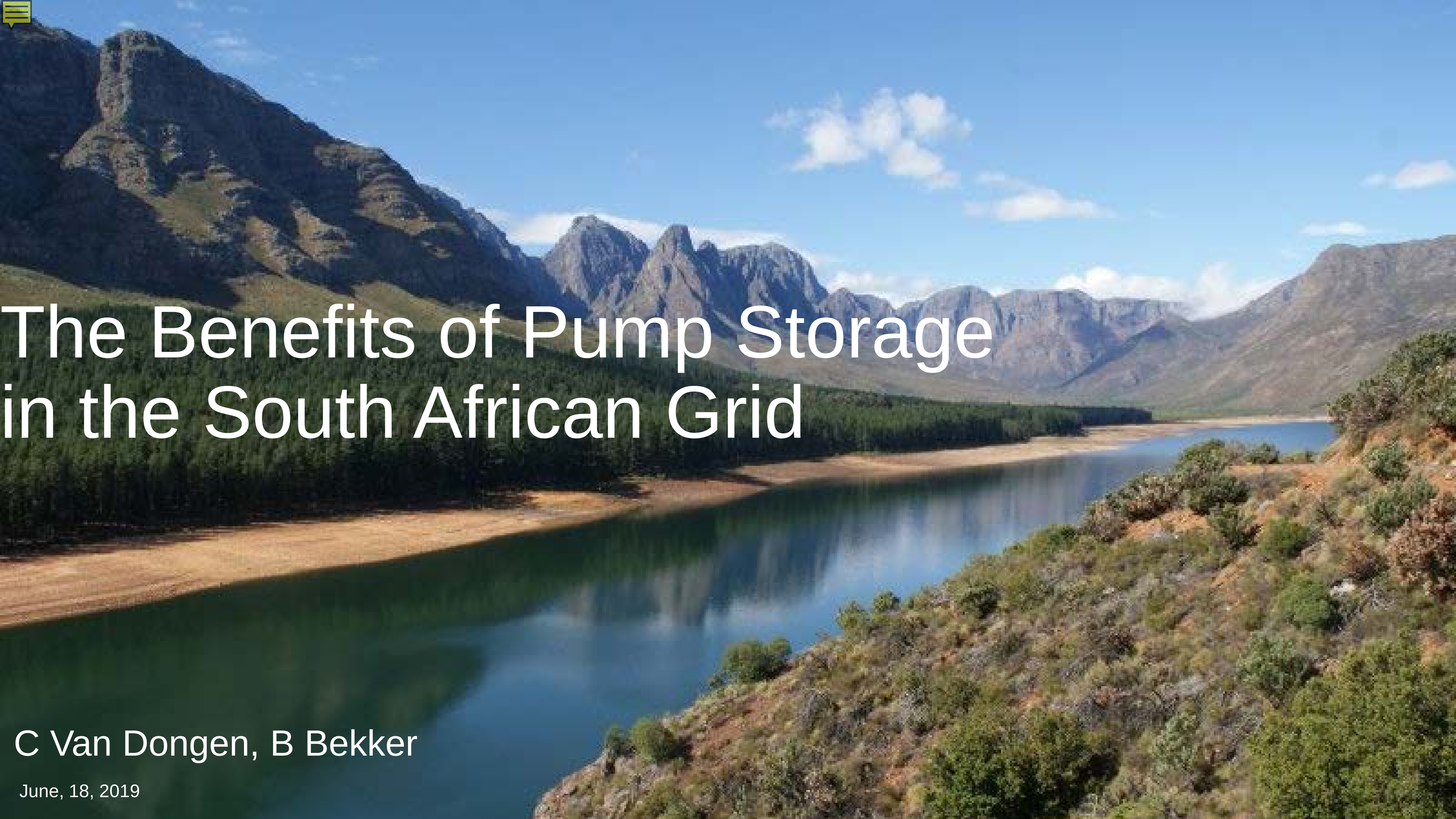


The Benefits of Pump Storage in the South African Grid

C Van Dongen, B Bekker

June, 18, 2019

Flexible Generation

Uncertainty in electricity demands are balanced in real-time using fast reacting flexible generators such as hydro and gas turbines.

IRP more flexible generation will be required to integrate the increased variable renewable energy generation & provided by gas turbines.

Verify renewables, gas and diesel combination.

Market based gas exposes the economy to a number of potential risks.

Pumped Storage Schemes (PSS) as an alternative technology for peaking and flexible generation.

Contents

PSS International

Pumped Storage History

161GW of PSS with another 78GW before 2030.

PSS technology development started after World War II.
Populations increased, rapid economic growth reshaped demand curves.
Increasing peak to baseload ratio & creating more distinctive seasonal peaks.

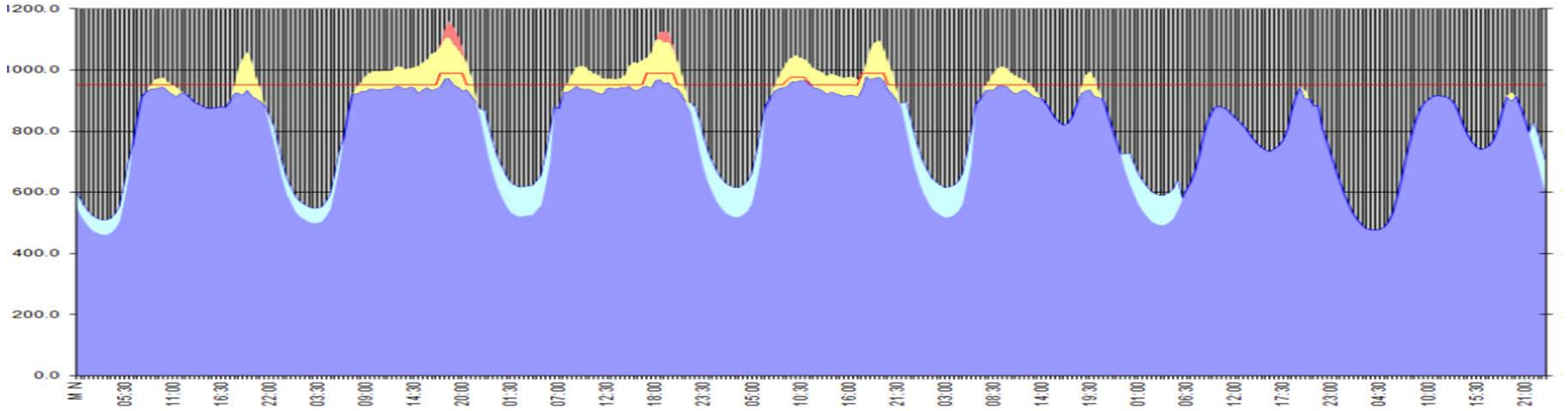
1960’s thermal generators were suited for constant high output, optimise efficiency,
Excessive ramping leads to more equipment stress & increased maintenance cost.

Dramatic increases in the price of oil & natural gas.
Powerplant and Industrial Fuel Use Act- limiting options to provide load-following and peaking services from gas turbines.

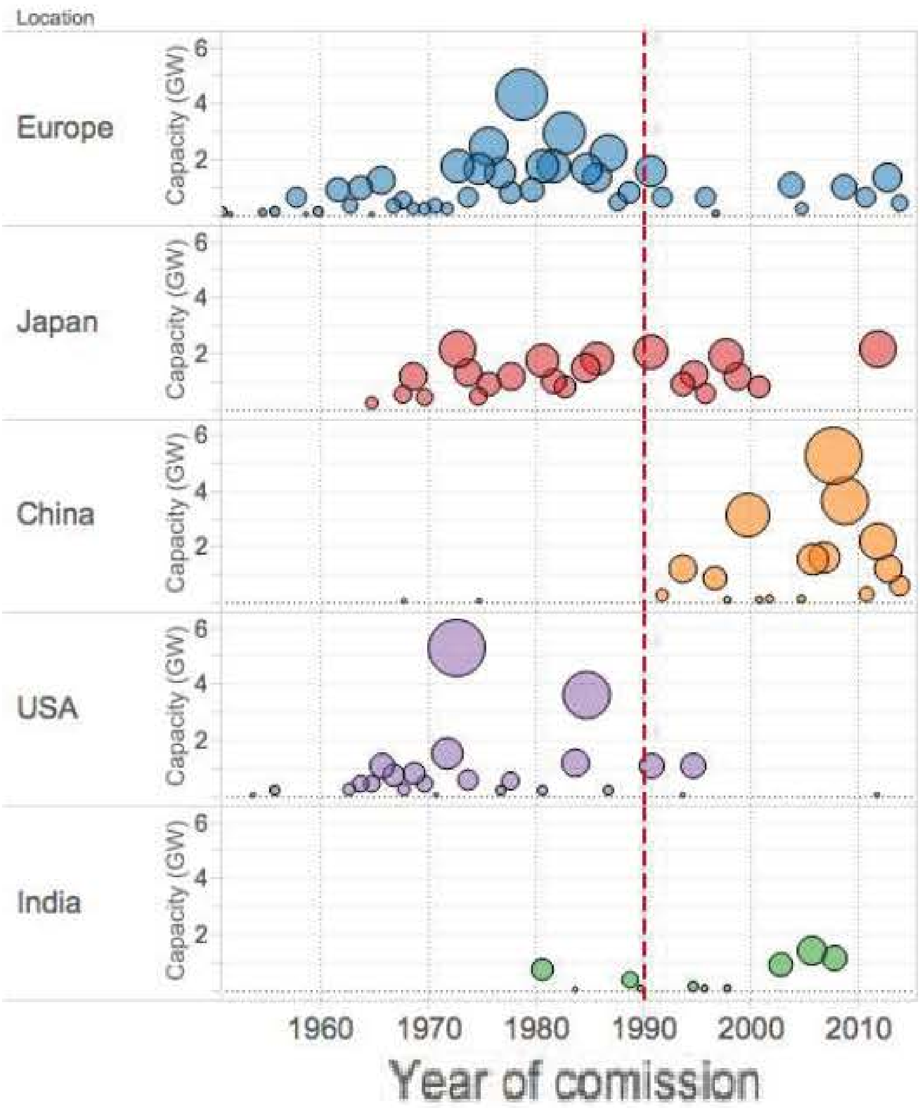
Pumped Storage History

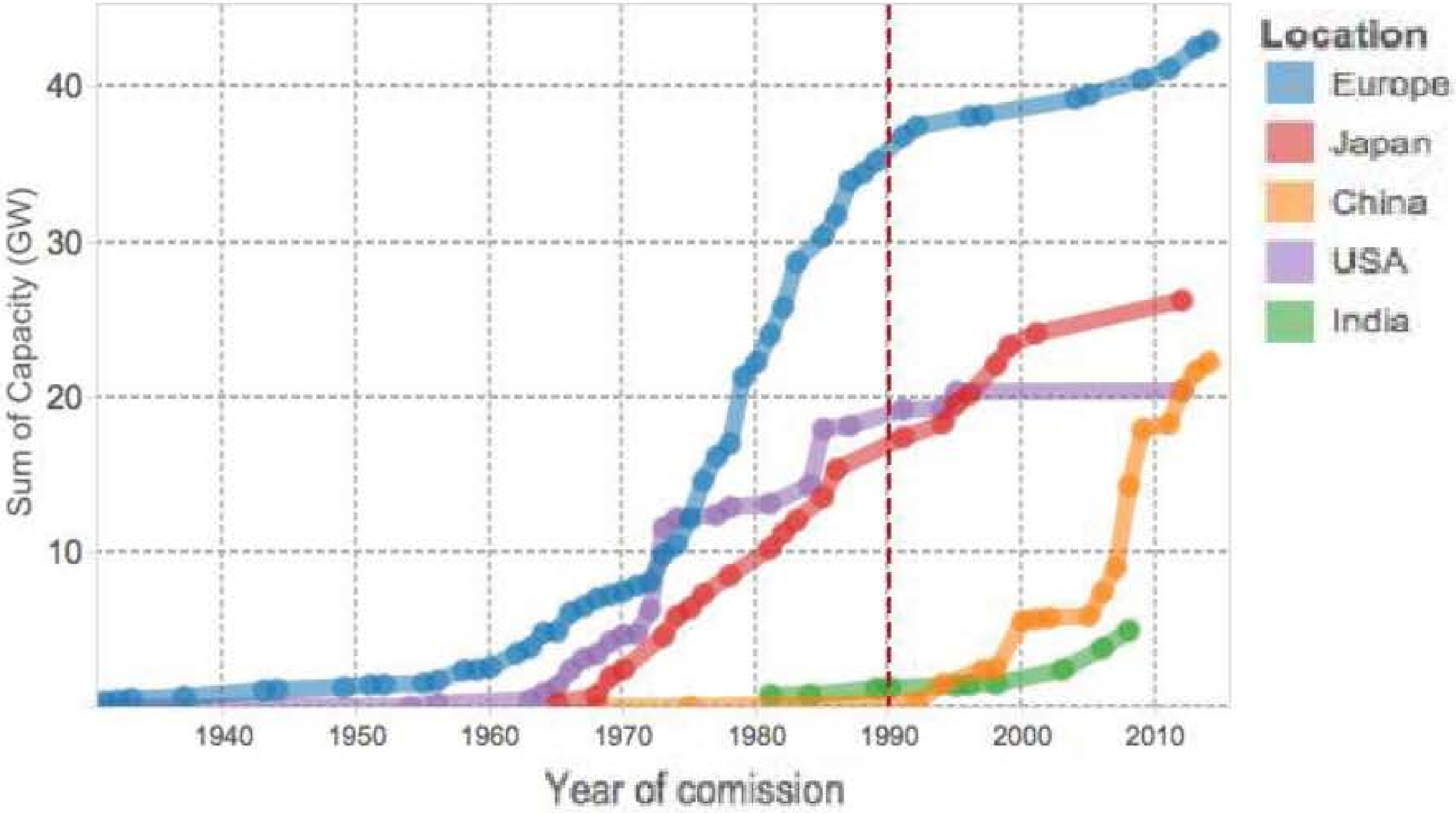
Many PSS projects were built between 1960 and 1980 also driven by nuclear energy development as PSS absorbed the surplus power and generated peaking capacity.

PSS ideally balanced the load and allowed nuclear and coal to operate at peak efficiencies. This resulted in PSS been evaluated as an alternative to fossil-fueled intermediate load and peaking units.



PSS Worldwide Yearly Increased Capacity





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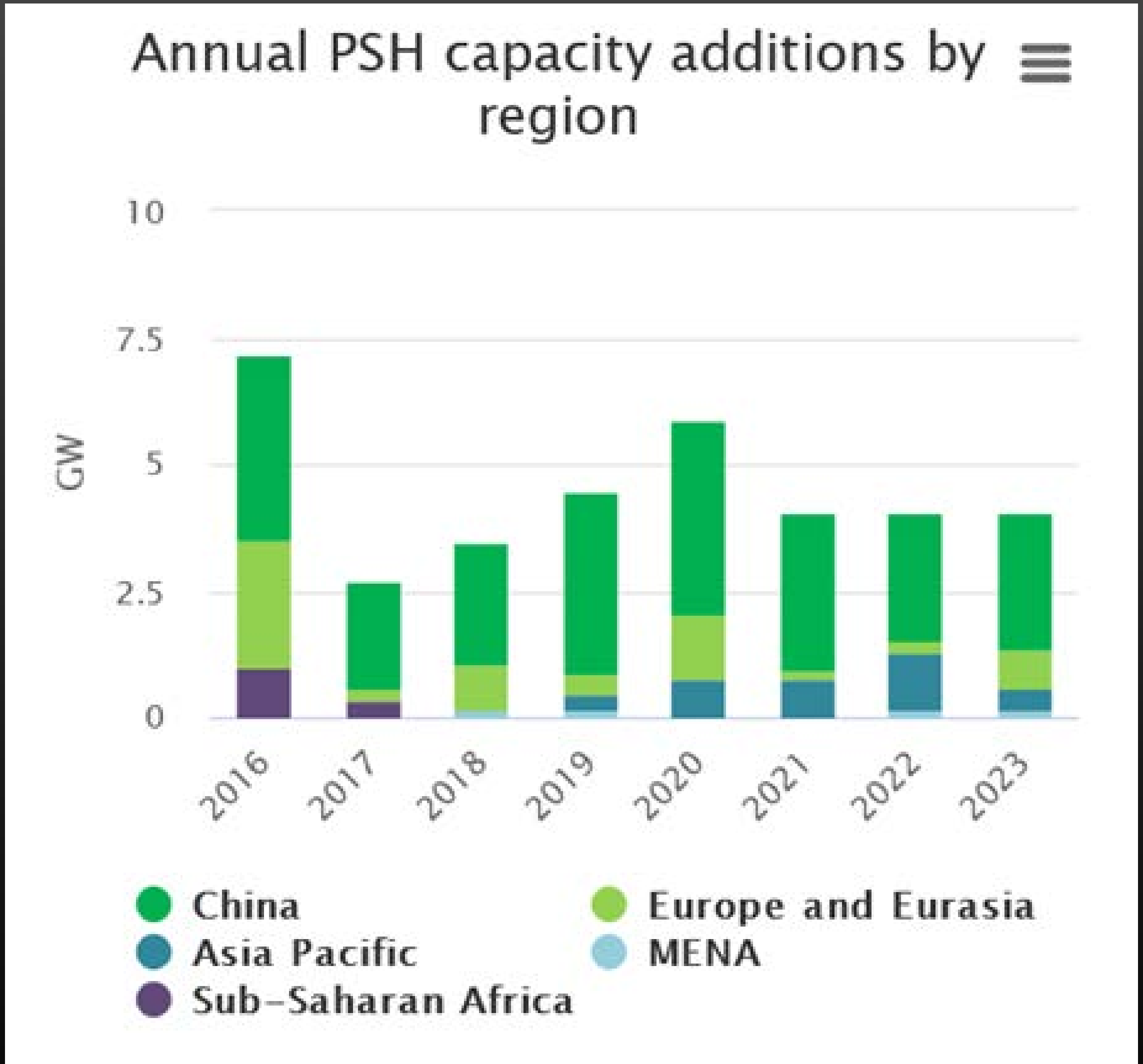
PSS Worldwide Yearly Increased Capacity



China, PSS was seen as beneficial for grid reliability, to assist with bridging the gap for on and off peak demand and was regarded as a way to aid renewable energy integration.

PSS increase again, driven by the need for increased flexibility and reduced curtailment of wind and solar PV.

Value of Pumped Storage Schemes

PSS Cost Comparison	
Blakers et al. 2017	$560/kW
Voith 2018	$1290/kW
Entura 2018 (6hrs)	$1036/kW
PHES (48hrs)	$1925/kW
Enel 2018	$2000/kW

- Value of bulk power capacity and energy arbitrage,
- Value of PSS ancillary services,
- Power system stability benefits,
- PSS impacts on reducing system cycling and ramping costs,
- Reduction of system production costs & transmission benefits

Country	Market Type	T&D owned?	Market mechanisms used	Example PHES project
Great Britain	Liberalised market, ownership unbundling	No	Competes for market services, utilities use for internal trading	Dinorwig. 1800MW, 9.1 GWh. Owned by First Hydro. Provides frequency response, Short Term Operating Reserve, peak capacity, blackstart
USA	Both liberalised and partially-liberalised markets exist, with unbundling ranging from accounting to none	No in liberalised markets	Competes for market services and used for internal trading in competitive markets, cost-of-service payment available in regulated markets although lack of transparency	Bath County Pumped Hydro. 3030 MW, 24 GWh. Owned by Dominion Power (60%) and FirstEnergy (40%). Provides peak capacity, electric time shift and reliability services.
Germany	Liberalised market and legal unbundling	No	Competes for market services, utilities use for internal trading	Goldisthal Pumped Storage Power Station. 1060 MW, 8.5 GWh. Provides peak capacity, Voltage Support, Frequency Regulation and Black Start services. First European plant to include variable speed pumps. Owned by Vattenfall.
China	Partially liberalised market, legal unbundling	Yes	Tariffs approved for individual projects based on average costs or a cost-plus system (includes single capacity based mechanism, T&D tariff, two-part price mechanism, single energy-based price mechanism)	Tianhuangping Pumped Storage Power Station. 1836MW, ~13 GWh. Owned by East China Electric Power (subsidiary SGCC). Used to stabilise power grid, improve power supply quality in east China, and ensure safe grid operation
Japan	Partially liberalised market, accounting unbundling	Yes	Cost-of-service payments and market participation	Okutataragi Pumped Storage Power Station. 1932 MW. Used as a T&D asset. Owned by Kansai Electric Power Company.
India	Competitive market, legal unbundling	Yes	Competes in electricity market. Long term PPA's to provide peak power.	Tehri Pumped Storage Plant. 1000 MW. Provides peak capacity. Being developed by THDC India, a joint venture of the Indian Government and the State Government of Uttar Pradesh

PSS in South Africa

Operational Advantages of Pumped Storage

Pumped storage offers flexibility, ramping speed and “demand” over low loading periods.

Compensates for the slow ramp rates of OCGTs and coal fired generators, ramp up for morning /evening peaks.

Assists the night minimum period, allows base load generators to remain synchronised to the power system by adding demand to the system.

SCO mode to add inertia and voltage control capability to the network. This decreases fault levels in the network and smooths out variation in voltage.

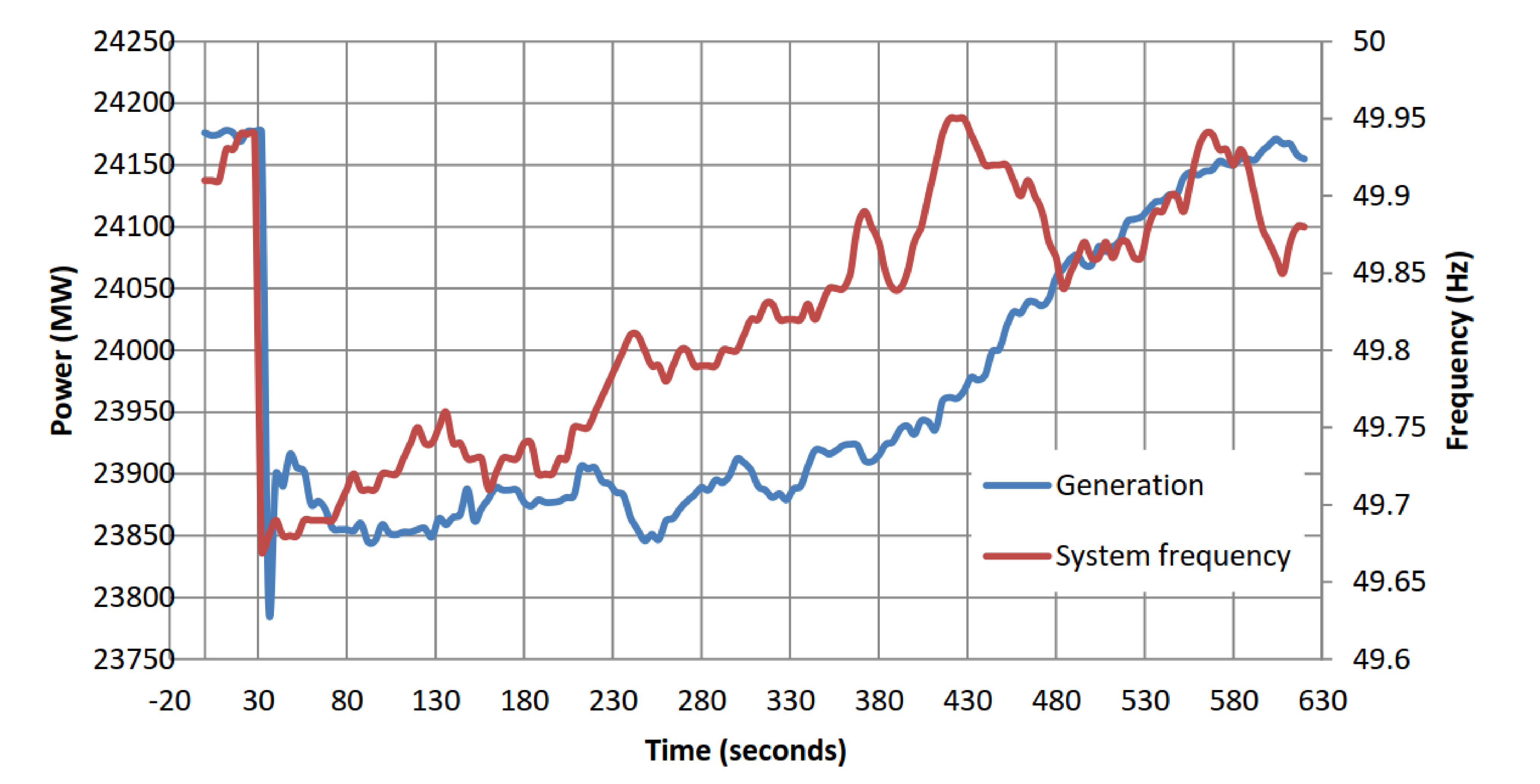
Blackstart facility as well as to arrest frequency drop following a severe frequency event.

Ramp Rates for Different Generation Technologies

OCGT Ramp Rate	5-50MW per minute
CCGT Ramp Rate	1-26MW per minute
PSS Ramp Rate	**200MW per minute**
Coal Ramp Rate	0.2-22MW per minute
Nuclear Ramp Rate	20MW per minute

Eskom has the following flexible resources: 2.7GW PSS, 3GW OCGT, 14 GW coal fired plants and Demand Response Resources.

Activation of Reserve to Restore Frequency



A low frequency incident caused by a unit trip, extracted from Eskom SCADA system

Problems for Grid Stability with Increased Share of Renewable Generation

<10%	10%	20%	40%	55%
• Fault level and protection • Power quality (harmonics and flickers) • Voltage stability (control) • Sub-synchronous interaction	• Transmission efficiency • Congestion management	• Secondary reserve (AGC & regulation) • Tertiary reserve (load following & balancing) • Short term scheduling (outage & hydro storage planning) • Market dispatch	• Transient stability (rotor angle & voltage)	• Frequency stability

RE share in annual electricity generation

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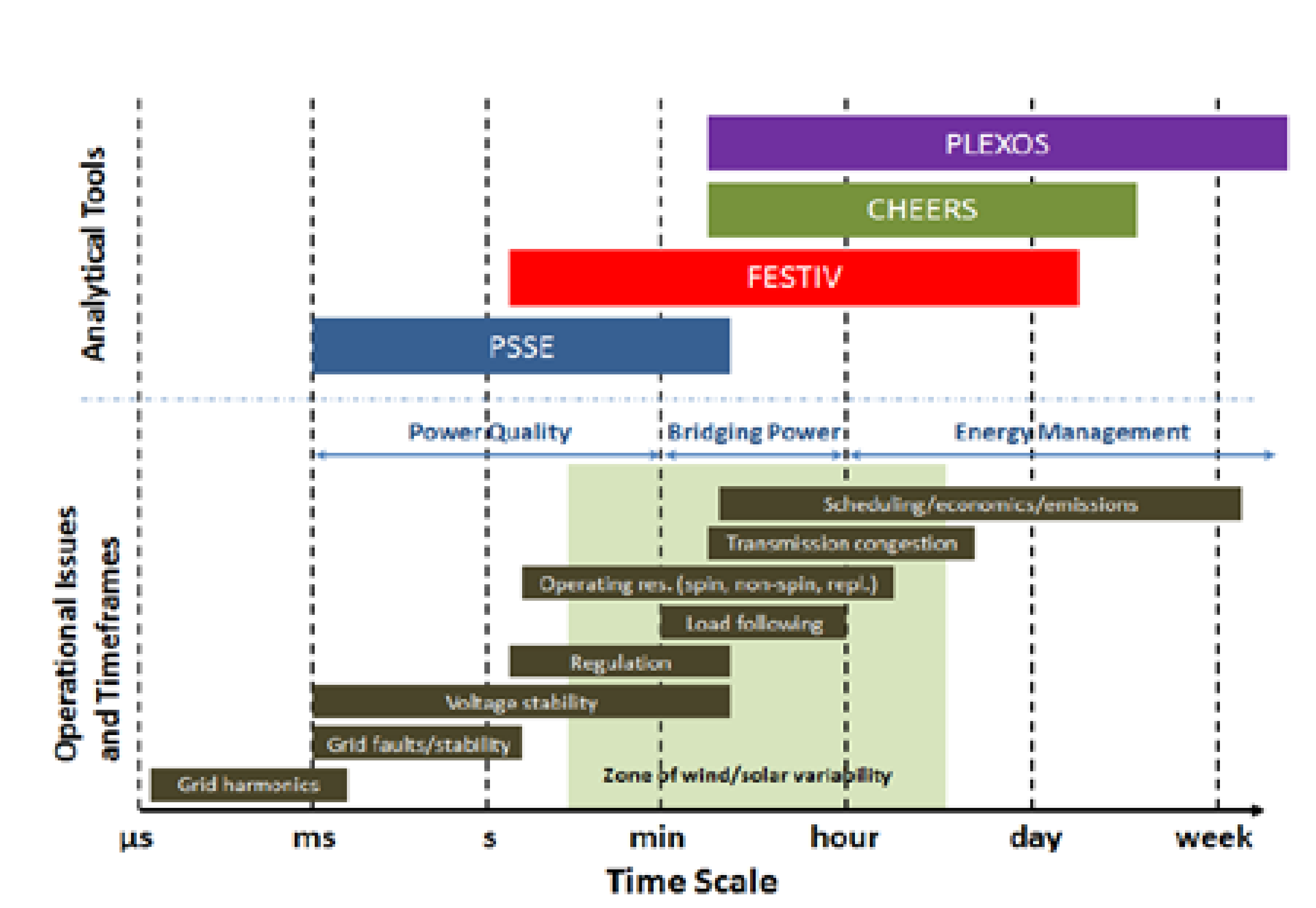
Energy Modelling Tools Time Frames



Problem with Long term Planning Tools

There is a requirement to study low-cost storage in long-term planning models, but the methodologies and metrics for representing storage are not yet well defined.

This is especially true for the interaction of variable renewable generators with storage technologies.

Issues such as chronology, capacity value and cost representation have yet to be addressed in most large-scale modelling frameworks.

Future Plan for South Africa

Why the need for additional PSS?

		Coal-Fired Plants				Nuclear Plants		Pumped Storage Plants					Renewable Plants	Total New Build	New DSM		
YR	Forecast Position (National plus Foreign) (MW)	PF (1) Medupi (6X738 MW Units)	PF (2) Bravo (6X723 MW Units)	PF (3) (6X774 MW Units)	(NX774 MW Units PF) (Proxy for additional Base	Nuclear AP 1000 (NX1039 MW Units)	Generic Co-gen	PS (A) Ingula	PS (B) Steelprt	PS (C)	PS (D)	PS (E)	Wind, CSP, Biomass, Hydro, Ocean & Wave			Reserve margin on Position	Unserved Energy on Position (GWh)
		Approved & Committed	Approved & Committed	Immediate Decision Required			Contingency	Final Approval Pending	Immediate Decision Required	Site Selection & Prep Work							
2007	37982						17							17		7%	159
2008	39539													478	245	7%	222
2009	41152						66						220	1022	617	10%	7
2010	42867						375						3	2016	485	11%	
2011	44628						49						230	49	313	8%	14
2012	46472	738					316	333						1387	163	7%	149
2013	48434	738					77	999					30	1814	120	7%	236
2014	50466	1476	1446	1548									120	4470	120	12%	
2015	52556	738	723	1548					1113				60	4122	143	15%	
2016	54753	738	1446	774					371				300	3329	143	16%	
2017	57091		723	774		1039							100	2536	143	16%	
						2078								2078	143	15%	
						2078							40	2078	143	14%	
						2078				1484			200	3562	143	14%	
					1548	2078							300	3626	143	14%	
						2078					1484			3562	143	14%	
					1548	2078								3626	143	14%	
					774	2078						1484		4336	143	14%	
					3096	2078								5174	143	14%	
					1548	2078								3626		13%	
TOTAL		4428	4338	4644	8514	19741	900	1332	1484	1484	1484	1484	1603	52908	3637		

Ingula Project

Project Lima 1st unit to commence 3Q2014 to fill energy gap (peaking to mid-merit range) and maintain planned reserve margin

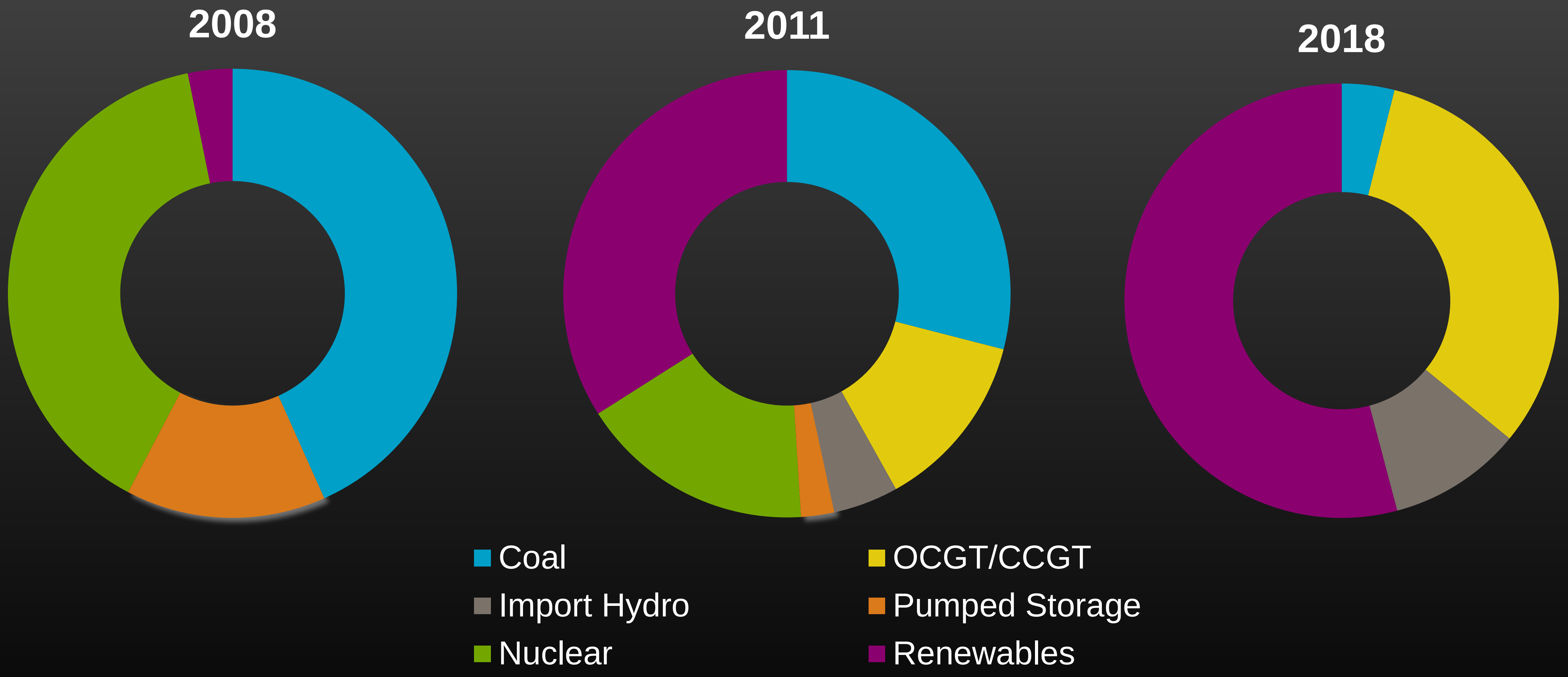
Assumptions:

1. Medupi and Bravo project implemented in 2012&2013 respectively

2. Accelerated DSM and excluding Coega CCGT

- **In the absence of other peaking plant, pump storage plant, reduce the rate at which base load plant need to be built in order to satisfy the increasing demand, specifically the peak demand,**
- **It will increase the base load plant utilization level and therefore will results in higher returns compared to alternative peak generation options utilizing relatively high cost fuel (diesel oil, LNG, gas).**

IRP Percentage Comparison



Pumped Storage

Total Installed:	2912MW
Drakensberg:	1000MW
Palmiet:	400MW
Steenbras:	180MW
Ingula:	1332MW

Proposed new Schemes

- Kobong 1200MW
- Ceres 1000MW
- Tubatse 1500MW

PS	MW	Billion	Years	Additional Information on Project
Ingula (Built)	1332	29.3 Overnight Cost R23000 /kW	12	Cost overruns incurred and underground accident delayed the project.
Tubatse (Lima) (2008)	1500	10 Overnight Cost R7 971/kW LCOE R525.51/MWh.	8	The lower De Hoop dam, constructed and the land for scheme bought by Eskom. The Environmental Authorisation obtained and Record of Decision previously received is still valid.
Kobong (2013)	1200	8.3	7	Kobong PSS is part of Phase II Lesotho Highlands Water Project (LHWP) agreement. Katse Dam, lower dam, already constructed from Phase I.
Ceres (2018)	1000	5	5	The higher dam (17million m^3) already constructed. Independent Power Producers willing to invest in the project.

LCOE of Competing Technologies

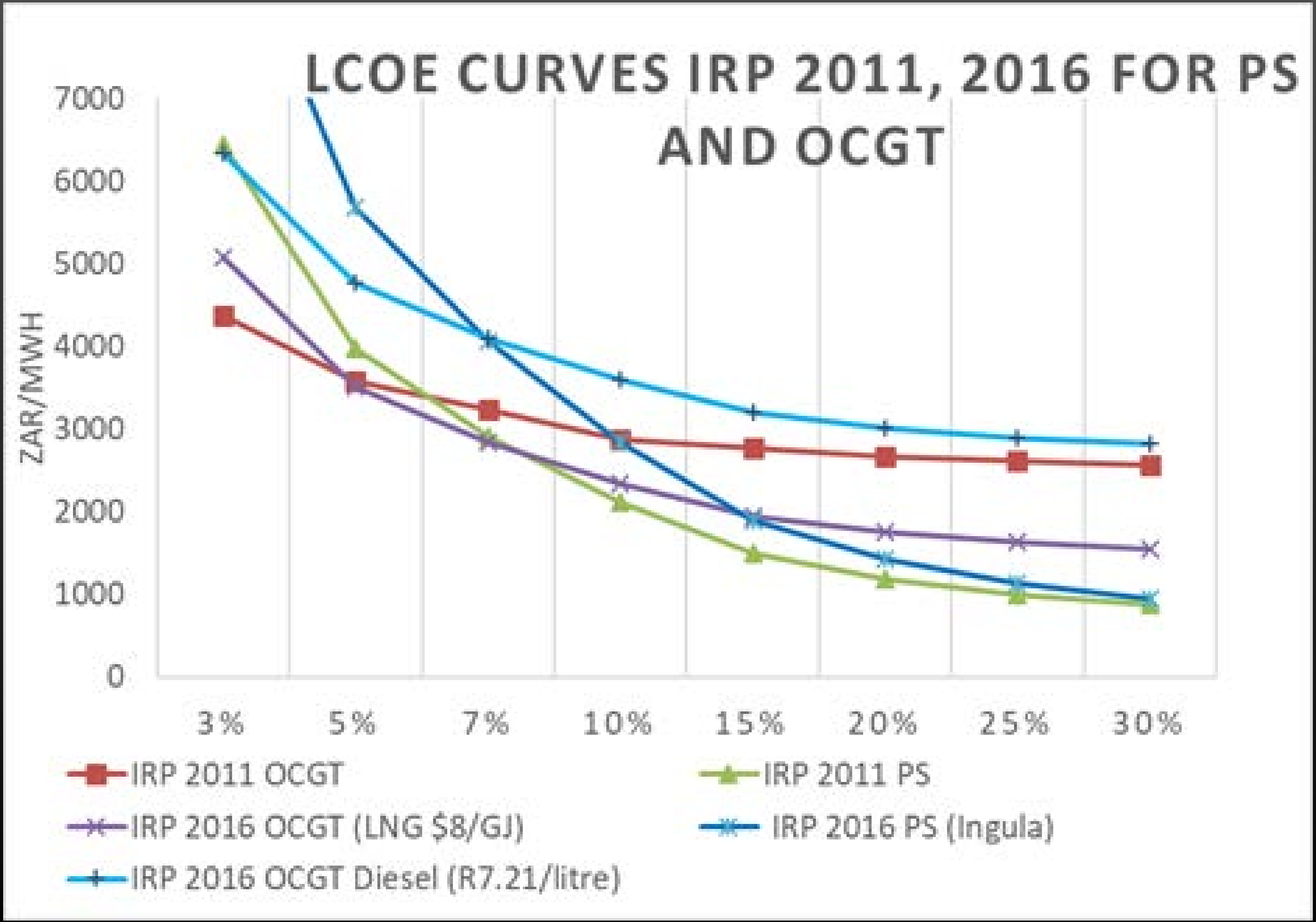
LCOE Comparison Pumped Storage Versus Gas Turbines

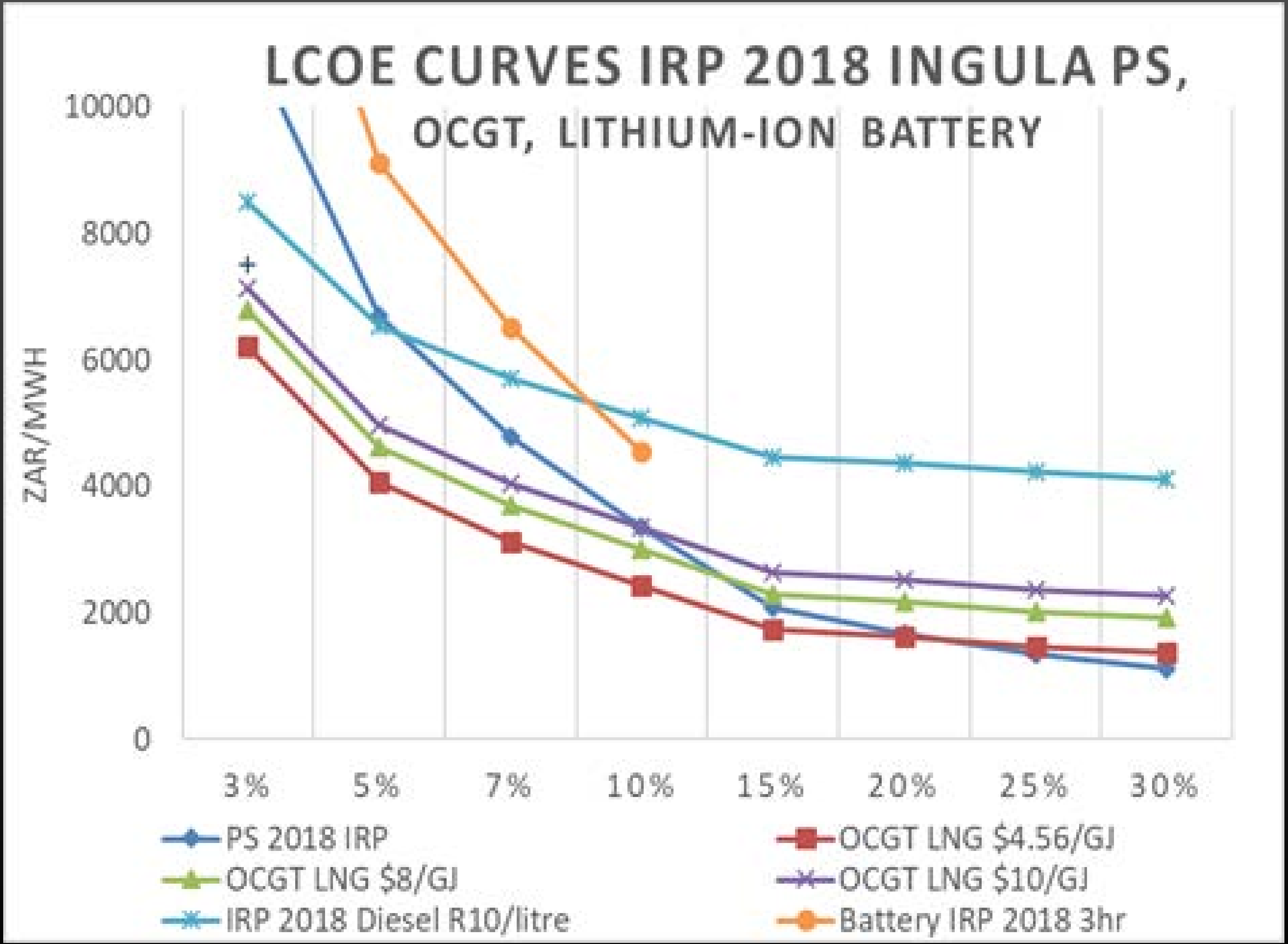
$$LCOE = \frac{Sum\ of\ cost\ over\ lifetime}{Sum\ \ of\ electric\ energy\ over\ the\ lifetime} = \frac{\sum_{t=1}^{n} \frac{C_t + OM_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

LCOE Comparison Pumped Storage Versus Gas Turbines

Technology Input	OCGT IRP 2011 Diesel	PS IRP 2011	OCGT IRP 2016 LNG $8/GJ	OCGT IRP 2016 Diesel	PS IRP 2016
cost overnight R/kW	3955	7913	7472	7472	20410
Fuel Cost	R200/GJ	-	R115/GJ	R200/GJ	0
Capacity MW	114.7	1500	132	132	333
O&M Variable R/MWh	0	4	2.2	2.2	0
O&M Fixed R/kW/a	70	123	147	147	184
Life time of project	30	50	30	30	50
Discount rate	8	8	8.2	8.2	8.2
Phasing in Capital Spent %	90,10	3,16,17, 21,20, 14,7,2	90,10	90,10	1,2,9, 16,22, 24,20,5

Technology Input	OCGT LNG $4.56/GJ	Ingula PS	Lithium -Ion (1hr)	Lithium -Ion (3hr)	Kobong PS	Tubatse PS	OCGT Diesel R10.8/l
cost overnight R/kW	9226	21997	11165	27432	13389	16446	9226
Capacity MW	132	333	3	3	1200	1500	132
O&M Variable R/MWh	2.7	0	3.6	3.6	0	0	2.7
O&M Fixed R/kW/a	181	184	697	697	184	184	181
Life time of project	30	50	20	20	50	50	30
Discount rate	8.2	8.2	8.2	8.2	8.2	8.2	8.2
Phasing in Capital Spent %	90,10	1,2,9, 16, 22 24,20, 5	100	100	14,8,12 17,15, 14,16	1,2,9, 16,22, 24,20,5	90,10


LCOE CURVES IRP 2011, 2016 FOR PS AND OCGT
ZAR/MWH
7000
6000
5000
4000
3000
2000
1000
0
3%
5%
7%
10%
15%
20%
25%
30%
IRP 2011 OCGT
IRP 2011 PS
IRP 2016 OCGT (LNG $8/GJ)
IRP 2016 PS (Ingula)
IRP 2016 OCGT Diesel (R7.21/litre)


LCOE CURVES IRP 2018 INGULA PS,
OCGT, LITHIUM-ION BATTERY
ZAR/MWH
10000
8000
6000
4000
2000
0
3%
5%
7%
10%
15%
20%
25%
30%
PS 2018 IRP
OCGT LNG $4.56/GJ
OCGT LNG $8/GJ
OCGT LNG $10/GJ
IRP 2018 Diesel R10/litre
Battery IRP 2018 3hr

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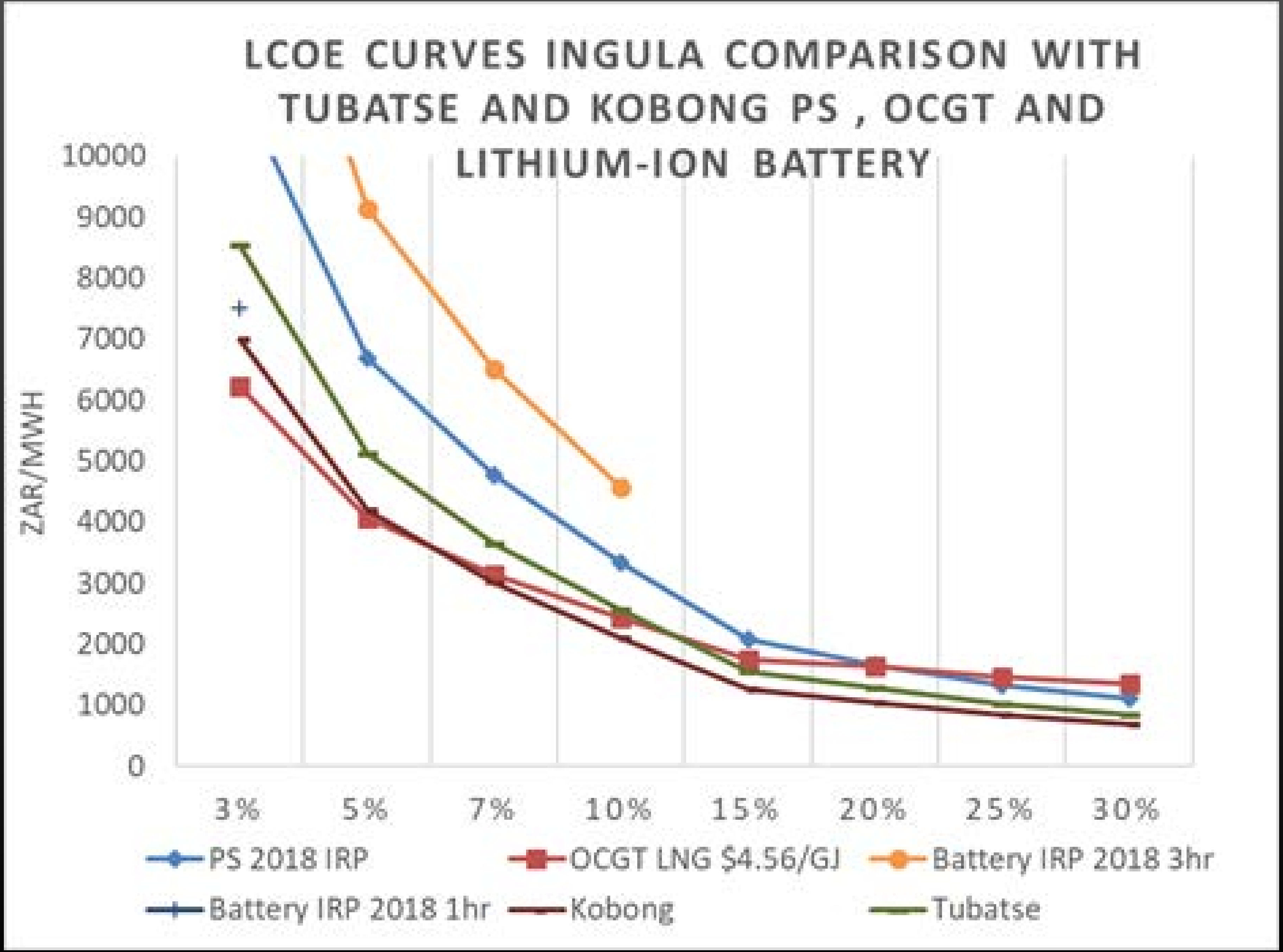
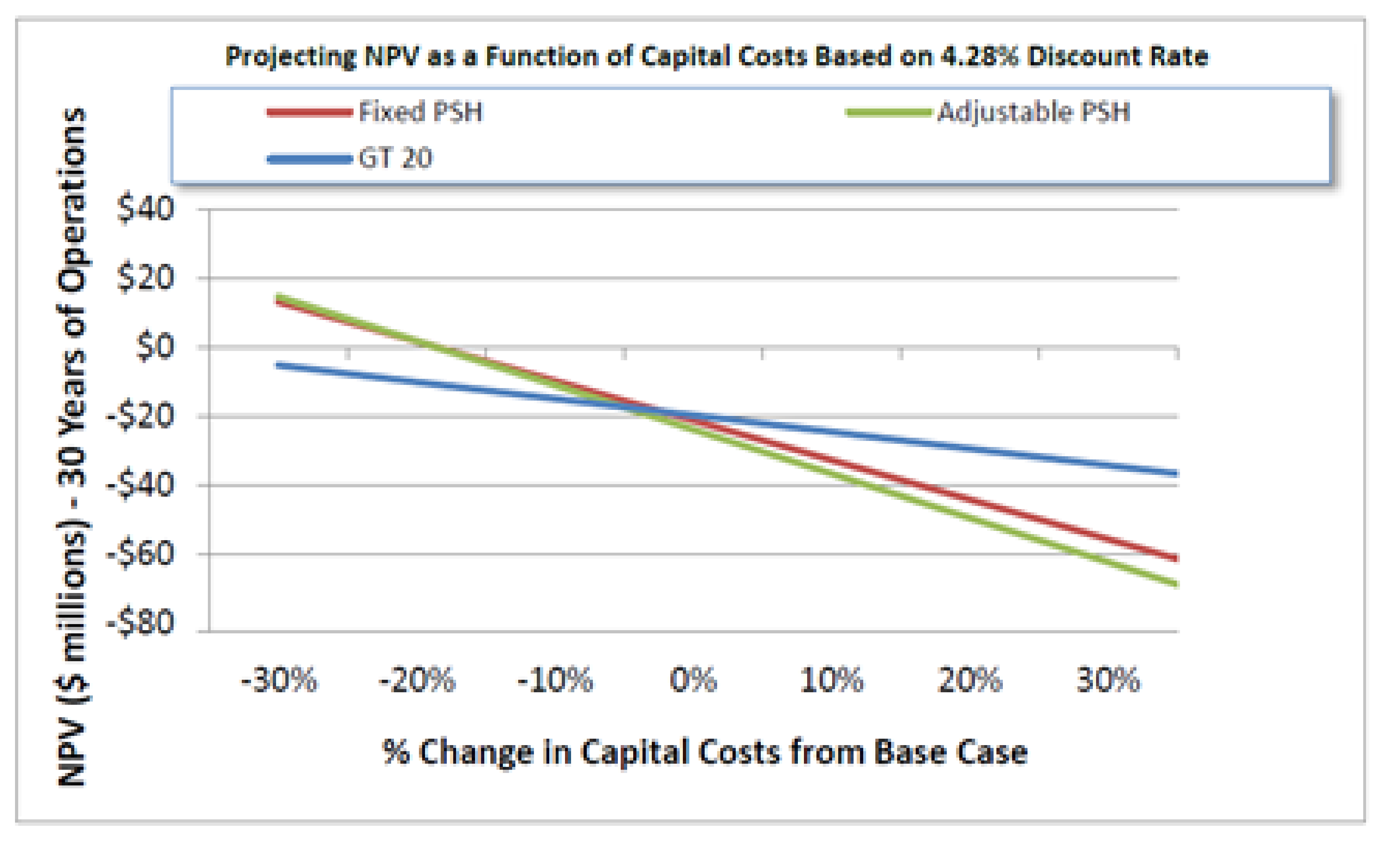
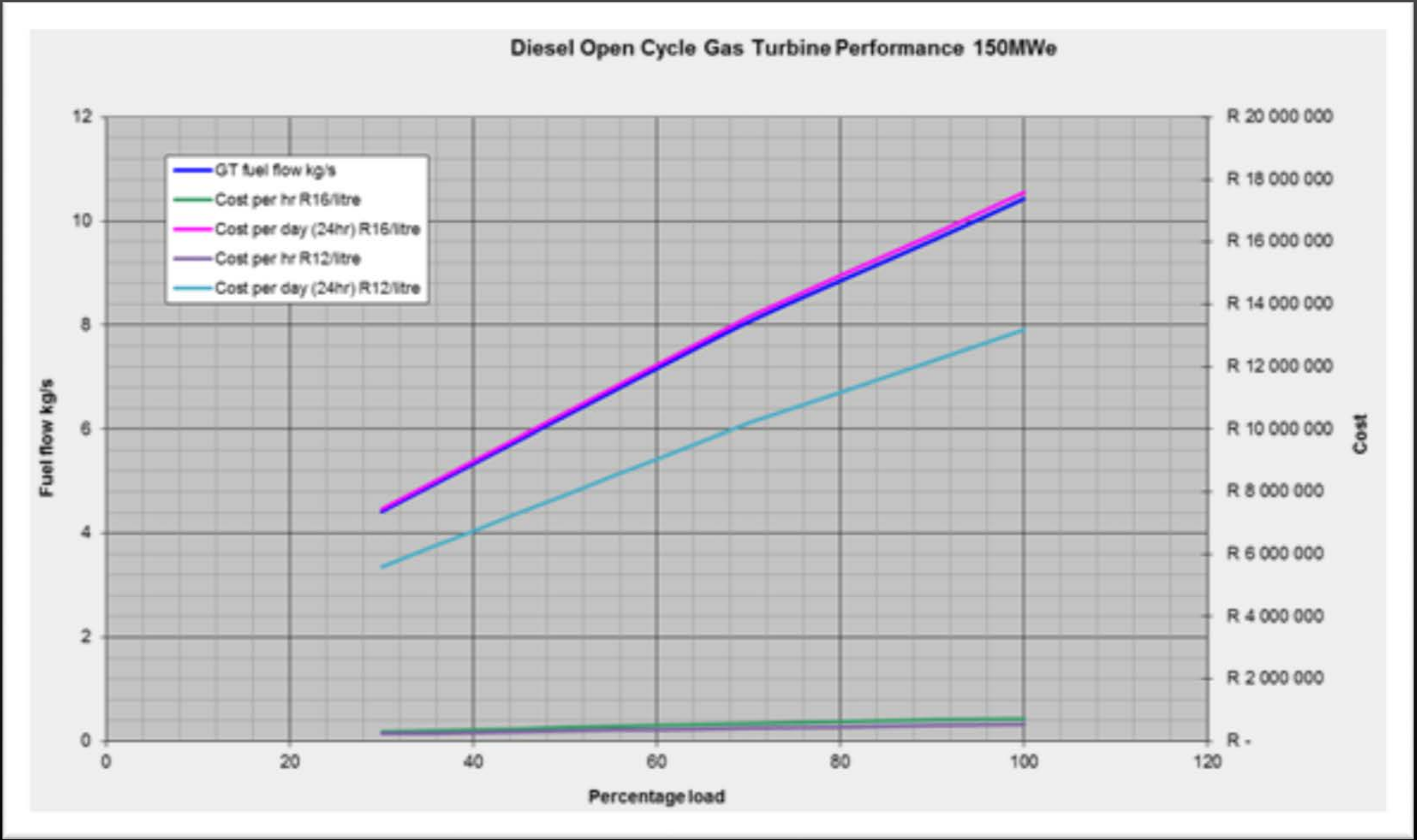


LCOE CURVES INGULA COMPARISON WITH TUBATSE AND KOBONG PS , OCGT AND LITHIUM-ION BATTERY
ZAR/MWH
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
3%
5%
7%
10%
15%
20%
25%
30%
PS 2018 IRP
OCGT LNG $4.56/GJ
Battery IRP 2018 3hr
Battery IRP 2018 1hr
Kobong
Tubatse



Projecting NPV as a Function of Capital Costs Based on 4.28% Discount Rate
Fixed PSH
Adjustable PSH
GT 20
$40
$20
$0
-$20
-$40
-$60
-$80
-30%
-20%
-10%
0%
10%
20%
30%
% Change in Capital Costs from Base Case
NPV ($ millions) - 30 Years of Operations


Diesel Open Cycle Gas Turbine Performance 150MWe
GT fuel flow kg/s
Cost per hr R16/litre
Cost per day (24hr) R16/litre
Cost per hr R12/litre
Cost per day (24hr) R12/litre
Fuel flow kg/s
0
2
4
6
8
10
12
Cost
R -
R 2 000 000
R 4 000 000
R 6 000 000
R 8 000 000
R 10 000 000
R 12 000 000
R 14 000 000
R 16 000 000
R 18 000 000
R 20 000 000
0
20
40
60
80
100
120
Percentage load

Flexible Generation Options

Battery Storage

- Fast response times
- 100MW Battery is been considered as a World Bank requirement
- R16000/kWh for lithium -ion battery pack in 2010 to between R8000/kWh and R4800/kWh in 2018. Market forecasts predict an even further drop to R1600/kWh by 2025. (PSS R200/kWh)
- Service life is 10 to 15 years (PSS 60 to 100 years)
- Batteries limited to < 5000 storage cycles (PSS over 50000)

Conclusion

Concluding Remarks

Increasing amount of intermittent electricity from renewable sources requires electricity industry introduce greater amount of flexible capacity.

South Africa currently has good sites for potential PSS in advanced stages of feasibility analysis.

Levelised Cost of Energy curves support the hypothesis that an economic case can still be made for Pumped Storage Schemes in South Africa

Further Recommended Studies

1. Addressing the value of storage that can shift energy across days which currently can not be reflected in a model that does not maintain chronology across periods longer than 24 hours

2. Costing ancillary services and the benefits PSS provides the grid for a clear understanding of the true value of this technology

3. To investigate a solution which focusses on a combination of PSS with fast response battery storage and OCGT generation maintained as a backup or support.

4. The cost estimate for Ingula investigated regarding project’s budget increase -which factors will be relevant to future projects

Thank you

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