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Department:
Energy
REPUBLIC OF SOUTH AFRICA

REPORT ON HIGH LEVEL COSTING FOR COLLECTOR STATIONS FOR GENERATION PREPARED FOR INPUT INTO THE INTEGRATED RESOURCE PLAN

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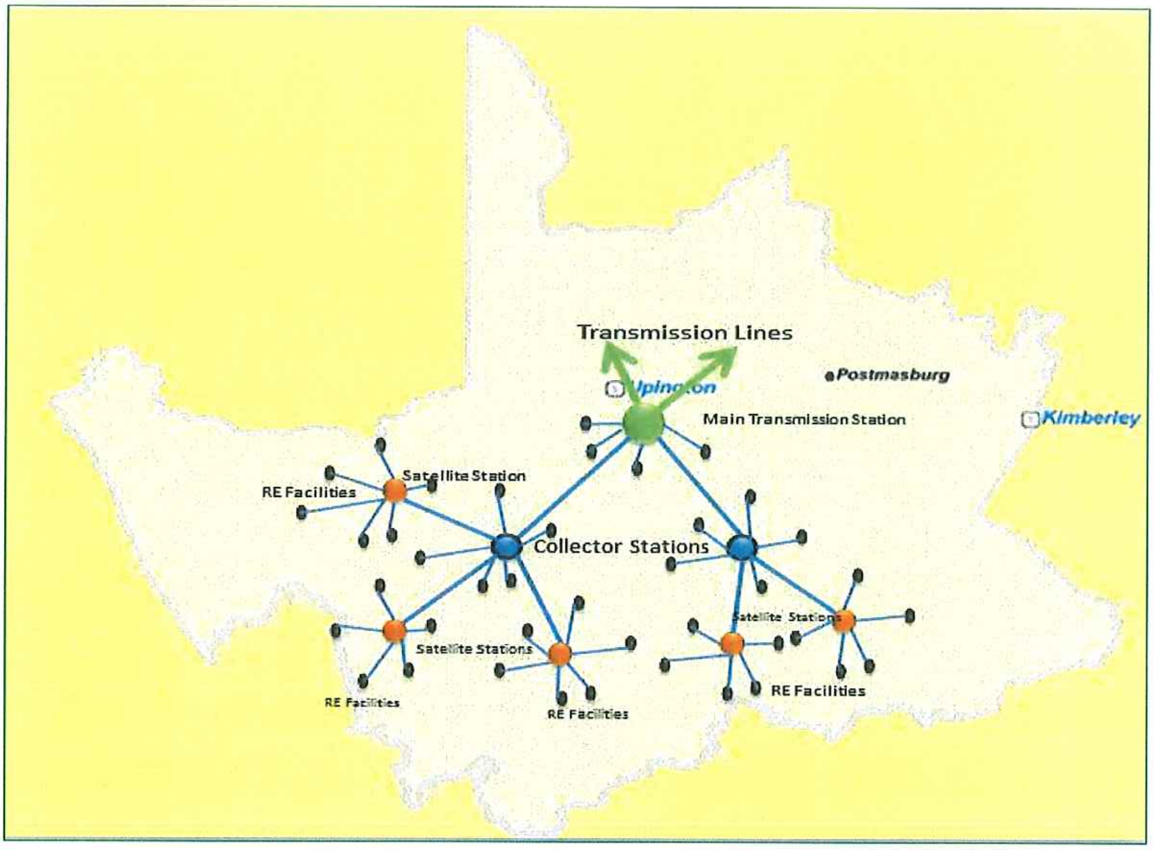
HIGH LEVEL COSTING OF COLLECTOR STATIONS FOR GENERATION



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Abstract

Energy Planning requested Grid Planning to cost collector substations for various capacities of RE and conventional plant in different areas. This document describes the assumptions used to determine the cost of collector stations for the purposes of integrating renewable energy. It also describes the method used to determine connecting substations for conventional power stations.

The costing is not design-based but high-level and based on recent average costs for various infrastructures. The output thereof may not be used to determine the cost of any specific project; however, it can be used to establish high level cost of collector infrastructure. Accurate costing will depend on site specific issues that can only be determined during the design phase of a project

Contents

1. Introduction

South Africa has embarked in a process of diversifying its energy-mix to enhance energy security while also lowering green-house gas emissions. The country is blessed with a climate that allows Renewable Energy (RE) technologies like solar photovoltaic (PV) and Wind generation to be installed almost anywhere in the country. The Department of Energy's (DOE) Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) was a driving force behind the installation of close to 7GW of RE from the year 2012. During this period lessons were quickly learned on how and how not to integrate RE, especially how they get connected to the Transmission Grid.

One of the crucial lessons learned was that it is not cost effective to connect each RE facility directly to the Transmission substation. This is because the number of connections that can be connected in a Transmission substation are limited resulting in fewer connections made. The best way to connect RE in a scenario where there is an abundance of RE facilities is to use collector stations as this enables much more facilities to be connected before the Transmission Substation is congested.

In order to determine the true cost of a generation plan, it is important to also take the cost of collector infrastructure into account. Apart from the collector infrastructure, it is also important to consider the total cost of the transmission infrastructure. Energy Planning requested Grid Planning to provide the cost of collector stations in various Customer Load Networks (CLN's) for different penetration levels of different generating technologies. For PV, the information was provided as shown in Table 1, and the wind allocations in Table 2 were provided at regional level. Energy Planning requested Grid Planning to allocate the Regional capacities to CLN's at our own discretion, the allocations were based on the perceived difficulty in terms of Land and Rights and CLN potential based on experience in terms of where most applications have been made in the past.

Table 1: Solar PV Allocation Provided by Energy Planning

CLN	CLNs	% Allocation
Bloemfontein	Bloemfontein	100%
Cape Town	Peninsula	100%
De Aar	Karoo	100%
Durban	Pinetown	100%
Johannesburg	Johannesburg	100%
Port Elizabeth	Port Elizabeth	100%
Upington	Kimberley	100%

Table 2: Wind PV Allocation Provided by Energy Planning

Regions	*CLNs	% Allocation
KZN Coast (Pinetown, Empangeni)		**100%**
	Pinetown	50%
	Empangeni	50%
West Coast (West Coast, Namaqualand)		**100%**
	West Coast	50%
	Namaqualand	50%
South Coast (Peninsula, Southern Cape, East London, Port Elizabeth)		**100%**
	Peninsula	25%
	Southern Cape	25%
	East London	25%
	Port Elizabeth	25%
Karoo (Karoo, Kimberley)		**100%**
	Karoo	70%
	Kimberley	30%
Limpopo (Waterberg, Polokwane, Warmbad, Rustenburg, Pretoria)		**100%**
	Waterberg	10%
	Polokwane	60%
	Warmbad	10%
	Rustenburg	10%
	Pretoria	10%
Gold Fields (Welkom, Bloemfontein, Carletonville)		**100%**
	Welkom	35%
	Bloemfontein	35%
	Carletonville	30%
Lowveld (Lowveld)		**100%**
	Lowveld	100%
Vaal (Johannesburg, Nigel, West Rand, Vaal Triangle)		**100%**
	Johannesburg	10%
	Nigel	40%
	West Rand	10%
	Vaal Triangle	40%
*For CLN allocation, Energy Planning Requested Grid Planning to allocate in the CLN's using our own discretion; the allocation in the CLN's considered factors like urbanisation and potential.		

This document describes how the costs of collector stations are determined and it will give results based on different scenarios for different CLN’s in the country. Although the total Transmission infrastructure like Transmission corridors is also important, it will not be covered in this document because it requires detailed generation plan-specific details to compute. The cost of other connecting substations for conventional generators is also included in this document. The cost of lines from individual RE facilities to the collectors are also not included as they are borne by the IPP’s.

2. The Collector Station Framework

2.1. Description of the Framework

The aim of using the collector station framework is to avoid premature congestion of Main Transmission Substations and reduce overall cost of connecting RE into the Grid. The collector station framework was jointly developed by Grid Planning, the IPP Office and Distribution Planning. Two examples of the collector station framework are shown in Figure 1, the diagram on left hand side gives the spatial view, whereas the one on the right shows a single line diagram. Costs from all the generators labelled (G) to the collectors as well as the bay costs for these facilities are excluded as they are borne by the IPP.

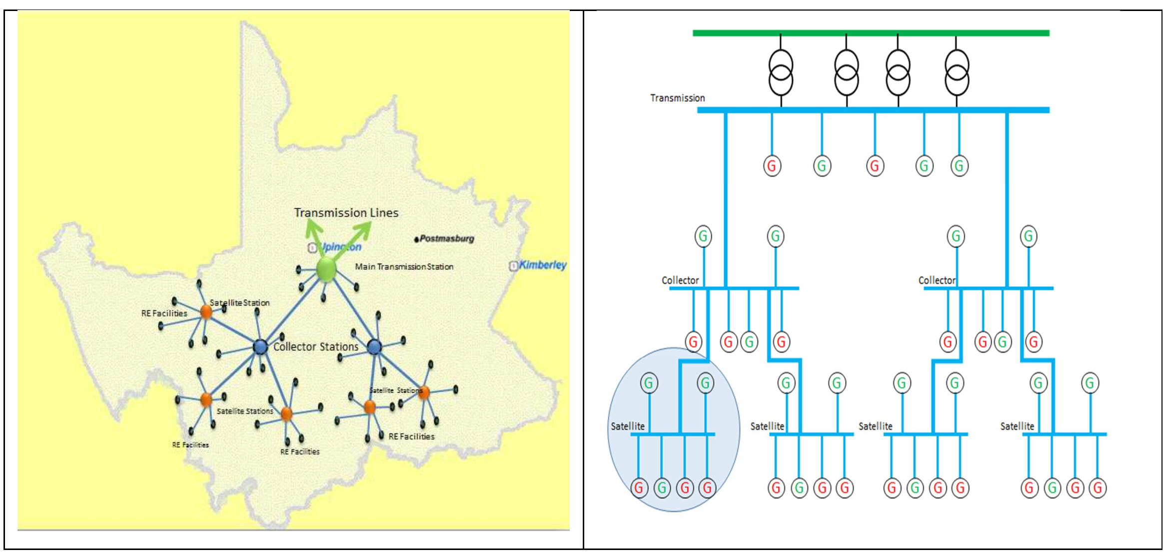

Figure 1: Examples of Collector Station Framework (not to scale)

In this framework, as many of the facilities are collected downstream in collector and satellite switching stations. A satellite station is a collector hub that is connected to a collector station, whereas a collector station is directly connected to a main transmission station and collects directly from RE Facilities and Satellite stations. The advantages of collector stations are as follows:

- Minimizes number of Transmission substations and associated life cycle costs
- Prevents premature congestion of Transmission substations and maximizes utilization of Transmission Substation Assets
- Collects much more generation from different hubs into a transmission station
- Allows for orderly planning of the network and minimizes land usage

2.2. Calculating maximum RE Facilities Connected in a Collector Unit

A collector station Unit consists of all the a single main Transmission Substation, Collector stations connected to it as well as the Satellite stations connected therein. For practical purposes the size of a unit is restricted by the number of transformers that are connected at a transmission Substations. Because of other considerations like maximum fault level tolerable, and avoidance of common mode failure, Transmission Grid Planning decided to limit the number of Transformers at a substation to 4x500MVA Transformers. Using the N-1 Grid Code Reliability Criteria, these transformers can evacuate 1500MW of power if load connected to the substation is not considered and more if it is considered.

2.3. Diversity, Coincidence and Utilisation Factors

It is not possible for all RE Facilities connected in a large area to be generating at 100% at the same time. This is due to the fact that atmospheric conditions will differ over a large area giving rise to different generation potential. These factors allow the number of connected RE facilities to be increased. In order to calculate the amount by which we can increase the installed capacity of a Collector unit we make use of diversity and coincidence factors. Although individual plants can achieve maximum capacity, they will not achieve this at the same time. A coincidence factor is a measure of the maximum output achievable from generating units compared. A 0.6 or 60% coincidence factor means that a maximum of 60% of the installed capacity in a local area can be realised. This does not mean that 60% will never be exceeded, if it gets exceeded it will only be on very rare occasions.

A diversity factor operates on a wider area, and it takes cognisance of the fact that conditions will differ over a wider area. It is applied after the coincidence factor has been applied; it operates in the same way because it will increase the installed capacity for a given

Substation evacuation capacity. The coincidence and diversity factors are estimated based on actual data for wind and PV generation.

Maximum substation utilisation factor recognises the fact that it is not possible to connect exactly 100% of export capacity, this is because the RE resources within an area might not match the substation export capacity 100% in a given catchment area. For instance, if a substation's export capacity is 1000MW and the total number of wind facilities in its catchment area total 800MW, then the Utilisation factor will be 80% or 800MW/1000MW.

The utilisation factor reduces the number of RE capacity that can be connected. Table 3 shows the illustration of the effect of the coincidence, diversity and utilisation factors, it can be seen that the overall effect is to increase the evacuation capacity that can be installed in an area. A substation that can evacuate 1500MW is capable of having an installed capacity of 2500MW or 1765MW depending on the factors used. For this study, a coincidence factor of 0.6 is used for Wind during the day and 0.85 at night based on observed actual data. For solar 0.85 is used during the day and 0 at night, also based on observed actual data. A diversity factor and Substation Utilisation factor of 0.85 is used at all times.

Table 3: Illustration of Installed Capacity Calculation

Evacuated Capacity (MW)	Coincidence Factor Adjustment (MW) (0.6;0.85)	Diversity Factor Adjustment (MW) (0.85; 0.85)	Utilisation Factor Adjustment (MW) (85%)	Installed Capacity (MW)
1500	1500/0.6=2500	2500/0.85=2942	2942*85%=**2500**	**2500**
1500	1500/0.85=1765	1765/0.85=2076	2076*85%=**1765**	**1765**

2.4. Costing Assumption

The costing values used in this report are shown in Table 4, these are general high level values used in Transmission studies, and they are given in today's costs.

Table 4: Values used to calculate Collector Substation Costs

Equipment	R mil/Unit
Transmission Substation (4 Transformers)	1 200
500MVA Transformer	150
132kV Transmission Bay	10
132kV Distribution line(per km)	2
132kV Distribution Bay	6
Distribution Collector/Satellite Station	25
SVC (per MVAR)	1

2.5. Determining Required Number of Collector Units

The calculations described in section 2.3 allow for the calculation of a number of collector units required per area, given the total capacity that will be installed in a CLN. For this exercise there was a requirement to calculate costs for connecting various capacities of Wind or Solar ranging from 5000MW to 40000MW. The calculations give the maximum that can be installed in one collector unit and to calculate the units required, the total capacity installed in a CLN has to be divided by the maximum per collector unit. The values of 5000MW to 40000MW were provided by Energy Planning.

2.6. Capacities Connected Per CLN

The allocation of the total capacity among the various CLN's for PV and Wind is show in Table 5 and Table 6 respectively. For Solar PV the CLN's were allocated the full capacity of 5000MW, 10000MW, 20000MW, 30000MW or 40000MW. For wind facilities, the areas were given as regions which can encompass a number of CLN's so the installed capacity was shared among the CLN's as shown in Table 6.

Table 5: PV Capacity per CLN per Scenario

Supply Area	Scenarios (installed Capacity)				
	5000MW	10000MW	20000MW	30000MW	40000MW
Bloemfontein	5000	10000	20000	30000	40000
Johannesburg	5000	10000	20000	30000	40000
Karoo(De Aar)	5000	10000	20000	30000	40000
Kimberley (Upington)	5000	10000	20000	30000	40000
Peninsula (Cape Town)	5000	10000	20000	30000	40000
Pinetown(Durban)	5000	10000	20000	30000	40000
Port Elizabeth	5000	10000	20000	30000	40000

Table 6: Wind Capacity per CLN per Scenario

Regions	CLNs	5000MW	10000MW	20000MW	30000MW	40000MW
KZN Coast (Pinetown, Empangeni)		**5000**	**10000**	**20000**	**30000**	**40000**
	Pinetown	2500	5000	10000	15000	20000
	Empangeni	2500	5000	10000	15000	20000
West Coast (West Coast, Namaqualand)		**5000**	**10000**	**20000**	**30000**	**40000**
	West Coast	2500	5000	10000	15000	20000
	Namaqualand	2500	5000	10000	15000	20000
South Coast (Peninsula, Southern Cape, East London, Port Elizabeth)		**5000**	**10000**	**20000**	**30000**	**40000**
	Peninsula	1250	2500	5000	7500	10000
	Southern Cape	1250	2500	5000	7500	10000
	East London	1250	2500	5000	7500	10000
	Port Elizabeth	1250	2500	5000	7500	10000
Karoo (Karoo, Kimberley)		**5000**	**10000**	**20000**	**30000**	**40000**
	Karoo	3500	7000	14000	21000	28000
	Kimberley	1500	3000	6000	9000	12000
Limpopo (Waterberg, Polokwane, Warmbad, Rustenburg, Pretoria)		**5000**	**10000**	**20000**	**30000**	**40000**
	Waterberg	500	1000	2000	3000	4000

	Polokwane	3000	6000	12000	18000	24000
	Warmbad	500	1000	2000	3000	4000
	Rustenburg	500	1000	2000	3000	4000
	Pretoria	500	1000	2000	3000	4000
Gold Fields (Welkom, Bloemfontein, Cartonville)		**5000**	**10000**	**20000**	**30000**	**40000**
	Welkom	1750	3500	7000	10500	14000
	Bloemfontein	1750	3500	7000	10500	14000
	Carletonville	1500	3000	6000	9000	12000
Lowveld (Lowveld)		**5000**	**10000**	**20000**	**30000**	**40000**
	Lowveld	5000	10000	20000	30000	40000
Vaal (Johannesburg, Nigel, West Rand, Vaal Triangle)		**5000**	**10000**	**20000**	**30000**	**40000**
	Johannesburg	500	1000	2000	3000	4000
	Nigel	2000	4000	8000	12000	16000
	West Rand	500	1000	2000	3000	4000
	Vaal Triangle	2000	4000	8000	12000	16000

2.7. Existing Infrastructure

To cater for infrastructure that already exists and avoid “double-counting” of costs, the existing substation fleet was examined per CLN. The CLN’s existing qualifying transformer fleet was used as existing transmission infrastructure. To qualify, transformers must have had a secondary voltage of 88kV or 132kV. The capacity of all qualifying transformers was added to get the equivalent 500MVA transformers in a CLN; this was divided by four to get equivalent number of collector main transformer substations existing. The reason why the total capacity was divided by 500MVA is that the collector station framework uses 500MVA transformers, and the reason why that was divided by four is that there are four transformers in the collector station framework. These calculations are designed to give the equivalent number of Transmission Substations in a CLN. The capacity calculations are based on the 2017 available substation capacities for qualifying transformers.

Table 7: Existing Infrastructure Discounted

Supply Area	Sum of Qualifying Transformation Capacity	500MVA Equivalent	Available Substation Equivalent
Bloemfontein	1250	2.5	0.6
Carletonville	6030	12.1	3.0
East London	2240	4.5	1.1
Empangeni	3000	6.0	1.5
Highveld North	7350	14.7	3.7
Highveld South	2960	5.9	1.5
Johannesburg	6785	13.6	3.4
Karoo	1875	3.8	0.9
Kimberley	3425	6.9	1.7
Ladysmith	1110	2.2	0.6
Lowveld	4450	8.9	2.2
Namaqualand	625	1.3	0.3
Newcastle	2570	5.1	1.3
Nigel	3805	7.6	1.9
Peninsula	5500	11.0	2.8
Pinetown	4500	9.0	2.3
Polokwane	5000	10.0	2.5
Port Elizabeth	4470	8.9	2.2
Pretoria	2130	4.3	1.1
Rustenburg	5780	11.6	2.9
Southern Cape	2240	4.5	1.1
Vaal Triangle	3300	6.6	1.7
Warmbad	750	1.5	0.4
Waterberg	2130	4.3	1.1
Welkom	3000	6.0	1.5
West Coast	1740	3.5	0.9
West Rand	5035	10.1	2.5

3. Calculated Costs

The collector costs for RE and Conventional Energy are given in the tables below, for conventional energy the number of assumed substations for any given capacity is given. The conventional generation costing is relatively easier as the power is concentrated in one location and there is no need for diversification. The total cost of a unit includes Main Transmission Substations (or balance thereof), Collector Stations, Satellite Stations, SVC devices and lines that interconnect these different stations.

Table 8: Costs for different Wind Capacities (R' Millions)

Regions	CLNs	5000MW	10000MW	20000MW	30000MW	40000MW
KZN Coast		**7 210**	**16 720**	**37 940**	**59 159**	**80 379**
	Pinetown	3 605	7 910	18 520	29 130	39 740
	Empangeni	3 605	8 810	19 420	30 030	40 640
West Coast		**9 191**	**19 801**	**41 021**	**62 240**	**83 460**
	West Coast	4 261	9 566	20 176	30 786	41 396
	Namaqualand	4 930	10 235	20 845	31 455	42 065
South Coast		**7 210**	**15 132**	**33 770**	**54 989**	**76 209**
	Peninsula	1 802	3 605	7 310	12 615	17 920
	Southern Cape	1 802	3 961	9 266	14 571	19 876
	East London	1 802	3 961	9 266	14 571	19 876
	Port Elizabeth	1 802	3 605	7 928	13 233	18 538
Karoo		**8 465**	**18 055**	**39 260**	**60 479**	**81 699**
	Karoo	6 302	13 729	28 583	43 437	58 290
	Kimberley	2 163	4 326	10 677	17 043	23 409
Limpopo		**7 210**	**15 730**	**35 074**	**55 613**	**76 153**
	Waterberg	721	1 442	2 966	5 088	7 210
	Polokwane	4 326	9 732	22 464	35 196	47 927
	Warmbad	721	1 672	3 794	5 916	8 038
	Rustenburg	721	1 442	2 884	4 326	5 768
	Pretoria	721	1 442	2 966	5 088	7 210
Gold Fields		**7 650**	**16 630**	**36 272**	**57 491**	**78 711**
	Welkom	2 523	5 627	13 054	20 481	27 908
	Bloemfontein	2 963	6 677	14 104	21 531	28 958
	Carletonville	2 163	4 326	9 114	15 480	21 846
Lowveld		**7 940**	**18 550**	**39 770**	**60 989**	**82 209**
	Lowveld	7 940	18 550	39 770	60 989	82 209
Vaal		**7 210**	**15 597**	**35 457**	**55 316**	**75 176**
	Johannesburg	721	1 442	2 884	4 326	5 768
	Nigel	2 884	6 205	14 693	23 181	31 669
	Westrand	721	1 442	2 884	4 326	5 768
	Vaal Triangle	2 884	6 508	14 996	23 484	31 972

Table 9: Costs for different PV Capacities (R' Millions)

CLN	CLNs	5000MW	10000MW	20000MW	30000MW	40000MW
Bloemfontein	Bloemfontein	9860	20470	41690	62909	84129
Cape Town	Peninsula	7310	17920	39140	60359	81579
De Aar	Karoo	9485	20095	41315	62534	83754
Durban	Pinetown	7910	18520	39740	60959	82179
Johannesburg	Johannesburg	7210	17149	38369	59588	80808
Port Elizabeth	Port Elizabeth	7928	18538	39758	60977	82197
Upington	Kimberley	8555	19165	40385	61604	82824

Table 10: Costs for different Coal Capacities (R' Millions)

Penetration and collector cost	Number of Sites Assuming 5000MW per site	Limpopo	Mpumalanga
Installed Capacity (MW)	1	5 000	5 000
Tx collector cost		1 280	1 280
Installed Capacity (MW)	2	10 000	10 000
Tx collector cost		2 560	2 560
Installed Capacity (MW)	4	20 000	20 000
Tx collector cost		5 120	5 120
Installed Capacity (MW)	6	30 000	30 000
Tx collector cost		7 680	7 680
Installed Capacity (MW)	8	40 000	40 000
Tx collector cost		10 240	10 240

Table 11: Costs for different Biomass/Landfill Gas Capacities (R' Millions)

Penetration and collector cost	Number of Sites Assuming 5000MW per site	JHB	Cape Town	Durban
Installed Capacity (MW)	5	250	250	250
Tx collector cost		0	0	0
Installed Capacity (MW)	20	1000	1000	1000
Tx collector cost		644	630	630

Table 12: Costs for different Pumped Storage Gas Capacities (R' Millions)

Penetration and collector cost	Number of Sites Assuming 1332MW per site	Western Cape	KZN
Installed Capacity (MW)	1	333	333
Tx collector cost		330	330
Installed Capacity (MW)	1	666	666
Tx collector cost		330	330
Installed Capacity (MW)	1	1332	1332
Tx collector cost		330	330
Installed Capacity (MW)	2	2664	2664
Tx collector cost		660	660
Installed Capacity (MW)	6	7992	7992
Tx collector cost		1980	1980

Table 13: Costs for different CSP Capacities (R' Millions)

Penetration and collector cost	Number of Sites Assuming 200MW per site	Upington
Installed Capacity (MW)	5	1000
Tx collector cost		1500
Installed Capacity (MW)	10	2000
Tx collector cost		3000
Installed Capacity (MW)	20	4000
Tx collector cost		6000
Installed Capacity (MW)	30	6000
Tx collector cost		9000
Installed Capacity (MW)	40	8000
Tx collector cost		12000

Table 14: Costs for different Nuclear Capacities (R' Millions)

Penetration and collector cost	Number of Sites Assuming 5000MW per site	Western Cape	Port Elizabeth
Installed Capacity (MW)	1	5000	5000
Tx collector cost		1280	1280
Installed Capacity (MW)	2	10000	10000
Tx collector cost		2560	2560
Installed Capacity (MW)	4	20000	20000
Tx collector cost		5120	5120
Installed Capacity (MW)	6	30000	30000
Tx collector cost		7680	7680
Installed Capacity (MW)	8	40000	40000
Tx collector cost		10240	10240

Table 15: Costs for different Gas Capacities (R' Millions)

Penetration and collector cost	Number of Sites Assuming 2500MW per site	Cape Coast	Durban Coast
Installed Capacity (MW)	2	5000	5000
Tx collector cost		2400	2400
Installed Capacity (MW)	4	10000	10000
Tx collector cost		4800	4800
Installed Capacity (MW)	8	20000	20000
Tx collector cost		9600	9600
Installed Capacity (MW)	12	30000	30000
Tx collector cost		14400	14400
Installed Capacity (MW)	16	40000	40000
Tx collector cost		19200	19200

Table 16: Costs for different Inga Capacities (R' Millions)

Penetration and collector cost	HVDC Collector Stations	
Installed Capacity (MW)	2	500
Tx collector cost		[1] 4190
Installed Capacity (MW)	2	1000
Tx collector cost		7720
Installed Capacity (MW)	2	1500
Tx collector cost		11580
Installed Capacity (MW)	2	2000
Tx collector cost		15440
Installed Capacity (MW)	2	2500
Tx collector cost		[2] 17650

4. Conclusion

The costing for collector stations for various installed capacities calculated in this exercise gives an initial high level indication of costs. However, to get more accurate costing, designs would have to be done for individual projects. The costing here should thus be taken as high level.

5. References

[1] "ABB wins $110 million power order to interconnect Lithuania and Poland." [Online]. Available: http://www.abb.com/cawp/seitp202/e33f0222195b2559c1257b130034f0c0.aspx. [Accessed: 29-Aug-2017].

[2] "Wecc transmission line costing." [Online]. Available: https://www.wecc.biz/Reliability/2014_TEPPC_Transmission_CapCost_Report_B+V.pdf. [Accessed: 29-Aug-2017].

Appendix A: Wind Costs Collector station Cost Calculation Spreadsheet

Refer to attached Spreadsheet (Corridors.xlsx)

Appendix B: PV Costs Collector station Cost Calculation Spreadsheet

Refer to attached Spreadsheet (Corridors.xlsx)