	31	21	105
Repairs and maintenance - 2014	1.3	9	4	5	18
Other operating costs - 2014	1.3	8	4	5	16
Company overheads - 2014	1.3	32	19	13	65
Transmission charges charged to generation - 2014	1.3	131			131
Depreciation - 2014		41	14	14	69
Total - 2014		**273**	**336**	**64**	**673**
"As-is Scenario"					
Primary energy costs - 2015	1.1		284	6	290
Wages and salaries - 2015	1.2	49	30	20	99
Repairs and maintenance - 2015	1.3	9	4	34	48
Other operating costs - 2015	1.3	9	4	5	17
Company overheads - 2015	1.3	34	21	14	69
Transmission charges charged to generation - 2015	1.3	139			139
Depreciation - 2015		41	14	14	69
Total "As is Scenario"- 2015		**281**	**356**	**93**	**731**

		2009	2010	2011	2012	2013	2014	2015
1.1 Feedstock costs								
Cost of coal NA$ per tonne		1,295	1,297	1,401	1,513	1,634	1,765	1,906
Coal consumed - '000's tonnes "As is Scenario"		64	45	120	159	36	159	159
Coal consumed - '000's tonnes "Pinpoint Scenario"								36
Van Eck - MWh per tonne of coal input	1.3							
Litres diesel per KWh	0.2							
1.2 Salary cost allocation								
Total salaries and wages - NA$ millions		288	318	350	395	419	444	470
Total number of employees		888	910	945	1006	1006	1006	1006
Cost per employee (company) - NA$'000		324	349	370	393	416	441	468
Number of employees - generation		187	187	187	237	237	237	237
Proportion of wage bill		21%	21%	20%	24%	24%	24%	24%
Salaries and wages allocated to generation - NA$ millions		61	65	69	93	99	105	111
1.3 Other costs absorbed into cost of electricity								
Assumptions from 2002 inputs								
Inflation on repairs and overheads - 2002 - 2010	6%							
Repairs and maintenance - NA$'000' - 2002	6,673							
Other operating costs - NA$'000' - 2002	5,981							
Company overheads - NA$'000' - 2002	32,262							
Ruacana transmission charges - NA$'000' - 2002	65,109							
1.4 Cost per KWh of shortfall								
	Mix							
Cost per KWh - Eskom	33%				38.1	47.2	58.5	72.7
Cost per KWh - van Eck (marginal cash cost)	33%				116.4	125.7	135.7	146.6
Cost per KWh - Agrekko @20 Usc per KWh	33%				160.0	169.4	179.4	189.9
Weighted average	100%				104.8	114.1	124.5	136.4

17.1.1.2.1 Cost of other imports

Zimbabwe (ZESA) Hwange cost per KWh estimate

	2009	2010	2011	2012	2013	2014	2015
Electricity sold in GWh	648	891	900	900	900	0	0
Capacity provided	150	150	150	150	150	0	0
US$ per KWh	1.0	0.9	0.9	0.9	0.9	n/a	n/a
US$ per KW per month	5.14	5.14	5.14	5.14	5.14	n/a	n/a
MW on which capacity was billed	100	130	130	130	130	n/a	n/a
Monthly payment in US$	514	668	668	668	668	n/a	n/a
Annual loan repayment - US$'million	6.2	8.0	8.0	8.0	8.0	n/a	n/a
Annual estimated costs in NA$	47.9	61.4	61.9	64.1	67.9	n/a	n/a

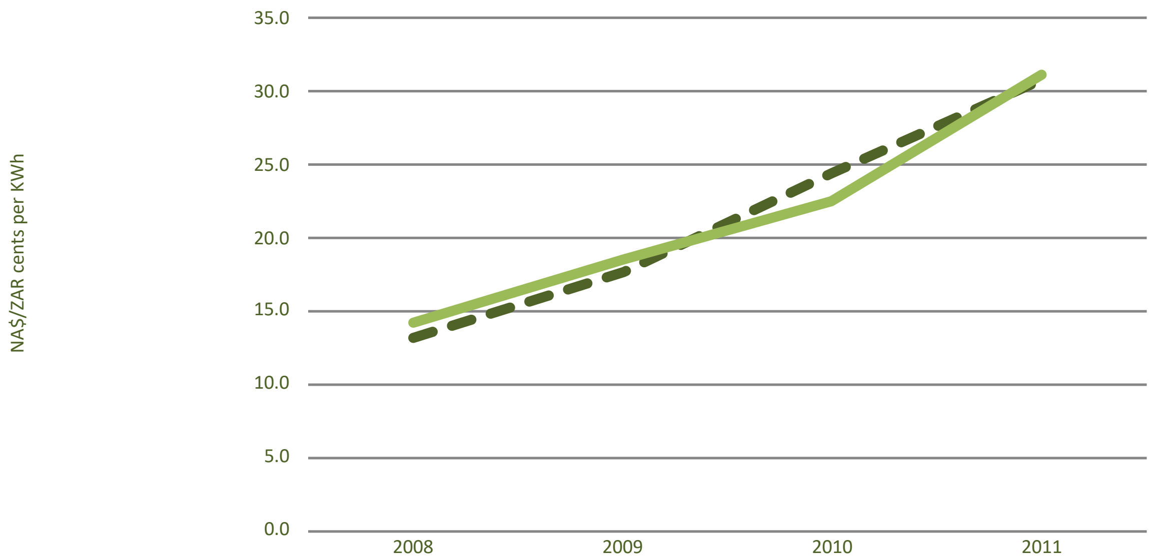
Other imports

"As is scenario"	2009	2010	2011	2012	2013	2014	2015
ZESCO	29	47					
EDM	24	95					
STEM	0	0					
Total - "other" imports	**53**	**142**	**150**	**400**	**400**	**400**	**400**
Estimated price of other imports	17.6	24.3	30.7	38.1	47.2	58.5	72.7
Costs in NA$'millions	**9**	**34**	**46**	**152**	**189**	**234**	**291**

17.1.2 Model validation

17.1.2.1 Eskom pricing model

Figure 83 – Validating the Eskom model
ANE's model vs. Eskom's published export revenues

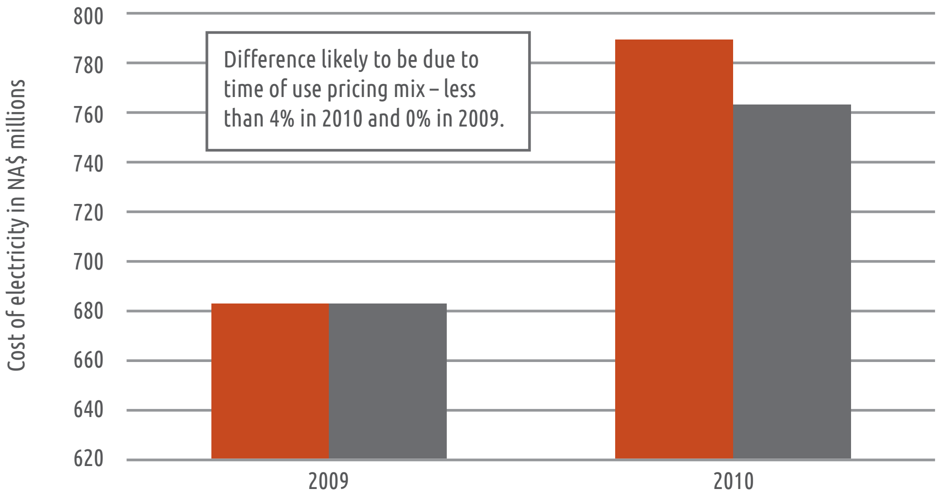


	2008	2009	2010	2011
Estimated Eskom cost of sales price - NA$ cents per KWh	13.2	17.6	24.3	30.7
Exports unit revenue - average Zar cents per KWh	14.2	18.5	22.5	31.0

Note that the model assumes that the tariffs are based on the local municipal rates table – for zone 4 – which will mean that Namibia will face the same rates as the City of Cape Town. This graph suggests that the model is fairly accurate. Any discrepancies can be explained by the fact that ANE can only assume average time of use, whereas the actuals will reflect differences.

17.1.2.2 Validating the NamPower fully absorbed cost pricing model

Figure 84 – Comparing ANE’s pricing model with published cost of electricity in the NamPower financial statements



	2009	2010
ANE’S model	683	790
Published electricity costs	683	764

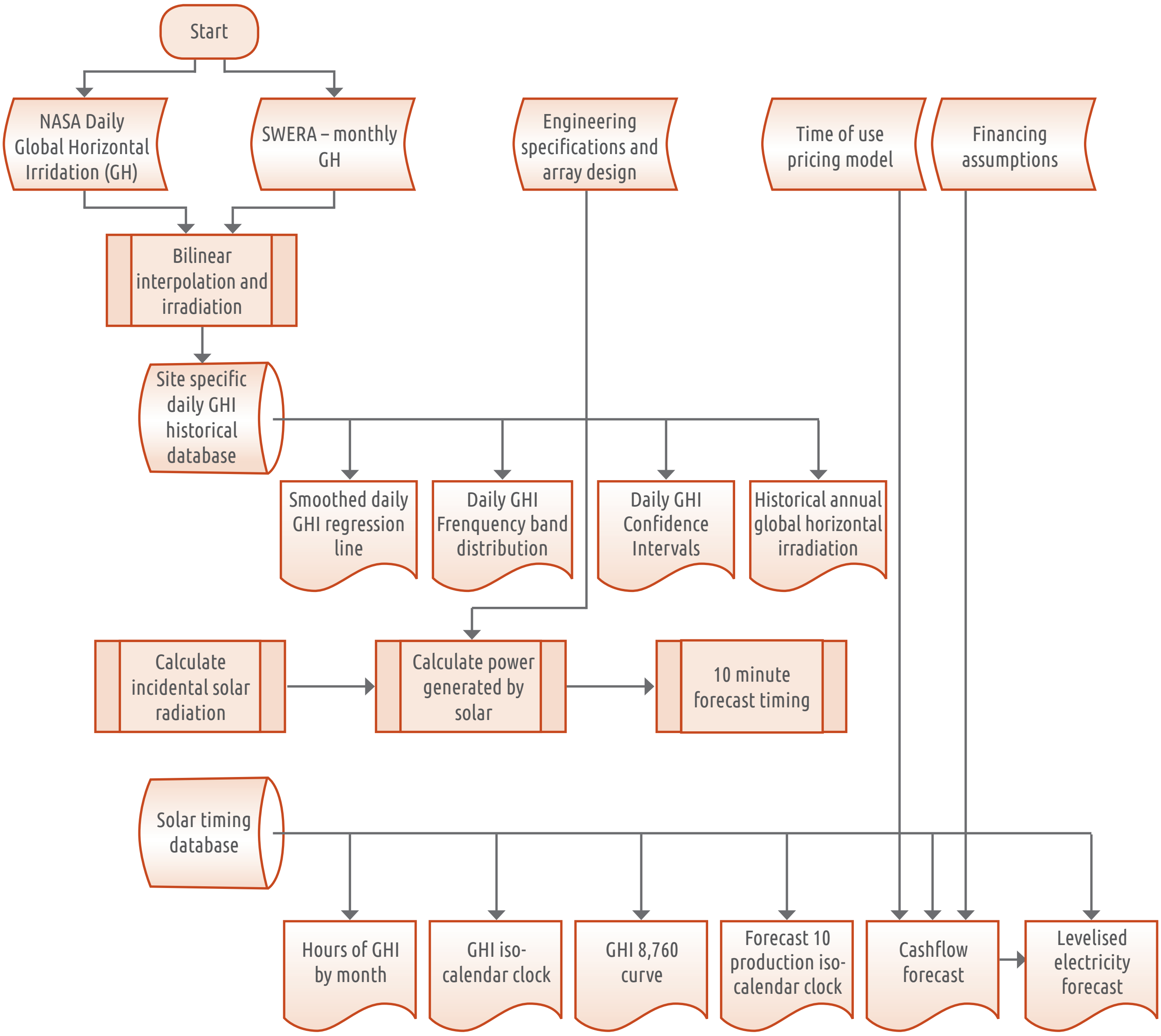
The ANE model will never be perfect, until all volume, time of use and pricing information is known, as well as policies of cost absorption. In the ECB pricing study, the local costs of absorption put forward by NamPower were stated, so as the capacity has not changed in the last ten years, it was reasonable to assume that these cost allocations have not changed.

A 4% price difference is leaves the model fairly robust – it implies that a 7.5USc per KWh cost of electricity, that ANE deems as an independent power producer rate, could be as high as 7.8 USc per KWh or as low as 7.2 USc per KWh, an 8% range.

18. Solar performance and levelised electricity cost calculations

19.1. Process map

Figure 100 – Solar calculation process



The solar calculation is based on solar geometry and combined with basic engineering inputs to give volume and simple statistical confidence intervals of performance. It locates data from the NASA Homer Database initially, in the pre-feasibility stage – although this can be modified to include satellite and ground data calculation at later stages for more accuracy. The model then adds engineering specification data, pricing and financing assumptions to arrive at a levelised electricity cost, as well as various other technical outputs.[34]

34 The model is based on the algorithms explained in the standard text on the subject – *Solar Engineering of Thermal Process – Third Edition– 2006* by John A. Duffie and William A. Beckman. The author is also indebted to the RetScreen chapter on Solar Photovoltaics and the website www.PVeducation.org. The equations created within this process are identical to none of them, but are influenced by all.

19.2. Calculating solar volume

19.2.1 Estimating global horizontal irradiation for a specific site

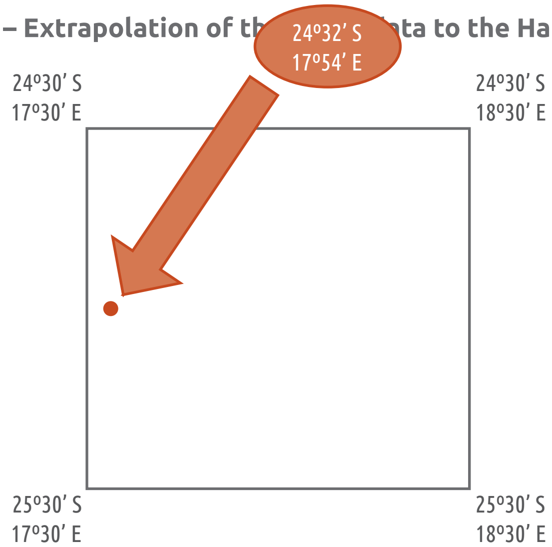
Solar performance is affected seasonally as well as by time of day, so the first input required is the latitude and longitude of the location for which solar performance is required.

Namibia is South of the Equator and East of Greenwich. The site selected in Namibia, for purposes of this illustration, was one in the centre of the country – Hardap Dam, near the town of Mariental with the following co-ordinates:

Latitude: 24° 32' S Longitude: 17° 54' E

These data are feed are used to find the four points on the NASA Homer database, for which there are data with a resolution of 1 degree latitude, by 1 degree longitude, with the mid-point at the middle of each degree interval – see below:

Figure 101 – Extrapolation of th… ta to the Hardap Dam site



The four data points are then subject to a bilinear interpolation to give appropriate weighting to the site selected.

The daily data for each day from 1 January 1984 to 31 December 2005 are then aggregated into monthly average data is then compared to the SWERA database, which has a tighter interval – approximately 40km by 40 km, or 6 times smaller granularity. The monthly averages from the SWERA algorithm are then extrapolated back to the daily averages of the interpolated value calculated from the Homer database – and checked for accuracy. In this case, the two values were less than 1% different, so were accepted. Where they are greater than 3% different, more analysis needs to be done and perhaps more granular satellite data purchased – where 3km by 3km can be purchased for all of Southern Africa.

The daily data enables a 6-degree polynomial line to be fitted to the average daily data – where the daily value for each of the 22 years is averaged. The polynomial for Hardap Dam was calculated as:

The smoothed weekly peak to average demand ratio for Namibia is represented by the following 6th degree polynomial equation:

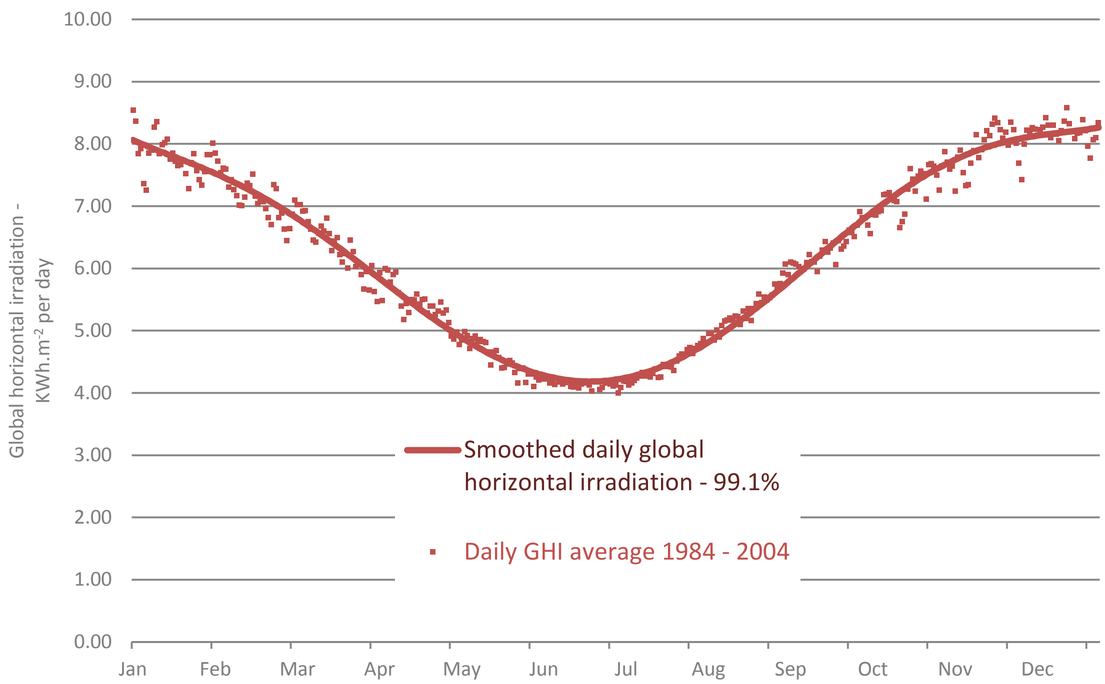
Equation 3 – the smoothed fitted polynomial equation for Hardap Dam in Namibia

$$GHI_d = 1.1602.10^{-13}d_n^6 - 1.2500.10^{-10}d_n^5 + 4.5922.10^{-8}d_n^4 - 6.2289.10^{-6}d_n^3 + 2.3027.10^{-4}d_n^2 - 1.9725.10^{-2}d_n + 8.0806$$

$$GHI_d = average\ historical\ global\ horizontal\ irradiation - in\ KWh.m^{-2}.day^{-1}$$

$$d_n = the\ n^{th}\ day\ of\ the\ calender\ year - i.e.\ 1\ January = 1\ and\ 31\ December = 365$$

Figure 102 – Comparing average GHI to smoothed irradiation



As can be seen from the curve, there is an exceptionally high correlation- 99.1% - where 100% is perfect correlation.

Once the daily smoothed GHI is calculated, a sheet called solar data calculates the following on a daily basis for that specific location:

19.2.1.1 Declination angle

The declination is the angular position of the sun at solar noon, with respect to the plane of the equator. Its value in degrees is given by Cooper's equation:

Equation 4 – Angle of declination

$$\delta = 23.45 sin\left(2\pi\frac{284+n}{365}\right)$$

Where δ = angle of declination on day n – where n = 1 on 1 January and 365 on 31 December.

19.2.1.2 Solar time angle and sunset hour angle

The solar time angle is the angular displacement of the sun east or west of the local meridian; with the morning negative, afternoon positive. The solar time angle is equal to zero at solar noon and varies by 15 degrees per hour from solar noon. For example at 9 a.m. (solar time2) the hour angle is equal to –45° (9 a.m. is three hours from noon; three times 15 is equal to 45, with a negative sign because it is morning). Solar time is the time based on the apparent motion of the sun across the sky. Solar noon corresponds to the momentwhen the sun is at its highest point in the sky.

The sunset hour angle ω_s is the solar hour angle corresponding to the time when the sun sets and is given by the following equation:

Equation 5 – Solar sunset angle

$$\cos\omega_s = -\tan\varphi\tan\delta$$

$$where\ \delta\ is\ the\ declination, calculated\ in\ \text{Equation 4 Angle of declination}$$

$$and\ \varphi\ is\ the\ latitude\ of\ the\ site\ all\ in\ radians$$

19.2.1.3 Extra-terrestrial irradiation

Solar radiation outside the earth's atmosphere is called extra-terrestrial radiation. Daily extra-terrestrial radiation on a horizontal surface, H0 can be computed for day n from the following equation:

Equation 6 – Extra-terrestrial irradiation

$$H_0 = \frac{86400 G_{sc}}{\pi}\left(1 + 0.033\cos\left(2\pi\frac{n}{365}\right)\right)(\cos\varphi\cos\delta\sin\omega_s + \omega_s\sin\varphi\sin\delta)$$

$$where\ H_0 = extra - terrestrial\ irradiation$$

$$a\ and\ where\ G_{SC}\ is\ the\ solar\ constant\ equal\ to\ 1{,}367\ W.m^{-2},$$

$$and\ all\ other\ variables\ have\ the\ same\ meaning\ as\ before$$

19.2.1.4 Clearness index

Before reaching the surface of the earth, radiation from the sun is attenuated by the atmosphere and the clouds. The ratio of solar radiation at the surface of the earth to extra-terrestrial radiation is called the clearness index. Thus the monthly average clearness index, where $\overline{H}$ is the monthly average daily solar radiation on a horizontal surface and $\overline{Ho}$ is the monthly average extra-terrestrial daily solar radiation on a horizontal surface.

Equation 7 – Clearness index

$$\overline{K_T} = \frac{\overline{H}}{\overline{H_0}}$$

$\overline{K_T}$ values depend on the location and the time of year considered; they are usually between 0.3 (for very overcast climates) and 0.8 (for very sunny locations). Namibia is closer to 0.8.

19.2.2 Tilted irradiance calculation

19.2.2.1 Calculation of 10-minute interval global and diffuse irradiance

Solar radiation can be broken down into two components: beam radiation, which emanates from the solar disk, and diffuse radiation, which emanates from the rest of the sky. The tilting algorithm used in the ANE model requires the knowledge of beam and diffuse radiation for every ten minutes of an "average day", which is defined as the average irradiation over the 22 year period and, in the case of this specific site, smoothed as per *Equation 3 – the smoothed fitted polynomial equation for Hardap Dam in Namibia*. The tilt equations are based on Duffie and Blackman – 2006.

The standard formula for the split between average diffuse and beam irradiation is calculated from averagedailyglobal radiation using the Erbs et al. correlation (Duffie and Beckman, 2006):

Equation 8 – Erbs et al diffuse irradiation correlation

$$\frac{\overline{H_d}}{\overline{H}} = 1.391 - 3.560\overline{K_T} + 4.189\overline{K_T^2} - 2.137\overline{K_T^3}$$

when the sunset hour angle for the average day of the month is less than 81.4º

$$\frac{\overline{H_d}}{\overline{H}} = 1.311 - 3.022\overline{K_T} + 3.427\overline{K_T^2} - 1.821\overline{K_T^3}$$

when the sunset hour angle for the average day of the month is greater than 81.4º

where $\overline{H_d}$ is the total diffuse irradiation onto a horizontal surface for a particular location

$\overline{H}$ *is the daily global horizontal irradiation*

K_T *is the clearness factor as calculated above*

However this correlation is more suited for cloudy winter-rainfall climates than a hot dry summer rainfall climate like Namibia, so was rejected. With no rainfall in many parts of the country in June – September period, the Erbs correlation over estimates diffuse irradiation by 25% in the winter months when electricity demand is at a premium.

Instead the ANE model uses the SWERA monthly data, and fits it to a daily curve, with a small correction to ensure that the daily diffuse irradiation adds up to the annual number based on the following polynomial equation:

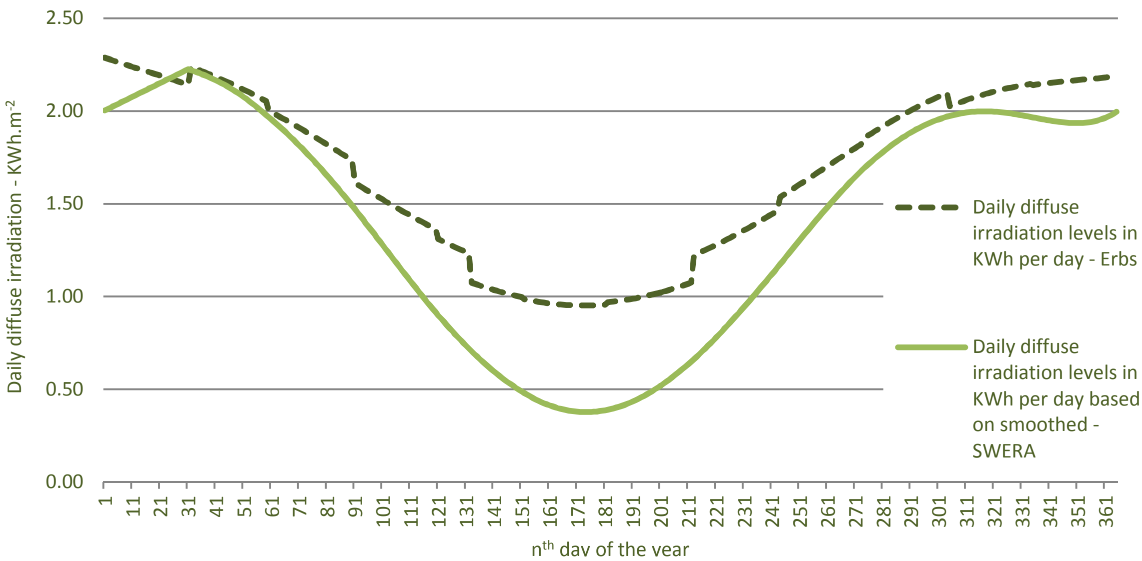
Equation 9 – ANE's 6th degree polynomial diffuse irradiation estimate based on the SWERA African irradiation satellite study

$$\overline{H}_d = 0.000124081m_n^6 - 0.004674024m_n^5 + 0.064671663m_n^4 - 0.3974m_n^3 + 1.07388m_n^2 - 1.4532m_n + 3.00629545$$

$$\overline{H}_d = expected\ diffuse\ irradiation - in\ KWh.m^{-2}.day^{-1}$$

$$m_n = the\ m^{th}\ month\ of\ the\ calender\ year\ (apportioned\ for\ dates\ during\ the\ month - i.e.15\ January = 0.48\ and\ 31\ December = 12$$

Figure 103 – Comparing ANE's 6th degree polynominal regression curve with the Erbs Correlation for Mariental, Namibia



The SWERA approximation has a high correlation co-efficient with the underlying data – over 98%. Perhaps as importantly, it deals with the winter dry season resulting in lower diffuse irradiation, and therefore will forecast more accurately the direct normal irradiation levels that are used to calculate concentrated solar power performance. The Erbs et al correlation will greatly underestimate the direct normal irradiation as a result of the over-estimation of the diffuse irradiation.

Once the ratio between Daily BeaM and Diffuse average daily irradiation is calculated, the daily global horizontal irradiation is then broken into average 10 minute values. This is done withformulae from Collares-Pereira and Rabl for global irradiance:

Equation 10 – splitting daily global horizontal irradiation into 10-minute intervals based on the Collares-Pereira and Rabl relationship

$$r_t = \pi\,(a + b\,cos\omega)\frac{cos\omega - \cos\omega_s}{sin\omega_s - \omega_s\,cos\omega_s}$$

where $$a = 0.409 + 0.5016\,sin\left(\omega_s - \frac{\pi}{3}\right)$$

$$b = 0.6609 - 0.4767\,\sin(\omega_s - \frac{\pi}{3})$$

$r_t =$ *the ratio of hourly total to daily total global radiation*

$\omega_s =$ *the sunset hourangle, expressed in radians*

ω $=$ *is the solar hour angle for the midpoint of the 10 minute interval for which the calculation is made, also expressed in radians*

The diffuse irradiation apportionment through the day is based on the Jordan and Liu formula

Equation 11 –– splitting daily diffuse irradiation on a horizontal surface into 10-minute intervals, based on the Jordan and Liu relationship

$$r_d = \frac{\pi}{144}\frac{\cos\omega - \cos\omega_s}{\sin\omega_s - \omega_s\cos\omega_s}$$

where

$r_d =$ *the ratio of hourly total to daily diffuse radiation*

$\omega =$ *is the solar hour angle for the midpoint of the 10 minute interval for which the calculation is made, also expressed in radians*

$\omega_s =$ *the sunset hourangle, expressed in radians*

For ten-minute interval of the "average day", global horizontal irradiance H and its diffuse and beam components H_d and H_b are therefore given by:

Equation 12 – relationships between diffuse irradiation and global horizontal irradiation

$$H = r_t\overline{H}$$

$$H_d = r_d\overline{H_d}$$

$$H_b = H - H_d$$

10-minute irradiance in the plane of the PV panel or solar collector tube H_t is calculated using an isotropic model, described in section 1.6 of Duffie and Beckman (2006).

$$H_t = H_b R_b + H_d\left(\frac{1+\cos\beta}{2}\right) + H\rho\left(\frac{1-\cos\beta}{2}\right)$$

where ρ represents the diffuse reflectance of the ground (also called ground albedo) and β represents the slope of the PV or thermal surface. Ground albedo is set to 0.2 if the average monthly temperature is greater than 0°C, 0.7 if it is less than –5°C, with a linear interpolation for temperatures between these values. In Namibia, where temperature never goes below zero, ground Albedo is low, although reflection off the dunes could be higher in certain desert regions. R_b is the ratio of beam radiation on the PV array to that on the horizontal, which can be expressed as:

$$\frac{\cos\theta}{\cos\theta_z}$$

where θ the incidence is angle of beam irradiance on the array and θ_z is the zenith angleof the sun.

The advantage of the algorithm above is that it can accommodate situations where the positionof the arrayvaries through the day, as is the case with tracking arrays. For tracking surfaces, the slope β of the array and the incidence angle θ for every hour are determined according to section 1.6 of Duffie and Beckman (2006).

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