# Valuation of pumped storage in capacity expansion planning – a South African case study

Caroline Loraine Erica Van Dongen

Thesis presented in partial fulfilment of the requirements for the degree of Master of Engineering (Electrical) in the Faculty of Engineering at Stellenbosch University

Supervisor: Dr B Bekker

April 2022

# Plagiarism declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Date: April 2022..............................

# Abstract

On the South African grid, pump storage schemes offer a range of benefits which can assist in the integration of increased variable renewable energy generation. The Integrated Resource Plan for South Africa currently proposes adding gas turbines and batteries to the future grid for peaking capacity and increased flexibility, with no added pump storage schemes. This thesis investigates the value of the services and contributions pumped storage provides the grid, the capital costs and history of this technology in order to determine its potential future role. The research aims to address the possible misconception of limited pump storage scheme site availability by providing an overview of site feasibility studies, including estimated cost projections and utilises these values in an energy optimisation model to investigate the economic case for pump storage.

# Opsomming

Op die Suid-Afrikaanse netwerk bied pompopbergingskemas 'n verskeidenheid voordele wat kan help met die integrasie van verhoogde opwekking van veranderlike hernubare energie. Die geïntegreerde hulpbronplan vir Suid-Afrika stel tans voor dat gasturbines en batterye by die toekomstige netwerk gevoeg moet word vir 'n maksimum kapasiteit en verhoogde buigsaamheid, sonder bykomende skema's vir die stoor van pompe. Hierdie referaat ondersoek die waarde van die dienste en bydraes wat gepomp word, bied die netwerk, die kapitaalkoste en die geskiedenis van hierdie tegnologie om die potensiële toekomstige rol daarvan te bepaal. Die navorsing is daarop gemik om die moontlike wanopvatting van die beskikbaarheid van beperkte pompopbergingsterreine aan te spreek deur 'n oorsig te gee van haalbaarheidstudies op die terrein, insluitend geskatte kosteprojeksies, en gebruik hierdie waardes in 'n energie-optimaliseringsmodel om die ekonomiese geval vir pompopberging te ondersoek.

# Acknowledgements

I would like to acknowledge and express my gratitude to the following individuals and institutions:

- My academic supervisor, Dr Bernard Bekker, and my industrial mentor, Dr Jarrad Wright, for their invaluable assistance, advice and academic guidance during my studies. As well as the Centre for Renewable and Sustainable Energy Studies and the Power Systems Research Group for their support and information sharing.

- The EPPEI (Eskom Power Plant Engineering Institute), for affording me this opportunity with part sponsorship towards the study.

- AECOM who provided a bursary for the first two years of my research and Rudolf Van Wyk associate for Dams and Hydropower who granted me the time off from work to pursue my MSc.

- The Eskom employees for their assistance, especially Coert Venter for his knowledge and support in providing me with valuable information on pumped storage, Callie Fabricius who allowed me access to the GEP 2017 report, Gav Hurford and Rudolph Binneman on the advantages of pumped storage to the grid and Frans Louwinger, the previous head of hydropower at Eskom in 2009 for the information on the history of pumped storage in South Africa.

# Table of contents

Page

# List of figures

Page

# List of tables

**Page**

# List of abbreviations

AGC- automatic generation control

CCGT- combined-cycle gas turbines

DOE- Department of Energy

DWS - Department of Water and Sanitation

IRP- Integrated Resource Plan

ISEP -Integrated Strategic Electricity Plan

LCOE- Levelised Cost of Energy

LHWP- Lesotho Highlands Water Project

OCGT- open-cycle gas turbines

PSH- Pumped Storage Hydropower

SCO- Synchronous Condenser Operation

SU Stellenbosch University

T&D- transmission and distribution

US- United States

# 1 Introduction

Uncertainty in electricity demands are balanced in real-time using fast reacting flexible generators. By increasing the amount of intermittent or variable electricity from renewable sources, the electricity industry will need to introduce more flexible systems to ensure successful integration [1]. According to the Integrated Resource Plan 2019 (IRP) this will be provided by gas turbines and batteries [2]. Batteries are still considered too expensive for large scale grid storage over 100MW and South Africa does not have the gas infrastructure nor abundant local reserves to supply the gas contingent modelled in the IRP. The significant planned future dependence of the South African power system on market based gas exposes the economy to a number of potential risks [3]. This thesis investigates Pumped Storage Hydropower (PSH) as an alternative technology to gas turbines and batteries for peaking, flexible generation and whether there is potential for additional PSH development in South Africa.

The thesis explores the valuation of PSH by analysing the capital outlay, determining ancillary services and potential revenue streams, and juxtaposing the reasons for development with the causes for the attenuation of the technology. The research broadly assesses PSH internationally and focusses in detail on South Africa in order to understand the complete value and benefit that this technology provides to the grid.

Currently in South Africa no future development of PSH is planned according to the 2019 IRP [2]. This research explores the reasons why new PSH was excluded from recent IRPs and highlights the rigid costing inputs, the assumptions of limited ancillary service provision and the constraints inherent in the modelling methodology used in the long-term capacity expansion planning model.

## 1.1 Background

In recent years, interest has grown in energy storage technologies. Substantial research is being conducted internationally into the development of grid-scale energy storage due to the cost effective flexibility it provides operators to manage instability in networks. Current storage technologies include PSH, electro-chemical batteries, flywheels, and compressed-air energy storage.

When comparing battery storage to PSH it is important to note that battery industrial applications only began in the past 10 years for Lithium -Ion. This is a relatively new energy system which has made an inroad into the generation market mainly because it is becoming more affordable as battery prices progressively decrease from R16000/kWh for lithium -ion battery pack in 2010 to between R8000/kWh and R4800/kWh in 2018 [4]. Market forecasts predict an even further drop to R1600/kWh by 2025. However, PSH is estimated at a low R200/kWh in comparison and has over 50 000 storage cycles while batteries are limited to 5000. Batteries definitely have faster response times within the milli-seconds and will be required on the grid however their service life may be limited to within 10 to 15 years compared to 50 year to 100 years for PSH and plants with capacities larger than 100MW are still far more expensive than PSH [5].

PSH is a proven technology which can be more favourable in cost, provide higher power ratings and longer discharge times than most other energy storage technologies [5]. PSH constitutes 98% of the energy storage capacity at a global scale [5]. With improved battery technology in future, pumped storage technology may become lesser attractive, also due to its much longer development lead times and higher construction risks. However, in favourable topographical and geotechnical conditions it may still prove to be a cost effective and favourable option [6]. South Africa currently relies on PSH and has just under 3GW installed, however with new plans for an increased amount of renewables to penetrate the grid [2], energy storage is likely to play a larger role. The potential future role of PSH will depend on the services and contributions that the technology can provide to the grid for improving the integration of generation from renewable sources for effective grid operations. Furthermore the technology will need to prove cost effective in order for it to be included in South Africa's energy planning.

Long-term energy planning is critical for a country to meet future energy demand at minimum cost while supporting various policy objectives. In South Africa the national utility, Eskom, and the Department of Energy (DoE) utilize modelling to identify the most compatible and cost-effective energy alternatives to meet the country's future energy demands. By running different scenarios, alternative energy mixes can be compared and the costs and benefits for each plan estimated. The IRP of South Africa is based on the outcomes of this modelling process. Additional PSH was not included in the most recently published South African long-term energy plan, the 2019 IRP. Instead, gas turbines and batteries were selected for storage, peaking and flexible generation [2].

## 1.2 Project motivation

The South African electricity public utility is Eskom which generates 95% of South Africa's used electricity [6A]. The government have been investing in energy infrastructure over the past years incorporating 3.5 GW of new renewable energy onto the grid and plans on increasing renewable generation towards 2030 [2]. According to Eskom's latest IRP, Eskom will have to invest in flexible generation technology in support of long-term commitment to renewables. By 2030 Eskom will need to meet a peak demand of up to 48GW and also be able to accommodate large fluctuations during the day [2]. The fluctuations are due to the highly variable nature of renewables mainly wind power which supplies electricity on average only 34% of the annual rated capacity generation. Solar is considered more predictable but intermittent and estimated to generate at a 26% capacity factor [7]. The result is that a high portion of wind and solar energy increases grid instability.

Eskom has been looking at alternative means to store energy for the last 15 years as base load stations can only accommodate some fluctuation in load at a very high cost. Currently the IRP has recommended increased capacity for gas turbines however the gas volume required, as well as its sources, are not known and infrastructure to supply this gas is not in place [3]. This would require several years to implement before gas can be purchased at viable fuel costs [3]. The large volume of gas fired capacity proposed in the IRP could expose the electricity price to external factors such as the oil price and exchange rate. Given the risks associated with gas and that the renewable allocation depends on this, pumped storage might be an attractive option to replace some of the gas and thus lower the risks and costs should gas prices increase.

Therefore this research investigates the benefits of PSH as a storage technology and alternative to gas turbines for peaking, flexible generation and whether South Africa should still invest in PSH in the future energy mix.

## 1.3 Project description

### *1.3.1 Problem Statement*

Of all the grid-scale energy storage technologies available today, an option which is technologically and commercially mature, cost-effective and currently operational on a large-scale is PSH [5]. However, the technology does not feature anymore in South Africa's future planned energy mix.

### *1.3.2 Hypothesis*

This thesis explores the following hypothesis that new PSH was excluded from the South African IRP due to rigid costing inputs, limited ancillary service provision and constraints inherent in the modelling methodology used in the current long-term capacity expansion planning model. Further the research investigates whether it is likely that PSH will still feature in a future SA least-cost planning scenario for the provision of energy storage, if costs for ancillary services were addressed in the planning process and options developed for PSH were based on different proposed sites to see the impact on cost and whether an economic case could be made.

### *1.3.3 Research Questions*

The research will focus on four main questions to address this problem. The first question looks at, whether there is potential PSH site availability in South Africa?

Then how PSH in the IRP is handled and what improvements can be made? The third question asks is there a better way to value PSH and cost the ancillary services provided? The last question explores the impact if we brought together new modelling inputs for PSH into the energy model and if there is still potential for future development of the technology?

### 1.3.4 Research objectives and scope

The objective will be to determine if PSH still has a place in the future energy mix for South Africa by investigating potential site availability, the proposed supply mix and grid stabilisation requirements necessary for the future grid.

The study will analyse South Africa's evolving grid detailed in the IRP. The inputs for modelling PSH in capacity expansion models will be investigated and compared with competing technologies to understand if an economic case can still be made for PSH. The study will provide details on the PSH technology and its role in providing reliability and integrating variable renewable energy sources into the power grid. Thereby determining the value of PSH on the South African grid with additional potential revenue streams for ancillary services.

### 1.3.5 Assumptions and limitations.

In this study the assumed future energy generation is limited to the case study of South Africa and is based on the Integrated Resource Plan (IRP) which forecasts the electrical supply leading up to 2030 and 2050. This plan requires extensive work and develops from the legal framework set up by policies and guidelines such as: the White Paper on Renewable Energy, 2003, The Electricity Regulation Act, 2006, The National Energy Act (NEA), 2008 and Integrated Energy Plan 2016. However, the IRP is updated annually based on economic data and political uncertainty could affect the economic environment changing the future-orientated plan to maintain supply security. Delays on project construction also induce cost and may create problems with future planning. These concerns limit accurate projections for the future energy generation for 2030 and 2050. IRP 2018 was initially used at the start of the research then IRP 2019 was later adapted.

Furthermore the study does not include the non-financial criteria and social impacts such as job-creation when comparing the different technologies from the IRP.

### 1.3.6 Research methodology and tasks

In order to answer the question on whether there is potential future development the literature review had to uncover the previous reasons for PSH development. The project will therefore describes historical and future local and worldwide development trends of PSH, the utility structures where PSH development occurs and which market mechanisms negates the benefits of PSH services leading to no further development requirements. In each of the market types certain services provided by the technology are valued differently and these have been recorded in order to understand the benefits and potential revenues of PSH in different market structures.

To understand whether there is potential PSH site availability in South Africa the research had to examine several feasibility studies and understand why certain PSH sites were previously chosen in the country. The study also focusses on the current schemes in operation and details the selected studies completed for future project sites. The recent attenuation in development of this technology is then described where a previous PSH project over budget capital cost helps to elucidate the matter.

How PSH in the IRP is handled and what improvements can be made required a breakdown of the IRP technology inputs, modelling methodologies, understanding of the increase in renewable energy capacity and the role of electrical storage. Where flexible competitive technologies such as gas turbines, batteries and PSH can assist in improving the integration of generation from renewable sources for effective grid operations. Further analysing the current electrical utility structure and the predicted future market mechanisms the country may adopt when the unbundling occurs. Thereby allowing for new potential revenue streams to motivate for PSH development.

The question on exploring the impact if we brought together new modelling inputs for PSH into the energy model and if there is still potential for future development of the technology was addressed by updating how PSH could be handled in the IRP. The input assumptions in the modelling software used for the IRP will be investigated and compared to previous and global values as well as the competing technology inputs. The PSH costs incorporated into the model will mainly be compared with the chosen technologies of gas turbines and batteries as these were the competing technologies for peaking and flexible generation. In order to test the results of the long-term modelling software, the inputs for each technology will be used to create Levelized Cost of Energy (LCOE) curves. The calculation will be utilized to show a comparison of the competing technologies as it measures lifetime costs divided by energy production. After this the inputs will be used in Temoa which is an energy system optimization model to check the impact of the changing inputs in the system model as a whole.

The final question involves ascertaining if there is a better way to value PSH and cost the ancillary services provided. Therefore the investigated services PSH provides the South African grid with additional revenue streams was associated to the Plexos timeframes to understand what ancillary services could be included.

## 1.4 Document overview

The research will be separated into four sections in this thesis.

The first section will provide a literature overview of pumped storage history in South Africa and cover the global and local development trends of PSH. The section will include the associated costs and highlight the contributions and services of pumped storage in different market mechanisms.

Section II will develop an energy modelling system according to the IRP to show the potential for storage in the future South African grid. The predicted capacity requirement for storage and flexible generation will be determined and reasons provided whether or not additional PSH should feature in this set contingency. This will be done by investigating the use of PSH for peaking and low demand, smoothing fluctuation as well alleviating midday fall into baseload.

Section III will determine the sensitivity of the modelling outcomes to uncertainty in the technology costings used as input into capacity expansion modelling. Within the South African context, the thesis will analyse the PSH costs historically used to inform IRPs, and compare PSH, gas and batteries through levelized cost of energy (LCOE) calculations to investigate the importance of accurate estimation of PSH costs. The results shown in section III part 1 will further be investigated in part 2 to test the findings through the use of an energy optimisation software. The recommended capital costs will be incorporated into an energy planning program and tested to see if pumped storage has a possibility of been included with different chosen input values.  Section III part 3 explores the cost estimations of PSH and its value specifically for the provision of ancillary services using international literature. Within this context the South African case is then considered, analysing the constraint that current modelling software cannot account for the value of these ancillary services separately.

In section IV, the hypothesis will be revisited and the validity of the research verified. before concluding the thesis. The final section will offer recommendations for future pumped storage modelling inputs and parameters to be included as well as commenting on valuing ancillary services for effective grid operations and potential PSH requirements to improve the integration of increased generation of renewable energy in South Africa

# 2 Literature review

## 2.1 Introduction

Eskom, South Africa's national power utility, has the following flexible resources based on a 2017 study: 2.7 GW Pumped Storage Hydropower (PSH), 3 GW Open Cycle Gas Turbines (OCGT) running on diesel fuel, 14 GW of fast-ramping capacity from coal fired plants and meaningful quantities of Demand Response Resources [8]. The overall energy generation capacity of South Africa is currently increasing with 9.5 GW from two large coal-fired power stations, Medupi and Kusile, which are nearing completion, and with more than 20 GW of renewable energy by 2030 [2].

Coal fired plants are considered as base-load stations as far as generation is concerned and previously their production was supported by additional peaking capacity to allow for constant production and reduced ramping. Looking into the next 15 years, Eskom's coal fired generation is still the dominant supplier of energy. However, these coal stations will most likely be under-utilized with the increasing penetration of renewable energy generation. Furthermore, the additional variable renewable generation will most likely result in an increased requirement for flexibility from Eskom's fleet [8]. Utility-scale storage can provide a solution for grid flexibility and increase the baseload plants' utilization factors.

The South African Integrated Resource Plan (IRP) released in 2019 [2] proposes gas turbines and batteries as the new flexible generation technologies to manage peaking capacity and the variability associated with increased renewables. The significant planned future dependence of the South African power system on market-based gas exposes the economy to a number of potential risks, discussed in more detail in section 2.6.

In this thesis, PSH is being proposed as an alternative technology to gas turbines and batteries for peaking and flexible generation. Therefore the key areas for the literature review will broadly focus first on PSH history and development in South Africa. A common misconception, of the limited PSH scheme site availability in South Africa, is also addressed by providing an overview of studies conducted in the last ten years for potential PSH scheme sites and their estimated cost projections. The detailed review in Section 2.3 will provide information on PSH technology development internationally and the future PSH predicted trends and their benefits to the grid with the integration of variable renewable energy generation. Section 2.4 looks at how PSH was incorporated into South African IRPs over the years. PSH contributions and benefits specifically to the South African grid is then analysed and the ancillary services assessed in Section 2.5. The final section concludes the literature review and provides recommendations.

## 2.2 Role of Pumped Storage in South Africa

### 2.2.1 History of PSH schemes in South Africa

South Africa does not have an abundance of hydropower potential. The development of macro hydropower in this country has been historically associated with the development of primary water supply infrastructure and inter-basin transfers such as the Orange River Project involving the Gariep and Vanderkloof hydropower schemes as shown in Figure 2-1 [9].

*Figure 2-1: Largest Dam in South Africa: Vanderkloof*

South Africa's arid climate allows for few pumped storage schemes, yet four are currently operational. The first pumped storage scheme in Africa, the Steenbras scheme, some 50 km from Cape Town, was commissioned in 1979 with a generating capacity of 180 MW [9]. Three years later, Eskom completed its first pumped storage scheme, the Drakensberg scheme in the Little Drakensberg mountain range near Harrismith, with a generating capacity of 1000 MW [9]. Their second 400 MW pumped storage, Palmiet, was completed for commercial operation in 1988 [9]. This scheme is located near Grabouw, not far from the Steenbras scheme. Eskom has recently constructed the Ingula Pumped Storage Scheme, also located in the Little Drakensberg Mountains, by Ladysmith in

KwaZulu-Natal. This scheme has a generating capacity of 1332 MW and was commissioned in 2017 [9]. Eskom has also completed feasibility and environmental studies for the proposed 1500 MW Tubatse Pumped Storage Scheme, but further development has been put on hold [6]. The pumped storage schemes in Eskom have proven to be highly reliable and very valuable in supplying peak power to smooth out the load demand curve for the coal fired and nuclear base load plants [10]. The location of the developed pumped storage schemes in South Africa are shown in Figure 2.2 along with several potential schemes.


*Figure 2-2: Locality Map for Pumped Storage Schemes in South Africa [11]*

### 2.2.1.1 Reasons for previous Pumped Storage Development

In the late sixties Cape Town experienced shortages in peak electric power, leading to a recommendation for Steenbras Dam as a potential PSH scheme [12].

The project increased the head for generation and doubled the effective capacity of the original Dam for augmentation. Construction started in 1973 and the station was completed for commercial operation in 1979 at a cost of R60 million [13]. The scheme consists of 4 x 45 MW units under a head of 275 m [12]. This scheme turned out to be a good investment for Cape Town as it saves electricity costs significantly and, at the same time, provides additional water to the city. The saving in peak electricity costs is shown in Figure 2-3.

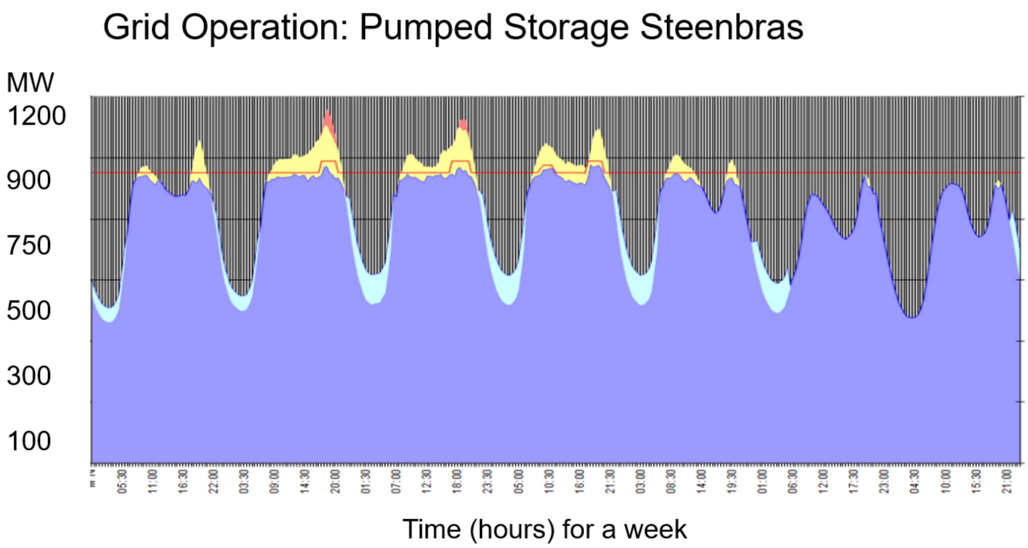



*Figure 2-3: Steenbras PSH generating operation shown in yellow, pumping operation shown in light blue and red line showing the maximum baseload required and saving in peak costs for Cape Town's Supply [13]*

In 1974 Department of Water and Sanitation (DWS) operated the Jagersrust pumping station to pump water from the Thukela over the watershed to augment the water supply in the Vaal Basin and this supply had to be duplicated by 1980 [12]. During this time Eskom were searching for economical peak supply options and required a back-up supply in case the long transmission line from Cahora Bassa went out of service. It therefore made sense for the joint development as DWS would save pumping costs and Eskom's need for a back-up and economical peak supply would be satisfied [12]. The Drakensberg PSH scheme was the first pumped storage in Eskom with a pumping head of 470 m and capacity of 4 fixed speed units of 250 MW each, shown in Figure 2-4, with storage of 26 hours and a generating weekly load factor of 30% [12]. The construction time was five years and began in 1977 and was completed by 1982 [9].

*Figure 2-4: Underground machine hall of Drakensberg Pumped Storage Scheme [12]*

After commissioning of the Drakensberg scheme, Eskom initiated an extensive programme in the search for other possible sites throughout South Africa. This process resulted in the identification of 90 sites in total. Potential capacities of these schemes varied from approximately 400 MW to 2 000 MW, with heads ranging from 220 m to 610 m [12].

The Elandsberg scheme in the Western Cape was identified as an attractive site, suitable for a 1200 MW scheme [12]. Geotechnical investigations, including an exploratory tunnel, were conducted which supported the technical feasibility of this site. However, the Palmiet scheme was selected to be developed instead as Eskom required a back-up for the long transmission line to the Cape from Mpumalanga, where most of the base load stations were situated and the Palmiet scheme was also suitable for augmenting water to the Cape Town area. The scheme started construction in 1983 and finished in 1988 with two fixed speed units of 200 MW each with a head of 260m and a weekly generating load factor of 30% [9].

In the late nineties, Eskom’s Integrated Strategic Electricity Plan (ISEP) identified the need for additional pumped storage supply of some 3 000 MW [12]. Seven sites of 1000 MW, already identified earlier by Eskom, were narrowed down to the best sites Ingula and Steelpoort (Tubatse). Feasibility studies started in 1998 and environmental approval was obtained in 2000 for Steelpoort and in 2002 for Ingula [15]. The business case of the Ingula scheme was based on the least cost option for supply of peaking energy [15].

Screening curves were developed for all possible candidate plants and used as part of the input for the system modelling. These curves are relationships of the levelised costs, expressed in cost/MWh, versus generating load factor. A software model was used which progressively dispatched the available capacity to meet the demand in the most cost effective way. This was repeated for various scenarios such as growth, demand side management, and economical parameters [15] etc. The results obtained provided an indication of the range in optimum load factor for each supply option. Scenarios for different capacities were also analysed, which eventually provided the best installed capacity. An example of screening curves which were used at the time is illustrated Figure 2-5. It can be seen that pumped storage was the lowest cost option between 5% load factor and its practical cut-off point of 26%. Therefore Ingula was constructed with 4 x 333MW units totalling 1 332 MW with 16 hours of continuous generation, allowing a 23% to 26% weekly generating load factor [12].

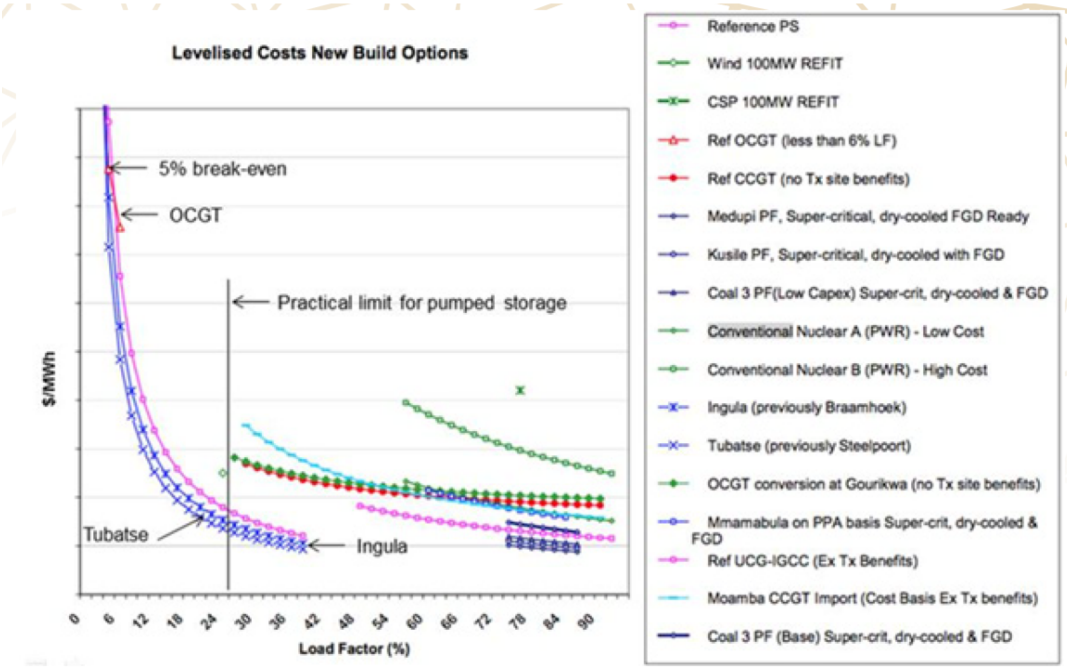



*Figure 2-5: Example Eskom's screening curves [15]*

The project was divided into a number of contract packages with different start times leading from 2005 to 2012. The main civil works, electrical and mechanical contract was awarded in 2008 and the first unit was set to begin operation for 2014 however an underground accident occurred in 2013 [12]. A gantry on which the workers accessed the grouting operation dislodged and ran down the shaft, collided with the monorail and two other gantries below, causing loss of lives and destruction. Construction in the shaft was delayed which shifted the expected completion date of the scheme to 2017.

The project was originally estimated at $1 billion and was finally completed in 2017 at a cost of $2.24 billion [16], this coverts to roughly $1682/kW and without the accident estimated costs were $1140/kW [6]. The following associated and additional contributing factors for price increase and cost overruns for Ingula PS scheme are listed in [6] as:

- Scope creep of the civil works, mainly due to unforeseen geotechnical conditions - approximately 10-15% of the civil costs.
- Claims from interactions between the civil and electro-mechanical contractors.

- The cost for contract acceleration.
- Weakening of the Rand exchange rate.
- $36 million over budget for the turbines.

### 2.2.2 Future pumped storage in South Africa

During the early phases of the development of the Steelpoort Lima Pumped Storage Scheme, a possibility of a joint development between the DWS and Eskom was investigated in sharing the function of the lower reservoir (De Hoop Dam) for both water supply and generation. The lower reservoir was moved from the river towards the escarpment while the upper reservoir placed nearer to the escarpment which would increase the head and shorten the waterways as displayed in Figure 2-6. A detailed design study conducted in 2007 proposed a capacity of the scheme of 1500 MW and renamed the scheme Tubatse, consisting of four variable speed turbine units of 375 MW each operating with a net head of 629 m [15].

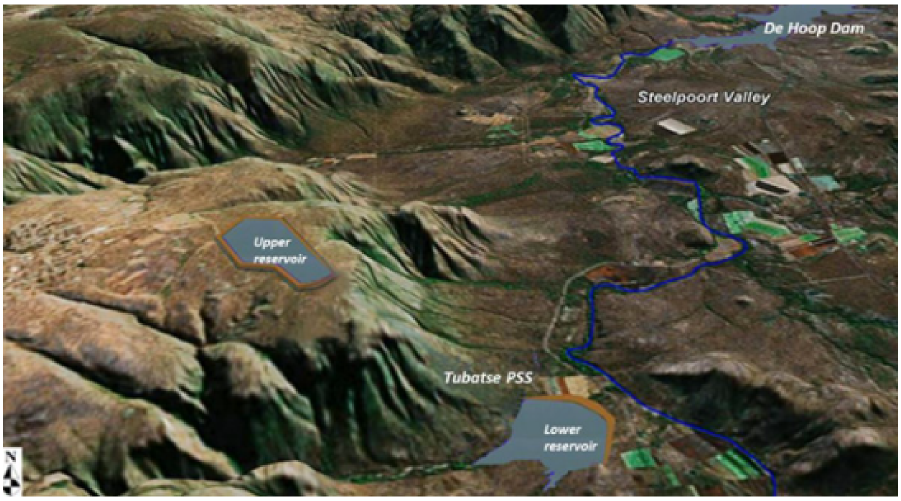



Figure 2-6: Tubatse PSH scheme project layout [15]

The feasibility report from March 2008 [15] estimated the construction cost at $1,28 billion resulting in $1023/kW and a Levelised Cost of Energy of $67,4/MWh. Eskom applied to the National Energy Regulator of South Africa for a license to operate the scheme and expected the plant to come on stream by 2014. The water would be secured through an off-take from De Hoop Dam. As part of the agreement

Eskom would also supply 400 000 people with water through the Olifants River Water Resource Development project.

The highlighted advantages of the project were that the De Hoop Dam had been constructed, transmission routes were strengthened in that area, there was a high head with a short penstock in good rock with granites, the Record of Decision had already been granted, Environmental Impact Assessment completed and the land for the scheme was already owned by Eskom [15].

The Eskom Board approved the business case and the investment decision for Tubatse in 2008. However, the project was put on hold due to the financial crisis in 2008 [6] when development finance became expensive and forecast of future peak energy demand more uncertain. Eskom therefore decided to stop further development of Tubatse. The economic crisis did have a substantial effect on peak demand, and Eskom's interest in additional PSH decreased. Eskom's main focus was then on the already committed base load supply coal power stations of Medupi and Kusile, and the Ingula PSH scheme [6].

While Tubatse's development was placed on hold Lesotho started investigating pumped storage sites as well and a new proposition for a more cost effective PSH scheme called Kobong was developed. Kobong PSH scheme formed then part of the agreement for Phase II of the Lesotho Highlands Water Project (LWHP) [17]. LHWP is the largest bi-national infrastructure project between Lesotho and South Africa. It incorporates a system of tunnels and dams to divert water from Lesotho's mountains to South Africa. Phase 1 of the project involved the construction of Katse Dam, which could form the lower dam of the Kobong PSH scheme. Figure 2-7 shows the function of the Katse Dam in the integrated Vaal river supply system.

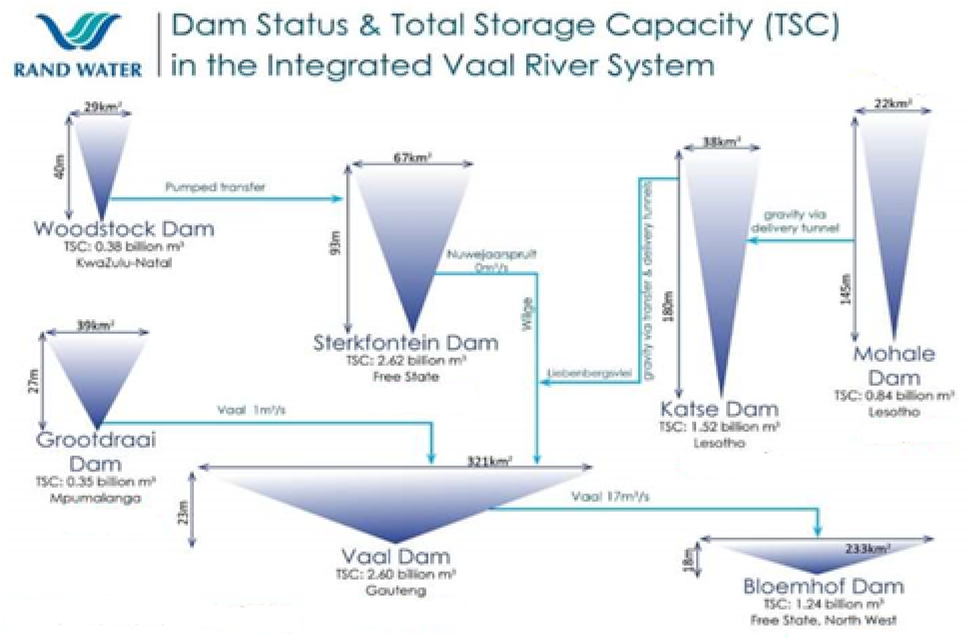



*Figure 2-7: Katse Dam function in Integrated Vaal River System [18]*

Construction costs for the Kobong PSH were estimated at $0.78 billion [17] and this was assumed to be financed from a concessional loan from the World Bank. A capacity of 1200 MW was assumed, with a construction time of seven years. In 2013 a feasibility study [17] for Kobong indicated that the project was technically feasible, but only economically feasible subject to a series of assumptions: a market for the peaking power, a price differential between the buying and selling rates, project capital cost, interest rates, availability of funding and finally agreeing on a Power Purchase Agreement with South Africa for integration of the PSH scheme into the Lesotho and South African grid. At the time Eskom saw no requirement for future energy storage capacity on the South African grid and therefore the project remained technically but not economically feasible. The built Katse Dam is shown Figure 2-8 and currently the Phase II LHWP is under construction.

*Figure 2-8: Katse Dam [12]*

Finally the last PSH scheme to be proposed to Eskom was in 2018 where a feasibility study by Ceres Hydro Electrical [19] for a PSH scheme of 1000 MW with variable turbines, in the Western Cape, was started. The estimated cost for the project is currently $0.4billion with a construction time of 5 years, but the study is still in progress. The higher dam containing 17 million $m^3$ of water is already constructed and the lower dam will be 16 million $m^3$, with a head of 240 m [19]. The lower dam will provide irrigation (36 million $m^3$ per annum) for agricultural use allowing for land reform and providing water security and food security for one thousand farms. The project could feed into the grid, providing improved flexible generation through variable turbines, but network strengthening will be required. A relatively simple Environmental and Social Impact Assessment is required as only two property owners are involved; the Witzenberg municipality and the University of Cape Town. The proposed scheme would be an Independent Power Producer and would also require a Power Purchase Agreement with Eskom [19].

### 2.2.3 Other pumped storage techniques

In the search of other pumped storage techniques, the following possibilities were also considered by Eskom:

• Pumped storage in used mines. This technology makes use of a worked-out mine with the underground voids forming the lower reservoir. The advantages are reduced environmental impacts, large heads with smaller storage required, shorter construction times, perceived lower costs and utilisation of existing works. There are unfortunately disadvantages, such as flooding risks of adjacent mines, the ongoing costs for water treatment to avoid mine water pollution once it is pumped to the surface reservoir, the unknown behaviour of the underground water body and its effect on the rock quality with the constant water motion. These risks were deemed unacceptable and the studies were terminated [12].

• Wave energy storage. Conceptual studies were also carried out using wave pumps to pump seawater into elevated reservoirs and to release it again when required. This technology has potential but a number of technical issues need to be resolved first, such as the capability of the wave pumps, the effective inter connectivity of a large number of pumps and the maintenance requirements of the pumps, waterways and turbine [12]. A realistic economic assessment must still be carried out but further investigations are currently on hold.

### 2.2.4 Future development

An assessment of the past PSH schemes indicates a previous beneficial relationship between DWS and Eskom which allowed for large PSH scheme development to occur in South Africa. The collaboration of Eskom together with DWS perhaps also allowed leveraging of each other’s knowledge in electrical, mechanical and civil engineering fields to construct these immense projects. Future PSH would benefit from this multi purpose arrangement.

Studies also indicated at the time when PSH was 10% of the total installed capacity this would be the limit for pumped storage in Eskom’s supply mix [12].

The current ratio is approximately 5% once Medupi, Kusile are fully commissioned [2]. If the 10% is still valid, there may be an opportunity for further pumped storage in future, although development of shale gas could have an influence on this. Currently there has been a shortage of base load and all efforts have been focused to rectify this.

Once this is normalised, the focus may be shifted towards storage facilities again. With the increase in renewable energy, smaller storage plants on a regional scale may be more attractive than larger plants. If large pumped storage is to be developed again, Tubatse would be a good candidate. However, Lesotho's investigated pumped storage site (Kobong) importing peaking power could also be an attractive alternative for South Africa.

Therefore this research focussed on the next key question: is there still a requirement for new pumped storage schemes in South Africa? This question can be answered by understanding what the driving factors are that influence development and capacity expansion for certain technologies in South Africa and what benefits to the grid PSH can provide with the integration of increased renewable energy generation. By investigating these aspects; this thesis explores PSH and its potential future role for the South African grid.

## 2.3 PSH International development influences and benefits to the grid

This section of the thesis summarises research on the development trends internationally of PSH and the relation to different market types and structures as well as the value of ancillary services provided by PSH.

### 2.3.1 PSH history and trends

Internationally PSH technology development started after World War II when populations increased and rapid economic growth reshaped demand curves by increasing the peak to baseload ratio and creating more distinctive seasonal peaks [20].

By the 1960s thermal generators were designed for constant high output to optimize efficiency and to reduce equipment stress and lower maintenance cost. Dramatic increases in the price of oil and natural gas led to the Powerplant and Industrial Fuel Use Act limiting options to provide load-following and peaking services from gas turbines [21].

Within this context, along with the development of nuclear energy, many PSH projects were built between 1960 and 1980 to absorb surplus power and generate peaking capacity. PSH's capability to balance the load allowed nuclear and coal to operate at peak efficiencies, resulting in PSH being evaluated as an alternative to fossil-fuelled intermediate load and peaking units. Other services provided by the technology were largely ignored during this time [21].

Pumped storage scheme project development declined from the 1990's in Europe, United States (US) and Japan, in part due to:

- the decline in nuclear growth (with then-recent nuclear disasters of Three Mile Island occurring in 1979 and Chernobyl, in 1986) [22];
- market deregulation (previously PSH schemes were almost exclusively built by state-owned entities) [20];
- the repeal of the Powerplant and Industrial Fuel Use Act in 1987 [21]; and
- the dramatic drop in natural gas price.

In the 1970s combined-cycle gas turbines (CCGT) and PSH schemes were similar in costs, however by the 2000s PSH schemes were estimated to cost twice as much as CCGT, thereby limiting its economic competitiveness. However, in countries with rapid economic development, such as China, PSH was seen as beneficial for grid reliability and for bridging the gap between on and off peak demand, and was regarded as a way to aid renewable energy integration [21].

Currently the world has 161 GW of PSH plants and this is expected to increase by another 78 GW before 2030 [20]. There have been studies which state that with the current growth in renewables the number of new PSH schemes internationally have begun to increase again [20], driven by the need for increased flexibility for grid stability and for reduced curtailment of wind and solar PV, especially in China, Europe and Asia-Pacific. The historic and expected future growth in PSH worldwide is shown in Figure 2-9 and Figure 2-10 below.

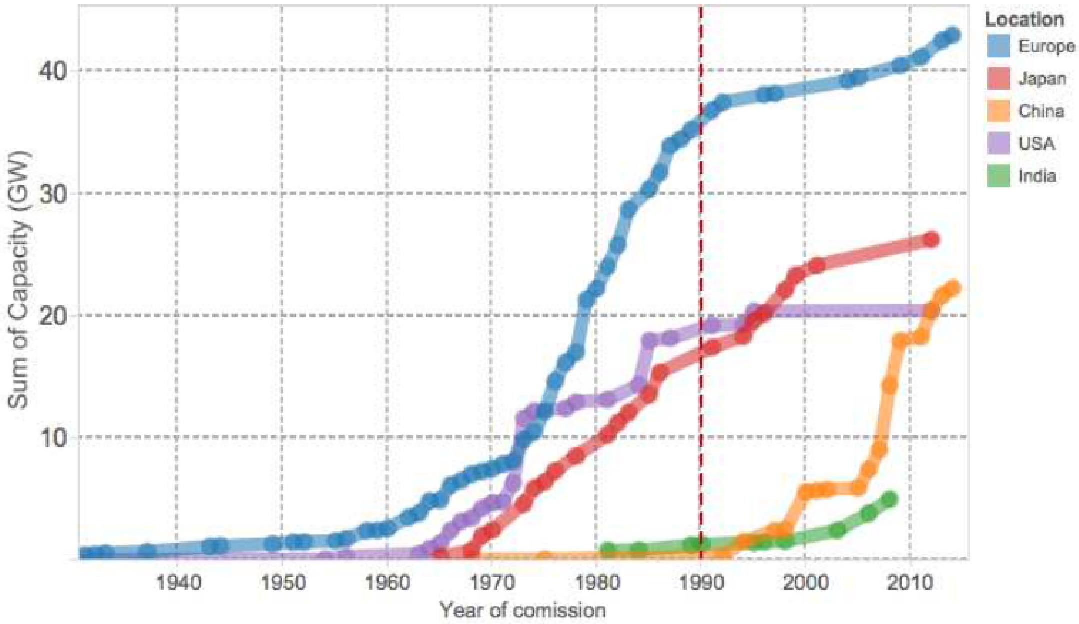



*Figure 2-9. PSH worldwide yearly increased capacity [20] with a decline shown after 1990 for Europe, United States and Japan and increase for China and India*

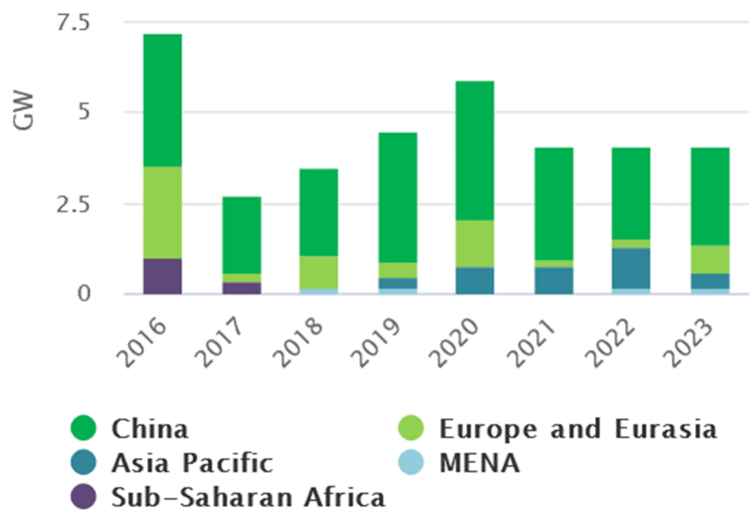



*Figure 2-10. Annual PSH capacity additions by region [23]*

### 2.3.2 PSH schemes in vertically integrated, liberalized and unbundled markets

There is however also evidence to the contrary: in Germany, considered a leader in renewables, PSH scheme proposals were abandoned and in 2014 several PSH schemes were mothballed. Solar generated electricity reduced the price of daytime energy, and thereby the viability of PSH which was previously used to discharge during this time. PSH schemes with variable generators received revenue from not just providing peak capacity but also ancillary services for voltage support, frequency regulation and black start services [20]. Revenue streams based solely on time-shifting energy have become a risk as dramatic market changes can occur from one year to the next.

The uncertainty of revenue with PSH has also caused Switzerland to suspend two new large PSH schemes in preliminary stages of construction. Switzerland typically uses PSH to exploit market prices in neighbouring countries and makes particular use of France's low-cost nuclear electricity for charging [20].

A study reasoned that the attenuation of PSH in Europe was due to the unfavourable market conditions where spot prices are depressed, and the markets are unbundled and liberalized [20].

In comparison, vertically integrated companies or state-owned utilities with transmission and distribution (T&D) infrastructure which used PSH schemes as a T&D asset were increasing capacity. They valued the technology highly for its benefits in stabilizing the power grid, providing peaking power, improving power supply quality and ensuring safe grid operation.

The largest PSH schemes development has occurred in countries with substantial capacity expansion plans and no overcapacity, either for supply or flexibility. The issues with PSH in the US was also highlighted where PSH competes in the Day-Ahead market and costs for charging or discharging are unknown, putting the technology at a risk of making a loss. A study showed the US does not use the value of PSH to assist with lowering overall energy costs, and neither has the mechanisms to reward PSH for its benefits or allow more stable revenue streams for PSH [24].

Unbundled and liberalized markets have a divided incentive problem to promote PSH scheme investment as they are typically focused in one market segment. Vertically integrated utilities in comparison can accrue the benefits of PSH throughout the network value chain resulting in lower risk premiums and therefore lower capital cost. Of the total 171 GW PS schemes installed or currently been constructed, only 4.9 GW were shown to be developed in unbundled and liberalised markets [20].

Table 2-1 arranges the different market types and mechanisms in certain countries with examples of PSH projects and their valued services. Important to note is the constant referral to peak capacity and grid stability and then in liberalised markets with variable speed turbines the frequency regulation, voltage control and black start capability.

.

*Table 2-1: PSH Benefits in Liberalised and Unbundled Markets [20]*

| 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 |

### 2.3.3 Cost and value of PSH ancillary services internationally

As an energy storage technology, PSH supports a wide variety of power system operations through various services. These PSH services range from inertial response and flexible ramping to primary/secondary frequency control and reduced curtailment of variable renewables [24]. The financial value of such services are expected to increase in the future as the percentage of variable renewable energy sources in the power system increases: a study estimated that ancillary services and energy arbitrage in the US offered by 100 MW of storage can result in yearly revenues in excess of $30 million [25]. More specifically, the estimated cost for ancillary services have been given in Lazard's Cost of Storage. This includes frequency regulation up/down at $9.71/MWh and for Australia ancillary services (lower & raise, 6-second, 5-minute, regulation, restart and reactive) at $10.56/MW [26].

Recently the United States Department of Energy completed several studies through the Argonne National Laboratory on PSH. One of the studies specifically focused on the modelling and analysis of the value of this technology [24] [27]. The study was done in collaboration with National Renewable Energy Laboratory, Siemens and Energy Exemplar. A main goal of this was to determine the value of PSH by calculating the saving in production cost of the power system and revenue analyses using Energy Exemplar's PLEXOS model. The benefits and value of PSH was analysed for different types of PSH in both regulated and competitive electricity market environments in the United States. The study highlighted that currently, in most existing markets, there are no established mechanisms to provide revenues for many of the services and contributions of PSH to the power grid. Both in traditional and restructured market environments, most of the PSH services are not explicitly monetized [27], and since PSH plants inherently provide multiple services, it is difficult to distinguish the value of certain benefits (e.g., inertial response, voltage support, transmission deferral, energy security) [24].

In the US, PSH can only receive revenue for limited services including energy generation, regulation reserve, spinning reserve, non-spinning reserve and the provision of black-start capability arranged through a long-term contract. Estimates were calculated for PSH providing these ancillary services and were given as $10/MW for up/down regulation, $5/MW for increase/decrease flexibility, and for spinning and non-spinning reserves $1-3/MW [24].

PSH supports various aspects of power system operations. However, determining the true value of PSH schemes and their many services and contributions to the system is a challenge. The United States Department of Energy has recognized this challenge and are in the process of developing a guide to assess the value of PSH schemes and their contributions to the power system [27]. The analysis should be complete by December 2021 and is investigating the following aspects:

- value of bulk power capacity and energy arbitrage,
- value of PSH ancillary services,
- power system stability benefits,
- PSH impacts on reducing system cycling and ramping costs,
- reduction of system production costs, and
- PSH transmission and non-energy benefits.

The benefits provided by PSH for the integration of variable renewable energy discovered by the United States Department of Energy is provided in Appendix A [5]. These services will undoubtably become more valuable to assist with renewable energy grid integration issues to resolve the problems for grid stability with increased share of renewable generation.

#### 2.3.3.1 Cost of Pumped Storage

The international estimated costs for PSH technologies differ widely as these costs are highly site dependent and depends on which type of pumped storage unit is used. Various worldwide cost comparisons are shown in Table 2-2, highlighting the dependency of such costs on site availability, risk premiums and storage time.

*Table 2-2. PSH Scheme Cost Comparison*

| PSH Scheme Cost Comparison | | |
|---|---|---|
| **Study reference** | **Hour storage** | **$/kW** |
| Blakers et al. 2017[28] | - | 560 |
| Voith 2018 (1400 MW) [4] | 10 | 1290 |
| Entura 2018 [28] | 6 | 1036 |
| PHES [28] | 48 | 1925 |
| Enel 2018 [27] | - | 2000 |
| US Department of Energy [25] | - | 2638 |

Furthermore, PSH units generally fall within three categories of technology: fixed speed, variable/adjustable speed, and ternary. Compared to the traditional fixed speed units, adjustable speed units can adjust the rate in which water is pumped thereby giving more regulation services while ternary units have a separate pump and turbine which allows for higher flexibility, efficiency and response times as quick as 25 seconds [29].

Estimated cost for adjustable speed units are 10–20 percent higher than for fixed speed units [29]. For a 10-hour, 300 to 1 000 MW plant, 2017 costs were estimated to be in the wide range of $1 700–$5 100/kW [25]. Estimates from the US Department of Energy in 2019 have placed PSH between $1 700/kW and $3 200/kW, averaging $2 638/kW [25].

## 2.4 The historic role of PSH in South African long-term resource plans

PSH used to feature strongly in South Africa's capacity expansion plans with a predicted 7.3 GW required from 2008 to 2030 [15] =. However, interest in PSH has declined in South Africa since 2008. In essence capacity expansion models since 2010 saw no economic justification to install PSH, rather increasing Open Cycle Gas Turbine (OCGT) capacity. The IRP 2010 stipulated 4.9 GW peaking capacity which could be PSH or OCGT, however gas turbines were assumed [17].

Ntsone, et al (2016), established that Eskom is finding it difficult to cope with the demands for electricity, which are notoriously outstripping (almost daily) the conventional supply options. The existing PSH schemes are generating far more frequently than they were operationally designed for (i.e. weekly operational cycle). This implies that Eskom pumped storage installations are forced to change from a weekly balance to be balanced on a daily basis [9].

A possible misconception with energy modelers is that there are limited sites available for PSH schemes in South Africa, potentially leading to high implementation costs for these schemes. We know from the costs used in the IRP that PSH was initially modelled at R7914/kW [31] and then was modelled in the next IRP solely on the high price of Ingula pumped storage at R20410/KW [30] as shown in Appendix D. This was done as there was a public request Eskom use actual prices to include in their modelling inputs however other potential PSH could possibly be constructed at far lower costs since geotechnical drilling and lower or upper dams had been constructed already for several projects such as Elandsberg, Tubatse, Kobong and Ceres.

A comparison of South African new build plans over the past 10 years is shown in Table 2-3 below and in Appendix C.

*Table 2-3: Summary of South African Capacity Expansion Plans [2] [15] [30] [31] [32]*

| **Energy Sources** | **2008 Plan** | **IRP 2010** | **IRP 2016** | **IRP 2018** | **IRP 2019** |
|---|---|---|---|---|---|
| New Capacity for 2030 | MW | MW | MW | MW | MW |
| Coal | 21924 | 16 383 | 6250 | 6732 | 7232 |
| OCGT | – | 4930 | 3910 | 8100 | 3000 |
| CCGT | – | 2370 | 2370 | | - |
| Pumped storage | 7268 | 1332 | – | - | - |
| Battery Storage | - | - | - | - | 2088 |
| Nuclear | 19741 | 9600 | 9600 | - | 1860 |
| Imported hydropower | – | 2659 | 2609 | 2500 | 2500 |
| Wind | 1603 | 9200 | 8400 | 9462 | 15762 |
| CSP | | 1200 | 1000 | 300 | 300 |
| PV | | 8400 | 8400 | 6484 | 6814 |
| SHP, biomass, landfill, etc. | | 465 | – | 2600 | 4000 |
| Total | 50536 | 56 539 | 42 539 | 35878 | 43556 |

A summary comparison in Table 2-4 is shown below and provides the cost estimates for some of these projects mentioned in Section 2.2.

*Table 2-4: PSH Potential Costs in South Africa*

| PSH Scheme | Capacity (MW) | Billion (ZAR) | Years to build | Additional Information on Project |
|---|---|---|---|---|
| Ingula (Built) | 1332 | 29.3 | 12 | Cost overruns incurred and underground accident delayed the project. |
| Tubatse (Lima) (2008) | 1500 | 10 | 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 m³) already constructed. Independent Power Producers willing to invest in the project. |

## 2.5 Value and function of PS on the South African Grid

The following requirements are defined by Eskom as ancillary services for the South African grid: reserves, black start, islanding, reactive power supply, voltage control, and constrained generation [33].

### 2.5.1 Reserves and Black Start

Figure 2-11 describes the activation and sustained times of reserve for Eskom in response to frequency deviations outside the dead band of 49.85 Hz to 50.15 Hz [33].

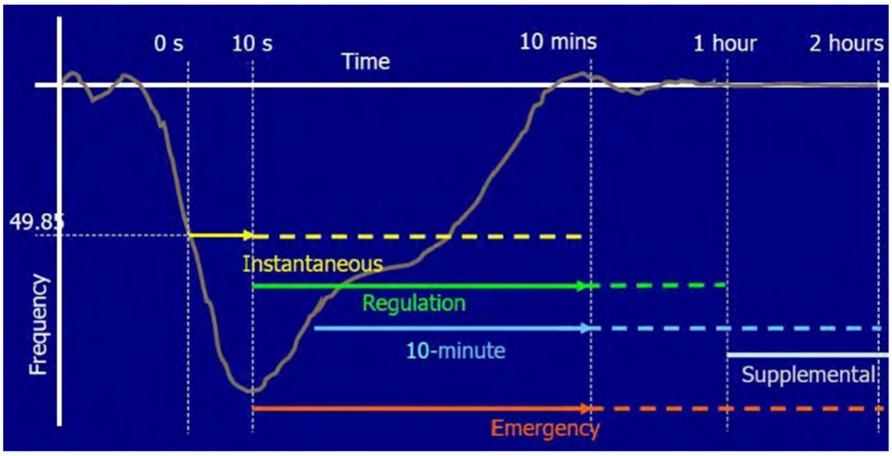



*Figure 2-11. Activation and sustained times of reserve for Eskom to restore frequency. [34]*

Coal units on automatic generation control (AGC) are used for the regulation reserve and operate at partial load in order to increase their output to balance the minute by minute supply and demand. PSH units are currently fixed speed units and not on AGC and operate in the 10-minute reserve as shown in Table 2-5 [34].

*Table 2-5. Operating Reserve for Eskom to Restore Frequency. [34]*

| Reserves | Response Time | Full Activation | Sustained for | Type | Control | Main Function | Minimum Requirements |
|---|---|---|---|---|---|---|---|
| **Instantaneous** | Immedi-ately | 10 s | 10 min | Spinning | Direct | Quick arrest of frequency excursion beyond dead band | Sufficient for largest single contingency |
| **Regulating** | 10 seconds | 10 min | 1 hr | Spinning | AGC | Bring frequency back to 50Hz and regulate tie-line flows | Cater for expected/ forecasted deviations and meets CPS1 and CPS2 |
| **Ten-minute** | - | 10 min | 2 hr | Spinning or non-spinning | Direct or manual | Restore shortfall of instantaneous and regulating reserve and forecast errors | Ten-minute = Total operating - instantaneous - regulating |

Currently Eskom's operating reserves for 2020 require 438 MW spinning reserve, 438 MW quick reserve and 876 MW operating reserve [35]. PSH in the South African reserve allows the system operator to export 200 – 250 MW to the grid in approximately 2-3 minutes. The speed of response is quicker than the response of a coal station which is only 15 MW/minute [34]. Table 2-6 shows the advantage of PSH quick ramp rates when compared to other technologies.

*Table 2-6. Technology Ramp Rates [33] [34] [35]*

| **Technology** | **Ramping Rate** |
|---|---|
| OCGT Ramp Rate | 5-50MW per minute |
| CCGT Ramp Rate | 1-26MW per minute |
| PSH Ramp Rate | 100MW- 200MW per minute |
| Coal Ramp Rate | 0.2-22MW per minute |

From an emergency point of view, the PSH can also be used as a black start facility as well as to arrest frequency drop following a severe frequency event as shown in Figure 2-12.

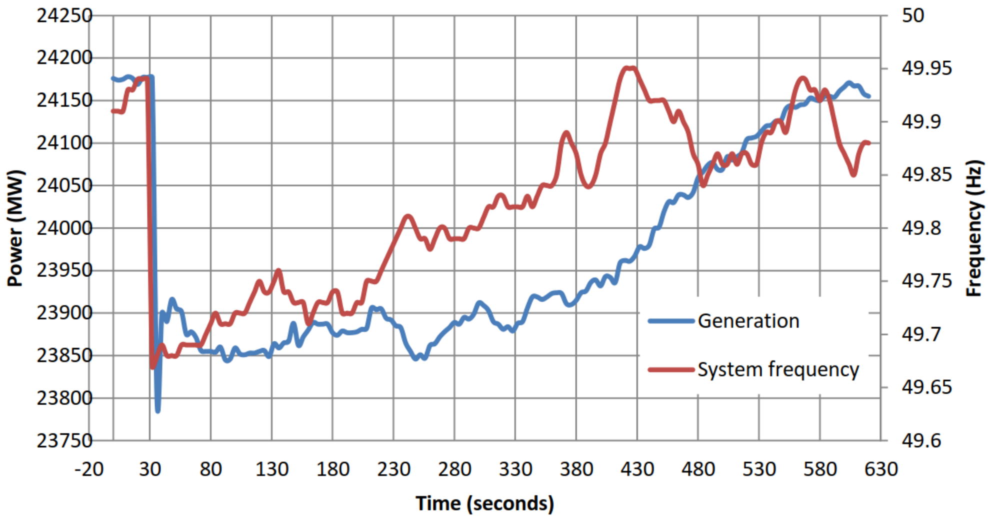



*Figure 2-12: A low frequency incident caused by a unit trip, extracted from Eskom SCADA system [34]*

Hydro generators also have the advantage of stable operations during a Rate of Change of Frequency (RoCoF) event ranging from 0.5 Hz/s to 2 Hz/s [35].

On the South African grid, the PSH units' response to frequency deviations is controlled by the primary governor which is installed at local plant level. The System Operator ensures that there is PSH capacity in the reserves at all times, except during the morning and evening peak times as pumped storage is used to compensate for the slower ramp rates of OCGTs and coal fired generators [34].This improves the economics of the overall system, as excessive ramping leads to a less than optimal operating efficiency for thermal plants designed for high constant output, and leads to more equipment stress and increased maintenance costs. Over the night minimum period, the pumped storage allows base load generators to remain synchronized to the power system by adding demand to the system, thereby increasing the base load utilization level and optimizing operating costs [10].

### 2.5.2 Reactive power supply and voltage control

PSH is highly valued on the grid for its reactive power and voltage control services [10]. PSH units are synchronous machines and when unloaded act as synchronous condensers. The PSH generator supplies reactive power to the grid which can also be the action of a capacitor bank. In large sizes synchronous condensers are cheaper than capacitor banks and provide convenient and continuous control of reactive power by adjusting the field current. As they inject reactive power into the power system to increase voltage and absorb reactive power to decrease voltage in order to control the voltage level and minimise real power losses. Reactive power is required to maintain voltage to deliver active power through transmission lines: when there is not enough reactive power the voltage sags down and it is not possible to push the voltage demanded by the loads through the lines. Reactors also limit the fault current as they are essentially a linear inductive reactance, their impedance will add arithmetically to the system impedance and result in a reduction of the fault currents.

Generally, there are one or two hydro/PSH units at a plant generating or providing voltage control through Synchronous Condenser Operation (SCO) mode [33]. This mode adds inertia and voltage control capability to the network. This decreases fault levels in the network and smooths out variation in voltage caused by load changes and disturbances [10]. Currently the Palmiet PSH units provide around -3 MW output during SCO pump mode [34]. Changes in mode from pump, generate, SCO pump, SCO generate and standstill are estimated at 5 to 20 times a day per unit by Eskom Operators [10] as shown in Figure 2-13.

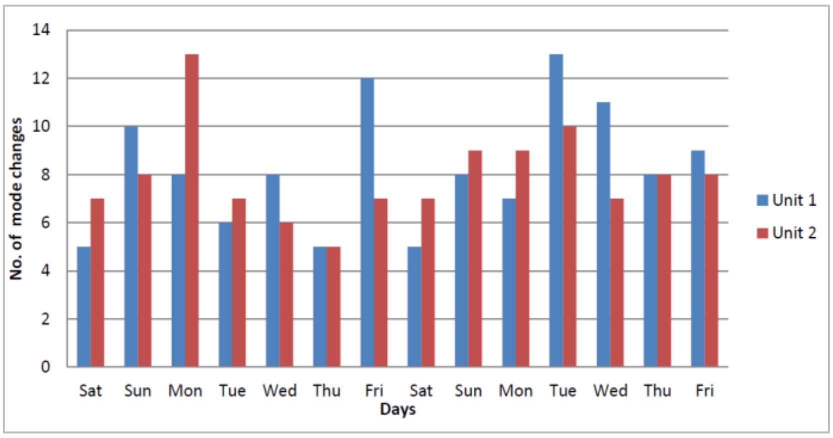



*Figure 2-13. Daily mode changes for Palmiet PS. [34]*

Frequent mode changes of the same unit in one hour are not recommended since this can put stress on the pony motor as at the Drakensberg plant. There should preferably be less than 3 changes per hour [10].

### 2.5.3 PSH for Renewable Integration

The current fixed speed turbines used in all PSH plants in South Africa have a non-minimum phase response, which means that immediately after a request for power increase, which opens the guide vanes, the power actually drops before increasing to the new setpoint. This means frequency regulation using fixed speed pumped storage is not recommended [34]. However, international PSH has been installed with variable speed turbines, which can also be used in frequency regulation [20] and further studies show they strongly improve rotor angle and voltage transient stability of the power system [36]. PSH should also be equipped with governing, under frequency auto start and automatic generation control (AGC) capabilities to enable them to provide better frequency control [10]. Some stations will be required to have black start capabilities, however, this depends on the location. Further improvements in design have also been done with different arrangements where the turbine runner is placed on its own runner shaft with a fly wheel between turbine and generator which decreases water hammer and can increase the units requirements for synchronization, isolated mode and grid conditions [5].

These services PSH provides the grid will become more valued with the future increased penetration of renewable energy. Figure 2-14 shows the problems for grid stability with increased share of renewable generation where frequency stability is shown to be the main issue at over 55% penetration but at lower renewable energy shares issues arise in voltage stability, fault levels, secondary reserve, short term scheduling and transient stability all of which PSH can assist with.

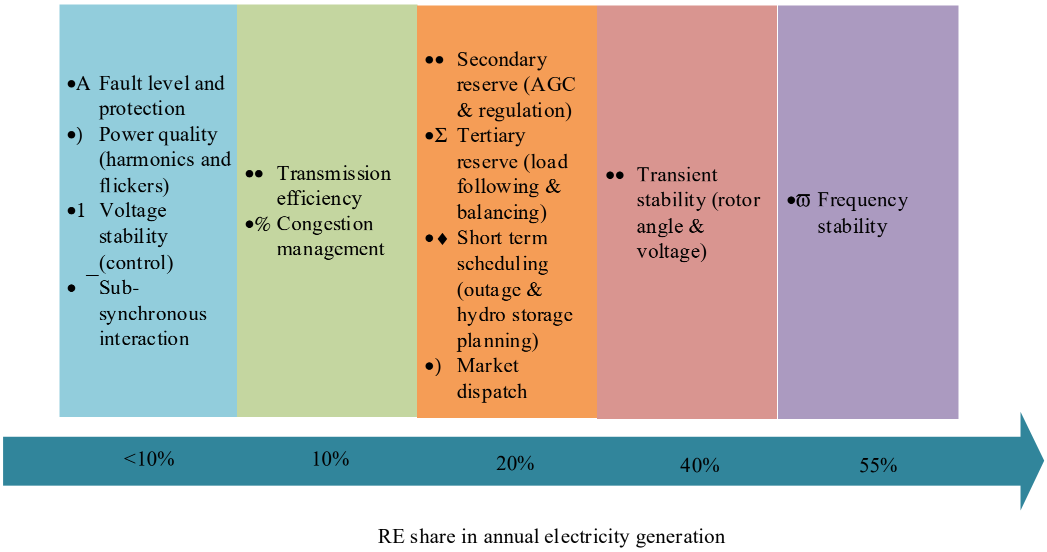



*Figure 2-14: Grid Issues with Increased Renewable Energy Penetration [37]*

## 2.6 Future PSH outlook in South Africa

### 2.6.1 Issues with the Future Energy Plan

As shown in the previous section, increased capacity for PSH currently does not feature in the future South African grid. The alternatives to PSH that do feature presently are OCGT and battery storage. More studies are still required to verify whether the renewables, gas and diesel combination will provide the energy security currently received from base load stations.

The likely reasons why PSH have not featured in the past ten years' capacity expansion plans include the high cost presumed with this storage technology versus gas-based OCGT for peaking generation as shown in section 2.4. PSH scheme cost estimates used in modelling were solely based on the high cost of the Ingula PSH scheme project [2]. In addition, gas based OCGT costings were based on the assumption of adequate gas distribution and storage infrastructure, which South Africa currently does not have [3]. There is a risk that the volume requirement for gas would be too low to motivate development of this gas infrastructure [8]. Therefore diesel might have to be used instead as fuel for peaking and flexible generation [2], driving up the cost of electricity generation in South Africa (OCGT run off diesel costs $50c/kWh compared to coal which ranges between $0.9c/kWh to $3c/kWh, while the current marginal cost for pumped storage is around $2.9c/kWh which is based on the cost of coal [35] [15]).

Furthermore capacity expansion planning tools may not be able to capture the full benefits to the grid of PSH accurately in the modelling process, especially in calculating the impact of PSH on the overall system energy costs.

PSH has a role to play in a diversified energy mix, as has gas turbines, but the risk of sole investment in a gas industry for flexible generation could have detrimental effects on the South African economy if substantial local economic gas reserves are not found [3]. Incorporating new PSH schemes for dispatchable power could reduce exposure to international markets from large imports of gas and could allow more cost conservative operation of the OCGT generation.

Previously Eskom and the South African Department of Energy (DoE) have made it clear that there was no requirement for additional PSH capacity in the foreseeable future [21]. However the DoE have subsequently included 2.1 GW of new storage as a requirement before 2030 in the latest IRP 2019 [2] as shown in Table 2-3. It is known that 360 MW of electro-chemical batteries are been considered in South Africa as a World Bank requirement for funding the Medupi and Kusile coal fired power plants [38]. The recommended 2.1 GW storage has been suggested to be battery storage [2], however for such a large storage capacity requirement PSH might be the more cost-effective option.

### 2.6.2 Gas Turbines

The problem with modelling gas as a fuel in the IRP is currently South Africa does not have substantial gas reserves and no infrastructure to supply this gas. The risk associated with increasing gas volumes to support renewable energy is real unless gas becomes available locally. As the large volume of gas-fired capacity proposed in the IRP could expose the electricity price to external factors such as the oil price and exchange rates unless well contracted for [3]. Further the different types of gas turbines and engines have different functions and need to be carefully selected for supporting the system.

#### 2.6.2.1 Difference between OCGT, CCGT and Gas Engines

There are three gas generation options namely, gas engines, Open Cycle Gas Turbines (OCGT) and Combined Cycle Gas Turbines (CCGT). Current peaking generation is provided by OCGT using diesel as well as Pumped Storage. The three gas generation options fulfil different roles to support a system in industry norms. Gas engines provide fast response backup for renewable options as well as peaking generation operating in a 6-12% capacity factor range. OCGT provides only peaking capacity with a capacity factor of less than 5% while CCGT operates between 20-40% [30] [39]. Gas engines can be used in conjunction with Pumped Storage for fast response and to accommodate for the lower ramp rate of OCGT.

(In the case of Pumped Storage a ramp rate of 200MW per minute was shown in Table 2-6 whereas with OCGT a ramp rate of 20-50 MW per minute can only be expected)

CCGT is the dominant gas-based technology for intermediate and base-load power generation. These plants have the same basic components as the OCGT plants, but the heat associated with the gas-turbine exhaust is used in a Heat Recovery Steam Generator (HRSG) to produce steam that in return drives a steam turbine and generates additional electric energy. CCGT have far better efficiencies of around 60% compared to the low 35% to 42% of OCGT. However the heating time for CCGT ranges anywhere from 30 minutes (from GE's rapid response systems) to several hours. [39]

Gas engines less than 20MW are small in size as they have a low power output to weight ratio due to the reciprocating engine design with pistons and cylinders. They become slightly problematical because of the number of engines required however they have the advantage of fast start and loading with 7 minutes to start up and 3 minutes to synchronise. Their efficiency is around 45%, they require less maintenance and have quicker construction times than gas turbines. The main disadvantage for reciprocating engines is their lower power density, which means that over a certain capacity the physical size or quantity of equipment can become an issue. [39]

The breakeven point between an industrial gas turbine and a diesel engine using liquid fuel is at approximately 2% capacity factor and 5% for gas fuel but this is for an installation less than 50MW [39]. Therefore OCGT generation was used for the comparison against pumped storage in the later sections of this thesis.

#### 2.6.2.2 The risks associated with Gas Supply and Infrastructure

The necessary infrastructure to deliver gas via pipeline resources to power plants is not sufficiently developed in South Africa to meet the generating contingent set aside by the IRP. However it will take two to three years to develop LNG terminals in the harbours between Coega and Mossel Bay so LNG is the preferred option. But for LNG to be affordable landside storage and regas will also be required where one terminal will take up to 7 years to build at a cost between 11-14 ZAR billion (2016 costs escalated today to 15.8 ZAR billion) [40]. More studies need to be done to ensure that the development, contracting and construction of a gas infrastructure can be done within the timeframes.

Another foreseeable problem is the low gas supply required around 2020 to 2030. A modelled version of the grid showed the total gas requirement only consistently exceeds 100MW for combined cycle gas turbines running at 90% generation load factor after 2035 [8].

Assumptions in the modelling for the gas prices in the PLEXOS model potentially need to be updated to show the high initial cost of LNG before storage and regas is developed, the low capacity factors and the costs for gas terminal construction needs to be included. Also gas prices were based on inflation linked gas price but since the gas will be imported this will more likely be market related.

Socio-economic impact studies should be done on the proposed future energy mix to determine the impacts to the coal industry and increased exposure to international markets [8]. The use of gas exposes the cost of the system to the exchange rate and market price risks, where the primary fuel price and production is out of Eskom’s hands [3]. Also gas is still a carbon dioxide emitting technology and the lifecycle emissions of some LNG plants catch up to coal emissions.

## 2.7 Literature Review Conclusion

As an energy storage technology, PSH supports a wide variety of power system operations. Some of the benefits PSH provide include flexibility (inertia, frequency response, ramping support, etc.), improved system utilization (increased utilization factor of coal fired power plants and reduced curtailment of variable renewables) and peaking support. The value of these benefits is expected to increase in the future with the potential of higher penetration of wind and solar generation in the system.

This section highlighted that South Africa currently has several potential PSH scheme sites in advanced stages of feasibility analysis, which compare favourably to international PSH schemes in terms of cost.

In terms of benefits to the grid, literature highlighted that the value of PSH is most accurately captured in vertically integrated utilities like South Africa's Eskom, and that the largest PSH scheme developments internationally occurred in contexts of substantial capacity expansion plans and no overcapacity, again like in South Africa. If Eskom does not realise the value of PSH currently in its structure then there is still the chance these services will be monetarised as Eskom looks into its potential unbundling scenarios they might increase the value associated with the ancillary services that PSH can provide.

Given the risks associated with gas and that the amount of renewable allocation is dependent on flexible generation, pumped storage is an attractive option to replace some of the gas contingent and thereby lower the risks and costs should gas prices increase. Eskom supports pumped storage as a technically sound option and its advantages in managing the grid. The assumptions of using Ingula costs in the PLEXOS model for the IRP needs to be investigated and new costs used related to feasibility studies from proposed projects incorporated into the model as pumped storage costs are very site-dependant.

PHS in South Africa has been shown to still be a potentially valuable technology to support the future power system. The fact that current capacity expansion planning modelling for South Africa does not allocate any future PSH capacity might indicate that further research is required to accurately inform the inputs, assumptions and methodologies used in these models. Ultimately there is a need to better understand the costs, value and sensitivities of flexible technologies like PSH, OCGT and batteries in future power systems, not only in South Africa but internationally.

Therefore the next section of this research explored the inputs into energy models and determined whether pumped storage can still be an economical solution when compared to battery and gas power generation based on cost and available off peak energy.

# 3 Potential for additional PSH

Before the economic case could be investigated, an energy model of the future energy system needed to be developed in order to replicate at least the essence of the PLEXOS model and IRP planned generation mix. As the first aspect to consider is the demand curve, and whether the baseload generation can support further storage leading into 2030. Currently Eskom have the following energy storage installations which were included in the simulation; Ingula Pumped Storage (1332MW for 14hours), Palmiet Pumped Storage (400MW for 28 hours) and Drakensburg Pumped Storage (1000MW for 28 hours) [9].

An investigation was done for the potential future installations: when they would be required and at what magnitude. The calculation was determined for the years leading up to 2030 giving a comprehensive projection for the energy storage potential. The model presented here was developed in 2018 and therefore was based on the 2018 IRP. The model used Eskom data from 2017 for the hourly South African system demand, renewable energy generation and pumped storage usage in order to develop the energy forecast model.

## 3.1 Energy Model Forecast

The objective was to determine the future residual load, dispatch requirement and the amount of pumping available from the South African power system. This was determined through creating an energy model for the current grid system, analysing the operation of pumped storage then utilising the energy model to predict the future supply leading up to the year 2030.

### 3.1.1 Developing the Energy Model

The energy model was developed by using the excel framework developed by Steve Clark, at the time a PhD student at Stellenbosch University's engineering faculty. The framework already contained the initial forecast model with Eskom's historical hourly generation data from 2017 which included the following:

- The national renewable energy data [41];
- The national energy generation supply data [41];

The model displayed the predicted generation mix for 2030 and showed when excess energy would be available or would require curtailment as shown in Figure 3.1 depending on different IRP forecasts.

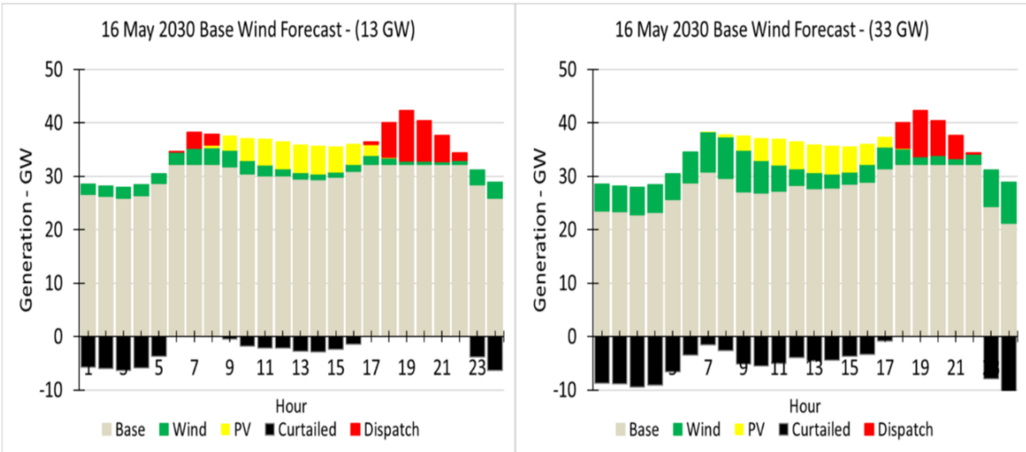



*Figure 3-1: Initial IRP model forecast for 2030 without pumped storage data [41]*

The Pumped Storage data was collected from Eskom for the years 2016 to 2018 and included in the model [10]. The storage hours for the following Pumped Storage Plants in South Africa were provided: Drakensburg, Palmiet and Ingula plants. The hourly power produced or consumed by the Pumped Storage Plant was calculated by using Equation 1:

$$E_{PS} = \frac{S_2 - S_1}{t} \times \frac{E_{max}}{S_{max}} \qquad \textit{Equation 1.}$$

*Where*

$(S_2 - S_1)$ *-change in the storage capacity (hr)*

*t - time (hr)*

$S_{max}$ *-maximum storage capacity (hr)*

$E_{max}$*-maximum energy output (MWh)*

$E_{PS}$- *Power produced/consumed. (MW)*

The hourly energy consumed was multiplied by the cycle efficiency for each plant to account for the energy loss. The data was then combined to create the energy model of the South African system. This energy model formed the basis for the development of the future energy system for the years leading up to 2030.

#### 3.1.1.1 Pumped Storage Operation

Typically, Pumped Storage was operated in weekly cycles due to the limited pumping hours available during the night. The historical hourly generation data collected from Eskom allowed the analysis of each week in various seasons to demonstrate how individual existing PSH projects were being operated. Figure 3-2 shows how pumped storage operation has increased and is currently operated on a daily basis. This could be due to the requirement for Pumped Storage to assist with meeting the night minimum as two shift coal fired power plants are been decommissioned as well as the need for more flexible generation required to regulate the grid frequency. This was shown by the frequent mode changes for the Pumped Storage schemes which typically were over 10 times per day [9].

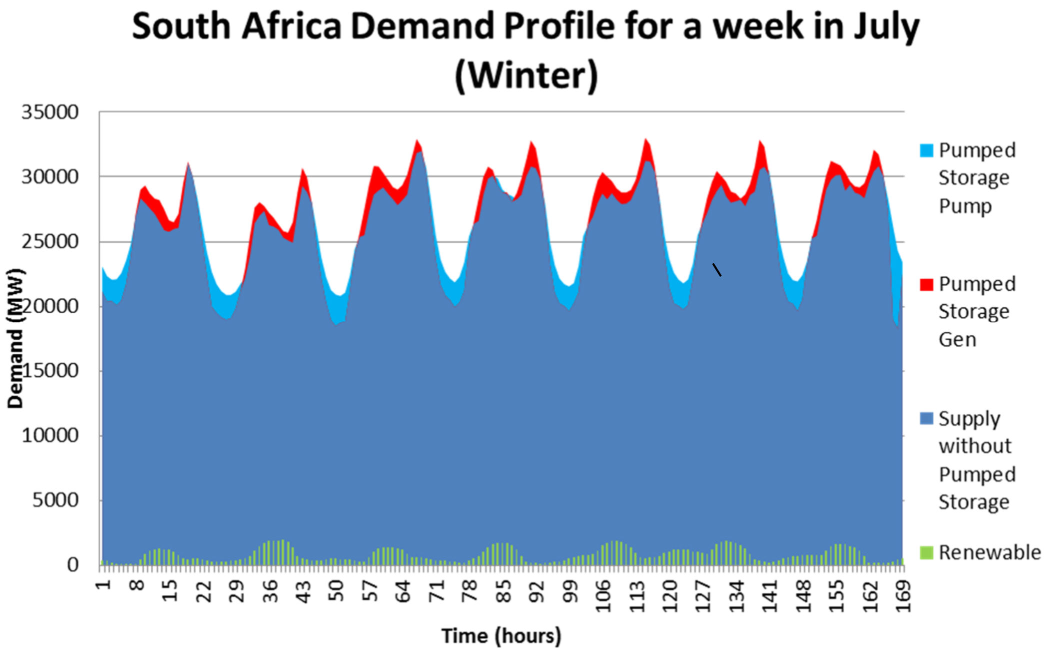



*Figure 3-2: South Africa Winter Demand Profile from Energy model*

The graph clearly shows the benefits of the reduced ramp rates for the morning and evening peaks and how PSH currently generates mainly as a mid-merit plant rather than a peaking plant. This is probably due to the low availability of baseload coal fired stations as Eskom waits for Medupi and Kusile power plants to come fully online. The figure displays the correlation between Pumped Storage and renewables, it is important to note the flexibility of PSH generation and how PSH assists with the evening peak as solar PV falls away.

### 3.1.2 Input assumptions for Future Energy Model

The following considerations and assumptions were chosen in order to create the 2030 energy model. The predicted increase in generation capacity and demand were assumed to be in line with the draft 2018 IRP. The baseload was modelled as a combination for coal, nuclear, hydropower and embedded generation. The energy model was set up to determine the residual load and despatch required by escalating the renewable generation, demand and pumped storage as explained below.

#### 3.1.2.1 Renewable generation escalation

The future hourly renewable generation was estimated using the renewable hourly generation data from 2017. This was done as a percentage of the renewable installed capacity to account for the variable nature of renewable generation as shown in Figure 3-3. The percentage of installed capacity was then used to predict the variable hourly generation for 2030 as shown by Equation 2.

$$\text{Hourly Generation}_{2030} = \frac{\text{Hourly Generation}_{2017}}{\text{Renewable Capacity}_{2017}} \times \text{Renewable Capacity}_{2030}$$

*Equation 2*

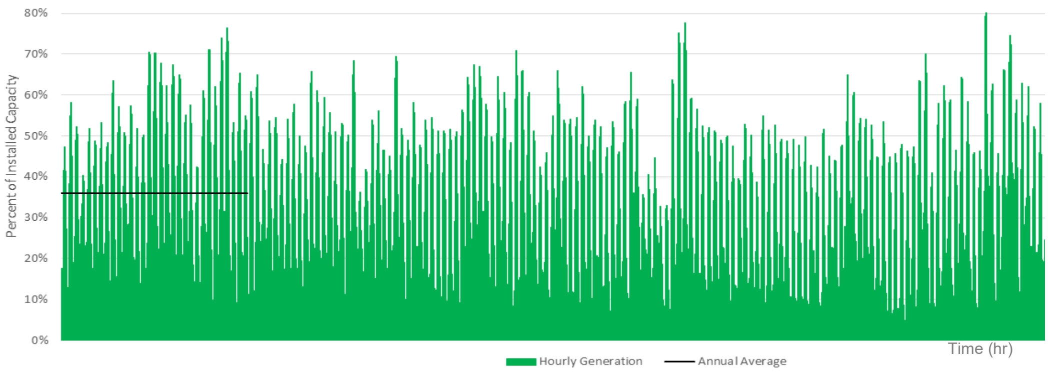



*Figure 3-3: South Africa Renewable Energy Generation (Percentage of Capacity) for 2017and 2030*

#### 3.1.2.2 Demand

The equation below was used to calculate the factor in order to escalate Eskom's 2017 demand data to account for the demand in 2030.

$$F = (1 + r)^t \quad \text{Equation 3}$$

F - *Escalation factor*

*r -2% (The 2018 IRP predicted an upper forecast in expected electricity demand with an average annual growth of 2% by 2030)*

*t – 12 years (escalation from 2018 till 2030)*

#### 3.1.2.3 Pumped storage

According to the IRP, there is no increase planned for Pumped Storage by 2030 therefore the 2017 pumped storage data was used in the model. The objective was to determine the amount of pumping available for Pump Storage from the South African power system. This was done by the calculating the residual and dispatch using the Equations 4 and 5.

$$\text{Residual} = \text{Demand} - \text{Renewable generation} \quad \text{Equation 4}$$

$$\text{Dispatch} = \text{Residual} - \text{baseload} - \text{pumped storage} \quad \text{Equation 5}$$

Residual is defined as the demand left after subtracting the amount of generation from non-dispatchable renewable sources. Dispatch are energy sources that can be used on demand and dispatched according to market needs. Dispatchable energy generators can be turned on or off, or can adjust their power output according to an order. Dispatch could be considered baseload generation through load changes albeit at lower ramp rates but for this study it is only considered to be either gas generation or pumped storage.

By determining the dispatch forecast for the years to come, the potential for pump storage in the future was identified. Using the results from dispatch, the Pumped Storage was increased and if there was not sufficient storage available at any point in time, gas generation was added. This allowed an investigation for additional pumped storage to be included in the energy model through an iterative approach.

### 3.1.3 Results of Energy Model

Using the energy model it was possible to determine the supplementary gas energy generation required to support the grid for different total Pumped Storage capacities.

Due to Eskom's interest in both the Kobong Pumped Storage scheme (1000MW) and Tubatse Pumped Storage Scheme (1500MW), an additional 2500 MW of pump storage was initially selected for the 2030 energy model developed.

The results of the energy model are shown below.
Figure 3-4 shows the South African predicted demand profile for the month of April in 2030. Figure 3-5 shows the optimised predicted energy demand profile for the same month but with an additional 2.27 GW of installed Pumped Storage.

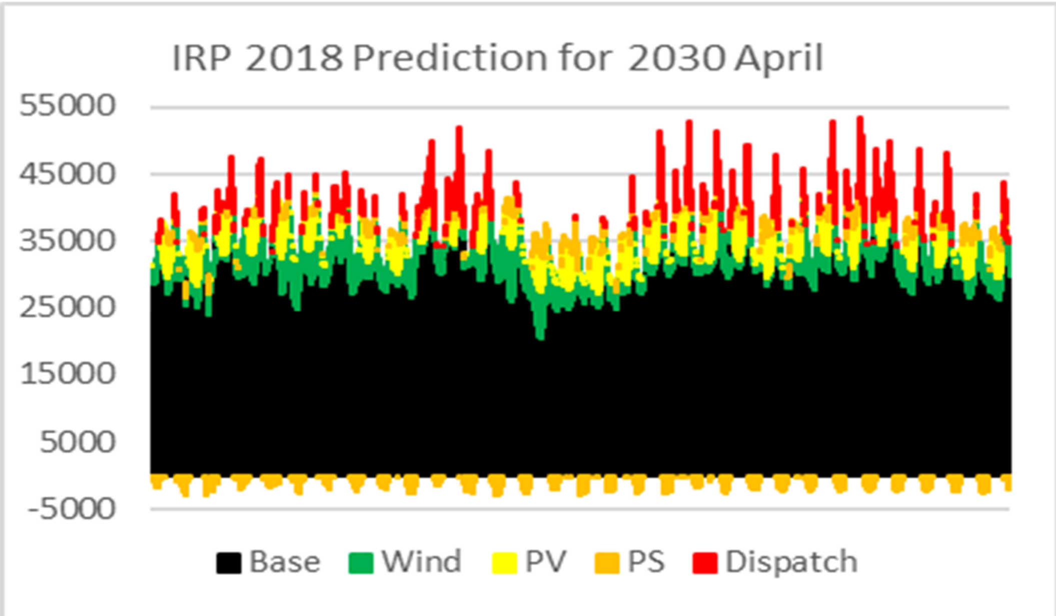



*Figure 3-4: South Africa Demand Profile for April 2030 from Energy model*

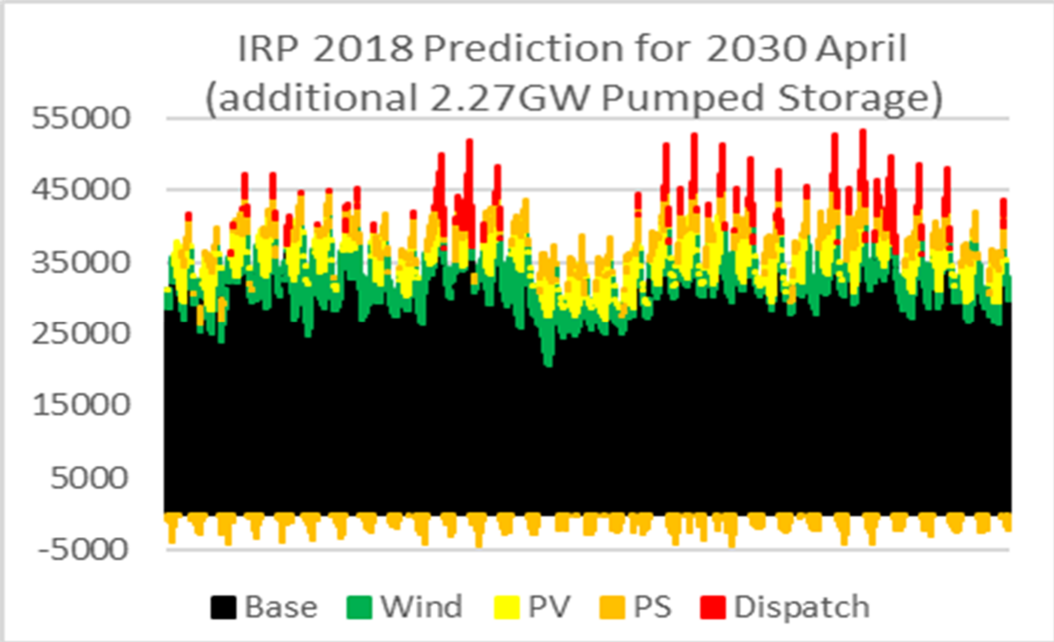



*Figure 3-5: South Africa Demand Profile April 2030 from Energy model*

### 3.1.4 Results Analysis of Energy model

The results showed a utilisation for the proposed pumped storage schemes of 71%. Where 2270MW generation could be supplied by pumped storage for a load factor of 15% of the time for the year 2030. Gas generation could be reduced by 4000 GWh and its utilisation decreased from 7% to 4% and the required capacity lowered from 4GW to 1.7GW. The current OCGT diesel fuel costs are around the order of ZAR 3000/MWh. This amounts to an estimated saving on fuel costs of approximately ZAR 12 billion per annum.

The results prove enough capacity is available for pumping and demonstrate the potential saving with lower required gas generation and capacity through the implementation of additional pumped storage schemes.

### 3.1.5 Validation of model

The IRP 2019 corresponds and validates these results as gas turbine capacity was lowered and additional battery storage of 2.1GW was recommended to be installed before 2030.

### 3.1.6 Consequence of overuse of OCGT

As mentioned previously running OCGT over the recommended load factors results in high losses for Eskom. A potential problem with the current IRP 2019 planning is the mention of having to constantly run the OCGTs to make up the shortfall in supply before additional storage can be installed or CCGT with LNG infrastructure can be developed in South Africa. Eskom face cost implications for running OCGT above the recommended 5% load factor. This has resulted in Eskom spending an additional ZAR10.6 billion in 2013/14 and a further R7.7Billion by the end of January 2015 [42]. Table 3-1 below shows the cost of fuel for operation of the OCGT's [42], Pumped storage and coal [35]. The installed capacity of OCGT was 2409MW resulting in load factors of the Ankerlig and Gourikwa power stations operating at 20% to ensure power production higher than 3600 GWh [9]. PSH had then 1400MW installed capacity and was operating at 25% load factor to ensure production higher back then 2800 GWh [9].

Using this information, the estimated loss incurred through the operation of OCGT was estimated at ZAR 11.72 billion while the profit for operation of pumped storage for close to the same production was ZAR 3.25billion.

*Table 3-1. Cost of fuel for operation of the OCGT and Pumped storage*

| **Production Cost Comparison** | **2014** | **2013/2014** | | **2014/2015** | | **2 years Revenue** |
|---|---|---|---|---|---|---|
| | c/kwh | Output GWh | ZAR (billion) | Output GWh | ZAR (billion) | ZAR (billion) |
| OCGT diesel fuel cost | 230.7 | 3621 | 8.35 | 3709 | 8.56 | / |
| OCGT income (Eskom tariff) | 70.75 | 3621 | 2.56 | 3709 | 2.62 | / |
| Revenue from OCGT | / | / | -5.79 | / | -5.93 | **-11.72** |
| | | | | | | |
| Pumped storage fuel cost | 12.75 | 2881 | 0.37 | 3107 | 0.40 | / |
| Coal fuel cost (30% of output efficiency loss) | 12.34 | 864.3 | 0.11 | 932 | 0.12 | / |
| PS income (Eskom tariff) | 70.75 | 2881 | 2.04 | 3107 | 2.20 | / |
| Revenue Pumped Storage | / | / | 1.56 | / | 1.69 | **3.25** |

This was even after rebates for the fuel levies of ZAR3.40 per litre of diesel were given [42]. Diesel refunds to the value of ZAR 8.8 billion were also claimed in 2015/16 for OCGT generation, compared to ZAR 6.5 billion in the 2014/15 fiscal year. National Treasury and SARS went as far as calling this disproportional increase in the refunds by the electricity sector as an indication of the perverse incentive of the 100 per cent relief for the OCGT peak power plants. [42].

The part we need to consider is the implications if this cycle is to keep repeating itself. As stated in the IRP 2019 and previously in the IRP 2018 “If the performance of existing Eskom coal plants does not improve to the levels assumed, there will be an increase in the total costs because other plants such as diesel or gas plants will have to be run to make up for the shortfall” [32]. The risk is that Eskom is running at very low EAF (Energy Availability Factor) of around 75% and lower, compared to the planned 80 % in 2030 from the IRP 2018 [32]. To use OCGT plants over 5% load factor will result in losses of billions of rands which Eskom can only recover by increasing tariffs

The graph below shows the turbine performance used to calculate the amount fuel required and the cost implications of running 150MW OCGT for an hour and a 24 hour day using an Eskom excel formulation sheet for OCGT operation. The hourly data was used and divided by 150 to determine the cost per MWh.

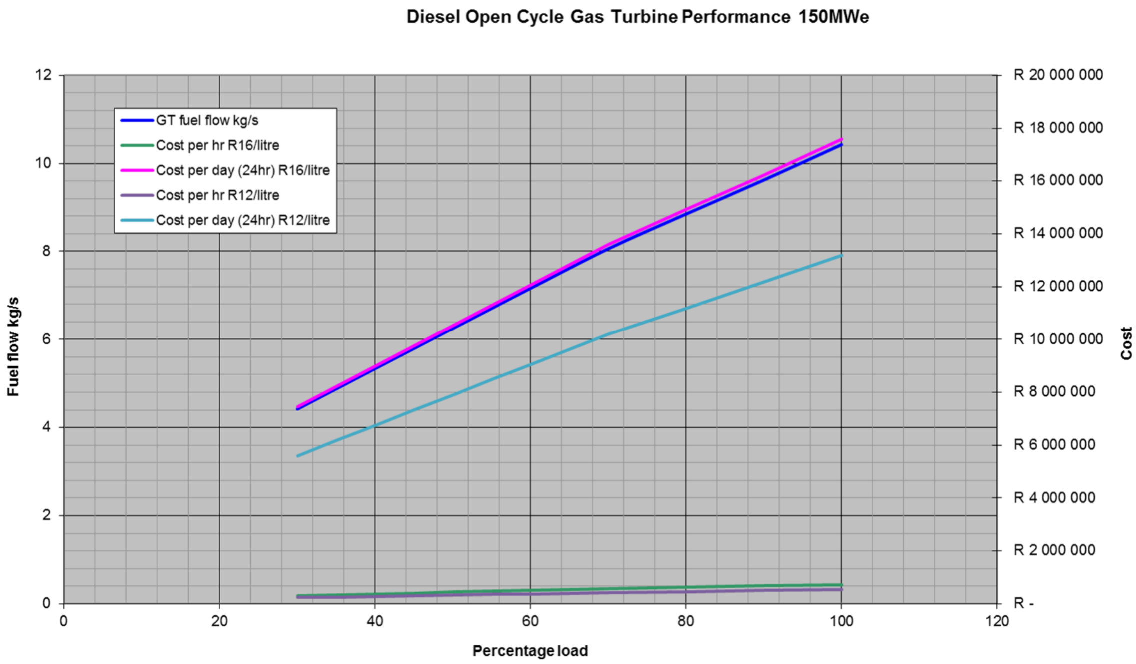



*Figure 3-6: Eskom provided OCGT Performance Graph with costs of Diesel at R12/litre and R16/litre*

# 4 Valuation of PSH and ancillary services in capacity expansion planning

Long-term energy planning is important for South Africa to meet the future energy demand  cost effectively with the most compatible energy alternatives..
During long-term energy modelling two processes are typically used; capacity expansion modelling which models a few selected days in a typical year for the next e.g. thirty years and optimizes the energy mix based on certain criteria, and adequacy assessment modelling which simulates a full year at much higher resolution for a selected scenario.

Additional pumped storage was not included in the recently published South African long-term energy plan, the 2019 IRP [2]. Instead, gas turbines and batteries were selected for peaking and flexible generation. This chapter specifically explores the hypothesis that new PS was excluded from the most recent South African IRP due to inaccurate costing inputs used in the long-term capacity expansion modelling, and constraints inherent to the current modelling methodology. This hypothesis was informed by literature [43] which highlighted that methodologies and model input values for representing storage during capacity expansion modelling are not yet well defined, especially in the interaction between variable renewable energy generators and storage technologies. Issues such as chronology, capacity value and cost representation have yet to be addressed in most large-scale modelling frameworks used for this purpose. An example would be where the value of storage that can shift energy across days (such as PSH) cannot be reflected in a model that does not maintain chronology across periods longer than 24 hours [43].

The above hypothesis will specifically be investigated from two perspectives in this thesis chapter. Firstly, a perspective is explored of the sensitivity of the modelling outcomes to uncertainty in the technology costings used as input into capacity expansion modelling. Within the South African context, the thesis will analyse the PSH costs historically used to inform IRPs, and compare PSH, gas and batteries through levelized cost of energy (LCOE) calculations to investigate the importance of accurate estimation of PSH costs. This will then be tested using an Energy Model Optimization and Analysis tool for a power system modelled on the IRP 2019 system. Secondly PSH and its value to the grid specifically for the provision of ancillary services are explored using international literature. Within this context the South African case is then considered, analysing the constraint that current modelling software cannot currently account for the value of these ancillary services separately.

## 4.1 PSH inputs into capacity expansion modelling

### 4.1.1 PS allocations in recent South African IRPs

PSH has not been included in new capacity solutions for South Africa since the capacity expansion modelling software used to inform the South African IRP changed from Egeas to PLEXOS in 2008 [15]. The estimated costs for PSH technologies differ widely as these costs are highly site dependent (as shown in section 2.4) and depends on which type of pumped storage unit is used. Previous costs showed PSH was modelled as R7 913/kW in 2011 IRP [31] to R21 997/kW in 2018 IRP [32]. A potential reason why PSH is not chosen anymore in the cost optimizing energy model (PLEXOS) relates to the model’s cost inputs which are based on the escalated cost implications from the sole pumped storage project Ingula.

This may have allowed for other technologies such as OCGT and batteries [20] to replace PSH as the main generating capacity for peaking generation in South Africa’s future energy mix as shown in IRP 2019 [2].

Current local estimates for costs of PSH in South Africa ranges from R13 000/kW [17] to R22 000/kW [32] based on the recently constructed Ingula PSH, and the feasibility study for the proposed Kobong PSH. The implications for choosing an incorrect cost value for PSH may considerably affect the results in PLEXOS. This theory is investigated in the next section.

### 4.1.2 Background to LCOE curves

The input assumptions in the PLEXOS model for the IRP was investigated and the costs incorporated into the model compared for PSH, OCGT and batteries as these were the competing technologies for peaking and flexible generation.

In order to test the results of the long-term modelling software PLEXOS, the inputs for each technology were used to create Levelized Cost of Energy (LCOE) curves. LCOE is merely an aggregate but can be used as a comparison tool for different technologies with unequal capacity, capital cost, lifespan, risk and return. The calculation was utilized to show a comparison of the competing technologies as it measures lifetime costs divided by energy production [44].

As a cost optimizing tool an energy modelling software such as PLEXOS should chose the lowest cost prediction. A power plant should be designed to have the lowest LCOE over the life time of the plant in order to ensure a viable project. LCOE for a power plant is calculated by the following formula in Equation 6 [44]:

$$\mathbf{LCOE} = \frac{\textbf{Sum of cost over lifetime}}{\textbf{Sum of electric energy over the lifetime}} = \frac{\sum_{t=1}^{n} \frac{C_t + OM_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \qquad \textit{Equation 6}$$

*where* $C_t$*= The capital cost expenditure in a year;* $OM_t$ *= The Operation and Maintenance (O&M) expenditure in a year;* $E_t$ *= The annual energy generation (kWh); r = The economic discount rate, and* $n$ *= The lifetime of the plant.*

By calculating and comparing the LCOEs of PSH and the competing flexible generation technologies, value can be measured across the longer term, showing projected life-cycle costs. Each of the technologies were calculated for the different load factors for each plant. Load factor is the ratio of the actual power output of the plant over one year compared to the amount of electricity it would produce if it ran continuously at its rated capacity for a year.

### 4.1.3 LCOE technology inputs and assumptions

The LCOEs for PSH, OCGT and Lithium-Ion batteries were calculated from the inputs for the modelling in PLEXOS for IRP 2011 [31], IRP 2016 [30] and IRP 2018 [32].

To compare the sensitivity of the model inputs the different costs for PSH were included from the feasibility studies for Tubatse PSH [15] and Kobong PSH [17], and different fuel prices were used to compare OCGT costs. Table 3-2 and Table 3-3 show the data used to develop the curves.

*Table 3-2. IRP Technology Inputs 2010 and 2016*

| 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 |

*Table 3-3. IRP Technology Inputs 2018 with Kobong And Tubatse PSH*

| 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 |

The following assumptions were made in order to generate the curves:

- For the debt model a total loan facility of the overnight cost amount was made available, at 8% (IRP 2010) and 8.2% (IRP 2016, 2018) rate and for a period of 20 years. An assumed interest and capital payment moratorium for the first years of the loan, during construction, then an amortized loan facility.
- For the IRP 2011 the pump storage pumping cost was according to the methodology of Egeas, based on the variable cost of coal of the “available” base load plants in the system, i.e. base load plants with a relatively high variable coal cost [16]. For purposes of comparing the screening curves, an average coal cost of R200/t [15] was assumed with a variable component, i.e. the pumping cost was based on a coal cost estimated at R200/MWh as the energy charge (fuel) component of the total levelized cost.
- The IRP 2018 input values for OCGT and Lithium-Ion batteries were taken from the EPRI report 2018 while the pumped storage costs were based on the Ingula PSH scheme. The storage technologies do not include a marginal or variable cost for the power [32].
- Kobong and Tubatse feasibility costs used compounded South African inflation rate to give an estimate of the overnight costs.

### 4.1.4 Model Calibration and Validation

The model was validated by comparing and matching certain shown LCOE points from the IRP 2011 and 2016 for each OCGT and PSH while batteries were checked against their LCOE values provided in the IRP 2018. The latest released IRP LCOE curves for PSH are in Appendix B and points between 18 to 22% load factor match accordingly.

### 4.1.5 LCOE curves results

The results for the developed LCOE curves for IRP 2011 and 2016 are shown in Figure 3-7 while IRP 2018 is shown in Figure 3-8. Figure 3-9 provides a comparison for IRP 2018 with Ingula, Kobong and Tubatse PSH costs included.

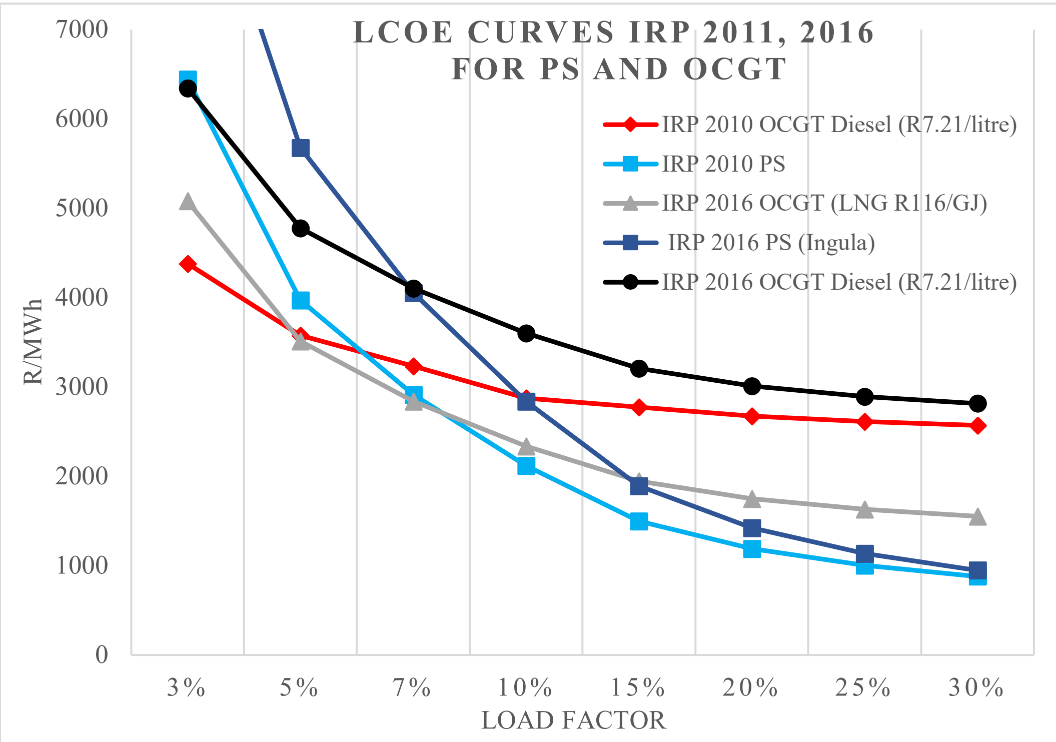



*Figure 3-7. LCOE curves for IRP 2011 and 2016*

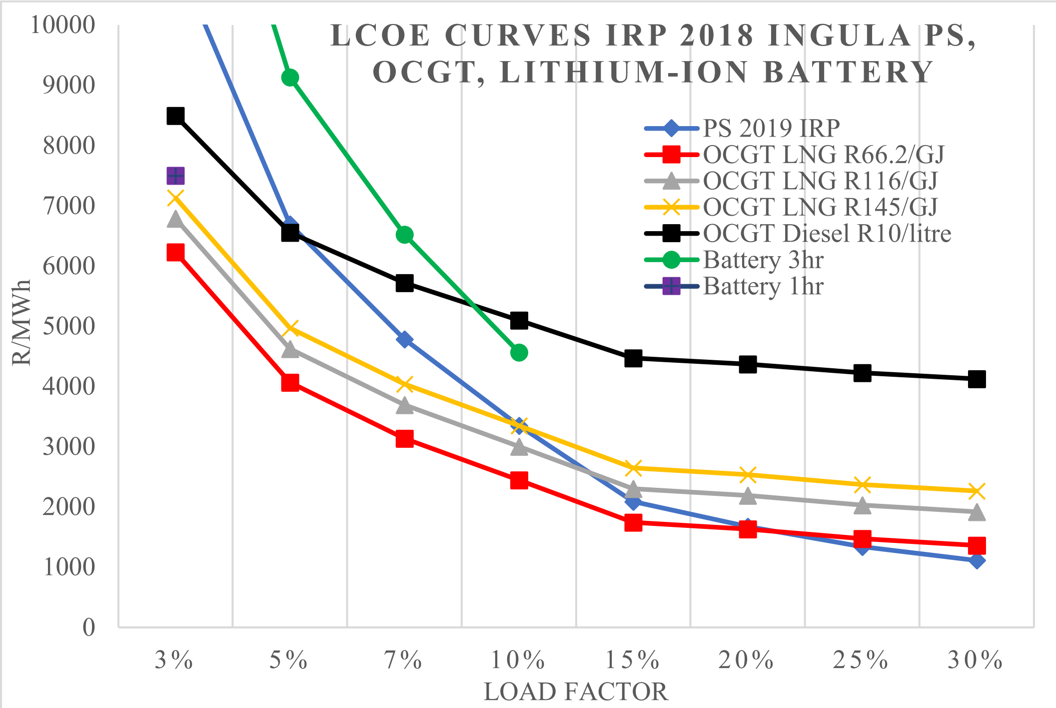



*Figure 3-8. LCOE curves for IRP 2018*

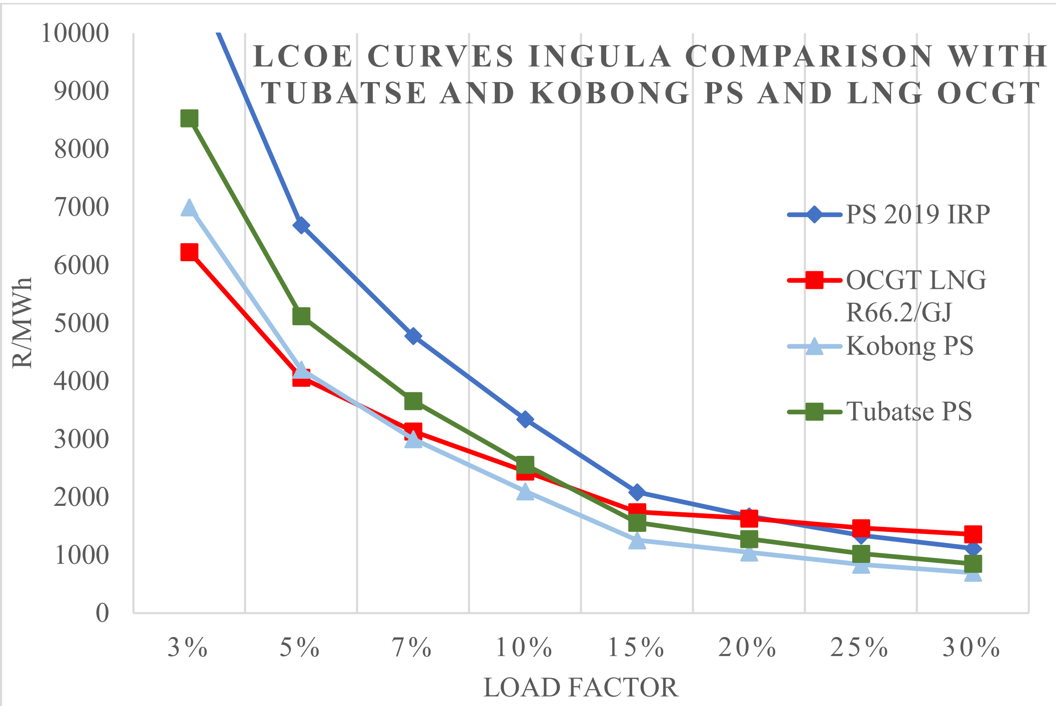



*Figure 3-9. LCOE curves for IRP 2018 including Tubatse and Kobong*

### 4.1.6 Results Analysis of LCOE curves

Analysing the results from the curves shown in Figure 3-7 from the IRP 2010; OCGT diesel at (R7.26/litre) [31] is favoured at load factors below 6%. This is including a pumping 'fuel' cost for pumped storage. There is concern for this result as OCGT was modelled at a load factor of 10% in the IRP and was still chosen instead of the more cost effective PSH. However peaking power could have been assumed as gas and it was stated in the IRP that OCGT could be replaced for peaking and quick response operations. "Further work on this option is required and continued assessment of the viability of demand response and pumped storage options as alternatives to OCGT capacity are to be undertaken." [31 (page 20)]

For IRP 2016 the Figure 3-8 curves demonstrate OCGT using LNG ($8/GJ) [30] is favoured at load factors below 15%. The results show how pumped storage was competitive before in 2010 at a cost of R7913/kW [30] but when Ingula's PSH cost of R20410/kW [30] was used PSH was replaced by OCGT LNG as the new competing technology in IRP 2016. For diesel as the fuel for OCGT as the input for IRP 2016 then PSH was competitive at load factors above 7%. Lithium Ion batteries however were shown not to be cost competitive yet against PSH and only against OCGT run on diesel at 10% load factor.

The graph was further updated to include Kobong PSH and Tubatse PSH LCOE curves in comparison to OCGT LNG to show the sensitivity if PSH is currently valued incorrectly and if the technology can be competitive. Figure 3-9 showed the impact of different cost assumptions and how this changes the competitiveness of PSH versus OCGT. From the results the preferred scheme is shown to be Kobong PSH and competes with OCGT LNG at $4.56/GJ to load factors of 5%.

The levelized costs for each technology were given for certain load factors in the IRP reports. These values were used to compare and verify the developed LCOE curves. The curves showed PSH can be competitive with OCGT especially with decreased capital costs. Therefore, there is a valid argument for PSH as a more cost-effective option for peaking generation than OCGT.

These results also correspond to the outcomes of a study done in the US with Capital Costs for PSH at R30 000/kW and Gas Turbines (GT) at R9 400/kW [24]. The study showed that lowered capital costs for PSH, with ancillary services costed in, would be competitive with gas turbines as demonstrated in Figure 3-10.

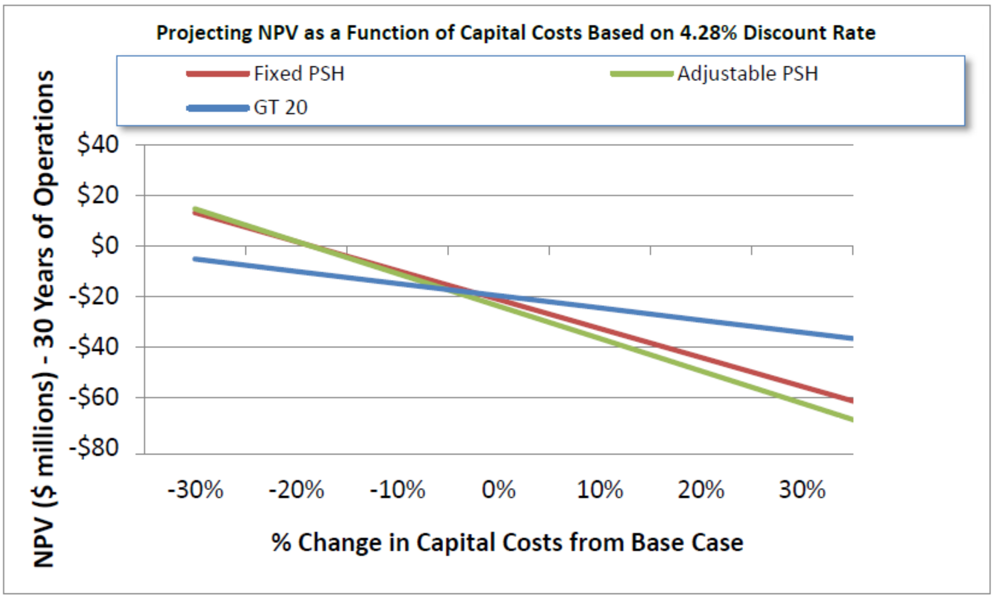



*Figure 3-10. Net positive value of PSH versus Gas turbines [24]*

Figure 3-11 shows the results from another study conducted in the US [25] in 2019, with PSH as more cost effective than Lithium ion and gas turbines even when valued at R37 000/kW.

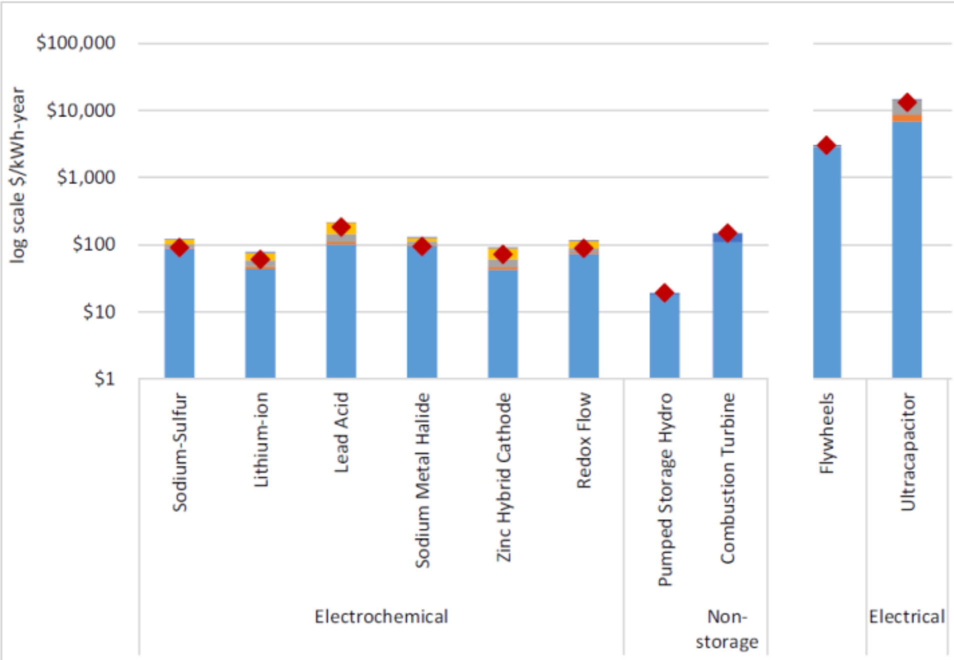



*Figure 3-11. Cost comparison between Batteries, Pumped Storage and Gas Turbines [25]*

Correctly valuing pumped storage and the ancillary services the technology provides is vital to accurately modelling the technology in long term energy planning models.

## 4.2 Energy Model Optimization and Analysis

In order to understand how the difference in chosen inputs of PSH affected the system model as a whole the theory had to be tested in an energy model which could replicate the South African grid. Therefore Tools for Energy Model Optimization and Analysis (Temoa) was used as it is an open source modelling framework for conducting energy system analysis [45]. The core component of Temoa is similar to PLEXOS as it is also an energy system optimization model. Technologies are linked to one another in a network via model constraints representing the allowable flow of energy commodities. The model objective is to minimize the present cost of energy supply by deploying and utilizing energy technologies and commodities over time to meet a set of end-use demands. The energy system enables an assessment of the economic and technical characteristics of individual technologies and their interactions within a well-defined system. The energy system is described algebraically as a network of linked processes that convert a raw energy commodity (e.g., coal, oil, uranium) into an end-use demand (e.g., lighting, heating, transport), through an intermediate commodity (e.g., electricity, gasoline) Temoa is formulated as a linear programming problem and is implemented in Python using Pyomo, a Python-based open source software package. The design of Temoa is intended to address the difficulty of conducting rigorous uncertainty analysis with large, complex models. Each technology is defined by a set of engineering, economic, and environmental characteristics (e.g., capital cost, capacity factor, efficiency, emissions rate) associated with converting an energy commodity from one form to another.

### 4.2.1 Model assumptions and Input Data

A few of the key inputs required in creating the system are summarised in Table 3-4 below.

*Table 3-4: Temoa Inputs and Assumptions*

| **Name** | **Description** |
|---|---|
| Sets | |
| Commodities | list of commodities used within the database (Coal- HCO, Diesel-DSL, Uranium-URN, Solar/wind- RE) |
| Technologies | list of technologies used within the database (E01- coal power station, E21- nuclear and hydro power station, E31- renewables, E51- pumped storage, E70- gas turbines) |
| Time Periods | list of both past and future time periods considered in the database (2010, 2020, 2030, 2040, 2050) |
| Time Season | time season: seasons modelled in the database (winter, summer, intermediate) |
| Time of Day | time of day: time of day segments modelled in the database (day, night) |
| Time slice | Time slice which represents the time split of each modelled year, therefore the time resolution of the model. Common to several energy systems modelling tools, the annual demand is ‘sliced’ into representative fractions of the year. It is necessary to assess times of the year when demand is high separately from times when demand is low, for fuels that are expensive to store. In order to reduce the computation time, these ‘slices’ are often grouped. Thus, the annual demand was split into aggregate seasons where demand levels are similar (‘summer, winter and intermediate’). Those seasons were subdivided into ‘day types’ (day and night) to create the level of demand. |
| Global Parameters | |

| | |
|---|---|
| Discount Rate [r] | Region specific value for the discount rate, expressed in decimals (e.g. 0.08) |
| Annual Demand [r,t,y] | Total specified demand for the year in PJ, linked to a specific 'time of use' during the year |
| Specified Demand Profile[r,f,l,y] | Annual fraction of energy-service or commodity demand that is required in each time slice. For each year, all the defined Specified Demand Profile input values should sum up to 1. |
| Efficiency [r] | Efficiency of technology |
| Year split [l,y] | Duration of a modelled time slice, expressed as a fraction of the year. The sum of each entry over one modelled year should equal 1. |
| Performance | |
| Capacity To Activity Unit [r,t] | Conversion factor relating the energy that would be produced when one unit of capacity is fully used in one year. |
| Capacity Factor [r,t,l,y] | Capacity available per each TimeSlice expressed as a fraction of the total installed capacity, with values ranging from 0 to 1. It gives the possibility to account for forced outages. |
| Lifetime of Technology [r,t] | Useful lifetime of a technology, expressed in years |
| Technology Costs | |
| Fixed Cost [r,t,y] | Fixed O&M cost of a technology, per unit of capacity. |
| Capital Cost [r,t,y] | Capital investment cost of a technology, per unit of capacity. |
| Variable Cost [r,t,m,y] | Cost of a technology for a given mode of operation (Variable O&M cost), per unit of activity. |
| Emissions | |

| | |
|---|---|
| Emission ActivityRatio[r,t,e,m,y] | Emission factor of a technology per unit of activity, per mode of operation |

The inputs used to create the model were based on the IRP 2019 forecast, EPRI and CSIR 2016 Report (refer to Appendix E for the written code and the values used for the parameters).

Figure 3-12 presents the diagram configured by Temoa from the inputs showing the relationships between the commodities, technologies and energy use.

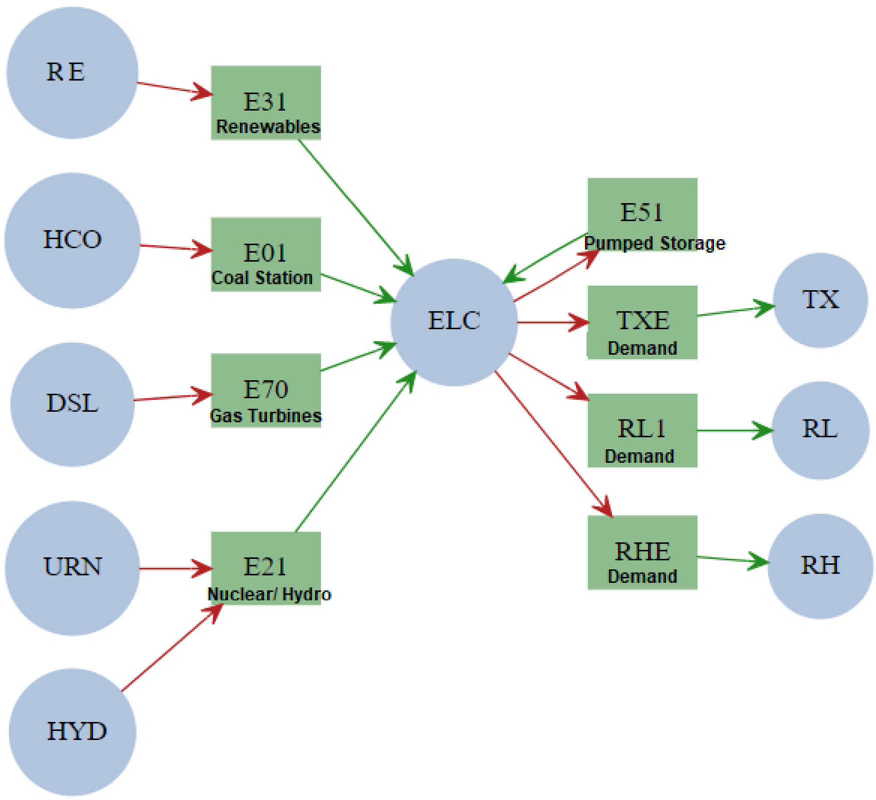



*Figure 3-12: Temoa Model Diagram*

### 4.2.2 Model Calibration and Validation

In order to verify the model was computing correctly the results were checked against IRP 2019 results for 2030, 2040 and 2050. In order to simplify the model wind and solar was considered renewables and nuclear and hydropower were grouped together.

The results correlated with the IRP 2019 2030, 2040 and 2050 capacity results however the gas turbine capacity is set to grow from 6.3GW to 23,24GW from 2030 to 2050 according to the IRP 2019 and the model chose rather to include 24GW from 2030. The resultant capacity chosen is still the same so this minor deviation was considered acceptable. Another point to note is the IRP 2019 is not clear on future storage requirements after 2030 therefore the model was checked to match the 2030 requirements and left to estimate the system requirements for 2040 and 2050 within the same energy mix as IRP 2019.

### 4.2.3 Temoa Results

The results for the initial run with the similar inputs used for the IRP 2019 are shown in Figure 3-13. The figure shows comparable results to the IRP 2019 proposed energy mix in Appendix F.

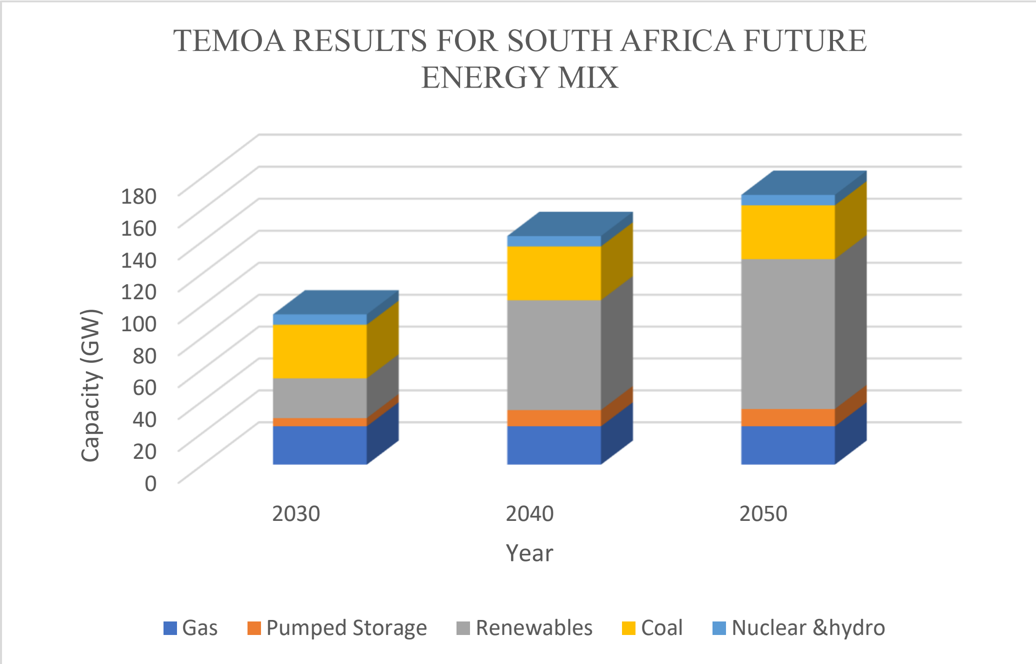



*Figure 3-13: Temoa Results for South Africa Future Energy Mix (Inputs same as IRP for PSH)*

The next step was then to alter the inputs for PSH to understand the changes in the system model output results. The capital cost was changed from the initial modelled value of $2100/kW to Kobong's $956/kW and the following changes in the results shown in Figure 3-14 were noted.

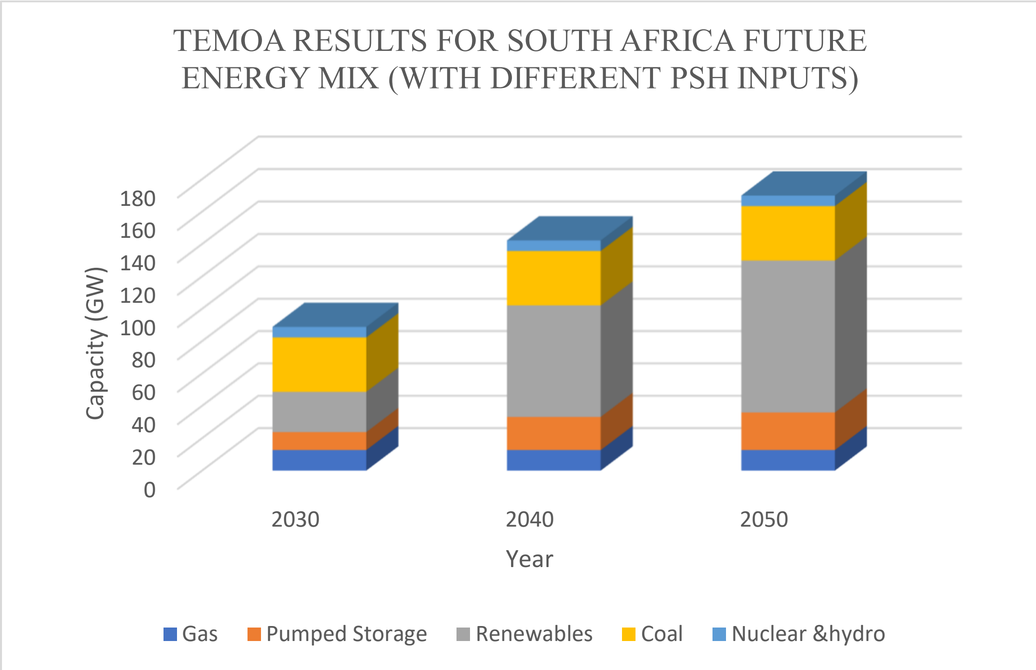



*Figure 3-14: Temoa Results for South Africa Future Energy Mix (with different PSH inputs)*

### 4.2.4 Results Analysis of Temoa

The results showed gas turbine capacity requirement dropped by almost half from 24GW to 12,7GW leading to 2050 while PSH capacity requirement doubled for 2030 to 10GW and changed from 10,9GW to 23,9GW by 2050.

Other points worth mentioning were observed for the following adjustments:

- When the gas turbine fuel price was increased from \$4,56/GJ to \$8/GJ the results showed a decrease only of 1,5GW gas turbine capacity and an increase of 1 GW for PSH capacity
- When the lifetime was extended from 50 to 60 years 0,5GW increase for PSH capacity.
- When coal or nuclear capacity increased, gas turbine capacity dropped significantly and PSH capacity increased. (Example showed with an increase of 6,5GW for coal, this dropped peak generation gas turbine capacity by 8GW and increased PSH by 5GW).

The energy model was a decent indication of the potential changes in PSH development potential if different costs for PSH were to be utilised in the PLEXOS model inputs. However, the model system had several limitations where the model input values for representing storage during capacity expansion modelling were not yet well defined. This is further discussed in the next section.

### 4.2.5 Valuation of PSH ancillary services in capacity expansion planning

Capacity expansion modelling has several limitations as researched and realised during the capacity expansion model development especially in the high level time slices chosen and where a model that does not maintain chronology across periods longer than 24 hours to model the benefit of shifting energy across days and the interaction between variable renewable energy generators and storage technologies is not yet well defined. The value of storage in lowering production costs of grid systems should be addressed as well.

As was demonstrated in the previous sections, PSH can provide a range of services to the power system, which again is attributed a range of values depending on the market structure and grid characteristics of the specific region. Specific to South Africa, PSH operations currently fall within a vertically integrated national utility where its services are not explicitly valued [10]. This is about to change, with Eskom to be unbundled resulting in an independent system operator, and the IRP allocating more than 30% of the country’s total generating capacity to VRES by 2030. Within this context it is likely that an ancillary services market will develop, resulting in more realistic valuation of PSH-supplied ancillary services. Current capacity expansion modelling in South Africa is done using an analytic tool called PLEXOS, which at the time of modelling the IRP did not model ancillary services as separate costs but only as implicit outcomes of different cost-optimizations when including ancillary services as an explicit system requirement.

PLEXOS at the time of writing is further limited in time scale variations as shown in Figure 3-15 and therefore cannot account for the value contained in services such as operating reserves, voltage stability, grid faults/stability or regulation, and the potential revenue streams these represent.

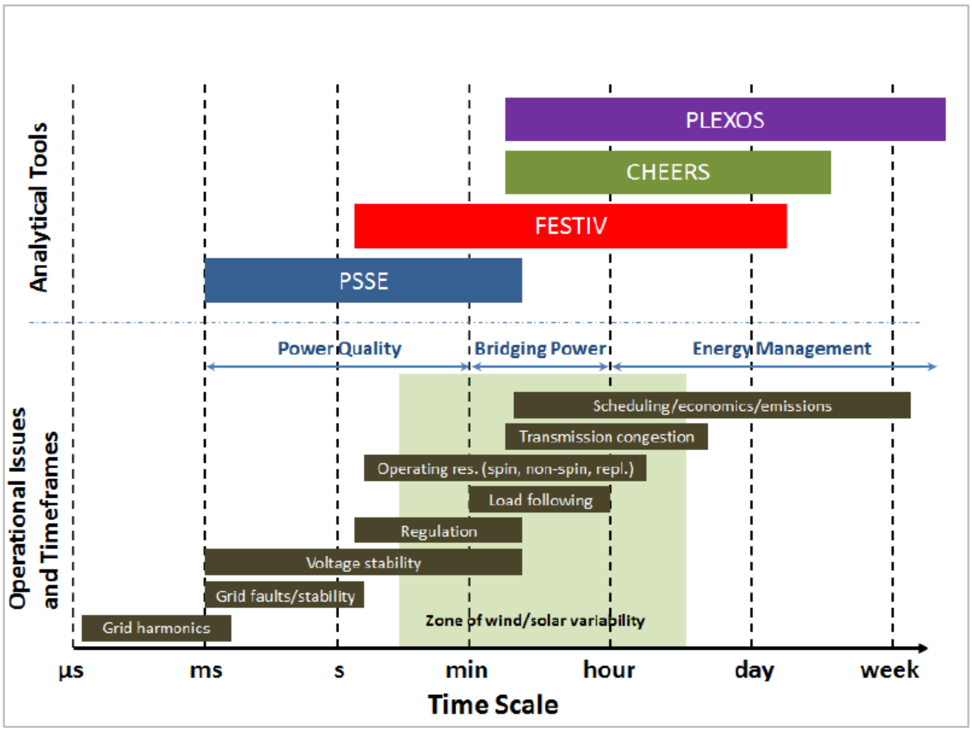



*Figure 3-15. Power System Timeframes and Operational Issues [24]*

International markets with Day Ahead dispatch value the different ancillary services and consider marginal energy costs, start-up costs, ramping rates, operating reserves, and transmission constraints [20]. The current ancillary services provided by PSH in South Africa can be valued by analysing such international market mechanisms especially concerning the spinning/non spinning, flexible ramping up and down and reactive power/ voltage control. Potential revenues from frequency regulation can also be included for future variable turbines with improvements in turbine-generator arrangements.

In system planning and economic operation of power systems, generators are typically not operated at their limits but at equal incremental costs (taking into consideration the line losses) on an instantaneous basis. PSH, however, is different as the incremental cost is not known. The cost is varying as it may be based on excess VRES or on generation from thermal power stations [10]. Therefore prediction and forecasting is required to allow for PSH to reduce the overall production cost of the system by generating at the peak times, lowering capacity building, storing excess energy generation and operating during off peak to allow for constant operation of the thermal units at night [20].

# 5 Conclusions

## 5.1 Summary of findings

The additional services PSH provides to the grid in the form of ancillary services was investigated in order to understand potential future revenues for the technology. The benefits of instantaneous frequency control provided by the inertia of the synchronous generators was researched to account for the increased wind and solar penetration with asynchronous generation. Typically traditional synchronous generators are used at coal, nuclear and hydropower plants and these turbines spin in unison close to a regulated standard thereby controlling the frequency. PSH Synchronous Condenser Operation (SCO) mode was also investigated for adjusting conditions on the electric power transmission grid by either generating or absorbing reactive power to adjust grid voltage or improve the power factor. The study showed PSH can not only minimize the fault current level but also improves the voltage profile as well as the transient stability of the system.

On a power system dominated by base load coal fired generation, pumped storage also offers flexibility, ramping speed and "demand" over low loading periods. The pumped storage is used to compensate for the slow ramp rates of OCGTs and coal fired generators, particularly during the ramp up for morning and evening peaks. Over the night minimum period, the pumped storage allows base load generators to remain synchronised to the power system by adding demand to the system. When not generating or pumping, the pumped storage units are capable of operating in SCO mode to add inertia and voltage control capability to the network. PSH thereby assists with the voltage control as units provide reactive power reserve to compensate for voltage fluctuations and to maintain voltage following the loss of system voltage support devices. This decreases fault levels in the network and smooths out variation in voltage caused by load changes and disturbances. From an emergency point of view, the pumped storage is used as a blackstart facility as well as to arrest frequency drop following a severe frequency event by automatically starting in generator mode or tripping from pump mode. PSH should be equipped with governing, under frequency auto start and automatic generation control (AGC) capabilities to enable them to provide better frequency control.

The power generation mix was analysed to understand the future reserve required to account for the fluctuation of renewable energy and the adverse effects on power quality. These services were measured against other storage and flexible generation technologies to understand the importance and role of PSH. In order to track current and future load changes, an Energy and Power System Simulation model was developed to replicate the Eskom grid operation to examine the future effects of the predicted increased amounts of renewable energy. The model will analyse the influence of fluctuating Renewable energy on the system as well as weekly and seasonal differences in electricity. This determines how PSH can facilitate grid stabilisation and allow for a higher infiltration of variable renewables into the future electrical grid. The thesis investigates the potential future installations when they would be required and what magnitude. The calculation will determine for years leading up to 2030 giving a comprehensive overview for the energy storage required.

Cost comparisons of the competing technologies through the use of levelized cost of energy curves were developed versus PSH to understand which options are the most viable and cost effective. PSH was shown to be far more cost competitive than batteries and could even compete with gas turbines run off LNG at $4,56/GJ when costs of $956/kW were used for PSH. This was then further verified by using a Tool for Energy Model Optimization and Analysis (Temoa) to understand the future grid and how the changed inputs could decrease the requirement for gas turbines if the PSH capital cost were lower then previously modelled.

## 5.2 Conclusions from findings

This thesis explored the hypothesis that new PS was excluded from the most recent South African IRP due to inaccurate costing inputs used in the long-term capacity expansion modelling, and constraints inherent to the current modelling methodology. The thesis focused on the costs related to pumped storage and the ancillary services the technology provides the grid. The thesis showed that, on a power system dominated by base load coal fired generation, PS offered flexibility, voltage control, ramping speed and demand over low loading periods. Currently these services do not have revenue streams for PS on the South African grid. Further potential revenue for ancillary services provided by PS were also limited by the inability of the modelling software's timeframes to capture fully the operational issues on the power system.

The questions initially raised were answered as several potential PSH sites in advanced stages of feasibility were found to be available in South Africa. The modelling of PSH in the IRP was investigated and it was discovered the inputs were solely based on the Ingula project and therefore the cost estimation and duration of the project as well as the capital phasing is very subjective and it is recommended the inputs be improved upon by looking at the feasibility studies and other PSH projects to have a more accurate representation of the model. In this way there will be a better way to represent PSH and further to value it by including the revenues of the ancillary services it provides. Several costs were given for specific services to assist in future revenue determinations for these benefits currently freely provided. The final part of the research explored the impact if new modelling inputs for PSH were to be incorporated into the energy model. The initial calculations through Levelised Cost of Energy curves showed Gas turbines to be more cost effective however with the new inputs for PSH from the feasibility studies there was a clear indication an economic case could still be made for PSH. Therefore the new inputs were used in the optimisation model which proved there was still potential for PSH to be chosen as a more cost effective option for the future development.

## 5.3 Summary of contributions

Uncertainty in electricity demands are balanced in real-time using fast reacting flexible generators such as hydro and gas turbines. The generation needs to act as a fast ramping reserve for frequency control. According to the 2019 draft IRP more flexible generation will be required to integrate the increased variable renewable energy generation and this will be provided by mainly gas turbines. More studies need to be done to verify whether renewables, gas and diesel combination will provide the energy security South Africa currently obtains from base load stations. The significant planned future dependence of the South African power system on market based gas exposes the economy to a number of potential risks. This thesis investigated PSH as an alternative technology to gas turbines for peaking, flexible generation and whether South Africa should still invest in PSH in the future energy mix.

The literature review covered the history of PSH development both locally and on a global scale and showed the future emerging trends. The associated capital costs were compared internationally and with reference to recent feasibility studies conducted in South Africa. The services and contributions the technology currently provides was investigated and the associated revenue streams in different market structures was highlighted. The value of PSH on the South African grid was detailed with the potential additional revenue streams for ancillary services.

The thesis investigated if there is still potential for additional pumped storage on the future grid, and what further research should be done in order to analyse and better inform the energy modelling inputs and assumptions which are currently being used.

The input assumptions for PSH in the PLEXOS model for the IRP was investigated in this thesis. The LCOE curves and Temoa model developed assisted in supporting the hypothesis that an economic case can still be made for PSH in South Africa, however this is dependent on how PSH is currently modelled in the energy planning software. The results showed PS to have far lower LCOE values than batteries and diesel turbines. The cost competitiveness of PSH and gas turbines was shown to be dependent on the gas price used and the chosen PSH overnight cost. From this it was concluded that the chosen value of PSH should rather be a comparative value instead of only been related to a single previous scheme and should also reference feasibility studies from proposed projects as PSH costs are very site dependent.

The research is important for understanding the contribution of PSH in improving the integration of generation from renewable sources for effective grid operations. This a valuable topic for improving the traditionally coal dominated electricity system to create an opportunity for a sustainable transition to a more environmentally conscious energy future in South Africa.

## 5.4 Future research

Future studies should include additional costs for these services in the PLEXOS energy model to understand the benefits PSH provides the grid. The value of storage in lowering production costs of grid systems should be addressed as well as modelling the benefit of shifting energy across days. This issue needs to be resolved as currently it cannot be reflected in a model that does not maintain chronology across periods longer than 24 hours.

The current IRP solution involves incorporating gas turbines for the flexible generation. The ranking of coal versus nuclear versus PV and wind will probably change many times during the next decade. Especially with the prospect of cheap gas prices, ranging from $10/GJ to even $4.5/GJ, which seems to be the game changer in the energy industry. More studies need to be done to verify the proposed renewable and gas turbine solution will give us the same security we get from the coal fired baseload generation. Further a study should be done on a solution which involves large capacity PSH with small capacity batteries for fast response and gas turbines run off diesel for back-up. This would assist in resolving the issue of the gas infrastructure development required for LNG. The LNG costings used in the PLEXOS model should also be checked to ensure they account for the gas infrastructure costs as well.

# Appendix A PSH Benefits to Grid Stability for the Integration of Variable Renewable Energy

Table 9 Primary Benefits of Pumped Storage Hydro Technologies (Source: Koritarov et al. 2014)

| System or Plant Capability | Conventional with FS Synchronous Motor/Generators | AS with DFIM Motor/Generators | Ternary Type with Hydraulic Bypass and FS Synchronous Motor/Generators – Based on Kops II |
|---|---|---|---|
| Energy arbitrage | Yes | Yes | Yes |
| Minimum unit capacity rating (MW) | 25 | 31.5 | 25 |
| Maximum unit capacity rating (MW) | 400 + | 400 + | 400 + |
| **Generation Mode** | | | *Pelton turbines are used at Kops II* |
| Spinning reserve | Yes | Yes | Yes |
| Efficiency | Less than the pumping mode | Changes with speed | Per turbine design |
| Range of operation (% of rated capacity) | 30% to 110% | 20% to 120% | 30% to 110% |
| **Pumping Mode** | | | Francis pump |
| Spinning reserve | No | Yes | Yes |
| Efficiency | Per pump design | Changes with speed | Per pump design |
| Range of operation % | Only pump at full capacity | 75% to 125% | 100% |

Table 10 Secondary Benefits of Pumped Storage Hydro Technologies (Source: Koritarov et al. 2014)

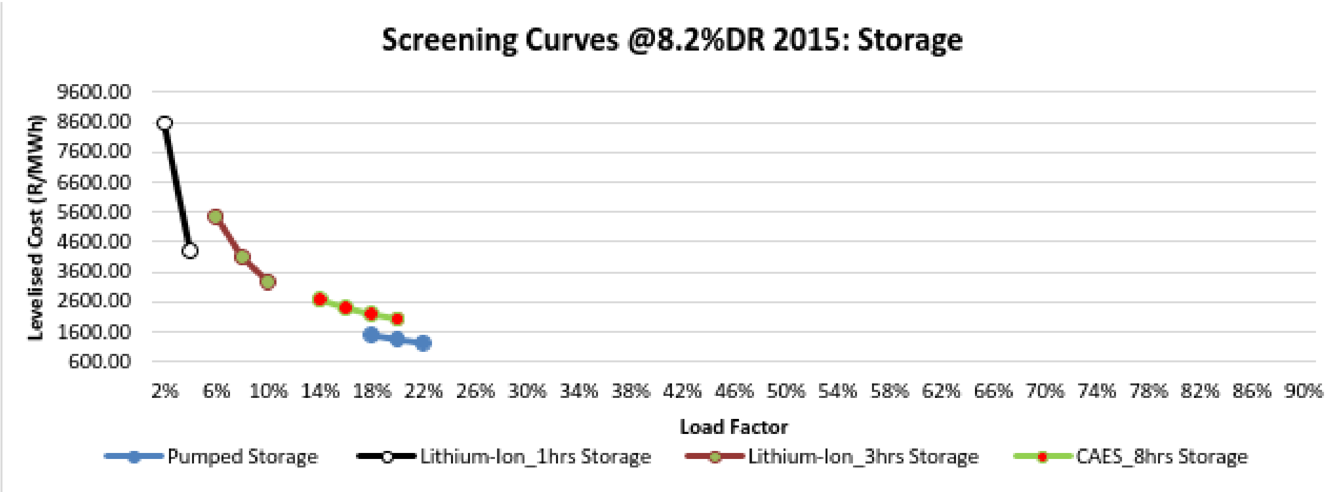
| System or Plant Capability | Conventional with FS Synchronous Motor/Generators | AS with DFIM Motor/Generators | Ternary Type with Hydraulic Bypass and FS Synchronous Motor/Generators – Based on Kops II |
|---|---|---|---|
| Synchronize at less than system frequency? | No | Yes | No |
| Mode change time | Base Case | Faster[a] | Fastest |
| Change direction of rotation for mode change | Yes | Yes | No |
| Hydraulic churning during mode change? | Yes | Yes | No |

Table 10 (Cont.)

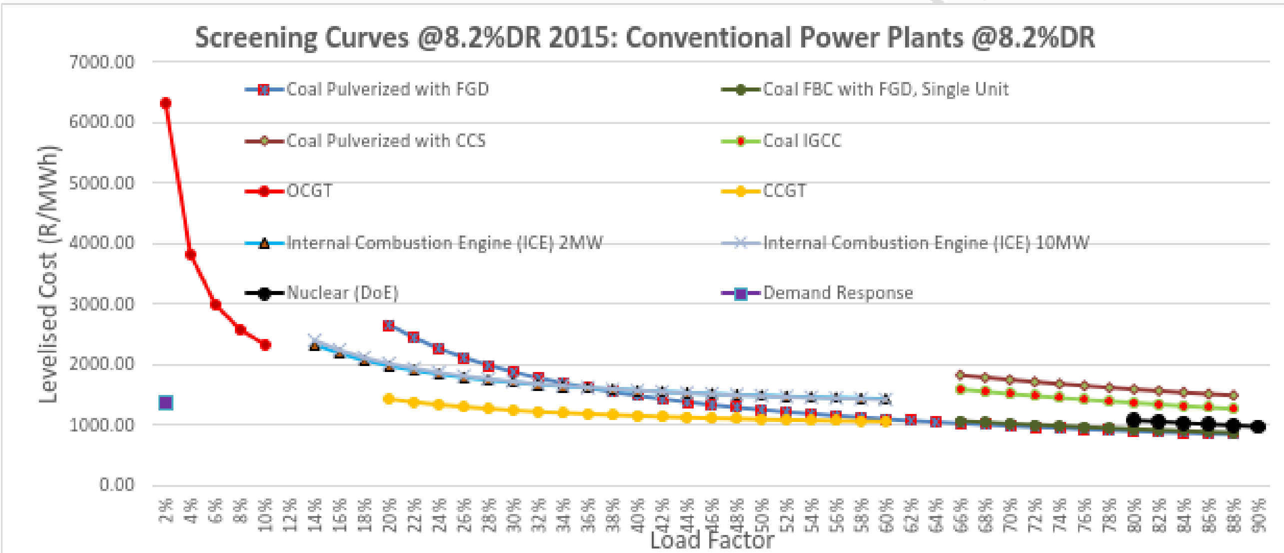
| System or Plant Capability | Conventional with FS Synchronous Motor/Generators | AS with DFIM Motor/Generators | Ternary Type with Hydraulic Bypass and FS Synchronous Motor/Generators – Based on Kops II |
|---|---|---|---|
| **Generation Mode** | | | |
| Regulate frequency | Yes | Yes | Yes |
| Load following | Yes | Yes | Yes |
| Ramp rate | Yes | Yes | Yes |
| Flywheel effect | No | Yes | No |
| Reactive power | Yes | Yes | Yes |
| Generator dropping | Yes | Yes | Yes |
| **Pumping Mode** | | | |
| Shoulder pumping | No | Yes | No |
| Regulate frequency | No | Yes | Yes |
| Load following | No | Yes | Yes |
| Ramp rate | No | Yes – fast | Yes |
| Reactive power | Yes | Yes | Yes |
| Load shedding | Yes, 100% | Yes, partial to 100% | Yes, 100% |
| Flywheel effect | No | Yes | No |
| Hydraulic churning | No | No | Continuous in hydraulic bypass mode |

[a] Note that PSH units with AS capability can provide regulation service in both pumping and generation modes, and therefore, fast mode change capability is not necessary for regulation.

# Appendix B IRP LCOEs PSH, OCGT and Lithium Ion Batteries




[12] Pumped Storage data was submitted by Eskom for the IRP 2010 Update and was adjusted for South African inflation since the bulk of the costs is local.




Source: IRP Analysis

Figure 5: Conventional Power Plants screening curves

# Appendix C Eskom Capacity Expansion Plans

**Table 5: IRP 2019**

| | Coal | Coal (Decommissioning) | Nuclear | Hydro | Storage | PV | Wind | CSP | Gas & Diesel | Other (Distributed Generation, CoGen, Biomass, Landfill) |
|---|---|---|---|---|---|---|---|---|---|---|
| Current Base | 37 149 | | 1 860 | 2 100 | 2 912 | 1 474 | 1 980 | 300 | 3 830 | 499 |
| 2019 | 2 155 | -2373 | | | | | 244 | 300 | | Allocation to the extent of the short term capacity and energy gap. |
| 2020 | 1 433 | -557 | | | | 114 | 300 | | | |
| 2021 | 1 433 | -1403 | | | | 300 | 818 | | | |
| 2022 | 711 | -844 | | | 513 | 400 / 1000 | 1600 | | | |
| 2023 | 750 | -555 | | | | 1000 | 1600 | | | 500 |
| 2024 | | | 1860 | | | | 1600 | | 1000 | 500 |
| 2025 | | | | | | 1000 | 1600 | | | 500 |
| 2026 | | -1219 | | | | | 1600 | | | 500 |
| 2027 | 750 | -847 | | | | | 1 600 | | 2000 | 500 |
| 2028 | | -475 | | | | 1000 | 1 600 | | | 500 |
| 2029 | | -1694 | | | 1575 | 1000 | 1 600 | | | 500 |
| 2030 | | -1050 | | 2 500 | | 1 000 | 1 600 | | | 500 |
| TOTAL INSTALLED CAPACITY by 2030 (MW) | 33364 | | 1860 | 4600 | 5000 | 8288 | 17742 | 600 | 6380 | |
| % Total Installed Capacity (% of MW) | 43 | | 2.36 | 5.84 | 6.35 | 10.52 | 22.53 | 0.76 | 8.1 | |
| % Annual Energy Contribution (% of MWh) | 58.8 | | 4.5 | 8.4 | 1.2* | 6.3 | 17.8 | 0.6 | 1.3 | |

- Installed Capacity
- Committed / Already Contracted Capacity
- Capacity Decommissioned
- New Additional Capacity
- Extension of Koeberg Plant Design Life
- Includes Distributed Generation Capacity for own use

- 2030 Coal Installed Capacity is less capacity decommissioned between years 2020 and 2030
- Koeberg power station rated / installed capacity will revert to 1926 MW (original design capacity) following design life extension work.
- Other / Distributed generation includes all generation facilities in circumstances in which the facility is operated solely to supply electricity to an end-use customer within the same property with the facility
- Short term capacity gap is estimated at 2000 MW

INTEGRATED RESOURCE PLAN 2018

| | Coal | Nuclear | Hydro | Storage (Pumped Storage) | PV | Wind | CSP | Gas / Diesel | Other (CoGen, Biomass, Landfill) | Embedded Generation |
|---|---|---|---|---|---|---|---|---|---|---|
| 2018 | 39 126 | 1 860 | 2 196 | 2 912 | 1 474 | 1 980 | 300 | 3 830 | 499 | Unknown |
| 2019 | 2 155 | | | | | 244 | 300 | | | 200 |
| 2020 | 1 433 | | | | 114 | 300 | | | | 200 |
| 2021 | 1 433 | | | | 300 | 818 | | | | 200 |
| 2022 | 711 | | | | 400 | | | | | 200 |
| 2023 | 500 | | | | | | | | | 200 |
| 2024 | 500 | | | | | | | | | 200 |
| 2025 | | | | | 670 | 200 | | | | 200 |
| 2026 | | | | | 1 000 | 1 500 | | 2 250 | | 200 |
| 2027 | | | | | 1 000 | 1 600 | | 1 200 | | 200 |
| 2028 | | | | | 1 000 | 1 600 | | 1 800 | | 200 |
| 2029 | | | | | 1 000 | 1 600 | | 2 850 | | 200 |
| 2030 | | | 2 500 | | 1 000 | 1 600 | | | | 200 |
| TOTAL INSTALLED | 33 847 | 1 860 | 4 696 | 2 912 | 7 958 | 11 442 | 600 | 11 930 | 499 | 2600 |
| Installed Capacity Mix (%) | 44.6 | 2.5 | 6.2 | 3.8 | 10.5 | 15.1 | 0.9 | 15.7 | 0.7 | |

Installed Capacity
Committed / Already Contracted Capacity
New Additional Capacity (IRP Update)
Embedded Generation Capacity ( Generation for own use allocation)

**Table 7: Proposed Updated Plan for the Period Ending 2030**

| Technology option | 2030 | | 2050 | |
|---|---|---|---|---|
| | IRP 2017 Reference Case Moderate Decline (MW) | IRP 2017 Carbon Budget (MW) | IRP 2017 Reference Case Moderate Decline (MW) | IRP 2017 Carbon Budget (MW) |
| Existing Coal | 31616 | 31616 | 9791 | 9791 |
| New Coal | 0 | 0 | 8250 | 1500 |
| CCGT | 732 | 0 | 12444 | 13176 |
| OCGT | 3855 | 4251 | 12743 | 13535 |
| Gas Engines | 9150 | 9450 | 17550 | 16500 |
| Hydro Imports | 1500 | 1500 | 4000 | 4000 |
| Hydro Domestic | 696 | 696 | 696 | 696 |
| PS (incl Imports) | 2912 | 2912 | 1512 | 1512 |
| Nuclear | 1860 | 1860 | 0 | 5600 |
| PV | 8977 | 9287 | 25000 | 25000 |
| CSP | 600 | 700 | 100 | 0 |
| Wind | 13349 | 13849 | 36000 | 36000 |
| Other | 2284 | 2284 | 1229 | 1729 |
| **TOTAL** | **77631** | **78405** | **129315** | **129138** |
| **Peak demand** | **48030** | **48030** | **60516** | **60516** |

Table 12: IRP update base case results

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Base Case8.2% Dicount rate | | | | | | | | | | |
| | New Build Options | | | | | | | | | | | |
| | PV | Wind | LandfillGas | DR | Nuclear | OCGT | CCGT | Coal PF w FGD | Inga | CO2 Emissions | Peak Demand (MW) | Firm Reserve Margins (%) |
| 2016 | | | | | | | | | | | | |
| 2017 | | | | | | | | | | | | |
| 2018 | | | | | | | | | | | | |
| 2019 | | | | | | | | | | | | |
| 2020 | | | | | | | | | | 253 | 44916 | 24 |
| 2021 | 160 | | | | | | | | | 264 | 46130 | 28 |
| 2022 | 160 | | | | | | | | | 268 | 47336 | 23 |
| 2023 | 370 | 200 | | | | | | | | 272 | 48547 | 20 |
| 2024 | 440 | 500 | | 1000 | | 396 | | | | 279 | 49656 | 18 |
| 2025 | 650 | 1000 | 15 | 1000 | | 2176 | 732 | | | 278 | 51015 | 19 |
| 2026 | 580 | 1000 | 5 | 1000 | | 264 | 1464 | | | 278 | 52307 | 19 |
| 2027 | 580 | 1000 | 230 | 1000 | | 264 | 2196 | | | 276 | 53561 | 19 |
| 2028 | 580 | 1000 | | 500 | | 396 | 1464 | 1500 | | 277 | 54567 | 20 |
| 2029 | 580 | 1100 | | 1000 | | | 1464 | 1500 | | 273 | 56009 | 18 |
| 2030 | 580 | 1200 | | 1000 | | 1716 | | 2250 | 1000 | 274 | 57274 | 20 |
| 2031 | 580 | 1200 | | 1000 | | 1584 | | 750 | | 274 | 58630 | 20 |
| 2032 | 580 | 1000 | | 500 | | | 732 | 1500 | 1000 | 278 | 59878 | 22 |
| 2033 | 580 | 1200 | | | | | 1464 | 750 | 500 | 276 | 61388 | 23 |
| 2034 | 580 | 1600 | | 1000 | | 1452 | | | | 278 | 62799 | 22 |
| 2035 | 580 | 1600 | | 500 | | | 1464 | 1500 | | 278 | 64169 | 23 |
| 2036 | 580 | 1600 | | 1000 | | | | 1500 | | 278 | 65419 | 21 |
| 2037 | 580 | 1400 | | 500 | 1359 | | 732 | 2250 | | 277 | 66993 | 22 |
| 2038 | 580 | 1600 | | | | 1848 | 1464 | 750 | | 273 | 68375 | 22 |
| 2039 | 650 | 1500 | | | 1359 | | 2928 | | | 267 | 69584 | 22 |
| 2040 | 650 | 1600 | | 1000 | | 1056 | 732 | | | 261 | 70777 | 20 |
| 2041 | 650 | 1600 | | 1000 | 4077 | 792 | | 750 | | 236 | 72343 | 21 |
| 2042 | 650 | 1600 | | 500 | | | 2196 | | | 233 | 73800 | 21 |
| 2043 | 650 | 1600 | | 500 | | | | | | 232 | 75245 | 21 |
| 2044 | 650 | 1800 | | 500 | 1359 | | | | | 228 | 76565 | 21 |
| 2045 | 770 | 1600 | | | 2718 | | 2196 | | | 230 | 78263 | 23 |
| 2046 | 790 | 1600 | | 500 | 1359 | 924 | | | | 225 | 79716 | 20 |
| 2047 | 720 | 1800 | | 1000 | 1359 | | 732 | | | 219 | 81177 | 19 |
| 2048 | 720 | 1600 | | 500 | 2718 | 264 | | | | 211 | 82509 | 20 |
| 2049 | 660 | 1500 | | 500 | 1359 | | | | | 206 | 84213 | 20 |
| 2050 | 720 | 1400 | | 500 | 2718 | | | | | 196 | 85804 | 20 |
| Total (MW | 17600 | 37400 | 250 | 500 | 20385 | 13332 | 21960 | 15000 | 2500 | | | |

| | Committed build | | | | | | | | | | | New build options | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RTS Capacity (coal) | Medupi (coal) | Kusile (coal) | Ingula (pumped storage) | DOE OCGT IPP (diesel) | Co-generation, own build | Wind | CSP | Landfill, hydro | Sere (wind) | Decommissioning | Coal (PF, FBC, imports) | Co-generation, own build | Gas CCGT (natural gas) | OCGT (diesel) | Import Hydro | Wind | Solar PV, CSP | Renewables (Wind, Solar CSP, Solar PV, Landfill, Biomass, etc.) | Nuclear Fleet | Total new build | Total system capacity | Peak demand (net sent-out) forecast | Demand Side Management |
| | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW | MW |
| 2010 | 380 | 0 | 0 | 0 | 0 | 260 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 640 | 44535 | 38885 | 252 |
| 2011 | 679 | 0 | 0 | 0 | 0 | 130 | 200 | 0 | 0 | 0 | 0 | 0 | 103 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1112 | 45647 | 39956 | 494 |
| 2012 | 303 | 0 | 0 | 0 | 0 | 0 | 200 | 0 | 100 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 703 | 46350 | 40995 | 809 |
| 2013 | 101 | 722 | 0 | 333 | 1020 | 0 | 300 | 0 | 25 | 0 | 0 | 0 | 124 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2625 | 48975 | 42416 | 1310 |
| 2014 | 0 | 722 | 0 | 999 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 426 | 0 | 0 | 0 | 200 | 0 | 0 | 0 | 2447 | 51422 | 43436 | 1966 |
| 2015 | 0 | 1444 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | -180 | 0 | 600 | 0 | 0 | 0 | 400 | 0 | 0 | 0 | 2364 | 53786 | 44865 | 2594 |
| 2016 | 0 | 722 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -90 | 0 | 0 | 0 | 0 | 0 | 800 | 100 | 0 | 0 | 1532 | 55318 | 45786 | 3007 |
| 2017 | 0 | 722 | 1446 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 800 | 100 | 0 | 0 | 3068 | 58386 | 47870 | 3420 |
| 2018 | 0 | 0 | 723 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 800 | 100 | 0 | 0 | 1623 | 60009 | 49516 | 3420 |
| 2019 | 0 | 0 | 1446 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 474 | 0 | 0 | 800 | 100 | 0 | 0 | 2820 | 62829 | 51233 | 3420 |
| 2020 | 0 | 0 | 723 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 711 | 0 | 360 | 0 | 0 | 800 | 0 | 2594 | 65423 | 52719 | 3420 |
| 2021 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -75 | 0 | 0 | 711 | 0 | 750 | 0 | 0 | 800 | 0 | 2186 | 67609 | 54326 | 3420 |
| 2022 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1870 | 0 | 0 | 0 | 805 | 1110 | 0 | 0 | 800 | 0 | 845 | 68454 | 55734 | 3420 |
| 2023 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -2280 | 0 | 0 | 0 | 805 | 1129 | 0 | 0 | 800 | 1600 | 2054 | 70508 | 57097 | 3420 |
| 2024 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -909 | 0 | 0 | 0 | 575 | 0 | 0 | 0 | 800 | 1600 | 2066 | 72574 | 58340 | 3420 |
| 2025 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1520 | 0 | 0 | 0 | 805 | 0 | 0 | 0 | 1400 | 1600 | 2285 | 74859 | 60150 | 3420 |
| 2026 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 600 | 1600 | 2200 | 77059 | 61770 | 3420 |
| 2027 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 750 | 0 | 0 | 805 | 0 | 0 | 0 | 1200 | 0 | 2755 | 79814 | 63404 | 3420 |
| 2028 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -2850 | 2000 | 0 | 0 | 805 | 0 | 0 | 0 | 0 | 1600 | 1555 | 81369 | 64867 | 3420 |
| 2029 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1128 | 750 | 0 | 0 | 805 | 0 | 0 | 0 | 0 | 1600 | 2027 | 83396 | 66460 | 3420 |
| 2030 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1500 | 0 | 0 | 345 | 0 | 0 | 0 | 0 | 0 | 1845 | 85241 | 67809 | 3420 |
| TOTAL | 1463 | 4332 | 4338 | 1332 | 1020 | 390 | 700 | 200 | 125 | 100 | -10902 | 5000 | 1253 | 1896 | 5750 | 3349 | 3800 | 400 | 7200 | 9600 | 41346 | | | |

**Table 2. Revised Balanced scenario capacity**

| | Total generating capacity in 2030 | | Capacity added (including committed) from 2010 to 2030 | | New (uncommitted) capacity options from 2010 to 2030 | |
|---|---|---|---|---|---|---|
| | MW | % | MW | % | MW | % |
| Coal | 41074 | 48.2 | 16386 | 31.4 | 6253 | 16.3 |
| OCGT | 9170 | 10.8 | 6770 | 13.0 | 5750 | 15.0 |
| CCGT | 1896 | 2.2 | 1896 | 3.6 | 1896 | 5.0 |
| Pumped Storage | 2912 | 3.4 | 1332 | 2.5 | 0 | 0.0 |
| Nuclear | 11400 | 13.4 | 9600 | 18.4 | 9600 | 25.1 |
| Hydro | 5499 | 6.5 | 3399 | 6.5 | 3349 | 8.8 |
| Wind[1] | 11800 | 13.8 | 11800 | 22.6 | 11000 | 28.8 |
| CSP | 600 | 0.7 | 600 | 1.1 | 400 | 1.0 |
| PV | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Other | 890 | 1.0 | 465 | 0.8 | 0 | 0.0 |
| Total | 85241 | | 52248 | | 38248 | |

Notes: (1) Wind includes the "Renewables" bucket identified in the RBS after 2019
(2) Committed generation capacity includes projects approved prior to IRP 2010 (refer to Table 1).

2008 Capacity Expansion Plan

| | | 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).**

# Appendix D PLEXOS Model Technology Cost Inputs for IRP 2011 and IRP 2016

Table 28. Technology costs input (as at 2010, without learning rates)

| | Pulverised Coal with FGD | Fluidised bed with FGD | Nuclear Areva EPR | OCGT | CCGT | Wind | Concentrated PV | PV (crystalline silicon) | Forestry residue biomass | Municipal solid waste biomass | Pumped storage | Integrated Gasification Combined Cycle (IGCC) | CSP, parabolic trough, 9 hrs storage |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capacity, rated net | 6X750 MW | 6X250 MW | 6X1600 MW | 114,7 MW | 711,3 MW | 100X2 MW | 10 MW | 10MW | 25 MW | 25 MW | 4X375 MW | 1288 MW | 125 MW |
| Life of programme | 30 | 30 | 60 | 30 | 30 | 20 | 25 | 25 | 30 | 30 | 50 | 30 | 30 |
| Lead time | 9 | 9 | 16 | 2 | 3 | 3-6 | 2 | 2 | 3,5-4 | 3,5-4 | 8 | 5 | 4 |
| Typical load factor (%) | 85% | 85% | 92% | 10% | 50% | 29% (7,8m/s wind @ 80m) | 26,8% | 19,4% | 85% | 85% | 20% | 85% | 43,7% |
| Variable O&M (R/MWh) | 44,4 | 99,1 | 95,2 | 0 | 0 | 0 | 0 | 0 | 31,1 | 38,2 | 4 | 14,4 | 0 |
| Fixed O&M (R/kW/a) | 455 | 365 | - | 70 | 148 | 266 | 502 | 208 | 972 | 2579 | 123 | 830 | 635 |
| Variable Fuel costs (R/GJ) | 15 | 7,5 | 6,25 | 200 | 80 | - | - | - | 19,5 | 0 | - | 15 | - |
| Fuel Energy Content, HHV, kJ/kg | 19220 | 12500 | 3,900,000,000 | 39,3 MJ/SCM | 39,3 MJ/SCM | - | - | - | 11760 | 11390 | - | 19220 | - |
| Heat Rate, kJ/kWh, avg | 9769 | 10081 | 10760 | 11926 | 7468 | - | - | - | 14185 | 18580 | - | 9758 | - |
| Overnight capital costs (R/kW) | 17785 | 14965 | 26575 | 3955 | 5780 | 14445 | 37225 | 20805 | 33270 | 66900 | 7913 | 24670 | 50910 |
| Phasing in capital spent (% per year) (* indicates commissioning year of 1st unit) | 2%, 6%, 13%, 17%*, 17%, 16%, 15%, 11%, 3% | 2%, 6%, 13%, 17%*, 17%, 16%, 15%, 11%, 3% | 3%, 3%, 7%, 7%, 8%, 8%, 8%, 8%, 8%, 8%, 8%, 8%*, 6%, 6%, 2%, 2% | 90%, 10% | 40%, 50%, 10% | 2,5%, 2,5%, 5%, 15%, 75% | 10%, 90% | 10%, 90% | 10%, 25%, 45%, 20% | 10%, 25%, 45%, 20% | 3%, 16%, 17%, 21%, 20%, 14%, 7%, 2%* | 5%, 18%, 35%, 32%*, 10% | 10%, 25%, 45%, 20% |
| Equivalent Avail | 91,7 | 90,4 | 92-95 | 88,8 | 88,8 | 94-97 | 95 | 95 | 90 | 90 | 94 | 85,7 | 95 |
| Maintenance | 4,8 | 5,7 | N/A | 6,9 | 6,9 | 6 | 5 | 5 | 4 | 4 | 5 | 4,7 | - |
| Unplanned outages | 3,7 | 4,1 | <2% | 4,6 | 4,6 | - | - | - | 6 | 6 | 1 | 10,1 | - |
| Water usage, l/MWh | 229,1 | 33,3 | 6000 (sea) | 19,8 | 12,8 | - | - | - | 210 | 200 | - | 256,8 | 245 |
| Sorbent usage, kg/MWh | 15,2 | 28,4 | - | - | - | - | - | - | - | - | - | - | - |
| $CO_2$ emissions (kg/MWh) | 936,2 | 976,9 | - | 622 | 376 | - | - | - | 1287 | 1607 | - | 857,1 | - |
| SOx emissions (kg/MWh) | 0,45 | 0,19 | - | 0 | 0 | - | - | - | 0,78 | 0,56 | - | 0,21 | - |
| NOx emissions (kg/MWh) | 2,30 | 0,20 | - | 0,28 | 0,29 | - | - | - | 0,61 | 0,80 | - | 0,01 | - |
| Hg (kg/MWh) | 1,27E-06 | 0 | - | 0 | 0 | - | - | - | - | - | - | - | - |
| Particulates (kg/MWh) | 0,13 | 0,09 | - | 0 | 0 | - | - | - | 0,16 | 0,28 | - | - | - |
| Fly ash (kg/MWh) | 168,5 | 35,1 | - | - | - | - | - | - | 24,2 | 1226 | - | 9,7 | - |
| Bottom ash (kg/MWh) | 3,32 | 140,53 | - | - | - | - | - | - | 6,1 | 3000 | - | 79,8 | - |
| Expected COD of 1st unit | 2018 | 2016 | 2022 | 2013 | 2016 | 2013 | 2018 | 2012 | 2014 | 2014 | 2018 | 2018 | 2018 |
| Annual build limits | - | - | 1 unit every 18 months | - | 2500 MW after 2017 | 1600 MW | 100 MW | 1000MW | | | | | 500 MW |

| | Coal Pulverized with FGD | Coal FBC with FGD, Single Unit | Coal Pulverized with CCS | Coal IGCC | Nuclear (DoE) | OCGT | CCGT | Internal Combustion Engine (ICE) 2MW | Internal Combustion Engine (ICE) 10MW |
|---|---|---|---|---|---|---|---|---|---|
| Rated Capacity, MW Net | 4500 | 250 | 4500 | 644 | 1400 | 132 | 732 | 1.90 | 9.40 |
| Total Overnight Cost, ZAR/kW (Jan 2015 Rands) | 32420.0 | 39133.0 | 62712.0 | 50327.0 | 55260 | 7472.0 | 8205.0 | 11657.0 | 12494.0 |
| Lead-times and Project Schedule, years | 9.0 | 4.0 | 9.0 | 4.0 | 8 | 2.0 | 3.0 | 1.0 | 1.0 |
| Phasing in capital spent (% per year) (* indicates commissioning year of 1st unit) | 2%, 6%, 13%, 17%*, 17%, 16%, 15%, 11%, 3% | 10%, 25%, 45%, 20% | 2%, 6%, 13%, 17%*, 17%, 16%, 15%, 11%, 3% | 10%, 25%, 45%, 20% | 5%,5%,15%, 15%, 20%, 20%, 10%, 10% | 90%, 10% | 40%, 50%, 10% | 100.00% | 100.00% |
| Fuel Energy Content, HHV, kJ/kg | 17850.0 | 17850.0 | 17850.0 | 17850.0 | 1299000000 | 39.3 | 39.3 | 39.3 | 39.3 |
| Fuel Cost (R/GJ) | 25.0 | 12.5 | 25.0 | 25.0 | 7.35 | 115.5 | 115.5 | 115.5 | 115.5 |
| Heat Rate (kJ/kWh) | 9812.0 | 10788.0 | 14106.0 | 9758.0 | 10657 | 11519.0 | 7395.0 | 9477.0 | 8780.0 |
| Fixed O&M Cost (R/KW/Year) | 845.0 | 568.0 | 1441.0 | 1301.0 | 885 | 147.0 | 151.0 | 386.0 | 434.0 |
| Variable O&M Cost (R/MWh) | 73.1 | 158.2 | 134.9 | 69.0 | 34 | 2.2 | 20.0 | 64.0 | 100.1 |
| Equivalent Availability (%) | 91.5 | 91.5 | 91.5 | 85.2 | 92 | 88.5 | 88.5 | 88.5 | 88.8 |
| Planned Outage Rate (%) | 4.8 | 4.8 | 4.8 | 4.7 | 3 | 6.9 | 6.9 | 6.9 | 6.9 |
| Unplanned Outage Rate (%) | 3.7 | 3.7 | 3.7 | 10.1 | 6 | 4.6 | 4.6 | 4.6 | 4.6 |
| Typical Load Factor (%) | 85.0 | 85.0 | 85.0 | 85.0 | 90 | 8.0 | 48.0 | 48.0 | 50.0 |
| Economic Life | 30.0 | 30.0 | 30.0 | 30.0 | 60 | 30.0 | 30.0 | 30.0 | 30.0 |
| Water Usage (l/MWh) | 231.0 | 33.3 | 320.0 | 256.7 | 0 | 0.0 | 19.8 | 0.0 | 0.0 |
| Sorbent Usage (kg/MWh) | 15.8 | 41.0 | 22.8 | 0.0 | 0 | 0.0 | 0.0 | 0.0 | 0.0 |
| $CO_2$ Emissions (kg/MWh) | 947.3 | 1003.0 | 136.2 | 930.0 | 0 | 574.0 | 367.0 | 491.0 | 455.0 |
| SOx Emissions (kg/MWh) | 0.5 | 0.5 | 0.7 | 0.2 | 0 | 0.0 | 0.0 | 0.0 | 0.0 |
| NOx Emissions (kg/MWh) | 1.9 | 0.3 | 0.4 | 0.2 | 0 | 0.3 | 0.2 | 1.3 | 0.1 |
| Hg (kg/MWh) | 0.1 | 0.0 | 0.0 | 0.0 | 0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Particulates (kg/MWh) | 0.1 | 0.1 | 0.2 | 0.4 | 0 | 0.1 | 0.0 | 0.0 | 0.0 |

| | [12]Pumped Storage | Lithium-Ion_1hrs Storage | Lithium-Ion_3hrs Storage | CAES_8hrs Storage |
|---|---|---|---|---|
| Rated Capacity, MW Net | 333 | 3 | 3 | 180 |
| Total Overnight Cost, ZAR/kW (Jan 2015 Rands) | 20410.0 | 9042.0 | 22216.0 | 22390.0 |
| Lead-times and Project Schedule, years | 8.0 | 1.0 | 1.0 | 4.0 |
| Phasing in capital spent (% per year) (* indicates commissioning year of 1st unit) | 1%, 2%, 9%, 16%, 22%, 24%, 20%, 5% | 100% | 100% | 25%, 25%, 25%, 25%, |
| Fuel Energy Content, HHV, kJ/kg | N/A | N/A | N/A | 39.3 |
| Fuel Cost (R/GJ) | 0.0 | 0.0 | 0.0 | 51.8 |
| Fixed O&M Cost (R/KW/Year) | 184.0 | 565.0 | 565.0 | 194.0 |
| Variable O&M Cost (R/MWh) | 0.0 | 2.9 | 2.9 | 2.2 |
| Cycles/Year | No Limit | 300.0 | 300.0 | No Limit |
| Minimum Load | 0.0 | 0.0 | 0.0 | 0.0 |
| Round Trip AC/AC Efficiency/Pump Efficiency, % | 78% | 89% | 89% | 81% |
| Equivalent Availability (%) | 94.7 | 94.1 | 94.1 | 97.2 |
| Planned Outage Rate (%) | 3.0 | 1.9 | 1.9 | 2.3 |
| Unplanned Outage Rate (%) | 2.4 | 4.0 | 4.0 | 0.5 |
| Typical Load Factor (%) | 33.0 | N/A | N/A | 22.0 |
| Min Load Factor (%) | 0.18 | 0.1 | 0.1 | 0.14 |
| Max Load Factor (%) | 0.26 | 0.3 | 0.3 | 0.20 |
| Economic Life | 50.0 | 20.0 | 20.0 | 40.0 |
| $CO_2$ Emissions (kg/MWh) | 0.0 | 0.0 | 0.0 | 574.0 |
| NOx Emissions (kg/MWh) | 0.0 | 0.0 | 0.0 | 0.3 |
| Particulates (kg/MWh) | 0.0 | 0.0 | 0.0 | 0.1 |

# Appendix E Temoa Dat File

There are several open source software elements required to run Temoa. The easiest way to install these elements is to create a conda environment in which to run the model. Creating a customized environment ensures that the latest version of Temoa is compatible with the required software elements. Conda was installed via miniconda3 then environment.yml file from our Github repo was downloaded. Once the directory is open in the command prompt

$ cd temoa 2

Execute the following from the command line:

$ conda env create

Then activate the environment as follows:

$ conda activate temoa-py3

This new conda environment contains several elements, including Python 3 and a compatible version of Pyomo with Windows and a free solver GLPK can be downloaded to run the program.

Input datasets in Temoa can be constructed either as text files or relational databases. Input text files are referred to as 'DAT' files and follow a specific format. Dat file or sqlite file (http://sqliteonline.com ) can be used to run in Temoa.( http://model.temoacloud.com/modelrun). Dat file was chosen as the coding inputs is simplified and the program was chosen to run on python miniconda3 ( details on how to run the program using python is found here https://temoacloud.com/temoaproject/Documentation.html ).

Once the environment was functioning in python and the Temoa source code was obtained the following three codes of line would run the program:

- \Miniconda3>conda activate temoa-py3
- cd temoa 2
- python temoa_model/ data_files/utopia-15.dat

Below is an example code used for the PSH set at $956/kW, 50 year lifetime and capacity factor of 23% with an efficiency of 72%.

```
data ;

set time_exist :=
2000
2010
2020
;

set time_future :=
2030
2040
2050
2060
;

set time_season :=
inter
summer
winter
;

set time_of_day :=
day
night
;

set tech_resource :=
IMPDSL1
IMPGSL1
IMPHCO1
IMPOIL1
IMPURN1
IMPFEQ
IMPHYD
```

```
;

set tech_production :=
E01
E21
E31
E51
E70
RHE
RHO
RL1
SRE
TXD
TXE
TXG
;

set tech_baseload :=
E01
E21
E31
;

set tech_storage :=
E51
;

set commodity_physical :=
ethos
DSL
ELC
FEQ
GSL
HCO
```

```
HYD
OIL
URN
;

set commodity_emissions :=
co2
nox
;

set commodity_demand :=
RH
RL
TX
;

param SegFrac :=
   inter        day      0.1667
   inter        night     0.0833
   summer       day      0.1667
   summer       night     0.0833
   winter       day      0.3333
   winter       night     0.1667
;

param DemandSpecificDistribution :=
   inter        day        RH      0.12
   inter        night       RH      0.06
   winter       day        RH      0.5467
   winter       night       RH      0.2733
   inter        day        RL      0.15
   inter        night       RL      0.05
   summer       day        RL      0.15
   summer       night       RL      0.05
```

```
    winter          day           RL        0.5
    winter          night          RL        0.1
;

param CapacityToActivity :=
    E01        31.54
    E21        31.54
    E31        31.54
    E51        31.54
    E70        31.54
    RHE         1.0
    RHO         1.0
    RL1        1.0
    SRE         1.0
    TXD        1.0
    TXE        1.0
    TXG         1.0
;

param GlobalDiscountRate :=
0.08
;

param EmissionActivity :=
    co2          ethos          IMPDSL1       2030       DSL       0.075
    co2          ethos          IMPGSL1       2030       GSL       0.075
    co2          ethos          IMPHCO1       2030       HCO       0.089
    co2          ethos          IMPOIL1       2030       OIL       0.075
    nox          DSL          TXD        2010        TX        1.0
    nox          DSL          TXD        2020        TX        1.0
    nox          DSL          TXD        2030        TX        1.0
    nox          DSL          TXD        2040        TX        1.0
    nox          DSL          TXD        2050        TX        1.0
    nox          GSL          TXG        2010        TX        1.0
```

```
    nox     GSL     TXG     2020    TX      1.0
    nox     GSL     TXG     2030    TX      1.0
    nox     GSL     TXG     2040    TX      1.0
    nox     GSL     TXG     2050    TX      1.0
;

param Demand :=
2030    RH      25.2
2040    RH      37.8
2050    RH      56.7
2030    RL      1000
2040    RL      1200
2050    RL      1300
2030    TX      5.2
2040    TX      7.8
2050    TX      11.69
;

param TechOutputSplit :=
2030    SRE     DSL     0.7
2040    SRE     DSL     0.7
2050    SRE     DSL     0.7
2030    SRE     GSL     0.3
2040    SRE     GSL     0.3
2050    SRE     GSL     0.3
;

param MinCapacity :=
2030    E31     25.0
2040    E31     69.0
2050    E31     94.0
2030    SRE     0.1
2030    E01     34.0
2030    E51     3.0
```

```
2030        E21        6.5
;

param MaxCapacity :=
2030        E31        26.0
2040        E31        70.0
2050        E31        95.0
2030        RHE         0.0
2030        TXD        0.6
2040        TXD         1.76
2050        TXD        4.76
2040        E01        35.0
2030        E51        12
2040        E51        24.0
2050        E51        38.0
2030        E21        6.6
;

param LifetimeTech :=
   E01        40.0
   E21        40.0
   E31        100.0
   E51        50.0
   E70        40.0
   RHE         30.0
   RHO         30.0
   RL1        10.0
   SRE         50.0
   TXD        15.0
   TXE        15.0
   TXG        15.0
   IMPDSL1        1000.0
   IMPGSL1        1000.0
   IMPHCO1        1000.0
```

```
    IMPOIL1        1000.0
    IMPURN1        1000.0
    IMPHYD         1000.0
    IMPFEQ         1000.0
;

param LifetimeProcess :=
    RL1        2020     20.0
    TXD        2010     30.0
    TXD        2020     30.0
    TXG        2010     30.0
    TXG        2020     30.0
;

param LifetimeLoanTech :=
    E01        40.0
    E21        40.0
    E31        100.0
    E51        50.0
    E70        40.0
    RHE        30.0
    RHO        30.0
    RL1        10.0
    SRE        50.0
    TXD        15.0
    TXE        15.0
    TXG        15.0
;

param CapacityFactorTech :=
    inter          day          E01        0.82
    inter          night        E01        0.82
    winter         day          E01        0.82
    winter         night        E01        0.82
```

```
   summer        day        E01      0.82
   summer        night        E01      0.82
   inter      day        E21      0.9
   inter      night        E21      0.9
   winter        day        E21      0.9
   winter        night        E21      0.9
   summer        day        E21      0.9
   summer        night        E21      0.9
   inter      day        E31      0.3
   inter      night        E31      0.3
   winter        day        E31      0.3
   winter        night        E31      0.3
   summer        day        E31      0.3
   summer        night        E31      0.3
   inter      day        E51      0.23
   inter      night        E51      0.23
   winter        day        E51      0.23
   winter        night        E51      0.23
   summer        day        E51      0.23
   summer        night        E51      0.23
   inter      day        E70      0.8
   inter      night        E70      0.8
   winter        day        E70      0.8
   winter        night        E70      0.8
   summer        day        E70      0.8
   summer        night        E70      0.8
;

param CapacityFactorProcess :=
   inter      day        E31      2040    0.2753
   inter      night        E31      2040    0.2753
   winter        day        E31      2040    0.2753
   winter        night        E31      2040    0.2753
   summer        day        E31      2040    0.2753
```

| | | | | |
|---|---|---|---|---|
| summer | night | E31 | 2040 | 0.2753 |
| inter | day | E31 | 2050 | 0.2756 |
| inter | night | E31 | 2050 | 0.2756 |
| winter | day | E31 | 2050 | 0.2756 |
| winter | night | E31 | 2050 | 0.2756 |
| summer | day | E31 | 2050 | 0.2756 |
| summer | night | E31 | 2050 | 0.2756 |

;

param Efficiency :=

| | | | | |
|---|---|---|---|---|
| ethos | IMPDSL1 | 2030 | DSL | 1.0 |
| ethos | IMPGSL1 | 2030 | GSL | 1.0 |
| ethos | IMPHCO1 | 2030 | HCO | 1.0 |
| ethos | IMPOIL1 | 2030 | OIL | 1.0 |
| ethos | IMPURN1 | 2030 | URN | 1.0 |
| ethos | IMPFEQ | 2030 | FEQ | 1.0 |
| ethos | IMPHYD | 2030 | HYD | 1.0 |
| HCO | E01 | 2000 | ELC | 0.32 |
| HCO | E01 | 2010 | ELC | 0.32 |
| HCO | E01 | 2020 | ELC | 0.32 |
| HCO | E01 | 2030 | ELC | 0.32 |
| HCO | E01 | 2040 | ELC | 0.32 |
| HCO | E01 | 2050 | ELC | 0.32 |
| FEQ | E21 | 2030 | ELC | 0.32 |
| FEQ | E21 | 2040 | ELC | 0.32 |
| FEQ | E21 | 2050 | ELC | 0.32 |
| URN | E21 | 2030 | ELC | 0.4 |
| URN | E21 | 2040 | ELC | 0.4 |
| URN | E21 | 2050 | ELC | 0.4 |
| HYD | E31 | 2020 | ELC | 0.32 |
| HYD | E31 | 2030 | ELC | 0.32 |
| HYD | E31 | 2040 | ELC | 0.32 |
| HYD | E31 | 2050 | ELC | 0.32 |
| DSL | E70 | 2000 | ELC | 0.294 |

| | | | | |
|---|---|---|---|---|
| DSL | E70 | 2010 | ELC | 0.294 |
| DSL | E70 | 2020 | ELC | 0.294 |
| DSL | E70 | 2030 | ELC | 0.294 |
| DSL | E70 | 2040 | ELC | 0.294 |
| DSL | E70 | 2050 | ELC | 0.294 |
| ELC | E51 | 2020 | ELC | 0.72 |
| ELC | E51 | 2030 | ELC | 0.72 |
| ELC | E51 | 2040 | ELC | 0.72 |
| ELC | E51 | 2050 | ELC | 0.72 |
| ELC | RHE | 2030 | RH | 1.0 |
| ELC | RHE | 2040 | RH | 1.0 |
| ELC | RHE | 2050 | RH | 1.0 |
| DSL | RHO | 2010 | RH | 0.7 |
| DSL | RHO | 2020 | RH | 0.7 |
| DSL | RHO | 2030 | RH | 0.7 |
| DSL | RHO | 2040 | RH | 0.7 |
| DSL | RHO | 2050 | RH | 0.7 |
| ELC | RL1 | 2020 | RL | 1.0 |
| ELC | RL1 | 2030 | RL | 1.0 |
| ELC | RL1 | 2040 | RL | 1.0 |
| ELC | RL1 | 2050 | RL | 1.0 |
| OIL | SRE | 2030 | DSL | 1.0 |
| OIL | SRE | 2040 | DSL | 1.0 |
| OIL | SRE | 2050 | DSL | 1.0 |
| OIL | SRE | 2030 | GSL | 1.0 |
| OIL | SRE | 2040 | GSL | 1.0 |
| OIL | SRE | 2050 | GSL | 1.0 |
| DSL | TXD | 2010 | TX | 0.231 |
| DSL | TXD | 2020 | TX | 0.231 |
| DSL | TXD | 2030 | TX | 0.231 |
| DSL | TXD | 2040 | TX | 0.231 |
| DSL | TXD | 2050 | TX | 0.231 |
| ELC | TXE | 2030 | TX | 0.827 |
| ELC | TXE | 2040 | TX | 0.827 |

```
    ELC         TXE       2050       TX        0.827
    GSL         TXG       2010       TX        0.231
    GSL         TXG       2020       TX        0.231
    GSL         TXG       2030       TX        0.231
    GSL         TXG       2040       TX        0.231
    GSL         TXG       2050       TX        0.231
;

param ExistingCapacity :=
    E01        2020     37
    E01        2010     35
    E31        2020     3
    E51        2020     3
    E70        2000     0
    E70        2010     3
    E70        2020     3
    RHO        2010     2.5
    RHO        2020     2.5
    RL1        2020     5.6
    TXD        2010     0.4
    TXD        2020     0.2
    TXG        2010     3.1
    TXG        2020     1.5
;

param CostInvest :=
    E01        2030     2000.0
    E01        2040     2000.0
    E01        2050     2000.0
    E21        2030     5000.0
    E21        2040     5000.0
    E21        2050     5000.0
    E31        2030     1200.0
    E31        2040     1200.0
```

```
    E31     2050    1200.0
    E51     2030    956.0
    E51     2040    956.0
    E51     2050    956.0
    E70     2030    660.0
    E70     2040    660.0
    E70     2050    660.0
    RHE     2030    90.0
    RHE     2040    90.0
    RHE     2050    90.0
    RHO     2030    100.0
    RHO     2040    100.0
    RHO     2050    100.0
    SRE     2030    100.0
    SRE     2040    100.0
    SRE     2050    100.0
    TXD     2030    1044.0
    TXD     2040    1044.0
    TXD     2050    1044.0
    TXE     2030    2000.0
    TXE     2040    1750.0
    TXE     2050    1500.0
    TXG     2030    1044.0
    TXG     2040    1044.0
    TXG     2050    1044.0
;

param CostFixed :=
2030    E01    2010    40.0
2030    E01    2020    40.0
2030    E01    2030    40.0
2040    E01    2010    70.0
2040    E01    2020    70.0
2040    E01    2030    70.0
```

| | | | |
|---|---|---|---|
| 2040 | E01 | 2040 | 70.0 |
| 2050 | E01 | 2020 | 100.0 |
| 2050 | E01 | 2030 | 100.0 |
| 2050 | E01 | 2040 | 100.0 |
| 2050 | E01 | 2050 | 100.0 |
| 2030 | E21 | 2030 | 500.0 |
| 2040 | E21 | 2030 | 500.0 |
| 2050 | E21 | 2030 | 500.0 |
| 2040 | E21 | 2040 | 500.0 |
| 2050 | E21 | 2040 | 500.0 |
| 2050 | E21 | 2050 | 500.0 |
| 2030 | E31 | 2020 | 75.0 |
| 2030 | E31 | 2030 | 75.0 |
| 2040 | E31 | 2020 | 75.0 |
| 2040 | E31 | 2030 | 75.0 |
| 2040 | E31 | 2040 | 75.0 |
| 2050 | E31 | 2020 | 75.0 |
| 2050 | E31 | 2030 | 75.0 |
| 2050 | E31 | 2040 | 75.0 |
| 2050 | E31 | 2050 | 75.0 |
| 2030 | E51 | 2020 | 30.0 |
| 2030 | E51 | 2030 | 30.0 |
| 2040 | E51 | 2020 | 30.0 |
| 2040 | E51 | 2030 | 30.0 |
| 2040 | E51 | 2040 | 30.0 |
| 2050 | E51 | 2020 | 30.0 |
| 2050 | E51 | 2030 | 30.0 |
| 2050 | E51 | 2040 | 30.0 |
| 2050 | E51 | 2050 | 30.0 |
| 2030 | E70 | 2000 | 30.0 |
| 2030 | E70 | 2010 | 30.0 |
| 2030 | E70 | 2020 | 30.0 |
| 2030 | E70 | 2030 | 30.0 |
| 2040 | E70 | 2010 | 30.0 |

| | | | |
|---|---|---|---|
| 2040 | E70 | 2020 | 30.0 |
| 2040 | E70 | 2030 | 30.0 |
| 2040 | E70 | 2040 | 30.0 |
| 2050 | E70 | 2020 | 30.0 |
| 2050 | E70 | 2030 | 30.0 |
| 2050 | E70 | 2040 | 30.0 |
| 2050 | E70 | 2050 | 30.0 |
| 2030 | RHO | 2010 | 1.0 |
| 2030 | RHO | 2020 | 1.0 |
| 2030 | RHO | 2030 | 1.0 |
| 2040 | RHO | 2020 | 1.0 |
| 2040 | RHO | 2030 | 1.0 |
| 2040 | RHO | 2040 | 1.0 |
| 2050 | RHO | 2030 | 1.0 |
| 2050 | RHO | 2040 | 1.0 |
| 2050 | RHO | 2050 | 1.0 |
| 2030 | RL1 | 2020 | 9.46 |
| 2030 | RL1 | 2030 | 9.46 |
| 2040 | RL1 | 2040 | 9.46 |
| 2050 | RL1 | 2050 | 9.46 |
| 2030 | TXD | 2010 | 52.0 |
| 2030 | TXD | 2020 | 52.0 |
| 2030 | TXD | 2030 | 52.0 |
| 2040 | TXD | 2020 | 52.0 |
| 2040 | TXD | 2030 | 52.0 |
| 2040 | TXD | 2040 | 52.0 |
| 2050 | TXD | 2040 | 52.0 |
| 2050 | TXD | 2050 | 52.0 |
| 2030 | TXE | 2030 | 100.0 |
| 2040 | TXE | 2030 | 90.0 |
| 2040 | TXE | 2040 | 90.0 |
| 2050 | TXE | 2040 | 80.0 |
| 2050 | TXE | 2050 | 80.0 |
| 2030 | TXG | 2010 | 48.0 |

```
2030    TXG     2020    48.0
2030    TXG     2030    48.0
2040    TXG     2020    48.0
2040    TXG     2030    48.0
2040    TXG     2040    48.0
2050    TXG     2040    48.0
2050    TXG     2050    48.0
;

param CostVariable :=
2030    IMPDSL1     2030    4.5
2040    IMPDSL1     2030    4.5
2050    IMPDSL1     2030    4.5
2030    IMPGSL1     2030    15.0
2040    IMPGSL1     2030    15.0
2050    IMPGSL1     2030    15.0
2030    IMPHCO1     2030    2.0
2040    IMPHCO1     2030    2.0
2050    IMPHCO1     2030    2.0
2030    IMPOIL1     2030    8.0
2040    IMPOIL1     2030    8.0
2050    IMPOIL1     2030    8.0
2030    IMPURN1     2030    2.0
2040    IMPURN1     2030    2.0
2050    IMPURN1     2030    2.0
2030    E01     2010    0.3
2030    E01     2020    0.3
2030    E01     2030    0.3
2040    E01     2010    0.3
2040    E01     2020    0.3
2040    E01     2030    0.3
2040    E01     2040    0.3
2050    E01     2020    0.3
2050    E01     2030    0.3
```

| | | | |
|---|---|---|---|
| 2050 | E01 | 2040 | 0.3 |
| 2050 | E01 | 2050 | 0.3 |
| 2030 | E21 | 2030 | 1.5 |
| 2040 | E21 | 2030 | 1.5 |
| 2050 | E21 | 2030 | 1.5 |
| 2040 | E21 | 2040 | 1.5 |
| 2050 | E21 | 2040 | 1.5 |
| 2050 | E21 | 2050 | 1.5 |
| 2030 | E70 | 2000 | 0.4 |
| 2030 | E70 | 2010 | 0.4 |
| 2030 | E70 | 2020 | 0.4 |
| 2030 | E70 | 2030 | 0.4 |
| 2040 | E70 | 2010 | 0.4 |
| 2040 | E70 | 2020 | 0.4 |
| 2040 | E70 | 2030 | 0.4 |
| 2040 | E70 | 2040 | 0.4 |
| 2050 | E70 | 2020 | 0.4 |
| 2050 | E70 | 2030 | 0.4 |
| 2050 | E70 | 2040 | 0.4 |
| 2050 | E70 | 2050 | 0.4 |
| 2030 | SRE | 2030 | 10.0 |
| 2040 | SRE | 2030 | 10.0 |
| 2040 | SRE | 2040 | 10.0 |
| 2050 | SRE | 2030 | 10.0 |
| 2050 | SRE | 2040 | 10.0 |
| 2050 | SRE | 2050 | 10.0 |

;

# Appendix F Temoa Results

Temoa Results shown in python for the two scenarios:

First scenario $2100/kW PSH

Non-zero variable values:

117.72911673378935 Costs[V_DiscountedFixedCostsByProcess,E01,2010]

171.20478930858923 Costs[V_DiscountedFixedCostsByProcess,E01,2020]

32920.2352013373 Costs[V_DiscountedFixedCostsByProcess,E01,2030]

52458.4891292377 Costs[V_DiscountedFixedCostsByProcess,E21,2030]

121.0580518367024 Costs[V_DiscountedFixedCostsByProcess,E31,2020]

30143.4549073389 Costs[V_DiscountedFixedCostsByProcess,E31,2030]

26509.731278523657 Costs[V_DiscountedFixedCostsByProcess,E31,2040]

5729.536347299987 Costs[V_DiscountedFixedCostsByProcess,E31,2050]

242.1161036734048 Costs[V_DiscountedFixedCostsByProcess,E51,2020]

2663.277140407453 Costs[V_DiscountedFixedCostsByProcess,E51,2030]

1209.9003035395615 Costs[V_DiscountedFixedCostsByProcess,E51,2040]

63.195654756448846 Costs[V_DiscountedFixedCostsByProcess,E51,2050]

12.161732513466088 Costs[V_DiscountedFixedCostsByProcess,E70,2000]

19.62798128950049 Costs[V_DiscountedFixedCostsByProcess,E70,2010]

96.8464414693619 Costs[V_DiscountedFixedCostsByProcess,E70,2020]

11633.887810771603 Costs[V_DiscountedFixedCostsByProcess,E70,2030]

20.26955418911015 Costs[V_DiscountedFixedCostsByProcess,RHO,2010]

32.71330214916748 Costs[V_DiscountedFixedCostsByProcess,RHO,2020]

586.480315023538 Costs[V_DiscountedFixedCostsByProcess,RHO,2030]

429.5199610889197 Costs[V_DiscountedFixedCostsByProcess,RL1,2020]

114631.97576587298
Costs[V_DiscountedFixedCostsByProcess,RL1,2030]
84765.33263880639 Costs[V_DiscountedFixedCostsByProcess,RL1,2040]
56375.10791006719 Costs[V_DiscountedFixedCostsByProcess,RL1,2050]
168.64269085339643
Costs[V_DiscountedFixedCostsByProcess,TXD,2010]
136.08733694053672
Costs[V_DiscountedFixedCostsByProcess,TXD,2020]
542.7593280291827
Costs[V_DiscountedFixedCostsByProcess,TXD,2040]
632.4185826331761
Costs[V_DiscountedFixedCostsByProcess,TXD,2050]
1206.443865335836
Costs[V_DiscountedFixedCostsByProcess,TXG,2010]
942.1431018960235
Costs[V_DiscountedFixedCostsByProcess,TXG,2020]
1458.0635202677452
Costs[V_DiscountedFixedCostsByProcess,TXG,2040]
683.5107680874992
Costs[V_DiscountedFixedCostsByProcess,TXG,2050]
63307.23148099307 Costs[V_DiscountedInvestmentByProcess,E01,2030]
30571.842840004087
Costs[V_DiscountedInvestmentByProcess,E21,2030]
24299.549607816585
Costs[V_DiscountedInvestmentByProcess,E31,2030]
21370.295219063897
Costs[V_DiscountedInvestmentByProcess,E31,2040]
4618.752333764758 Costs[V_DiscountedInvestmentByProcess,E31,2050]
10211.993921171535
Costs[V_DiscountedInvestmentByProcess,E51,2030]
4639.207222376917 Costs[V_DiscountedInvestmentByProcess,E51,2040]
242.3156165109346 Costs[V_DiscountedInvestmentByProcess,E51,2050]
14916.03495412178 Costs[V_DiscountedInvestmentByProcess,E70,2030]

1089.5990112753789
Costs[V_DiscountedInvestmentByProcess,RHE,2040]
599.3427284395342
Costs[V_DiscountedInvestmentByProcess,RHE,2050]
3815.1386138613825
Costs[V_DiscountedInvestmentByProcess,RHO,2030]
8.841553178503494 Costs[V_DiscountedInvestmentByProcess,SRE,2030]
1049.835865308953 Costs[V_DiscountedInvestmentByProcess,TXD,2040]
1223.259879009328 Costs[V_DiscountedInvestmentByProcess,TXD,2050]
3055.2915567324662
Costs[V_DiscountedInvestmentByProcess,TXG,2040]
1432.2590543174547
Costs[V_DiscountedInvestmentByProcess,TXG,2050]
16.077601042401067
Costs[V_DiscountedVariableCostsByProcess,E01,2010]
18.152146979402367
Costs[V_DiscountedVariableCostsByProcess,E01,2020]
1432.7371744463333
Costs[V_DiscountedVariableCostsByProcess,E01,2030]
4315.377539207538
Costs[V_DiscountedVariableCostsByProcess,E21,2030]
1.3637073257613264
Costs[V_DiscountedVariableCostsByProcess,E70,2000]
2.20090532699683
Costs[V_DiscountedVariableCostsByProcess,E70,2010]
10.859489103172555
Costs[V_DiscountedVariableCostsByProcess,E70,2020]
1321.1435971766532
Costs[V_DiscountedVariableCostsByProcess,E70,2030]
54160.885354412785
Costs[V_DiscountedVariableCostsByProcess,IMPDSL1,2030]
5749.11955318714
Costs[V_DiscountedVariableCostsByProcess,IMPGSL1,2030]

30561.81088475281
Costs[V_DiscountedVariableCostsByProcess,IMPHCO1,2030]
192.5 Costs[V_UndiscountedFixedCostsByProcess,E01,2010]
367.5 Costs[V_UndiscountedFixedCostsByProcess,E01,2020]
70665.0 Costs[V_UndiscountedFixedCostsByProcess,E01,2030]
97500.0 Costs[V_UndiscountedFixedCostsByProcess,E21,2030]
225.0 Costs[V_UndiscountedFixedCostsByProcess,E31,2020]
56025.0 Costs[V_UndiscountedFixedCostsByProcess,E31,2030]
66000.0 Costs[V_UndiscountedFixedCostsByProcess,E31,2040]
18750.0 Costs[V_UndiscountedFixedCostsByProcess,E31,2050]
450.0 Costs[V_UndiscountedFixedCostsByProcess,E51,2020]
4950.0 Costs[V_UndiscountedFixedCostsByProcess,E51,2030]
3012.230459623812
Costs[V_UndiscountedFixedCostsByProcess,E51,2040]
206.8087982794284
Costs[V_UndiscountedFixedCostsByProcess,E51,2050]
15.0 Costs[V_UndiscountedFixedCostsByProcess,E70,2000]
30.0 Costs[V_UndiscountedFixedCostsByProcess,E70,2010]
180.0 Costs[V_UndiscountedFixedCostsByProcess,E70,2020]
21622.88850438942
Costs[V_UndiscountedFixedCostsByProcess,E70,2030]
25.0 Costs[V_UndiscountedFixedCostsByProcess,RHO,2010]
50.0 Costs[V_UndiscountedFixedCostsByProcess,RHO,2020]
1090.039603960395
Costs[V_UndiscountedFixedCostsByProcess,RHO,2030]
529.76 Costs[V_UndiscountedFixedCostsByProcess,RL1,2020]
141384.4314191419
Costs[V_UndiscountedFixedCostsByProcess,RL1,2030]
170297.0297029703
Costs[V_UndiscountedFixedCostsByProcess,RL1,2040]
184488.44884488446
Costs[V_UndiscountedFixedCostsByProcess,RL1,2050]
208.0 Costs[V_UndiscountedFixedCostsByProcess,TXD,2010]
208.0 Costs[V_UndiscountedFixedCostsByProcess,TXD,2020]

1216.8000000000002
Costs[V_UndiscountedFixedCostsByProcess,TXD,2040]
2069.6 Costs[V_UndiscountedFixedCostsByProcess,TXD,2050]
1488.0 Costs[V_UndiscountedFixedCostsByProcess,TXG,2010]
1440.0 Costs[V_UndiscountedFixedCostsByProcess,TXG,2020]
3268.8 Costs[V_UndiscountedFixedCostsByProcess,TXG,2040]
2236.8 Costs[V_UndiscountedFixedCostsByProcess,TXG,2050]
60292.6014104696
Costs[V_UndiscountedInvestmentByProcess,E01,2030]
29116.040800003895
Costs[V_UndiscountedInvestmentByProcess,E21,2030]
23142.428197920555
Costs[V_UndiscountedInvestmentByProcess,E31,2030]
33152.34195712461
Costs[V_UndiscountedInvestmentByProcess,E31,2040]
11671.35711219855
Costs[V_UndiscountedInvestmentByProcess,E31,2050]
9725.708496353842
Costs[V_UndiscountedInvestmentByProcess,E51,2030]
7196.933063844631
Costs[V_UndiscountedInvestmentByProcess,E51,2040]
612.3194944848748
Costs[V_UndiscountedInvestmentByProcess,E51,2050]
14205.747575354078
Costs[V_UndiscountedInvestmentByProcess,E70,2030]
1690.3256902937885
Costs[V_UndiscountedInvestmentByProcess,RHE,2040]
1514.50922472725
Costs[V_UndiscountedInvestmentByProcess,RHE,2050]
3633.46534653465
Costs[V_UndiscountedInvestmentByProcess,RHO,2030]
8.420526836669994
Costs[V_UndiscountedInvestmentByProcess,SRE,2030]
1628.64 Costs[V_UndiscountedInvestmentByProcess,TXD,2040]

3091.116790257803
Costs[V_UndiscountedInvestmentByProcess,TXD,2050]
4739.76 Costs[V_UndiscountedInvestmentByProcess,TXG,2040]
3619.247297136021
Costs[V_UndiscountedInvestmentByProcess,TXG,2050]
23.7614475
Costs[V_UndiscountedVariableCostsByProcess,E01,2010]
30.5504325
Costs[V_UndiscountedVariableCostsByProcess,E01,2020]
2388.9174261752173
Costs[V_UndiscountedVariableCostsByProcess,E01,2030]
7805.86714370494
Costs[V_UndiscountedVariableCostsByProcess,E21,2030]
1.68196512
Costs[V_UndiscountedVariableCostsByProcess,E70,2000]
3.36393024
Costs[V_UndiscountedVariableCostsByProcess,E70,2010]
20.18358144
Costs[V_UndiscountedVariableCostsByProcess,E70,2020]
2415.045474733617
Costs[V_UndiscountedVariableCostsByProcess,E70,2030]
99330.93880561409
Costs[V_UndiscountedVariableCostsByProcess,IMPDSL1,2030]
11409.090909090912
Costs[V_UndiscountedVariableCostsByProcess,IMPGSL1,2030]
50900.610545316966
Costs[V_UndiscountedVariableCostsByProcess,IMPHCO1,2030]
710764.4400421854 Objective[('TotalCost')]
33.65 V_Capacity[E01,2030]
6.5 V_Capacity[E21,2030]
24.9 V_Capacity[E31,2030]
44.0 V_Capacity[E31,2040]
25.0 V_Capacity[E31,2050]
5.5 V_Capacity[E51,2030]

5.02038409937302 V_Capacity[E51,2040]
0.689362660931428 V_Capacity[E51,2050]
24.0254316715438 V_Capacity[E70,2030]
2151.61506193884 V_Capacity[IMPDSL1,2030]
576.590625 V_Capacity[IMPFEQ,2030]
30.0 V_Capacity[IMPGSL1,2030]
1380.16986665167 V_Capacity[IMPHCO1,2030]
2612.22165 V_Capacity[IMPHYD,2030]
23.1673267326733 V_Capacity[RHE,2040]
33.5009900990099 V_Capacity[RHE,2050]
2.5 V_Capacity[RHO,2010]
2.5 V_Capacity[RHO,2020]
36.3346534653465 V_Capacity[RHO,2030]
5.6 V_Capacity[RL1,2020]
1494.5500150015 V_Capacity[RL1,2030]
1800.1800180018 V_Capacity[RL1,2040]
1950.19501950195 V_Capacity[RL1,2050]
0.1 V_Capacity[SRE,2030]
0.4 V_Capacity[TXD,2010]
0.2 V_Capacity[TXD,2020]
1.56 V_Capacity[TXD,2040]
3.98 V_Capacity[TXD,2050]
3.1 V_Capacity[TXG,2010]
1.5 V_Capacity[TXG,2020]
4.54 V_Capacity[TXG,2040]
4.66 V_Capacity[TXG,2050]
34.0 V_CapacityAvailableByPeriodAndTech[2030,E01]
6.5 V_CapacityAvailableByPeriodAndTech[2030,E21]
25.0 V_CapacityAvailableByPeriodAndTech[2030,E31]
6.0 V_CapacityAvailableByPeriodAndTech[2030,E51]
24.3254316715438 V_CapacityAvailableByPeriodAndTech[2030,E70]
2151.61506193884
V_CapacityAvailableByPeriodAndTech[2030,IMPDSL1]
576.590625 V_CapacityAvailableByPeriodAndTech[2030,IMPFEQ]

30.0 V_CapacityAvailableByPeriodAndTech[2030,IMPGSL1]

1380.16986665167

V_CapacityAvailableByPeriodAndTech[2030,IMPHCO1]

2612.22165 V_CapacityAvailableByPeriodAndTech[2030,IMPHYD]

41.3346534653465 V_CapacityAvailableByPeriodAndTech[2030,RHO]

1500.1500150015 V_CapacityAvailableByPeriodAndTech[2030,RL1]

0.1 V_CapacityAvailableByPeriodAndTech[2030,SRE]

0.6 V_CapacityAvailableByPeriodAndTech[2030,TXD]

4.6 V_CapacityAvailableByPeriodAndTech[2030,TXG]

34.0 V_CapacityAvailableByPeriodAndTech[2040,E01]

6.5 V_CapacityAvailableByPeriodAndTech[2040,E21]

69.0 V_CapacityAvailableByPeriodAndTech[2040,E31]

11.020384099373 V_CapacityAvailableByPeriodAndTech[2040,E51]

24.2754316715438 V_CapacityAvailableByPeriodAndTech[2040,E70]

2151.61506193884

V_CapacityAvailableByPeriodAndTech[2040,IMPDSL1]

576.590625 V_CapacityAvailableByPeriodAndTech[2040,IMPFEQ]

30.0 V_CapacityAvailableByPeriodAndTech[2040,IMPGSL1]

1380.16986665167

V_CapacityAvailableByPeriodAndTech[2040,IMPHCO1]

2612.22165 V_CapacityAvailableByPeriodAndTech[2040,IMPHYD]

23.1673267326733 V_CapacityAvailableByPeriodAndTech[2040,RHE]

38.8346534653465 V_CapacityAvailableByPeriodAndTech[2040,RHO]

1800.1800180018 V_CapacityAvailableByPeriodAndTech[2040,RL1]

0.1 V_CapacityAvailableByPeriodAndTech[2040,SRE]

1.76 V_CapacityAvailableByPeriodAndTech[2040,TXD]

6.04 V_CapacityAvailableByPeriodAndTech[2040,TXG]

33.825 V_CapacityAvailableByPeriodAndTech[2050,E01]

6.5 V_CapacityAvailableByPeriodAndTech[2050,E21]

94.0 V_CapacityAvailableByPeriodAndTech[2050,E31]

11.7097467603044 V_CapacityAvailableByPeriodAndTech[2050,E51]

24.2254316715438 V_CapacityAvailableByPeriodAndTech[2050,E70]

2151.61506193884

V_CapacityAvailableByPeriodAndTech[2050,IMPDSL1]

576.590625 V_CapacityAvailableByPeriodAndTech[2050,IMPFEQ]
30.0 V_CapacityAvailableByPeriodAndTech[2050,IMPGSL1]
1380.16986665167
V_CapacityAvailableByPeriodAndTech[2050,IMPHCO1]
2612.22165 V_CapacityAvailableByPeriodAndTech[2050,IMPHYD]
56.6683168316832 V_CapacityAvailableByPeriodAndTech[2050,RHE]
36.3346534653465 V_CapacityAvailableByPeriodAndTech[2050,RHO]
1950.19501950195 V_CapacityAvailableByPeriodAndTech[2050,RL1]
0.1 V_CapacityAvailableByPeriodAndTech[2050,SRE]
4.76 V_CapacityAvailableByPeriodAndTech[2050,TXD]
6.93 V_CapacityAvailableByPeriodAndTech[2050,TXG]
59.43713030059538
V_EmissionActivityByPeriodAndProcess[2030,co2,IMPDSL1,2030]
1.4935064935064937
V_EmissionActivityByPeriodAndProcess[2030,co2,IMPGSL1,2030]
104.81569344293437
V_EmissionActivityByPeriodAndProcess[2030,co2,IMPHCO1,2030]
0.4000000000000001
V_EmissionActivityByPeriodAndProcess[2030,nox,TXD,2010]
0.2 V_EmissionActivityByPeriodAndProcess[2030,nox,TXD,2020]
3.1000000000000005
V_EmissionActivityByPeriodAndProcess[2030,nox,TXG,2010]
1.5 V_EmissionActivityByPeriodAndProcess[2030,nox,TXG,2020]
50.22322121970348
V_EmissionActivityByPeriodAndProcess[2040,co2,IMPDSL1,2030]
1.9610389610389611
V_EmissionActivityByPeriodAndProcess[2040,co2,IMPGSL1,2030]
71.97250210965379
V_EmissionActivityByPeriodAndProcess[2040,co2,IMPHCO1,2030]
0.2 V_EmissionActivityByPeriodAndProcess[2040,nox,TXD,2020]
1.5599999999999998
V_EmissionActivityByPeriodAndProcess[2040,nox,TXD,2040]
1.5 V_EmissionActivityByPeriodAndProcess[2040,nox,TXG,2020]
4.54 V_EmissionActivityByPeriodAndProcess[2040,nox,TXG,2040]

55.891213155724614
V_EmissionActivityByPeriodAndProcess[2050,co2,IMPDSL1,2030]
2.25
V_EmissionActivityByPeriodAndProcess[2050,co2,IMPGSL1,2030]
49.71952137407234
V_EmissionActivityByPeriodAndProcess[2050,co2,IMPHCO1,2030]
0.7799999999999999
V_EmissionActivityByPeriodAndProcess[2050,nox,TXD,2040]
3.9800000000000004
V_EmissionActivityByPeriodAndProcess[2050,nox,TXD,2050]
2.27 V_EmissionActivityByPeriodAndProcess[2050,nox,TXG,2040]
4.66 V_EmissionActivityByPeriodAndProcess[2050,nox,TXG,2050]
0.2612819775797643 V_FlowIn[2030,inter,day,DSL,RHO,2010,RH]
0.2612819775797643 V_FlowIn[2030,inter,day,DSL,RHO,2020,RH]
3.7974360448404716 V_FlowIn[2030,inter,day,DSL,RHO,2030,RH]
0.28865800865800867 V_FlowIn[2030,inter,day,DSL,TXD,2010,TX]
0.14432900432900433 V_FlowIn[2030,inter,day,DSL,TXD,2020,TX]
0.559944 V_FlowIn[2030,inter,day,ELC,RL1,2020,RL]
149.440056 V_FlowIn[2030,inter,day,ELC,RL1,2030,RL]
96.1176571875 V_FlowIn[2030,inter,day,FEQ,E21,2030,ELC]
2.2370995670995666 V_FlowIn[2030,inter,day,GSL,TXG,2010,TX]
1.0824675324675324 V_FlowIn[2030,inter,day,GSL,TXG,2020,TX]
2.357757915625 V_FlowIn[2030,inter,day,HCO,E01,2010,ELC]
2.357757915625 V_FlowIn[2030,inter,day,HCO,E01,2020,ELC]
149.01919495552812 V_FlowIn[2030,inter,day,HCO,E01,2030,ELC]
0.4929110625 V_FlowIn[2030,inter,day,HYD,E31,2020,ELC]
122.73485456249999 V_FlowIn[2030,inter,day,HYD,E31,2030,ELC]
4.75298701298701 V_FlowIn[2030,inter,day,ethos,IMPDSL1,2030,DSL]
96.1176571875 V_FlowIn[2030,inter,day,ethos,IMPFEQ,2030,FEQ]
3.3195670995671 V_FlowIn[2030,inter,day,ethos,IMPGSL1,2030,GSL]
153.734710786778 V_FlowIn[2030,inter,day,ethos,IMPHCO1,2030,HCO]
123.227765625 V_FlowIn[2030,inter,day,ethos,IMPHYD,2030,HYD]
0.13064098878988215 V_FlowIn[2030,inter,night,DSL,RHO,2010,RH]
0.13064098878988215 V_FlowIn[2030,inter,night,DSL,RHO,2020,RH]

1.898718022420229 V_FlowIn[2030,inter,night,DSL,RHO,2030,RH]
0.14424242424242426 V_FlowIn[2030,inter,night,DSL,TXD,2010,TX]
0.07212121212121213 V_FlowIn[2030,inter,night,DSL,TXD,2020,TX]
9.65701284476521 V_FlowIn[2030,inter,night,ELC,E51,2030,ELC]
0.186648 V_FlowIn[2030,inter,night,ELC,RL1,2020,RL]
49.813352 V_FlowIn[2030,inter,night,ELC,RL1,2030,RL]
48.029999062499996 V_FlowIn[2030,inter,night,FEQ,E21,2030,ELC]
1.117878787878788 V_FlowIn[2030,inter,night,GSL,TXG,2010,TX]
0.5409090909090909 V_FlowIn[2030,inter,night,GSL,TXG,2020,TX]
1.178171771875 V_FlowIn[2030,inter,night,HCO,E01,2010,ELC]
1.178171771875 V_FlowIn[2030,inter,night,HCO,E01,2020,ELC]
74.46490065864126 V_FlowIn[2030,inter,night,HCO,E01,2030,ELC]
0.2463076875 V_FlowIn[2030,inter,night,HYD,E31,2020,ELC]
61.3306141875 V_FlowIn[2030,inter,night,HYD,E31,2030,ELC]
2.37636363636364 V_FlowIn[2030,inter,night,ethos,IMPDSL1,2030,DSL]
48.0299990625 V_FlowIn[2030,inter,night,ethos,IMPFEQ,2030,FEQ]
1.65878787878788 V_FlowIn[2030,inter,night,ethos,IMPGSL1,2030,GSL]
76.8212442023913
V_FlowIn[2030,inter,night,ethos,IMPHCO1,2030,HCO]
61.576921875 V_FlowIn[2030,inter,night,ethos,IMPHYD,2030,HYD]
58.072368749313945 V_FlowIn[2030,summer,day,DSL,E70,2030,ELC]
0.28865800865800867 V_FlowIn[2030,summer,day,DSL,TXD,2010,TX]
0.14432900432900433 V_FlowIn[2030,summer,day,DSL,TXD,2020,TX]
0.559944 V_FlowIn[2030,summer,day,ELC,RL1,2020,RL]
149.440056 V_FlowIn[2030,summer,day,ELC,RL1,2030,RL]
96.1176571875 V_FlowIn[2030,summer,day,FEQ,E21,2030,ELC]
2.2370995670995666 V_FlowIn[2030,summer,day,GSL,TXG,2010,TX]
1.0824675324675324 V_FlowIn[2030,summer,day,GSL,TXG,2020,TX]
2.357757915625 V_FlowIn[2030,summer,day,HCO,E01,2010,ELC]
2.357757915625 V_FlowIn[2030,summer,day,HCO,E01,2020,ELC]
166.6944475678178 V_FlowIn[2030,summer,day,HCO,E01,2030,ELC]
0.4929110625 V_FlowIn[2030,summer,day,HYD,E31,2020,ELC]
122.73485456249999 V_FlowIn[2030,summer,day,HYD,E31,2030,ELC]

58.5053557623008
V_FlowIn[2030,summer,day,ethos,IMPDSL1,2030,DSL]
96.1176571875 V_FlowIn[2030,summer,day,ethos,IMPFEQ,2030,FEQ]
3.3195670995671
V_FlowIn[2030,summer,day,ethos,IMPGSL1,2030,GSL]
171.409963399068
V_FlowIn[2030,summer,day,ethos,IMPHCO1,2030,HCO]
123.227765625 V_FlowIn[2030,summer,day,ethos,IMPHYD,2030,HYD]
0.14424242424242426 V_FlowIn[2030,summer,night,DSL,TXD,2010,TX]
0.07212121212121213 V_FlowIn[2030,summer,night,DSL,TXD,2020,TX]
1.36855856481481 V_FlowIn[2030,summer,night,ELC,E51,2020,ELC]
15.054144212963 V_FlowIn[2030,summer,night,ELC,E51,2030,ELC]
0.186648 V_FlowIn[2030,summer,night,ELC,RL1,2020,RL]
49.813352 V_FlowIn[2030,summer,night,ELC,RL1,2030,RL]
48.029999062499996 V_FlowIn[2030,summer,night,FEQ,E21,2030,ELC]
1.117878787878788 V_FlowIn[2030,summer,night,GSL,TXG,2010,TX]
0.5409090909090909 V_FlowIn[2030,summer,night,GSL,TXG,2020,TX]
1.178171771875 V_FlowIn[2030,summer,night,HCO,E01,2010,ELC]
1.178171771875 V_FlowIn[2030,summer,night,HCO,E01,2020,ELC]
83.29722544930563 V_FlowIn[2030,summer,night,HCO,E01,2030,ELC]
0.2463076875 V_FlowIn[2030,summer,night,HYD,E31,2020,ELC]
61.3306141875 V_FlowIn[2030,summer,night,HYD,E31,2030,ELC]
0.216363636363636
V_FlowIn[2030,summer,night,ethos,IMPDSL1,2030,DSL]
48.0299990625 V_FlowIn[2030,summer,night,ethos,IMPFEQ,2030,FEQ]
1.65878787878788
V_FlowIn[2030,summer,night,ethos,IMPGSL1,2030,GSL]
85.6535689930555
V_FlowIn[2030,summer,night,ethos,IMPHCO1,2030,HCO]
61.576921875 V_FlowIn[2030,summer,night,ethos,IMPHYD,2030,HYD]
1.430242448979592 V_FlowIn[2030,winter,day,DSL,E70,2000,ELC]
1.430242448979592 V_FlowIn[2030,winter,day,DSL,E70,2010,ELC]
5.720969795918368 V_FlowIn[2030,winter,day,DSL,E70,2020,ELC]
687.2438446340102 V_FlowIn[2030,winter,day,DSL,E70,2030,ELC]

1.190357142857143 V_FlowIn[2030,winter,day,DSL,RHO,2010,RH]
1.190357142857143 V_FlowIn[2030,winter,day,DSL,RHO,2020,RH]
17.300485714285717 V_FlowIn[2030,winter,day,DSL,RHO,2030,RH]
0.5771428571428571 V_FlowIn[2030,winter,day,DSL,TXD,2010,TX]
0.28857142857142853 V_FlowIn[2030,winter,day,DSL,TXD,2020,TX]
1.86648 V_FlowIn[2030,winter,day,ELC,RL1,2020,RL]
498.13352 V_FlowIn[2030,winter,day,ELC,RL1,2030,RL]
192.17765531249998 V_FlowIn[2030,winter,day,FEQ,E21,2030,ELC]
4.472857142857143 V_FlowIn[2030,winter,day,GSL,TXG,2010,TX]
2.164285714285714 V_FlowIn[2030,winter,day,GSL,TXG,2020,TX]
4.714101459375001 V_FlowIn[2030,winter,day,HCO,E01,2010,ELC]
4.714101459375001 V_FlowIn[2030,winter,day,HCO,E01,2020,ELC]
450.58241363625314 V_FlowIn[2030,winter,day,HCO,E01,2030,ELC]
0.9855264375 V_FlowIn[2030,winter,day,HYD,E31,2020,ELC]
245.3960829375 V_FlowIn[2030,winter,day,HYD,E31,2030,ELC]
716.372213613603 V_FlowIn[2030,winter,day,ethos,IMPDSL1,2030,DSL]
192.1776553125 V_FlowIn[2030,winter,day,ethos,IMPFEQ,2030,FEQ]
6.63714285714286 V_FlowIn[2030,winter,day,ethos,IMPGSL1,2030,GSL]
460.010616555002
V_FlowIn[2030,winter,day,ethos,IMPHCO1,2030,HCO]
246.381609375 V_FlowIn[2030,winter,day,ethos,IMPHYD,2030,HYD]
0.5950697039379129 V_FlowIn[2030,winter,night,DSL,RHO,2010,RH]
0.5950697039379129 V_FlowIn[2030,winter,night,DSL,RHO,2020,RH]
8.648660592124173 V_FlowIn[2030,winter,night,DSL,RHO,2030,RH]
0.28865800865800867 V_FlowIn[2030,winter,night,DSL,TXD,2010,TX]
0.14432900432900433 V_FlowIn[2030,winter,night,DSL,TXD,2020,TX]
3.65119305555556 V_FlowIn[2030,winter,night,ELC,E51,2020,ELC]
40.1631236111111 V_FlowIn[2030,winter,night,ELC,E51,2030,ELC]
0.373296 V_FlowIn[2030,winter,night,ELC,RL1,2020,RL]
99.626704 V_FlowIn[2030,winter,night,ELC,RL1,2030,RL]
96.1176571875 V_FlowIn[2030,winter,night,FEQ,E21,2030,ELC]
2.2370995670995666 V_FlowIn[2030,winter,night,GSL,TXG,2010,TX]
1.0824675324675324 V_FlowIn[2030,winter,night,GSL,TXG,2020,TX]
2.357757915625 V_FlowIn[2030,winter,night,HCO,E01,2010,ELC]

2.357757915625 V_FlowIn[2030,winter,night,HCO,E01,2020,ELC]
225.35880093958343 V_FlowIn[2030,winter,night,HCO,E01,2030,ELC]
0.4929110625 V_FlowIn[2030,winter,night,HYD,E31,2020,ELC]
122.73485456249999 V_FlowIn[2030,winter,night,HYD,E31,2030,ELC]
10.271787012987 V_FlowIn[2030,winter,night,ethos,IMPDSL1,2030,DSL]
96.1176571875 V_FlowIn[2030,winter,night,ethos,IMPFEQ,2030,FEQ]
3.3195670995671
V_FlowIn[2030,winter,night,ethos,IMPGSL1,2030,GSL]
230.074316770833
V_FlowIn[2030,winter,night,ethos,IMPHCO1,2030,HCO]
123.227765625 V_FlowIn[2030,winter,night,ethos,IMPHYD,2030,HYD]
0.2612819775797643 V_FlowIn[2040,inter,day,DSL,RHO,2020,RH]
3.7974360448404716 V_FlowIn[2040,inter,day,DSL,RHO,2030,RH]
0.14432900432900433 V_FlowIn[2040,inter,day,DSL,TXD,2020,TX]
1.1257662337662337 V_FlowIn[2040,inter,day,DSL,TXD,2040,TX]
1.69489738430583 V_FlowIn[2040,inter,day,ELC,RHE,2040,RH]
180.0 V_FlowIn[2040,inter,day,ELC,RL1,2040,RL]
96.1176571875 V_FlowIn[2040,inter,day,FEQ,E21,2030,ELC]
1.0824675324675324 V_FlowIn[2040,inter,day,GSL,TXG,2020,TX]
3.276268398268398 V_FlowIn[2040,inter,day,GSL,TXG,2040,TX]
0.4929110625 V_FlowIn[2040,inter,day,HYD,E31,2020,ELC]
122.73485456249999 V_FlowIn[2040,inter,day,HYD,E31,2030,ELC]
199.0243427425 V_FlowIn[2040,inter,day,HYD,E31,2040,ELC]
5.32881326051547 V_FlowIn[2040,inter,day,ethos,IMPDSL1,2030,DSL]
96.1176571875 V_FlowIn[2040,inter,day,ethos,IMPFEQ,2030,FEQ]
4.35873593073593 V_FlowIn[2040,inter,day,ethos,IMPGSL1,2030,GSL]
322.2521083675 V_FlowIn[2040,inter,day,ethos,IMPHYD,2030,HYD]
0.13064098878988215 V_FlowIn[2040,inter,night,DSL,RHO,2020,RH]
1.898718022420229 V_FlowIn[2040,inter,night,DSL,RHO,2030,RH]
0.07212121212121213 V_FlowIn[2040,inter,night,DSL,TXD,2020,TX]
0.5625454545454546 V_FlowIn[2040,inter,night,DSL,TXD,2040,TX]
6.05155833024707 V_FlowIn[2040,inter,night,ELC,E51,2030,ELC]
0.847448692152917 V_FlowIn[2040,inter,night,ELC,RHE,2040,RH]
60.0 V_FlowIn[2040,inter,night,ELC,RL1,2040,RL]

48.029999062499996 V_FlowIn[2040,inter,night,FEQ,E21,2030,ELC]
0.5409090909090909 V_FlowIn[2040,inter,night,GSL,TXG,2020,TX]
1.6371515151515152 V_FlowIn[2040,inter,night,GSL,TXG,2040,TX]
0.2463076875 V_FlowIn[2040,inter,night,HYD,E31,2020,ELC]
61.3306141875 V_FlowIn[2040,inter,night,HYD,E31,2030,ELC]
99.4524760075 V_FlowIn[2040,inter,night,HYD,E31,2040,ELC]
2.66402567787679 V_FlowIn[2040,inter,night,ethos,IMPDSL1,2030,DSL]
48.0299990625 V_FlowIn[2040,inter,night,ethos,IMPFEQ,2030,FEQ]
2.17806060606061 V_FlowIn[2040,inter,night,ethos,IMPGSL1,2030,GSL]
161.0293978825 V_FlowIn[2040,inter,night,ethos,IMPHYD,2030,HYD]
0.14432900432900433 V_FlowIn[2040,summer,day,DSL,TXD,2020,TX]
1.1257662337662337 V_FlowIn[2040,summer,day,DSL,TXD,2040,TX]
180.0 V_FlowIn[2040,summer,day,ELC,RL1,2040,RL]
96.1176571875 V_FlowIn[2040,summer,day,FEQ,E21,2030,ELC]
1.0824675324675324 V_FlowIn[2040,summer,day,GSL,TXG,2020,TX]
3.276268398268398 V_FlowIn[2040,summer,day,GSL,TXG,2040,TX]
2.357757915625 V_FlowIn[2040,summer,day,HCO,E01,2010,ELC]
2.357757915625 V_FlowIn[2040,summer,day,HCO,E01,2020,ELC]
94.15652662231437 V_FlowIn[2040,summer,day,HCO,E01,2030,ELC]
0.4929110625 V_FlowIn[2040,summer,day,HYD,E31,2020,ELC]
122.73485456249999 V_FlowIn[2040,summer,day,HYD,E31,2030,ELC]
199.0243427425 V_FlowIn[2040,summer,day,HYD,E31,2040,ELC]
1.27009523809524
V_FlowIn[2040,summer,day,ethos,IMPDSL1,2030,DSL]
96.1176571875 V_FlowIn[2040,summer,day,ethos,IMPFEQ,2030,FEQ]
4.35873593073593
V_FlowIn[2040,summer,day,ethos,IMPGSL1,2030,GSL]
98.8720424535645
V_FlowIn[2040,summer,day,ethos,IMPHCO1,2030,HCO]
322.2521083675 V_FlowIn[2040,summer,day,ethos,IMPHYD,2030,HYD]
0.07212121212121213 V_FlowIn[2040,summer,night,DSL,TXD,2020,TX]
0.5625454545454546 V_FlowIn[2040,summer,night,DSL,TXD,2040,TX]
1.36855856481482 V_FlowIn[2040,summer,night,ELC,E51,2020,ELC]
15.054144212963 V_FlowIn[2040,summer,night,ELC,E51,2030,ELC]

12.9573777922187 V_FlowIn[2040,summer,night,ELC,E51,2040,ELC]
60.0 V_FlowIn[2040,summer,night,ELC,RL1,2040,RL]
48.029999062499996 V_FlowIn[2040,summer,night,FEQ,E21,2030,ELC]
0.5409090909090909 V_FlowIn[2040,summer,night,GSL,TXG,2020,TX]
1.6371515151515152 V_FlowIn[2040,summer,night,GSL,TXG,2040,TX]
1.178171771875 V_FlowIn[2040,summer,night,HCO,E01,2010,ELC]
1.178171771875 V_FlowIn[2040,summer,night,HCO,E01,2020,ELC]
47.0500220014325 V_FlowIn[2040,summer,night,HCO,E01,2030,ELC]
0.2463076875 V_FlowIn[2040,summer,night,HYD,E31,2020,ELC]
61.3306141875 V_FlowIn[2040,summer,night,HYD,E31,2030,ELC]
99.4524760075 V_FlowIn[2040,summer,night,HYD,E31,2040,ELC]
0.634666666666667
V_FlowIn[2040,summer,night,ethos,IMPDSL1,2030,DSL]
48.0299990625 V_FlowIn[2040,summer,night,ethos,IMPFEQ,2030,FEQ]
2.17806060606061
V_FlowIn[2040,summer,night,ethos,IMPGSL1,2030,GSL]
49.4063655451825
V_FlowIn[2040,summer,night,ethos,IMPHCO1,2030,HCO]
161.0293978825
V_FlowIn[2040,summer,night,ethos,IMPHYD,2030,HYD]
1.430242448979592 V_FlowIn[2040,winter,day,DSL,E70,2010,ELC]
5.720969795918368 V_FlowIn[2040,winter,day,DSL,E70,2020,ELC]
621.0500395452653 V_FlowIn[2040,winter,day,DSL,E70,2030,ELC]
1.190357142857143 V_FlowIn[2040,winter,day,DSL,RHO,2020,RH]
17.300485714285717 V_FlowIn[2040,winter,day,DSL,RHO,2030,RH]
0.28857142857142853 V_FlowIn[2040,winter,day,DSL,TXD,2020,TX]
2.2508571428571424 V_FlowIn[2040,winter,day,DSL,TXD,2040,TX]
7.72167 V_FlowIn[2040,winter,day,ELC,RHE,2040,RH]
600.0 V_FlowIn[2040,winter,day,ELC,RL1,2040,RL]
192.17765531249998 V_FlowIn[2040,winter,day,FEQ,E21,2030,ELC]
2.164285714285714 V_FlowIn[2040,winter,day,GSL,TXG,2020,TX]
6.550571428571429 V_FlowIn[2040,winter,day,GSL,TXG,2040,TX]
4.714101459375001 V_FlowIn[2040,winter,day,HCO,E01,2010,ELC]
4.714101459375001 V_FlowIn[2040,winter,day,HCO,E01,2020,ELC]

430.7953643126031 V_FlowIn[2040,winter,day,HCO,E01,2030,ELC]
0.9855264375 V_FlowIn[2040,winter,day,HYD,E31,2020,ELC]
245.3960829375 V_FlowIn[2040,winter,day,HYD,E31,2030,ELC]
397.9292947575 V_FlowIn[2040,winter,day,HYD,E31,2040,ELC]
649.231523218735 V_FlowIn[2040,winter,day,ethos,IMPDSL1,2030,DSL]
192.1776553125 V_FlowIn[2040,winter,day,ethos,IMPFEQ,2030,FEQ]
8.71485714285714 V_FlowIn[2040,winter,day,ethos,IMPGSL1,2030,GSL]
440.223567231352
V_FlowIn[2040,winter,day,ethos,IMPHCO1,2030,HCO]
644.3109041325 V_FlowIn[2040,winter,day,ethos,IMPHYD,2030,HYD]
0.5950697039379129 V_FlowIn[2040,winter,night,DSL,RHO,2020,RH]
8.648660592124173 V_FlowIn[2040,winter,night,DSL,RHO,2030,RH]
0.14432900432900433 V_FlowIn[2040,winter,night,DSL,TXD,2020,TX]
1.1257662337662337 V_FlowIn[2040,winter,night,DSL,TXD,2040,TX]
3.65119305555556 V_FlowIn[2040,winter,night,ELC,E51,2020,ELC]
40.1631236111111 V_FlowIn[2040,winter,night,ELC,E51,2030,ELC]
36.6607831197046 V_FlowIn[2040,winter,night,ELC,E51,2040,ELC]
3.86012879275654 V_FlowIn[2040,winter,night,ELC,RHE,2040,RH]
120.0 V_FlowIn[2040,winter,night,ELC,RL1,2040,RL]
96.1176571875 V_FlowIn[2040,winter,night,FEQ,E21,2030,ELC]
1.0824675324675324 V_FlowIn[2040,winter,night,GSL,TXG,2020,TX]
3.276268398268398 V_FlowIn[2040,winter,night,GSL,TXG,2040,TX]
2.357757915625 V_FlowIn[2040,winter,night,HCO,E01,2010,ELC]
2.357757915625 V_FlowIn[2040,winter,night,HCO,E01,2020,ELC]
215.46230792352466 V_FlowIn[2040,winter,night,HCO,E01,2030,ELC]
0.4929110625 V_FlowIn[2040,winter,night,HYD,E31,2020,ELC]
122.73485456249999 V_FlowIn[2040,winter,night,HYD,E31,2030,ELC]
199.0243427425 V_FlowIn[2040,winter,night,HYD,E31,2040,ELC]
10.5138255341573
V_FlowIn[2040,winter,night,ethos,IMPDSL1,2030,DSL]
96.1176571875 V_FlowIn[2040,winter,night,ethos,IMPFEQ,2030,FEQ]
4.35873593073593
V_FlowIn[2040,winter,night,ethos,IMPGSL1,2030,GSL]

220.177823754775
V_FlowIn[2040,winter,night,ethos,IMPHCO1,2030,HCO]
322.2521083675 V_FlowIn[2040,winter,night,ethos,IMPHYD,2030,HYD]
3.7974360448404716 V_FlowIn[2050,inter,day,DSL,RHO,2030,RH]
0.5628831168831169 V_FlowIn[2050,inter,day,DSL,TXD,2040,TX]
2.872147186147186 V_FlowIn[2050,inter,day,DSL,TXD,2050,TX]
1.69489738430583 V_FlowIn[2050,inter,day,ELC,RHE,2040,RH]
2.45089738430583 V_FlowIn[2050,inter,day,ELC,RHE,2050,RH]
195.0 V_FlowIn[2050,inter,day,ELC,RL1,2050,RL]
27.07081498384456 V_FlowIn[2050,inter,day,FEQ,E21,2030,ELC]
1.638134199134199 V_FlowIn[2050,inter,day,GSL,TXG,2040,TX]
3.3628658008658006 V_FlowIn[2050,inter,day,GSL,TXG,2050,TX]
0.4929110625 V_FlowIn[2050,inter,day,HYD,E31,2020,ELC]
122.73485456249999 V_FlowIn[2050,inter,day,HYD,E31,2030,ELC]
199.0243427425 V_FlowIn[2050,inter,day,HYD,E31,2040,ELC]
113.2052406875 V_FlowIn[2050,inter,day,HYD,E31,2050,ELC]
7.23246634787078 V_FlowIn[2050,inter,day,ethos,IMPDSL1,2030,DSL]
27.0708149838445 V_FlowIn[2050,inter,day,ethos,IMPFEQ,2030,FEQ]
5.001 V_FlowIn[2050,inter,day,ethos,IMPGSL1,2030,GSL]
435.457349055 V_FlowIn[2050,inter,day,ethos,IMPHYD,2030,HYD]
1.898718022420229 V_FlowIn[2050,inter,night,DSL,RHO,2030,RH]
0.2812727272727273 V_FlowIn[2050,inter,night,DSL,TXD,2040,TX]
1.4352121212121212 V_FlowIn[2050,inter,night,DSL,TXD,2050,TX]
0.912615740740741 V_FlowIn[2050,inter,night,ELC,E51,2020,ELC]
4.71635286529594 V_FlowIn[2050,inter,night,ELC,E51,2030,ELC]
1.25824643088989 V_FlowIn[2050,inter,night,ELC,E51,2050,ELC]
0.847448692152917 V_FlowIn[2050,inter,night,ELC,RHE,2040,RH]
1.22544869215292 V_FlowIn[2050,inter,night,ELC,RHE,2050,RH]
65.0 V_FlowIn[2050,inter,night,ELC,RL1,2050,RL]
13.52728787135125 V_FlowIn[2050,inter,night,FEQ,E21,2030,ELC]
0.8185757575757576 V_FlowIn[2050,inter,night,GSL,TXG,2040,TX]
1.6804242424242424 V_FlowIn[2050,inter,night,GSL,TXG,2050,TX]
0.2463076875 V_FlowIn[2050,inter,night,HYD,E31,2020,ELC]
61.3306141875 V_FlowIn[2050,inter,night,HYD,E31,2030,ELC]

99.4524760075 V_FlowIn[2050,inter,night,HYD,E31,2040,ELC]

56.568665562499994 V_FlowIn[2050,inter,night,HYD,E31,2050,ELC]

3.61520287090509 V_FlowIn[2050,inter,night,ethos,IMPDSL1,2030,DSL]

13.5272878713512 V_FlowIn[2050,inter,night,ethos,IMPFEQ,2030,FEQ]

2.499 V_FlowIn[2050,inter,night,ethos,IMPGSL1,2030,GSL]

217.598063445 V_FlowIn[2050,inter,night,ethos,IMPHYD,2030,HYD]

0.5628831168831169 V_FlowIn[2050,summer,day,DSL,TXD,2040,TX]

2.872147186147186 V_FlowIn[2050,summer,day,DSL,TXD,2050,TX]

195.0 V_FlowIn[2050,summer,day,ELC,RL1,2050,RL]

96.1176571875 V_FlowIn[2050,summer,day,FEQ,E21,2030,ELC]

1.638134199134199 V_FlowIn[2050,summer,day,GSL,TXG,2040,TX]

3.3628658008658006 V_FlowIn[2050,summer,day,GSL,TXG,2050,TX]

29.710747296562122 V_FlowIn[2050,summer,day,HCO,E01,2030,ELC]

0.4929110625 V_FlowIn[2050,summer,day,HYD,E31,2020,ELC]

122.73485456249999 V_FlowIn[2050,summer,day,HYD,E31,2030,ELC]

199.0243427425 V_FlowIn[2050,summer,day,HYD,E31,2040,ELC]

113.2052406875 V_FlowIn[2050,summer,day,HYD,E31,2050,ELC]

3.4350303030303

V_FlowIn[2050,summer,day,ethos,IMPDSL1,2030,DSL]

96.1176571875 V_FlowIn[2050,summer,day,ethos,IMPFEQ,2030,FEQ]

5.001 V_FlowIn[2050,summer,day,ethos,IMPGSL1,2030,GSL]

29.7107472965621

V_FlowIn[2050,summer,day,ethos,IMPHCO1,2030,HCO]

435.457349055 V_FlowIn[2050,summer,day,ethos,IMPHYD,2030,HYD]

0.2812727272727273 V_FlowIn[2050,summer,night,DSL,TXD,2040,TX]

1.4352121212121212 V_FlowIn[2050,summer,night,DSL,TXD,2050,TX]

0.912615740740741 V_FlowIn[2050,summer,night,ELC,E51,2020,ELC]

10.0387731481481 V_FlowIn[2050,summer,night,ELC,E51,2030,ELC]

13.7413793157141 V_FlowIn[2050,summer,night,ELC,E51,2040,ELC]

1.25824643088989 V_FlowIn[2050,summer,night,ELC,E51,2050,ELC]

1.92983831683168 V_FlowIn[2050,summer,night,ELC,RHE,2040,RH]

0.167166626171971 V_FlowIn[2050,summer,night,ELC,RHE,2050,RH]

65.0 V_FlowIn[2050,summer,night,ELC,RL1,2050,RL]

48.029999062499996 V_FlowIn[2050,summer,night,FEQ,E21,2030,ELC]

0.8185757575757576 V_FlowIn[2050,summer,night,GSL,TXG,2040,TX]

1.6804242424242424 V_FlowIn[2050,summer,night,GSL,TXG,2050,TX]

14.846462206380467 V_FlowIn[2050,summer,night,HCO,E01,2030,ELC]

0.2463076875 V_FlowIn[2050,summer,night,HYD,E31,2020,ELC]

61.3306141875 V_FlowIn[2050,summer,night,HYD,E31,2030,ELC]

99.4524760075 V_FlowIn[2050,summer,night,HYD,E31,2040,ELC]

56.568665562499994 V_FlowIn[2050,summer,night,HYD,E31,2050,ELC]

1.71648484848485

V_FlowIn[2050,summer,night,ethos,IMPDSL1,2030,DSL]

48.0299990625 V_FlowIn[2050,summer,night,ethos,IMPFEQ,2030,FEQ]

2.499 V_FlowIn[2050,summer,night,ethos,IMPGSL1,2030,GSL]

14.8464622063805

V_FlowIn[2050,summer,night,ethos,IMPHCO1,2030,HCO]

217.598063445

V_FlowIn[2050,summer,night,ethos,IMPHYD,2030,HYD]

5.720969795918368 V_FlowIn[2050,winter,day,DSL,E70,2020,ELC]

687.2438446340102 V_FlowIn[2050,winter,day,DSL,E70,2030,ELC]

17.300485714285717 V_FlowIn[2050,winter,day,DSL,RHO,2030,RH]

1.1254285714285712 V_FlowIn[2050,winter,day,DSL,TXD,2040,TX]

5.742571428571429 V_FlowIn[2050,winter,day,DSL,TXD,2050,TX]

7.72167 V_FlowIn[2050,winter,day,ELC,RHE,2040,RH]

11.16588 V_FlowIn[2050,winter,day,ELC,RHE,2050,RH]

650.0 V_FlowIn[2050,winter,day,ELC,RL1,2050,RL]

192.17765531249998 V_FlowIn[2050,winter,day,FEQ,E21,2030,ELC]

3.2752857142857144 V_FlowIn[2050,winter,day,GSL,TXG,2040,TX]

6.723714285714285 V_FlowIn[2050,winter,day,GSL,TXG,2050,TX]

4.714101459375001 V_FlowIn[2050,winter,day,HCO,E01,2020,ELC]

337.9776913146906 V_FlowIn[2050,winter,day,HCO,E01,2030,ELC]

0.9855264375 V_FlowIn[2050,winter,day,HYD,E31,2020,ELC]

245.3960829375 V_FlowIn[2050,winter,day,HYD,E31,2030,ELC]

397.9292947575 V_FlowIn[2050,winter,day,HYD,E31,2040,ELC]

226.3425718125 V_FlowIn[2050,winter,day,HYD,E31,2050,ELC]

717.133300144216 V_FlowIn[2050,winter,day,ethos,IMPDSL1,2030,DSL]

192.1776553125 V_FlowIn[2050,winter,day,ethos,IMPFEQ,2030,FEQ]

9.999 V_FlowIn[2050,winter,day,ethos,IMPGSL1,2030,GSL]
342.691792774065
V_FlowIn[2050,winter,day,ethos,IMPHCO1,2030,HCO]
870.653475945 V_FlowIn[2050,winter,day,ethos,IMPHYD,2030,HYD]
8.648660592124173 V_FlowIn[2050,winter,night,DSL,RHO,2030,RH]
0.5628831168831169 V_FlowIn[2050,winter,night,DSL,TXD,2040,TX]
2.872147186147186 V_FlowIn[2050,winter,night,DSL,TXD,2050,TX]
3.65119305555556 V_FlowIn[2050,winter,night,ELC,E51,2020,ELC]
40.1631236111111 V_FlowIn[2050,winter,night,ELC,E51,2030,ELC]
36.6607831197046 V_FlowIn[2050,winter,night,ELC,E51,2040,ELC]
5.03399232070426 V_FlowIn[2050,winter,night,ELC,E51,2050,ELC]
3.86012879275654 V_FlowIn[2050,winter,night,ELC,RHE,2040,RH]
5.58191879275654 V_FlowIn[2050,winter,night,ELC,RHE,2050,RH]
130.0 V_FlowIn[2050,winter,night,ELC,RL1,2050,RL]
96.1176571875 V_FlowIn[2050,winter,night,FEQ,E21,2030,ELC]
1.638134199134199 V_FlowIn[2050,winter,night,GSL,TXG,2040,TX]
3.3628658008658006 V_FlowIn[2050,winter,night,GSL,TXG,2050,TX]
2.357757915625 V_FlowIn[2050,winter,night,HCO,E01,2020,ELC]
169.0395473812144 V_FlowIn[2050,winter,night,HCO,E01,2030,ELC]
0.4929110625 V_FlowIn[2050,winter,night,HYD,E31,2020,ELC]
122.73485456249999 V_FlowIn[2050,winter,night,HYD,E31,2030,ELC]
199.0243427425 V_FlowIn[2050,winter,night,HYD,E31,2040,ELC]
113.2052406875 V_FlowIn[2050,winter,night,HYD,E31,2050,ELC]
12.0836908951545
V_FlowIn[2050,winter,night,ethos,IMPDSL1,2030,DSL]
96.1176571875 V_FlowIn[2050,winter,night,ethos,IMPFEQ,2030,FEQ]
5.001 V_FlowIn[2050,winter,night,ethos,IMPGSL1,2030,GSL]
171.397305296839
V_FlowIn[2050,winter,night,ethos,IMPHCO1,2030,HCO]
435.457349055 V_FlowIn[2050,winter,night,ethos,IMPHYD,2030,HYD]
0.182897384305835 V_FlowOut[2030,inter,day,DSL,RHO,2010,RH]
0.182897384305835 V_FlowOut[2030,inter,day,DSL,RHO,2020,RH]
2.65820523138833 V_FlowOut[2030,inter,day,DSL,RHO,2030,RH]
0.06668 V_FlowOut[2030,inter,day,DSL,TXD,2010,TX]

0.03334 V_FlowOut[2030,inter,day,DSL,TXD,2020,TX]
1.97177566666667 V_FlowOut[2030,inter,day,ELC,E51,2020,ELC]
28.6425815815643 V_FlowOut[2030,inter,day,ELC,E51,2030,ELC]
0.559944 V_FlowOut[2030,inter,day,ELC,RL1,2020,RL]
149.440056 V_FlowOut[2030,inter,day,ELC,RL1,2030,RL]
30.7576503 V_FlowOut[2030,inter,day,FEQ,E21,2030,ELC]
0.51677 V_FlowOut[2030,inter,day,GSL,TXG,2010,TX]
0.25005 V_FlowOut[2030,inter,day,GSL,TXG,2020,TX]
0.754482533 V_FlowOut[2030,inter,day,HCO,E01,2010,ELC]
0.754482533 V_FlowOut[2030,inter,day,HCO,E01,2020,ELC]
47.686142385769 V_FlowOut[2030,inter,day,HCO,E01,2030,ELC]
0.15773154 V_FlowOut[2030,inter,day,HYD,E31,2020,ELC]
39.27515346 V_FlowOut[2030,inter,day,HYD,E31,2030,ELC]
4.75298701298701 V_FlowOut[2030,inter,day,ethos,IMPDSL1,2030,DSL]
96.1176571875 V_FlowOut[2030,inter,day,ethos,IMPFEQ,2030,FEQ]
3.3195670995671 V_FlowOut[2030,inter,day,ethos,IMPGSL1,2030,GSL]
153.734710786778
V_FlowOut[2030,inter,day,ethos,IMPHCO1,2030,HCO]
123.227765625 V_FlowOut[2030,inter,day,ethos,IMPHYD,2030,HYD]
0.0914486921529175 V_FlowOut[2030,inter,night,DSL,RHO,2010,RH]
0.0914486921529175 V_FlowOut[2030,inter,night,DSL,RHO,2020,RH]
1.32910261569416 V_FlowOut[2030,inter,night,DSL,RHO,2030,RH]
0.03332 V_FlowOut[2030,inter,night,DSL,TXD,2010,TX]
0.01666 V_FlowOut[2030,inter,night,DSL,TXD,2020,TX]
0.186648 V_FlowOut[2030,inter,night,ELC,RL1,2020,RL]
49.813352 V_FlowOut[2030,inter,night,ELC,RL1,2030,RL]
15.3695997 V_FlowOut[2030,inter,night,FEQ,E21,2030,ELC]
0.25823 V_FlowOut[2030,inter,night,GSL,TXG,2010,TX]
0.12495 V_FlowOut[2030,inter,night,GSL,TXG,2020,TX]
0.377014967 V_FlowOut[2030,inter,night,HCO,E01,2010,ELC]
0.377014967 V_FlowOut[2030,inter,night,HCO,E01,2020,ELC]
23.8287682107652 V_FlowOut[2030,inter,night,HCO,E01,2030,ELC]
0.07881846 V_FlowOut[2030,inter,night,HYD,E31,2020,ELC]
19.62579654 V_FlowOut[2030,inter,night,HYD,E31,2030,ELC]

2.37636363636364
V_FlowOut[2030,inter,night,ethos,IMPDSL1,2030,DSL]
48.0299990625 V_FlowOut[2030,inter,night,ethos,IMPFEQ,2030,FEQ]
1.65878787878788
V_FlowOut[2030,inter,night,ethos,IMPGSL1,2030,GSL]
76.8212442023913
V_FlowOut[2030,inter,night,ethos,IMPHCO1,2030,HCO]
61.576921875 V_FlowOut[2030,inter,night,ethos,IMPHYD,2030,HYD]
17.0732764122983 V_FlowOut[2030,summer,day,DSL,E70,2030,ELC]
0.06668 V_FlowOut[2030,summer,day,DSL,TXD,2010,TX]
0.03334 V_FlowOut[2030,summer,day,DSL,TXD,2020,TX]
0.657083333333333 V_FlowOut[2030,summer,day,ELC,E51,2020,ELC]
7.22791666666667 V_FlowOut[2030,summer,day,ELC,E51,2030,ELC]
0.559944 V_FlowOut[2030,summer,day,ELC,RL1,2020,RL]
149.440056 V_FlowOut[2030,summer,day,ELC,RL1,2030,RL]
30.7576503 V_FlowOut[2030,summer,day,FEQ,E21,2030,ELC]
0.51677 V_FlowOut[2030,summer,day,GSL,TXG,2010,TX]
0.25005 V_FlowOut[2030,summer,day,GSL,TXG,2020,TX]
0.754482533 V_FlowOut[2030,summer,day,HCO,E01,2010,ELC]
0.754482533 V_FlowOut[2030,summer,day,HCO,E01,2020,ELC]
53.3422232217017 V_FlowOut[2030,summer,day,HCO,E01,2030,ELC]
0.15773154 V_FlowOut[2030,summer,day,HYD,E31,2020,ELC]
39.27515346 V_FlowOut[2030,summer,day,HYD,E31,2030,ELC]
58.5053557623008
V_FlowOut[2030,summer,day,ethos,IMPDSL1,2030,DSL]
96.1176571875
V_FlowOut[2030,summer,day,ethos,IMPFEQ,2030,FEQ]
3.3195670995671
V_FlowOut[2030,summer,day,ethos,IMPGSL1,2030,GSL]
171.409963399068
V_FlowOut[2030,summer,day,ethos,IMPHCO1,2030,HCO]
123.227765625
V_FlowOut[2030,summer,day,ethos,IMPHYD,2030,HYD]
0.03332 V_FlowOut[2030,summer,night,DSL,TXD,2010,TX]

0.01666 V_FlowOut[2030,summer,night,DSL,TXD,2020,TX]
0.328278833333333 V_FlowOut[2030,summer,night,ELC,E51,2020,ELC]
3.61106716666666 V_FlowOut[2030,summer,night,ELC,E51,2030,ELC]
0.186648 V_FlowOut[2030,summer,night,ELC,RL1,2020,RL]
49.813352 V_FlowOut[2030,summer,night,ELC,RL1,2030,RL]
15.3695997 V_FlowOut[2030,summer,night,FEQ,E21,2030,ELC]
0.25823 V_FlowOut[2030,summer,night,GSL,TXG,2010,TX]
0.12495 V_FlowOut[2030,summer,night,GSL,TXG,2020,TX]
0.377014967 V_FlowOut[2030,summer,night,HCO,E01,2010,ELC]
0.377014967 V_FlowOut[2030,summer,night,HCO,E01,2020,ELC]
26.6551121437778 V_FlowOut[2030,summer,night,HCO,E01,2030,ELC]
0.07881846 V_FlowOut[2030,summer,night,HYD,E31,2020,ELC]
19.62579654 V_FlowOut[2030,summer,night,HYD,E31,2030,ELC]
0.216363636363636
V_FlowOut[2030,summer,night,ethos,IMPDSL1,2030,DSL]
48.0299990625
V_FlowOut[2030,summer,night,ethos,IMPFEQ,2030,FEQ]
1.65878787878788
V_FlowOut[2030,summer,night,ethos,IMPGSL1,2030,GSL]
85.6535689930555
V_FlowOut[2030,summer,night,ethos,IMPHCO1,2030,HCO]
61.576921875
V_FlowOut[2030,summer,night,ethos,IMPHYD,2030,HYD]
0.42049128 V_FlowOut[2030,winter,day,DSL,E70,2000,ELC]
0.42049128 V_FlowOut[2030,winter,day,DSL,E70,2010,ELC]
1.68196512 V_FlowOut[2030,winter,day,DSL,E70,2020,ELC]
202.049690322399 V_FlowOut[2030,winter,day,DSL,E70,2030,ELC]
0.83325 V_FlowOut[2030,winter,day,DSL,RHO,2010,RH]
0.83325 V_FlowOut[2030,winter,day,DSL,RHO,2020,RH]
12.11034 V_FlowOut[2030,winter,day,DSL,RHO,2030,RH]
0.13332 V_FlowOut[2030,winter,day,DSL,TXD,2010,TX]
0.06666 V_FlowOut[2030,winter,day,DSL,TXD,2020,TX]
0.657083333333333 V_FlowOut[2030,winter,day,ELC,E51,2020,ELC]
7.22791666666667 V_FlowOut[2030,winter,day,ELC,E51,2030,ELC]

1.86648 V_FlowOut[2030,winter,day,ELC,RL1,2020,RL]
498.13352 V_FlowOut[2030,winter,day,ELC,RL1,2030,RL]
61.4968497 V_FlowOut[2030,winter,day,FEQ,E21,2030,ELC]
1.03323 V_FlowOut[2030,winter,day,GSL,TXG,2010,TX]
0.49995 V_FlowOut[2030,winter,day,GSL,TXG,2020,TX]
1.508512467 V_FlowOut[2030,winter,day,HCO,E01,2010,ELC]
1.508512467 V_FlowOut[2030,winter,day,HCO,E01,2020,ELC]
144.186372363601 V_FlowOut[2030,winter,day,HCO,E01,2030,ELC]
0.31536846 V_FlowOut[2030,winter,day,HYD,E31,2020,ELC]
78.52674654 V_FlowOut[2030,winter,day,HYD,E31,2030,ELC]
716.372213613603
V_FlowOut[2030,winter,day,ethos,IMPDSL1,2030,DSL]
192.1776553125 V_FlowOut[2030,winter,day,ethos,IMPFEQ,2030,FEQ]
6.63714285714286
V_FlowOut[2030,winter,day,ethos,IMPGSL1,2030,GSL]
460.010616555002
V_FlowOut[2030,winter,day,ethos,IMPHCO1,2030,HCO]
246.381609375 V_FlowOut[2030,winter,day,ethos,IMPHYD,2030,HYD]
0.416548792756539 V_FlowOut[2030,winter,night,DSL,RHO,2010,RH]
0.416548792756539 V_FlowOut[2030,winter,night,DSL,RHO,2020,RH]
6.05406241448692 V_FlowOut[2030,winter,night,DSL,RHO,2030,RH]
0.06668 V_FlowOut[2030,winter,night,DSL,TXD,2010,TX]
0.03334 V_FlowOut[2030,winter,night,DSL,TXD,2020,TX]
0.373296 V_FlowOut[2030,winter,night,ELC,RL1,2020,RL]
99.626704 V_FlowOut[2030,winter,night,ELC,RL1,2030,RL]
30.7576503 V_FlowOut[2030,winter,night,FEQ,E21,2030,ELC]
0.51677 V_FlowOut[2030,winter,night,GSL,TXG,2010,TX]
0.25005 V_FlowOut[2030,winter,night,GSL,TXG,2020,TX]
0.754482533 V_FlowOut[2030,winter,night,HCO,E01,2010,ELC]
0.754482533 V_FlowOut[2030,winter,night,HCO,E01,2020,ELC]
72.1148163006667 V_FlowOut[2030,winter,night,HCO,E01,2030,ELC]
0.15773154 V_FlowOut[2030,winter,night,HYD,E31,2020,ELC]
39.27515346 V_FlowOut[2030,winter,night,HYD,E31,2030,ELC]

10.271787012987
V_FlowOut[2030,winter,night,ethos,IMPDSL1,2030,DSL]
96.1176571875 V_FlowOut[2030,winter,night,ethos,IMPFEQ,2030,FEQ]
3.3195670995671
V_FlowOut[2030,winter,night,ethos,IMPGSL1,2030,GSL]
230.074316770833
V_FlowOut[2030,winter,night,ethos,IMPHCO1,2030,HCO]
123.227765625 V_FlowOut[2030,winter,night,ethos,IMPHYD,2030,HYD]
0.182897384305835 V_FlowOut[2040,inter,day,DSL,RHO,2020,RH]
2.65820523138833 V_FlowOut[2040,inter,day,DSL,RHO,2030,RH]
0.03334 V_FlowOut[2040,inter,day,DSL,TXD,2020,TX]
0.260052 V_FlowOut[2040,inter,day,DSL,TXD,2040,TX]
1.97177566666667 V_FlowOut[2040,inter,day,ELC,E51,2020,ELC]
26.0466543311112 V_FlowOut[2040,inter,day,ELC,E51,2030,ELC]
19.798142408928 V_FlowOut[2040,inter,day,ELC,E51,2040,ELC]
1.69489738430583 V_FlowOut[2040,inter,day,ELC,RHE,2040,RH]
180.0 V_FlowOut[2040,inter,day,ELC,RL1,2040,RL]
30.7576503 V_FlowOut[2040,inter,day,FEQ,E21,2030,ELC]
0.25005 V_FlowOut[2040,inter,day,GSL,TXG,2020,TX]
0.756818 V_FlowOut[2040,inter,day,GSL,TXG,2040,TX]
0.15773154 V_FlowOut[2040,inter,day,HYD,E31,2020,ELC]
39.27515346 V_FlowOut[2040,inter,day,HYD,E31,2030,ELC]
63.6877896776 V_FlowOut[2040,inter,day,HYD,E31,2040,ELC]
5.32881326051547 V_FlowOut[2040,inter,day,ethos,IMPDSL1,2030,DSL]
96.1176571875 V_FlowOut[2040,inter,day,ethos,IMPFEQ,2030,FEQ]
4.35873593073593 V_FlowOut[2040,inter,day,ethos,IMPGSL1,2030,GSL]
322.2521083675 V_FlowOut[2040,inter,day,ethos,IMPHYD,2030,HYD]
0.0914486921529175 V_FlowOut[2040,inter,night,DSL,RHO,2020,RH]
1.32910261569416 V_FlowOut[2040,inter,night,DSL,RHO,2030,RH]
0.01666 V_FlowOut[2040,inter,night,DSL,TXD,2020,TX]
0.129948 V_FlowOut[2040,inter,night,DSL,TXD,2040,TX]
0.847448692152917 V_FlowOut[2040,inter,night,ELC,RHE,2040,RH]
60.0 V_FlowOut[2040,inter,night,ELC,RL1,2040,RL]
15.3695997 V_FlowOut[2040,inter,night,FEQ,E21,2030,ELC]

0.12495 V_FlowOut[2040,inter,night,GSL,TXG,2020,TX]

0.378182 V_FlowOut[2040,inter,night,GSL,TXG,2040,TX]

0.07881846 V_FlowOut[2040,inter,night,HYD,E31,2020,ELC]

19.62579654 V_FlowOut[2040,inter,night,HYD,E31,2030,ELC]

31.8247923224 V_FlowOut[2040,inter,night,HYD,E31,2040,ELC]

2.66402567787679
V_FlowOut[2040,inter,night,ethos,IMPDSL1,2030,DSL]

48.0299990625 V_FlowOut[2040,inter,night,ethos,IMPFEQ,2030,FEQ]

2.17806060606061
V_FlowOut[2040,inter,night,ethos,IMPGSL1,2030,GSL]

161.0293978825 V_FlowOut[2040,inter,night,ethos,IMPHYD,2030,HYD]

0.03334 V_FlowOut[2040,summer,day,DSL,TXD,2020,TX]

0.260052 V_FlowOut[2040,summer,day,DSL,TXD,2040,TX]

0.657083333333333 V_FlowOut[2040,summer,day,ELC,E51,2020,ELC]

7.22791666666667 V_FlowOut[2040,summer,day,ELC,E51,2030,ELC]

6.59762143725938 V_FlowOut[2040,summer,day,ELC,E51,2040,ELC]

180.0 V_FlowOut[2040,summer,day,ELC,RL1,2040,RL]

30.7576503 V_FlowOut[2040,summer,day,FEQ,E21,2030,ELC]

0.25005 V_FlowOut[2040,summer,day,GSL,TXG,2020,TX]

0.756818 V_FlowOut[2040,summer,day,GSL,TXG,2040,TX]

0.754482533 V_FlowOut[2040,summer,day,HCO,E01,2010,ELC]

0.754482533 V_FlowOut[2040,summer,day,HCO,E01,2020,ELC]

30.1300885191406 V_FlowOut[2040,summer,day,HCO,E01,2030,ELC]

0.15773154 V_FlowOut[2040,summer,day,HYD,E31,2020,ELC]

39.27515346 V_FlowOut[2040,summer,day,HYD,E31,2030,ELC]

63.6877896776 V_FlowOut[2040,summer,day,HYD,E31,2040,ELC]

1.27009523809524
V_FlowOut[2040,summer,day,ethos,IMPDSL1,2030,DSL]

96.1176571875
V_FlowOut[2040,summer,day,ethos,IMPFEQ,2030,FEQ]

4.35873593073593
V_FlowOut[2040,summer,day,ethos,IMPGSL1,2030,GSL]

98.8720424535645
V_FlowOut[2040,summer,day,ethos,IMPHCO1,2030,HCO]

322.2521083675
V_FlowOut[2040,summer,day,ethos,IMPHYD,2030,HYD]
0.01666 V_FlowOut[2040,summer,night,DSL,TXD,2020,TX]
0.129948 V_FlowOut[2040,summer,night,DSL,TXD,2040,TX]
0.328278833333333 V_FlowOut[2040,summer,night,ELC,E51,2020,ELC]
3.61106716666667 V_FlowOut[2040,summer,night,ELC,E51,2030,ELC]
2.73169057313807 V_FlowOut[2040,summer,night,ELC,E51,2040,ELC]
60.0 V_FlowOut[2040,summer,night,ELC,RL1,2040,RL]
15.3695997 V_FlowOut[2040,summer,night,FEQ,E21,2030,ELC]
0.12495 V_FlowOut[2040,summer,night,GSL,TXG,2020,TX]
0.378182 V_FlowOut[2040,summer,night,GSL,TXG,2040,TX]
0.377014967 V_FlowOut[2040,summer,night,HCO,E01,2010,ELC]
0.377014967 V_FlowOut[2040,summer,night,HCO,E01,2020,ELC]
15.0560070404584 V_FlowOut[2040,summer,night,HCO,E01,2030,ELC]
0.07881846 V_FlowOut[2040,summer,night,HYD,E31,2020,ELC]
19.62579654 V_FlowOut[2040,summer,night,HYD,E31,2030,ELC]
31.8247923224 V_FlowOut[2040,summer,night,HYD,E31,2040,ELC]
0.634666666666667
V_FlowOut[2040,summer,night,ethos,IMPDSL1,2030,DSL]
48.0299990625
V_FlowOut[2040,summer,night,ethos,IMPFEQ,2030,FEQ]
2.17806060606061
V_FlowOut[2040,summer,night,ethos,IMPGSL1,2030,GSL]
49.4063655451825
V_FlowOut[2040,summer,night,ethos,IMPHCO1,2030,HCO]
161.0293978825
V_FlowOut[2040,summer,night,ethos,IMPHYD,2030,HYD]
0.42049128 V_FlowOut[2040,winter,day,DSL,E70,2010,ELC]
1.68196512 V_FlowOut[2040,winter,day,DSL,E70,2020,ELC]
182.588711626308 V_FlowOut[2040,winter,day,DSL,E70,2030,ELC]
0.83325 V_FlowOut[2040,winter,day,DSL,RHO,2020,RH]
12.11034 V_FlowOut[2040,winter,day,DSL,RHO,2030,RH]
0.06666 V_FlowOut[2040,winter,day,DSL,TXD,2020,TX]
0.519948 V_FlowOut[2040,winter,day,DSL,TXD,2040,TX]

0.657083333333333 V_FlowOut[2040,winter,day,ELC,E51,2020,ELC]
7.22791666666667 V_FlowOut[2040,winter,day,ELC,E51,2030,ELC]
6.59762143725938 V_FlowOut[2040,winter,day,ELC,E51,2040,ELC]
7.72167 V_FlowOut[2040,winter,day,ELC,RHE,2040,RH]
600.0 V_FlowOut[2040,winter,day,ELC,RL1,2040,RL]
61.4968497 V_FlowOut[2040,winter,day,FEQ,E21,2030,ELC]
0.49995 V_FlowOut[2040,winter,day,GSL,TXG,2020,TX]
1.513182 V_FlowOut[2040,winter,day,GSL,TXG,2040,TX]
1.508512467 V_FlowOut[2040,winter,day,HCO,E01,2010,ELC]
1.508512467 V_FlowOut[2040,winter,day,HCO,E01,2020,ELC]
137.854516580033 V_FlowOut[2040,winter,day,HCO,E01,2030,ELC]
0.31536846 V_FlowOut[2040,winter,day,HYD,E31,2020,ELC]
78.52674654 V_FlowOut[2040,winter,day,HYD,E31,2030,ELC]
127.3373743224 V_FlowOut[2040,winter,day,HYD,E31,2040,ELC]
649.231523218735
V_FlowOut[2040,winter,day,ethos,IMPDSL1,2030,DSL]
192.1776553125 V_FlowOut[2040,winter,day,ethos,IMPFEQ,2030,FEQ]
8.71485714285714
V_FlowOut[2040,winter,day,ethos,IMPGSL1,2030,GSL]
440.223567231352
V_FlowOut[2040,winter,day,ethos,IMPHCO1,2030,HCO]
644.3109041325 V_FlowOut[2040,winter,day,ethos,IMPHYD,2030,HYD]
0.416548792756539 V_FlowOut[2040,winter,night,DSL,RHO,2020,RH]
6.05406241448692 V_FlowOut[2040,winter,night,DSL,RHO,2030,RH]
0.03334 V_FlowOut[2040,winter,night,DSL,TXD,2020,TX]
0.260052 V_FlowOut[2040,winter,night,DSL,TXD,2040,TX]
3.86012879275654 V_FlowOut[2040,winter,night,ELC,RHE,2040,RH]
120.0 V_FlowOut[2040,winter,night,ELC,RL1,2040,RL]
30.7576503 V_FlowOut[2040,winter,night,FEQ,E21,2030,ELC]
0.25005 V_FlowOut[2040,winter,night,GSL,TXG,2020,TX]
0.756818 V_FlowOut[2040,winter,night,GSL,TXG,2040,TX]
0.754482533 V_FlowOut[2040,winter,night,HCO,E01,2010,ELC]
0.754482533 V_FlowOut[2040,winter,night,HCO,E01,2020,ELC]
68.9479385355279 V_FlowOut[2040,winter,night,HCO,E01,2030,ELC]

0.15773154 V_FlowOut[2040,winter,night,HYD,E31,2020,ELC]
39.27515346 V_FlowOut[2040,winter,night,HYD,E31,2030,ELC]
63.6877896776 V_FlowOut[2040,winter,night,HYD,E31,2040,ELC]
10.5138255341573
V_FlowOut[2040,winter,night,ethos,IMPDSL1,2030,DSL]
96.1176571875 V_FlowOut[2040,winter,night,ethos,IMPFEQ,2030,FEQ]
4.35873593073593
V_FlowOut[2040,winter,night,ethos,IMPGSL1,2030,GSL]
220.177823754775
V_FlowOut[2040,winter,night,ethos,IMPHCO1,2030,HCO]
322.2521083675
V_FlowOut[2040,winter,night,ethos,IMPHYD,2030,HYD]
2.65820523138833 V_FlowOut[2050,inter,day,DSL,RHO,2030,RH]
0.130026 V_FlowOut[2050,inter,day,DSL,TXD,2040,TX]
0.663466 V_FlowOut[2050,inter,day,DSL,TXD,2050,TX]
2.628859 V_FlowOut[2050,inter,day,ELC,E51,2020,ELC]
25.0853063963464 V_FlowOut[2050,inter,day,ELC,E51,2030,ELC]
19.798142408928 V_FlowOut[2050,inter,day,ELC,E51,2040,ELC]
3.62447447090707 V_FlowOut[2050,inter,day,ELC,E51,2050,ELC]
1.69489738430583 V_FlowOut[2050,inter,day,ELC,RHE,2040,RH]
2.45089738430583 V_FlowOut[2050,inter,day,ELC,RHE,2050,RH]
195.0 V_FlowOut[2050,inter,day,ELC,RL1,2050,RL]
8.66266079483026 V_FlowOut[2050,inter,day,FEQ,E21,2030,ELC]
0.378409 V_FlowOut[2050,inter,day,GSL,TXG,2040,TX]
0.776822 V_FlowOut[2050,inter,day,GSL,TXG,2050,TX]
0.15773154 V_FlowOut[2050,inter,day,HYD,E31,2020,ELC]
39.27515346 V_FlowOut[2050,inter,day,HYD,E31,2030,ELC]
63.6877896776 V_FlowOut[2050,inter,day,HYD,E31,2040,ELC]
36.22567702 V_FlowOut[2050,inter,day,HYD,E31,2050,ELC]
7.23246634787078 V_FlowOut[2050,inter,day,ethos,IMPDSL1,2030,DSL]
27.0708149838445 V_FlowOut[2050,inter,day,ethos,IMPFEQ,2030,FEQ]
5.001 V_FlowOut[2050,inter,day,ethos,IMPGSL1,2030,GSL]
435.457349055 V_FlowOut[2050,inter,day,ethos,IMPHYD,2030,HYD]
1.32910261569416 V_FlowOut[2050,inter,night,DSL,RHO,2030,RH]

0.064974 V_FlowOut[2050,inter,night,DSL,TXD,2040,TX]

0.331534 V_FlowOut[2050,inter,night,DSL,TXD,2050,TX]

0.847448692152917 V_FlowOut[2050,inter,night,ELC,RHE,2040,RH]

1.22544869215292 V_FlowOut[2050,inter,night,ELC,RHE,2050,RH]

65.0 V_FlowOut[2050,inter,night,ELC,RL1,2050,RL]

4.3287321188324 V_FlowOut[2050,inter,night,FEQ,E21,2030,ELC]

0.189091 V_FlowOut[2050,inter,night,GSL,TXG,2040,TX]

0.388178 V_FlowOut[2050,inter,night,GSL,TXG,2050,TX]

0.07881846 V_FlowOut[2050,inter,night,HYD,E31,2020,ELC]

19.62579654 V_FlowOut[2050,inter,night,HYD,E31,2030,ELC]

31.8247923224 V_FlowOut[2050,inter,night,HYD,E31,2040,ELC]

18.10197298 V_FlowOut[2050,inter,night,HYD,E31,2050,ELC]

3.61520287090509

V_FlowOut[2050,inter,night,ethos,IMPDSL1,2030,DSL]

13.5272878713512 V_FlowOut[2050,inter,night,ethos,IMPFEQ,2030,FEQ]

2.499 V_FlowOut[2050,inter,night,ethos,IMPGSL1,2030,GSL]

217.598063445 V_FlowOut[2050,inter,night,ethos,IMPHYD,2030,HYD]

0.130026 V_FlowOut[2050,summer,day,DSL,TXD,2040,TX]

0.663466 V_FlowOut[2050,summer,day,DSL,TXD,2050,TX]

0.657083333333333 V_FlowOut[2050,summer,day,ELC,E51,2020,ELC]

7.22791666666667 V_FlowOut[2050,summer,day,ELC,E51,2030,ELC]

6.59762143725938 V_FlowOut[2050,summer,day,ELC,E51,2040,ELC]

0.905937430240719 V_FlowOut[2050,summer,day,ELC,E51,2050,ELC]

195.0 V_FlowOut[2050,summer,day,ELC,RL1,2050,RL]

30.7576503 V_FlowOut[2050,summer,day,FEQ,E21,2030,ELC]

0.378409 V_FlowOut[2050,summer,day,GSL,TXG,2040,TX]

0.776822 V_FlowOut[2050,summer,day,GSL,TXG,2050,TX]

9.50743913489988 V_FlowOut[2050,summer,day,HCO,E01,2030,ELC]

0.15773154 V_FlowOut[2050,summer,day,HYD,E31,2020,ELC]

39.27515346 V_FlowOut[2050,summer,day,HYD,E31,2030,ELC]

63.6877896776 V_FlowOut[2050,summer,day,HYD,E31,2040,ELC]

36.22567702 V_FlowOut[2050,summer,day,HYD,E31,2050,ELC]

3.4350303030303

V_FlowOut[2050,summer,day,ethos,IMPDSL1,2030,DSL]

96.1176571875
V_FlowOut[2050,summer,day,ethos,IMPFEQ,2030,FEQ]
5.001 V_FlowOut[2050,summer,day,ethos,IMPGSL1,2030,GSL]
29.7107472965621
V_FlowOut[2050,summer,day,ethos,IMPHCO1,2030,HCO]
435.457349055
V_FlowOut[2050,summer,day,ethos,IMPHYD,2030,HYD]
0.064974 V_FlowOut[2050,summer,night,DSL,TXD,2040,TX]
0.331534 V_FlowOut[2050,summer,night,DSL,TXD,2050,TX]
3.29617167005479 V_FlowOut[2050,summer,night,ELC,E51,2040,ELC]
1.92983831683168 V_FlowOut[2050,summer,night,ELC,RHE,2040,RH]
0.167166626171971 V_FlowOut[2050,summer,night,ELC,RHE,2050,RH]
65.0 V_FlowOut[2050,summer,night,ELC,RL1,2050,RL]
15.3695997 V_FlowOut[2050,summer,night,FEQ,E21,2030,ELC]
0.189091 V_FlowOut[2050,summer,night,GSL,TXG,2040,TX]
0.388178 V_FlowOut[2050,summer,night,GSL,TXG,2050,TX]
4.75086790604175 V_FlowOut[2050,summer,night,HCO,E01,2030,ELC]
0.07881846 V_FlowOut[2050,summer,night,HYD,E31,2020,ELC]
19.62579654 V_FlowOut[2050,summer,night,HYD,E31,2030,ELC]
31.8247923224 V_FlowOut[2050,summer,night,HYD,E31,2040,ELC]
18.10197298 V_FlowOut[2050,summer,night,HYD,E31,2050,ELC]
1.71648484848485
V_FlowOut[2050,summer,night,ethos,IMPDSL1,2030,DSL]
48.0299990625
V_FlowOut[2050,summer,night,ethos,IMPFEQ,2030,FEQ]
2.499 V_FlowOut[2050,summer,night,ethos,IMPGSL1,2030,GSL]
14.8464622063805
V_FlowOut[2050,summer,night,ethos,IMPHCO1,2030,HCO]
217.598063445
V_FlowOut[2050,summer,night,ethos,IMPHYD,2030,HYD]
1.68196512 V_FlowOut[2050,winter,day,DSL,E70,2020,ELC]
202.049690322399 V_FlowOut[2050,winter,day,DSL,E70,2030,ELC]
12.11034 V_FlowOut[2050,winter,day,DSL,RHO,2030,RH]
0.259974 V_FlowOut[2050,winter,day,DSL,TXD,2040,TX]

1.326534 V_FlowOut[2050,winter,day,DSL,TXD,2050,TX]
0.657083333333333 V_FlowOut[2050,winter,day,ELC,E51,2020,ELC]
7.22791666666667 V_FlowOut[2050,winter,day,ELC,E51,2030,ELC]
6.59762143725938 V_FlowOut[2050,winter,day,ELC,E51,2040,ELC]
0.905937430240719 V_FlowOut[2050,winter,day,ELC,E51,2050,ELC]
7.72167 V_FlowOut[2050,winter,day,ELC,RHE,2040,RH]
11.16588 V_FlowOut[2050,winter,day,ELC,RHE,2050,RH]
650.0 V_FlowOut[2050,winter,day,ELC,RL1,2050,RL]
61.4968497 V_FlowOut[2050,winter,day,FEQ,E21,2030,ELC]
0.756591 V_FlowOut[2050,winter,day,GSL,TXG,2040,TX]
1.553178 V_FlowOut[2050,winter,day,GSL,TXG,2050,TX]
1.508512467 V_FlowOut[2050,winter,day,HCO,E01,2020,ELC]
108.152861220701 V_FlowOut[2050,winter,day,HCO,E01,2030,ELC]
0.31536846 V_FlowOut[2050,winter,day,HYD,E31,2020,ELC]
78.52674654 V_FlowOut[2050,winter,day,HYD,E31,2030,ELC]
127.3373743224 V_FlowOut[2050,winter,day,HYD,E31,2040,ELC]
72.42962298 V_FlowOut[2050,winter,day,HYD,E31,2050,ELC]
717.133300144216
V_FlowOut[2050,winter,day,ethos,IMPDSL1,2030,DSL]
192.1776553125 V_FlowOut[2050,winter,day,ethos,IMPFEQ,2030,FEQ]
9.999 V_FlowOut[2050,winter,day,ethos,IMPGSL1,2030,GSL]
342.691792774065
V_FlowOut[2050,winter,day,ethos,IMPHCO1,2030,HCO]
870.653475945 V_FlowOut[2050,winter,day,ethos,IMPHYD,2030,HYD]
6.05406241448692 V_FlowOut[2050,winter,night,DSL,RHO,2030,RH]
0.130026 V_FlowOut[2050,winter,night,DSL,TXD,2040,TX]
0.663466 V_FlowOut[2050,winter,night,DSL,TXD,2050,TX]
3.86012879275654 V_FlowOut[2050,winter,night,ELC,RHE,2040,RH]
5.58191879275654 V_FlowOut[2050,winter,night,ELC,RHE,2050,RH]
130.0 V_FlowOut[2050,winter,night,ELC,RL1,2050,RL]
30.7576503 V_FlowOut[2050,winter,night,FEQ,E21,2030,ELC]
0.378409 V_FlowOut[2050,winter,night,GSL,TXG,2040,TX]
0.776822 V_FlowOut[2050,winter,night,GSL,TXG,2050,TX]
0.754482533 V_FlowOut[2050,winter,night,HCO,E01,2020,ELC]

54.0926551619886 V_FlowOut[2050,winter,night,HCO,E01,2030,ELC]

0.15773154 V_FlowOut[2050,winter,night,HYD,E31,2020,ELC]

39.27515346 V_FlowOut[2050,winter,night,HYD,E31,2030,ELC]

63.6877896776 V_FlowOut[2050,winter,night,HYD,E31,2040,ELC]

36.22567702 V_FlowOut[2050,winter,night,HYD,E31,2050,ELC]

12.0836908951545
V_FlowOut[2050,winter,night,ethos,IMPDSL1,2030,DSL]

96.1176571875 V_FlowOut[2050,winter,night,ethos,IMPFEQ,2030,FEQ]

5.001 V_FlowOut[2050,winter,night,ethos,IMPGSL1,2030,GSL]

171.397305296839
V_FlowOut[2050,winter,night,ethos,IMPHCO1,2030,HCO]

435.457349055 V_FlowOut[2050,winter,night,ethos,IMPHYD,2030,HYD]

0.657083333333333 V_StorageLevel[2030,inter,day,E51,2020]

0.274867418435715 V_StorageLevel[2030,inter,day,E51,2030]

0.657083333333333 V_StorageLevel[2030,inter,night,E51,2020]

7.22791666666667 V_StorageLevel[2030,inter,night,E51,2030]

0.657083333333333 V_StorageLevel[2030,summer,night,E51,2020]

7.22791666666667 V_StorageLevel[2030,summer,night,E51,2030]

0.657083333333333 V_StorageLevel[2040,inter,day,E51,2020]

2.87079466888878 V_StorageLevel[2040,inter,day,E51,2030]

6.59762143725938 V_StorageLevel[2040,inter,day,E51,2040]

0.657083333333333 V_StorageLevel[2040,inter,night,E51,2020]

7.22791666666667 V_StorageLevel[2040,inter,night,E51,2030]

6.59762143725938 V_StorageLevel[2040,inter,night,E51,2040]

0.657083333333333 V_StorageLevel[2040,summer,night,E51,2020]

7.22791666666667 V_StorageLevel[2040,summer,night,E51,2030]

6.59762143725938 V_StorageLevel[2040,summer,night,E51,2040]

3.83214260365359 V_StorageLevel[2050,inter,day,E51,2030]

6.59762143725938 V_StorageLevel[2050,inter,day,E51,2040]

0.657083333333333 V_StorageLevel[2050,inter,night,E51,2020]

7.22791666666667 V_StorageLevel[2050,inter,night,E51,2030]

6.59762143725938 V_StorageLevel[2050,inter,night,E51,2040]

0.905937430240719 V_StorageLevel[2050,inter,night,E51,2050]

0.657083333333333 V_StorageLevel[2050,summer,night,E51,2020]

7.22791666666667 V_StorageLevel[2050,summer,night,E51,2030]

6.59762143725938 V_StorageLevel[2050,summer,night,E51,2040]

0.905937430240719 V_StorageLevel[2050,summer,night,E51,2050]

Second scenario $956/kW for PSH

Non-zero variable values:

117.72911673378935

Costs[V_DiscountedFixedCostsByProcess,E01,2010]

171.20478930858923

Costs[V_DiscountedFixedCostsByProcess,E01,2020]

32920.2352013373 Costs[V_DiscountedFixedCostsByProcess,E01,2030]

52458.4891292377 Costs[V_DiscountedFixedCostsByProcess,E21,2030]

121.0580518367024 Costs[V_DiscountedFixedCostsByProcess,E31,2020]

30143.4549073389 Costs[V_DiscountedFixedCostsByProcess,E31,2030]

26509.731278523657

Costs[V_DiscountedFixedCostsByProcess,E31,2040]

5729.536347299987 Costs[V_DiscountedFixedCostsByProcess,E31,2050]

242.1161036734048 Costs[V_DiscountedFixedCostsByProcess,E51,2020]

5568.67038448831 Costs[V_DiscountedFixedCostsByProcess,E51,2030]

2276.3441639184775

Costs[V_DiscountedFixedCostsByProcess,E51,2040]

249.68568087791473
Costs[V_DiscountedFixedCostsByProcess,E51,2050]
12.161732513466088
Costs[V_DiscountedFixedCostsByProcess,E70,2000]
19.62798128950049 Costs[V_DiscountedFixedCostsByProcess,E70,2010]
96.8464414693619 Costs[V_DiscountedFixedCostsByProcess,E70,2020]
6135.789221878419 Costs[V_DiscountedFixedCostsByProcess,E70,2030]
20.26955418911015
Costs[V_DiscountedFixedCostsByProcess,RHO,2010]
32.71330214916748
Costs[V_DiscountedFixedCostsByProcess,RHO,2020]
586.480315023538 Costs[V_DiscountedFixedCostsByProcess,RHO,2030]
429.5199610889197 Costs[V_DiscountedFixedCostsByProcess,RL1,2020]
114631.97576587298
Costs[V_DiscountedFixedCostsByProcess,RL1,2030]
84765.33263880639 Costs[V_DiscountedFixedCostsByProcess,RL1,2040]
56375.10791006719 Costs[V_DiscountedFixedCostsByProcess,RL1,2050]
168.64269085339643
Costs[V_DiscountedFixedCostsByProcess,TXD,2010]
136.08733694053672
Costs[V_DiscountedFixedCostsByProcess,TXD,2020]
542.7593280291827
Costs[V_DiscountedFixedCostsByProcess,TXD,2040]
632.4185826331761
Costs[V_DiscountedFixedCostsByProcess,TXD,2050]
1206.443865335836
Costs[V_DiscountedFixedCostsByProcess,TXG,2010]
942.1431018960235
Costs[V_DiscountedFixedCostsByProcess,TXG,2020]
1458.0635202677452
Costs[V_DiscountedFixedCostsByProcess,TXG,2040]
683.5107680874992
Costs[V_DiscountedFixedCostsByProcess,TXG,2050]
63307.23148099307 Costs[V_DiscountedInvestmentByProcess,E01,2030]

30571.842840004087
Costs[V_DiscountedInvestmentByProcess,E21,2030]
24299.549607816585
Costs[V_DiscountedInvestmentByProcess,E31,2030]
21370.295219063897
Costs[V_DiscountedInvestmentByProcess,E31,2040]
4618.752333764758 Costs[V_DiscountedInvestmentByProcess,E31,2050]
9720.403564446742 Costs[V_DiscountedInvestmentByProcess,E51,2030]
3973.477041574601 Costs[V_DiscountedInvestmentByProcess,E51,2040]
435.83933234001404
Costs[V_DiscountedInvestmentByProcess,E51,2050]
7866.81528937592 Costs[V_DiscountedInvestmentByProcess,E70,2030]
1089.5990112753695
Costs[V_DiscountedInvestmentByProcess,RHE,2040]
599.3427284395307
Costs[V_DiscountedInvestmentByProcess,RHE,2050]
3815.1386138613825
Costs[V_DiscountedInvestmentByProcess,RHO,2030]
8.841553178503494 Costs[V_DiscountedInvestmentByProcess,SRE,2030]
1049.835865308953 Costs[V_DiscountedInvestmentByProcess,TXD,2040]
1223.259879009328 Costs[V_DiscountedInvestmentByProcess,TXD,2050]
3055.2915567324662
Costs[V_DiscountedInvestmentByProcess,TXG,2040]
1432.2590543174547
Costs[V_DiscountedInvestmentByProcess,TXG,2050]
16.077601042401067
Costs[V_DiscountedVariableCostsByProcess,E01,2010]
18.152146979402367
Costs[V_DiscountedVariableCostsByProcess,E01,2020]
2345.3646955895742
Costs[V_DiscountedVariableCostsByProcess,E01,2030]
3911.4322890324966
Costs[V_DiscountedVariableCostsByProcess,E21,2030]

1.3637073257613264
Costs[V_DiscountedVariableCostsByProcess,E70,2000]
1.3637073257613264
Costs[V_DiscountedVariableCostsByProcess,E70,2010]
7.51069709823054
Costs[V_DiscountedVariableCostsByProcess,E70,2020]
387.5862257719706
Costs[V_DiscountedVariableCostsByProcess,E70,2030]
18277.84856573188
Costs[V_DiscountedVariableCostsByProcess,IMPDSL1,2030]
5749.11955318714
Costs[V_DiscountedVariableCostsByProcess,IMPGSL1,2030]
49574.88424190372
Costs[V_DiscountedVariableCostsByProcess,IMPHCO1,2030]
192.5 Costs[V_UndiscountedFixedCostsByProcess,E01,2010]
367.5 Costs[V_UndiscountedFixedCostsByProcess,E01,2020]
70665.0 Costs[V_UndiscountedFixedCostsByProcess,E01,2030]
97500.0 Costs[V_UndiscountedFixedCostsByProcess,E21,2030]
225.0 Costs[V_UndiscountedFixedCostsByProcess,E31,2020]
56025.0 Costs[V_UndiscountedFixedCostsByProcess,E31,2030]
66000.0 Costs[V_UndiscountedFixedCostsByProcess,E31,2040]
18750.0 Costs[V_UndiscountedFixedCostsByProcess,E31,2050]
450.0 Costs[V_UndiscountedFixedCostsByProcess,E51,2020]
10350.0 Costs[V_UndiscountedFixedCostsByProcess,E51,2030]
5667.304328366862
Costs[V_UndiscountedFixedCostsByProcess,E51,2040]
817.1004131367599
Costs[V_UndiscountedFixedCostsByProcess,E51,2050]
15.0 Costs[V_UndiscountedFixedCostsByProcess,E70,2000]
30.0 Costs[V_UndiscountedFixedCostsByProcess,E70,2010]
180.0 Costs[V_UndiscountedFixedCostsByProcess,E70,2020]
11404.054120950988
Costs[V_UndiscountedFixedCostsByProcess,E70,2030]
25.0 Costs[V_UndiscountedFixedCostsByProcess,RHO,2010]

50.0 Costs[V_UndiscountedFixedCostsByProcess,RHO,2020]
1090.039603960395
Costs[V_UndiscountedFixedCostsByProcess,RHO,2030]
529.76 Costs[V_UndiscountedFixedCostsByProcess,RL1,2020]
141384.4314191419
Costs[V_UndiscountedFixedCostsByProcess,RL1,2030]
170297.0297029703
Costs[V_UndiscountedFixedCostsByProcess,RL1,2040]
184488.44884488446
Costs[V_UndiscountedFixedCostsByProcess,RL1,2050]
208.0 Costs[V_UndiscountedFixedCostsByProcess,TXD,2010]
208.0 Costs[V_UndiscountedFixedCostsByProcess,TXD,2020]
1216.8000000000002
Costs[V_UndiscountedFixedCostsByProcess,TXD,2040]
2069.6 Costs[V_UndiscountedFixedCostsByProcess,TXD,2050]
1488.0 Costs[V_UndiscountedFixedCostsByProcess,TXG,2010]
1440.0 Costs[V_UndiscountedFixedCostsByProcess,TXG,2020]
3268.8 Costs[V_UndiscountedFixedCostsByProcess,TXG,2040]
2236.8 Costs[V_UndiscountedFixedCostsByProcess,TXG,2050]
60292.6014104696
Costs[V_UndiscountedInvestmentByProcess,E01,2030]
29116.040800003895
Costs[V_UndiscountedInvestmentByProcess,E21,2030]
23142.428197920555
Costs[V_UndiscountedInvestmentByProcess,E31,2030]
33152.34195712461
Costs[V_UndiscountedInvestmentByProcess,E31,2040]
11671.35711219855
Costs[V_UndiscountedInvestmentByProcess,E31,2050]
9257.527204234992
Costs[V_UndiscountedInvestmentByProcess,E51,2030]
6164.167050137517
Costs[V_UndiscountedInvestmentByProcess,E51,2040]

1101.344286008987
Costs[V_UndiscountedInvestmentByProcess,E51,2050]
7492.205037500877
Costs[V_UndiscountedInvestmentByProcess,E70,2030]
1690.325690293774
Costs[V_UndiscountedInvestmentByProcess,RHE,2040]
1514.5092247272412
Costs[V_UndiscountedInvestmentByProcess,RHE,2050]
3633.46534653465
Costs[V_UndiscountedInvestmentByProcess,RHO,2030]
8.420526836669994
Costs[V_UndiscountedInvestmentByProcess,SRE,2030]
1628.64 Costs[V_UndiscountedInvestmentByProcess,TXD,2040]
3091.116790257803
Costs[V_UndiscountedInvestmentByProcess,TXD,2050]
4739.76 Costs[V_UndiscountedInvestmentByProcess,TXG,2040]
3619.247297136021
Costs[V_UndiscountedInvestmentByProcess,TXG,2050]
23.7614475
Costs[V_UndiscountedVariableCostsByProcess,E01,2010]
30.5504325
Costs[V_UndiscountedVariableCostsByProcess,E01,2020]
4318.921007256845
Costs[V_UndiscountedVariableCostsByProcess,E01,2030]
6919.0875 Costs[V_UndiscountedVariableCostsByProcess,E21,2030]
1.68196512
Costs[V_UndiscountedVariableCostsByProcess,E70,2000]
1.68196512
Costs[V_UndiscountedVariableCostsByProcess,E70,2010]
13.45572096
Costs[V_UndiscountedVariableCostsByProcess,E70,2020]
516.4226684389399
Costs[V_UndiscountedVariableCostsByProcess,E70,2030]

26357.75136066462
Costs[V_UndiscountedVariableCostsByProcess,IMPDSL1,2030]
11409.090909090912
Costs[V_UndiscountedVariableCostsByProcess,IMPGSL1,2030]
91109.01848451761
Costs[V_UndiscountedVariableCostsByProcess,IMPHCO1,2030]
684112.6275754565 Objective[('TotalCost')]
33.65 V_Capacity[E01,2030]
6.5 V_Capacity[E21,2030]
24.9 V_Capacity[E31,2030]
44.0 V_Capacity[E31,2040]
25.0 V_Capacity[E31,2050]
11.5 V_Capacity[E51,2030]
9.44550721394477 V_Capacity[E51,2040]
2.7236680437892 V_Capacity[E51,2050]
12.6711712455011 V_Capacity[E70,2030]
1174.87341389649 V_Capacity[IMPDSL1,2030]
576.590625 V_Capacity[IMPFEQ,2030]
30.0 V_Capacity[IMPGSL1,2030]
2747.9225 V_Capacity[IMPHCO1,2030]
2612.22165 V_Capacity[IMPHYD,2030]
23.1673267326731 V_Capacity[RHE,2040]
33.5009900990097 V_Capacity[RHE,2050]
2.5 V_Capacity[RHO,2010]
2.5 V_Capacity[RHO,2020]
36.3346534653465 V_Capacity[RHO,2030]
5.6 V_Capacity[RL1,2020]
1494.5500150015 V_Capacity[RL1,2030]
1800.1800180018 V_Capacity[RL1,2040]
1950.19501950195 V_Capacity[RL1,2050]
0.1 V_Capacity[SRE,2030]
0.4 V_Capacity[TXD,2010]
0.2 V_Capacity[TXD,2020]
1.56 V_Capacity[TXD,2040]

3.98 V_Capacity[TXD,2050]

3.1 V_Capacity[TXG,2010]

1.5 V_Capacity[TXG,2020]

4.54 V_Capacity[TXG,2040]

4.66 V_Capacity[TXG,2050]

34.0 V_CapacityAvailableByPeriodAndTech[2030,E01]

6.5 V_CapacityAvailableByPeriodAndTech[2030,E21]

25.0 V_CapacityAvailableByPeriodAndTech[2030,E31]

12.0 V_CapacityAvailableByPeriodAndTech[2030,E51]

12.9711712455011 V_CapacityAvailableByPeriodAndTech[2030,E70]

1174.87341389649

V_CapacityAvailableByPeriodAndTech[2030,IMPDSL1]

576.590625 V_CapacityAvailableByPeriodAndTech[2030,IMPFEQ]

30.0 V_CapacityAvailableByPeriodAndTech[2030,IMPGSL1]

2747.9225 V_CapacityAvailableByPeriodAndTech[2030,IMPHCO1]

2612.22165 V_CapacityAvailableByPeriodAndTech[2030,IMPHYD]

41.3346534653465 V_CapacityAvailableByPeriodAndTech[2030,RHO]

1500.1500150015 V_CapacityAvailableByPeriodAndTech[2030,RL1]

0.1 V_CapacityAvailableByPeriodAndTech[2030,SRE]

0.6 V_CapacityAvailableByPeriodAndTech[2030,TXD]

4.6 V_CapacityAvailableByPeriodAndTech[2030,TXG]

34.0 V_CapacityAvailableByPeriodAndTech[2040,E01]

6.5 V_CapacityAvailableByPeriodAndTech[2040,E21]

69.0 V_CapacityAvailableByPeriodAndTech[2040,E31]

21.4455072139448 V_CapacityAvailableByPeriodAndTech[2040,E51]

12.9211712455011 V_CapacityAvailableByPeriodAndTech[2040,E70]

1174.87341389649

V_CapacityAvailableByPeriodAndTech[2040,IMPDSL1]

576.590625 V_CapacityAvailableByPeriodAndTech[2040,IMPFEQ]

30.0 V_CapacityAvailableByPeriodAndTech[2040,IMPGSL1]

2747.9225 V_CapacityAvailableByPeriodAndTech[2040,IMPHCO1]

2612.22165 V_CapacityAvailableByPeriodAndTech[2040,IMPHYD]

23.1673267326731 V_CapacityAvailableByPeriodAndTech[2040,RHE]

38.8346534653465 V_CapacityAvailableByPeriodAndTech[2040,RHO]

1800.1800180018 V_CapacityAvailableByPeriodAndTech[2040,RL1]
0.1 V_CapacityAvailableByPeriodAndTech[2040,SRE]
1.76 V_CapacityAvailableByPeriodAndTech[2040,TXD]
6.04 V_CapacityAvailableByPeriodAndTech[2040,TXG]
33.825 V_CapacityAvailableByPeriodAndTech[2050,E01]
6.5 V_CapacityAvailableByPeriodAndTech[2050,E21]
94.0 V_CapacityAvailableByPeriodAndTech[2050,E31]
24.169175257734 V_CapacityAvailableByPeriodAndTech[2050,E51]
12.8711712455011 V_CapacityAvailableByPeriodAndTech[2050,E70]
1174.87341389649
V_CapacityAvailableByPeriodAndTech[2050,IMPDSL1]
576.590625 V_CapacityAvailableByPeriodAndTech[2050,IMPFEQ]
30.0 V_CapacityAvailableByPeriodAndTech[2050,IMPGSL1]
2747.9225 V_CapacityAvailableByPeriodAndTech[2050,IMPHCO1]
2612.22165 V_CapacityAvailableByPeriodAndTech[2050,IMPHYD]
56.6683168316828 V_CapacityAvailableByPeriodAndTech[2050,RHE]
36.3346534653465 V_CapacityAvailableByPeriodAndTech[2050,RHO]
1950.19501950195 V_CapacityAvailableByPeriodAndTech[2050,RL1]
0.1 V_CapacityAvailableByPeriodAndTech[2050,SRE]
4.76 V_CapacityAvailableByPeriodAndTech[2050,TXD]
6.93 V_CapacityAvailableByPeriodAndTech[2050,TXG]
30.72268478725397
V_EmissionActivityByPeriodAndProcess[2030,co2,IMPDSL1,2030]
1.493506493506494
V_EmissionActivityByPeriodAndProcess[2030,co2,IMPGSL1,2030]
139.00677947073825
V_EmissionActivityByPeriodAndProcess[2030,co2,IMPHCO1,2030]
0.4 V_EmissionActivityByPeriodAndProcess[2030,nox,TXD,2010]
0.20000000000000004
V_EmissionActivityByPeriodAndProcess[2030,nox,TXD,2020]
3.1 V_EmissionActivityByPeriodAndProcess[2030,nox,TXG,2010]
1.5 V_EmissionActivityByPeriodAndProcess[2030,nox,TXG,2020]
7.8989278679092045
V_EmissionActivityByPeriodAndProcess[2040,co2,IMPDSL1,2030]

1.9610389610389611
V_EmissionActivityByPeriodAndProcess[2040,co2,IMPGSL1,2030]
137.84388864284253
V_EmissionActivityByPeriodAndProcess[2040,co2,IMPHCO1,2030]
0.20000000000000004
V_EmissionActivityByPeriodAndProcess[2040,nox,TXD,2020]
1.5599999999999998
V_EmissionActivityByPeriodAndProcess[2040,nox,TXD,2040]
1.5 V_EmissionActivityByPeriodAndProcess[2040,nox,TXG,2020]
4.54 V_EmissionActivityByPeriodAndProcess[2040,nox,TXG,2040]
5.307972945944525
V_EmissionActivityByPeriodAndProcess[2050,co2,IMPDSL1,2030]
2.2500000000000004
V_EmissionActivityByPeriodAndProcess[2050,co2,IMPGSL1,2030]
128.5844641425226
V_EmissionActivityByPeriodAndProcess[2050,co2,IMPHCO1,2030]
0.7799999999999999
V_EmissionActivityByPeriodAndProcess[2050,nox,TXD,2040]
3.9800000000000004
V_EmissionActivityByPeriodAndProcess[2050,nox,TXD,2050]
2.27 V_EmissionActivityByPeriodAndProcess[2050,nox,TXG,2040]
4.66 V_EmissionActivityByPeriodAndProcess[2050,nox,TXG,2050]
0.2612819775797643 V_FlowIn[2030,inter,day,DSL,RHO,2010,RH]
0.2612819775797643 V_FlowIn[2030,inter,day,DSL,RHO,2020,RH]
3.7974360448404716 V_FlowIn[2030,inter,day,DSL,RHO,2030,RH]
0.28865800865800867 V_FlowIn[2030,inter,day,DSL,TXD,2010,TX]
0.14432900432900433 V_FlowIn[2030,inter,day,DSL,TXD,2020,TX]
0.559944 V_FlowIn[2030,inter,day,ELC,RL1,2020,RL]
149.440056 V_FlowIn[2030,inter,day,ELC,RL1,2030,RL]
96.1176571875 V_FlowIn[2030,inter,day,FEQ,E21,2030,ELC]
2.2370995670995666 V_FlowIn[2030,inter,day,GSL,TXG,2010,TX]
1.0824675324675324 V_FlowIn[2030,inter,day,GSL,TXG,2020,TX]
2.357757915625 V_FlowIn[2030,inter,day,HCO,E01,2010,ELC]
2.357757915625 V_FlowIn[2030,inter,day,HCO,E01,2020,ELC]

94.64174592585593 V_FlowIn[2030,inter,day,HCO,E01,2030,ELC]
0.4929110625 V_FlowIn[2030,inter,day,HYD,E31,2020,ELC]
122.73485456249999 V_FlowIn[2030,inter,day,HYD,E31,2030,ELC]
4.75298701298701 V_FlowIn[2030,inter,day,ethos,IMPDSL1,2030,DSL]
96.1176571875 V_FlowIn[2030,inter,day,ethos,IMPFEQ,2030,FEQ]
3.3195670995671 V_FlowIn[2030,inter,day,ethos,IMPGSL1,2030,GSL]
99.3572617571059 V_FlowIn[2030,inter,day,ethos,IMPHCO1,2030,HCO]
123.227765625 V_FlowIn[2030,inter,day,ethos,IMPHYD,2030,HYD]
0.13064098878988215 V_FlowIn[2030,inter,night,DSL,RHO,2010,RH]
0.13064098878988215 V_FlowIn[2030,inter,night,DSL,RHO,2020,RH]
1.898718022420229 V_FlowIn[2030,inter,night,DSL,RHO,2030,RH]
0.14424242424242426 V_FlowIn[2030,inter,night,DSL,TXD,2010,TX]
0.07212121212121213 V_FlowIn[2030,inter,night,DSL,TXD,2020,TX]
0.961840191286236 V_FlowIn[2030,inter,night,ELC,E51,2030,ELC]
0.186648 V_FlowIn[2030,inter,night,ELC,RL1,2020,RL]
49.813352 V_FlowIn[2030,inter,night,ELC,RL1,2030,RL]
48.029999062499996 V_FlowIn[2030,inter,night,FEQ,E21,2030,ELC]
1.117878787878788 V_FlowIn[2030,inter,night,GSL,TXG,2010,TX]
0.5409090909090909 V_FlowIn[2030,inter,night,GSL,TXG,2020,TX]
1.178171771875 V_FlowIn[2030,inter,night,HCO,E01,2010,ELC]
1.178171771875 V_FlowIn[2030,inter,night,HCO,E01,2020,ELC]
47.29248611651938 V_FlowIn[2030,inter,night,HCO,E01,2030,ELC]
0.2463076875 V_FlowIn[2030,inter,night,HYD,E31,2020,ELC]
61.3306141875 V_FlowIn[2030,inter,night,HYD,E31,2030,ELC]
2.37636363636364 V_FlowIn[2030,inter,night,ethos,IMPDSL1,2030,DSL]
48.0299990625 V_FlowIn[2030,inter,night,ethos,IMPFEQ,2030,FEQ]
1.65878787878788 V_FlowIn[2030,inter,night,ethos,IMPGSL1,2030,GSL]
49.6488296602695
V_FlowIn[2030,inter,night,ethos,IMPHCO1,2030,HCO]
61.576921875 V_FlowIn[2030,inter,night,ethos,IMPHYD,2030,HYD]
0.28865800865800867 V_FlowIn[2030,summer,day,DSL,TXD,2010,TX]
0.14432900432900433 V_FlowIn[2030,summer,day,DSL,TXD,2020,TX]
0.559944 V_FlowIn[2030,summer,day,ELC,RL1,2020,RL]
149.440056 V_FlowIn[2030,summer,day,ELC,RL1,2030,RL]

96.1176571875 V_FlowIn[2030,summer,day,FEQ,E21,2030,ELC]
2.2370995670995666 V_FlowIn[2030,summer,day,GSL,TXG,2010,TX]
1.0824675324675324 V_FlowIn[2030,summer,day,GSL,TXG,2020,TX]
2.357757915625 V_FlowIn[2030,summer,day,HCO,E01,2010,ELC]
2.357757915625 V_FlowIn[2030,summer,day,HCO,E01,2020,ELC]
203.39664398520063 V_FlowIn[2030,summer,day,HCO,E01,2030,ELC]
0.4929110625 V_FlowIn[2030,summer,day,HYD,E31,2020,ELC]
122.73485456249999 V_FlowIn[2030,summer,day,HYD,E31,2030,ELC]
0.432987012987013
V_FlowIn[2030,summer,day,ethos,IMPDSL1,2030,DSL]
96.1176571875 V_FlowIn[2030,summer,day,ethos,IMPFEQ,2030,FEQ]
3.3195670995671
V_FlowIn[2030,summer,day,ethos,IMPGSL1,2030,GSL]
208.112159816451
V_FlowIn[2030,summer,day,ethos,IMPHCO1,2030,HCO]
123.227765625 V_FlowIn[2030,summer,day,ethos,IMPHYD,2030,HYD]
0.14424242424242426 V_FlowIn[2030,summer,night,DSL,TXD,2010,TX]
0.07212121212121213 V_FlowIn[2030,summer,night,DSL,TXD,2020,TX]
0.91261574074074 V_FlowIn[2030,summer,night,ELC,E51,2020,ELC]
17.4395697575035 V_FlowIn[2030,summer,night,ELC,E51,2030,ELC]
0.186648 V_FlowIn[2030,summer,night,ELC,RL1,2020,RL]
49.813352 V_FlowIn[2030,summer,night,ELC,RL1,2030,RL]
48.029999062499996 V_FlowIn[2030,summer,night,FEQ,E21,2030,ELC]
1.117878787878788 V_FlowIn[2030,summer,night,GSL,TXG,2010,TX]
0.5409090909090909 V_FlowIn[2030,summer,night,GSL,TXG,2020,TX]
1.178171771875 V_FlowIn[2030,summer,night,HCO,E01,2010,ELC]
1.178171771875 V_FlowIn[2030,summer,night,HCO,E01,2020,ELC]
101.63731520076313 V_FlowIn[2030,summer,night,HCO,E01,2030,ELC]
0.2463076875 V_FlowIn[2030,summer,night,HYD,E31,2020,ELC]
61.3306141875 V_FlowIn[2030,summer,night,HYD,E31,2030,ELC]
0.216363636363636
V_FlowIn[2030,summer,night,ethos,IMPDSL1,2030,DSL]
48.0299990625 V_FlowIn[2030,summer,night,ethos,IMPFEQ,2030,FEQ]

1.65878787878788
V_FlowIn[2030,summer,night,ethos,IMPGSL1,2030,GSL]
103.993658744513
V_FlowIn[2030,summer,night,ethos,IMPHCO1,2030,HCO]
61.576921875 V_FlowIn[2030,summer,night,ethos,IMPHYD,2030,HYD]
1.430242448979592 V_FlowIn[2030,winter,day,DSL,E70,2000,ELC]
1.430242448979592 V_FlowIn[2030,winter,day,DSL,E70,2010,ELC]
5.720969795918368 V_FlowIn[2030,winter,day,DSL,E70,2020,ELC]
362.45693987210547 V_FlowIn[2030,winter,day,DSL,E70,2030,ELC]
1.190357142857143 V_FlowIn[2030,winter,day,DSL,RHO,2010,RH]
1.190357142857143 V_FlowIn[2030,winter,day,DSL,RHO,2020,RH]
17.300485714285717 V_FlowIn[2030,winter,day,DSL,RHO,2030,RH]
0.5771428571428571 V_FlowIn[2030,winter,day,DSL,TXD,2010,TX]
0.28857142857142853 V_FlowIn[2030,winter,day,DSL,TXD,2020,TX]
1.86648 V_FlowIn[2030,winter,day,ELC,RL1,2020,RL]
498.13352 V_FlowIn[2030,winter,day,ELC,RL1,2030,RL]
192.17765531249998 V_FlowIn[2030,winter,day,FEQ,E21,2030,ELC]
4.472857142857143 V_FlowIn[2030,winter,day,GSL,TXG,2010,TX]
2.164285714285714 V_FlowIn[2030,winter,day,GSL,TXG,2020,TX]
4.714101459375001 V_FlowIn[2030,winter,day,HCO,E01,2010,ELC]
4.714101459375001 V_FlowIn[2030,winter,day,HCO,E01,2020,ELC]
724.3397573862532 V_FlowIn[2030,winter,day,HCO,E01,2030,ELC]
0.9855264375 V_FlowIn[2030,winter,day,HYD,E31,2020,ELC]
245.3960829375 V_FlowIn[2030,winter,day,HYD,E31,2030,ELC]
391.585308851698 V_FlowIn[2030,winter,day,ethos,IMPDSL1,2030,DSL]
192.1776553125 V_FlowIn[2030,winter,day,ethos,IMPFEQ,2030,FEQ]
6.63714285714286 V_FlowIn[2030,winter,day,ethos,IMPGSL1,2030,GSL]
733.767960305002
V_FlowIn[2030,winter,day,ethos,IMPHCO1,2030,HCO]
246.381609375 V_FlowIn[2030,winter,day,ethos,IMPHYD,2030,HYD]
0.5950697039379129 V_FlowIn[2030,winter,night,DSL,RHO,2010,RH]
0.5950697039379129 V_FlowIn[2030,winter,night,DSL,RHO,2020,RH]
8.648660592124173 V_FlowIn[2030,winter,night,DSL,RHO,2030,RH]
0.28865800865800867 V_FlowIn[2030,winter,night,DSL,TXD,2010,TX]

0.14432900432900433 V_FlowIn[2030,winter,night,DSL,TXD,2020,TX]
3.65119305555556 V_FlowIn[2030,winter,night,ELC,E51,2020,ELC]
83.9774402777778 V_FlowIn[2030,winter,night,ELC,E51,2030,ELC]
0.373296 V_FlowIn[2030,winter,night,ELC,RL1,2020,RL]
99.626704 V_FlowIn[2030,winter,night,ELC,RL1,2030,RL]
96.1176571875 V_FlowIn[2030,winter,night,FEQ,E21,2030,ELC]
2.2370995670995666 V_FlowIn[2030,winter,night,GSL,TXG,2010,TX]
1.0824675324675324 V_FlowIn[2030,winter,night,GSL,TXG,2020,TX]
2.357757915625 V_FlowIn[2030,winter,night,HCO,E01,2010,ELC]
2.357757915625 V_FlowIn[2030,winter,night,HCO,E01,2020,ELC]
362.27854052291565 V_FlowIn[2030,winter,night,HCO,E01,2030,ELC]
0.4929110625 V_FlowIn[2030,winter,night,HYD,E31,2020,ELC]
122.73485456249999 V_FlowIn[2030,winter,night,HYD,E31,2030,ELC]
10.271787012987 V_FlowIn[2030,winter,night,ethos,IMPDSL1,2030,DSL]
96.1176571875 V_FlowIn[2030,winter,night,ethos,IMPFEQ,2030,FEQ]
3.3195670995671
V_FlowIn[2030,winter,night,ethos,IMPGSL1,2030,GSL]
366.994056354167
V_FlowIn[2030,winter,night,ethos,IMPHCO1,2030,HCO]
123.227765625 V_FlowIn[2030,winter,night,ethos,IMPHYD,2030,HYD]
0.2612819775797643 V_FlowIn[2040,inter,day,DSL,RHO,2020,RH]
3.7974360448404716 V_FlowIn[2040,inter,day,DSL,RHO,2030,RH]
0.14432900432900433 V_FlowIn[2040,inter,day,DSL,TXD,2020,TX]
1.1257662337662337 V_FlowIn[2040,inter,day,DSL,TXD,2040,TX]
0.456307870370376 V_FlowIn[2040,inter,day,ELC,E51,2020,ELC]
10.4950810185185 V_FlowIn[2040,inter,day,ELC,E51,2030,ELC]
8.62011856272619 V_FlowIn[2040,inter,day,ELC,E51,2040,ELC]
1.69489738430583 V_FlowIn[2040,inter,day,ELC,RHE,2040,RH]
180.0 V_FlowIn[2040,inter,day,ELC,RL1,2040,RL]
1.0824675324675324 V_FlowIn[2040,inter,day,GSL,TXG,2020,TX]
3.276268398268398 V_FlowIn[2040,inter,day,GSL,TXG,2040,TX]
0.4929110625 V_FlowIn[2040,inter,day,HYD,E31,2020,ELC]
122.73485456249999 V_FlowIn[2040,inter,day,HYD,E31,2030,ELC]
197.40804969748936 V_FlowIn[2040,inter,day,HYD,E31,2040,ELC]

5.32881326051549 V_FlowIn[2040,inter,day,ethos,IMPDSL1,2030,DSL]
4.35873593073593 V_FlowIn[2040,inter,day,ethos,IMPGSL1,2030,GSL]
320.635815322489 V_FlowIn[2040,inter,day,ethos,IMPHYD,2030,HYD]
0.13064098878988215 V_FlowIn[2040,inter,night,DSL,RHO,2020,RH]
1.8987180224202431 V_FlowIn[2040,inter,night,DSL,RHO,2030,RH]
0.07212121212121213 V_FlowIn[2040,inter,night,DSL,TXD,2020,TX]
0.5625454545454546 V_FlowIn[2040,inter,night,DSL,TXD,2040,TX]
0.847448692152913 V_FlowIn[2040,inter,night,ELC,RHE,2040,RH]
60.0 V_FlowIn[2040,inter,night,ELC,RL1,2040,RL]
0.5409090909090909 V_FlowIn[2040,inter,night,GSL,TXG,2020,TX]
1.6371515151515152 V_FlowIn[2040,inter,night,GSL,TXG,2040,TX]
0.2463076875 V_FlowIn[2040,inter,night,HYD,E31,2020,ELC]
61.3306141875 V_FlowIn[2040,inter,night,HYD,E31,2030,ELC]
98.64481427595 V_FlowIn[2040,inter,night,HYD,E31,2040,ELC]
2.66402567787679 V_FlowIn[2040,inter,night,ethos,IMPDSL1,2030,DSL]
2.17806060606061 V_FlowIn[2040,inter,night,ethos,IMPGSL1,2030,GSL]
160.22173615095 V_FlowIn[2040,inter,night,ethos,IMPHYD,2030,HYD]
0.14432900432900433 V_FlowIn[2040,summer,day,DSL,TXD,2020,TX]
1.1257662337662337 V_FlowIn[2040,summer,day,DSL,TXD,2040,TX]
180.0 V_FlowIn[2040,summer,day,ELC,RL1,2040,RL]
96.1176571875 V_FlowIn[2040,summer,day,FEQ,E21,2030,ELC]
1.0824675324675324 V_FlowIn[2040,summer,day,GSL,TXG,2020,TX]
3.276268398268398 V_FlowIn[2040,summer,day,GSL,TXG,2040,TX]
2.357757915625 V_FlowIn[2040,summer,day,HCO,E01,2010,ELC]
2.357757915625 V_FlowIn[2040,summer,day,HCO,E01,2020,ELC]
111.87212207377688 V_FlowIn[2040,summer,day,HCO,E01,2030,ELC]
0.4929110625 V_FlowIn[2040,summer,day,HYD,E31,2020,ELC]
122.73485456249999 V_FlowIn[2040,summer,day,HYD,E31,2030,ELC]
199.0243427425 V_FlowIn[2040,summer,day,HYD,E31,2040,ELC]
1.27009523809524
V_FlowIn[2040,summer,day,ethos,IMPDSL1,2030,DSL]
96.1176571875 V_FlowIn[2040,summer,day,ethos,IMPFEQ,2030,FEQ]
4.35873593073593
V_FlowIn[2040,summer,day,ethos,IMPGSL1,2030,GSL]

116.587637905027
V_FlowIn[2040,summer,day,ethos,IMPHCO1,2030,HCO]
322.2521083675 V_FlowIn[2040,summer,day,ethos,IMPHYD,2030,HYD]
0.07212121212121213 V_FlowIn[2040,summer,night,DSL,TXD,2020,TX]
0.5625454545454546 V_FlowIn[2040,summer,night,DSL,TXD,2040,TX]
0.912615740740741 V_FlowIn[2040,summer,night,ELC,E51,2020,ELC]
7.38898604580727 V_FlowIn[2040,summer,night,ELC,E51,2030,ELC]
17.2402371254524 V_FlowIn[2040,summer,night,ELC,E51,2040,ELC]
60.0 V_FlowIn[2040,summer,night,ELC,RL1,2040,RL]
48.029999062499996 V_FlowIn[2040,summer,night,FEQ,E21,2030,ELC]
0.5409090909090909 V_FlowIn[2040,summer,night,GSL,TXG,2020,TX]
1.6371515151515152 V_FlowIn[2040,summer,night,GSL,TXG,2040,TX]
1.178171771875 V_FlowIn[2040,summer,night,HCO,E01,2010,ELC]
1.178171771875 V_FlowIn[2040,summer,night,HCO,E01,2020,ELC]
55.90250611125156 V_FlowIn[2040,summer,night,HCO,E01,2030,ELC]
0.2463076875 V_FlowIn[2040,summer,night,HYD,E31,2020,ELC]
61.3306141875 V_FlowIn[2040,summer,night,HYD,E31,2030,ELC]
99.4524760075 V_FlowIn[2040,summer,night,HYD,E31,2040,ELC]
0.634666666666667
V_FlowIn[2040,summer,night,ethos,IMPDSL1,2030,DSL]
48.0299990625 V_FlowIn[2040,summer,night,ethos,IMPFEQ,2030,FEQ]
2.17806060606061
V_FlowIn[2040,summer,night,ethos,IMPGSL1,2030,GSL]
58.2588496550015
V_FlowIn[2040,summer,night,ethos,IMPHCO1,2030,HCO]
161.0293978825
V_FlowIn[2040,summer,night,ethos,IMPHYD,2030,HYD]
63.87734043290646 V_FlowIn[2040,winter,day,DSL,E70,2030,ELC]
1.190357142857143 V_FlowIn[2040,winter,day,DSL,RHO,2020,RH]
17.300485714285717 V_FlowIn[2040,winter,day,DSL,RHO,2030,RH]
0.28857142857142853 V_FlowIn[2040,winter,day,DSL,TXD,2020,TX]
2.2508571428571424 V_FlowIn[2040,winter,day,DSL,TXD,2040,TX]
7.72166999999995 V_FlowIn[2040,winter,day,ELC,RHE,2040,RH]
600.0 V_FlowIn[2040,winter,day,ELC,RL1,2040,RL]

192.17765531249998 V_FlowIn[2040,winter,day,FEQ,E21,2030,ELC]
2.164285714285714 V_FlowIn[2040,winter,day,GSL,TXG,2020,TX]
6.550571428571429 V_FlowIn[2040,winter,day,GSL,TXG,2040,TX]
4.714101459375001 V_FlowIn[2040,winter,day,HCO,E01,2010,ELC]
4.714101459375001 V_FlowIn[2040,winter,day,HCO,E01,2020,ELC]
906.4543663312501 V_FlowIn[2040,winter,day,HCO,E01,2030,ELC]
0.9855264375 V_FlowIn[2040,winter,day,HYD,E31,2020,ELC]
245.3960829375 V_FlowIn[2040,winter,day,HYD,E31,2030,ELC]
397.9292947575 V_FlowIn[2040,winter,day,HYD,E31,2040,ELC]
84.9076118614778 V_FlowIn[2040,winter,day,ethos,IMPDSL1,2030,DSL]
192.1776553125 V_FlowIn[2040,winter,day,ethos,IMPFEQ,2030,FEQ]
8.71485714285714 V_FlowIn[2040,winter,day,ethos,IMPGSL1,2030,GSL]
915.88256925 V_FlowIn[2040,winter,day,ethos,IMPHCO1,2030,HCO]
644.3109041325 V_FlowIn[2040,winter,day,ethos,IMPHYD,2030,HYD]
0.5950697039379129 V_FlowIn[2040,winter,night,DSL,RHO,2020,RH]
8.648660592124173 V_FlowIn[2040,winter,night,DSL,RHO,2030,RH]
0.14432900432900433 V_FlowIn[2040,winter,night,DSL,TXD,2020,TX]
1.1257662337662337 V_FlowIn[2040,winter,night,DSL,TXD,2040,TX]
3.65119305555556 V_FlowIn[2040,winter,night,ELC,E51,2020,ELC]
83.9774402777778 V_FlowIn[2040,winter,night,ELC,E51,2030,ELC]
68.9747406915101 V_FlowIn[2040,winter,night,ELC,E51,2040,ELC]
3.86012879275652 V_FlowIn[2040,winter,night,ELC,RHE,2040,RH]
120.0 V_FlowIn[2040,winter,night,ELC,RL1,2040,RL]
96.1176571875 V_FlowIn[2040,winter,night,FEQ,E21,2030,ELC]
1.0824675324675324 V_FlowIn[2040,winter,night,GSL,TXG,2020,TX]
3.276268398268398 V_FlowIn[2040,winter,night,GSL,TXG,2040,TX]
2.357757915625 V_FlowIn[2040,winter,night,HCO,E01,2010,ELC]
2.357757915625 V_FlowIn[2040,winter,night,HCO,E01,2020,ELC]
453.36316491875 V_FlowIn[2040,winter,night,HCO,E01,2030,ELC]
0.4929110625 V_FlowIn[2040,winter,night,HYD,E31,2020,ELC]
122.73485456249999 V_FlowIn[2040,winter,night,HYD,E31,2030,ELC]
199.0243427425 V_FlowIn[2040,winter,night,HYD,E31,2040,ELC]
10.5138255341574
V_FlowIn[2040,winter,night,ethos,IMPDSL1,2030,DSL]

96.1176571875 V_FlowIn[2040,winter,night,ethos,IMPFEQ,2030,FEQ]
4.35873593073593
V_FlowIn[2040,winter,night,ethos,IMPGSL1,2030,GSL]
458.07868075 V_FlowIn[2040,winter,night,ethos,IMPHCO1,2030,HCO]
322.2521083675 V_FlowIn[2040,winter,night,ethos,IMPHYD,2030,HYD]
3.7974360448404716 V_FlowIn[2050,inter,day,DSL,RHO,2030,RH]
0.5628831168831169 V_FlowIn[2050,inter,day,DSL,TXD,2040,TX]
2.872147186147186 V_FlowIn[2050,inter,day,DSL,TXD,2050,TX]
0.45630787037037 V_FlowIn[2050,inter,day,ELC,E51,2020,ELC]
10.4950810185185 V_FlowIn[2050,inter,day,ELC,E51,2030,ELC]
8.6201185627262 V_FlowIn[2050,inter,day,ELC,E51,2040,ELC]
2.48566232931456 V_FlowIn[2050,inter,day,ELC,E51,2050,ELC]
1.69489738430582 V_FlowIn[2050,inter,day,ELC,RHE,2040,RH]
2.45089738430582 V_FlowIn[2050,inter,day,ELC,RHE,2050,RH]
195.0 V_FlowIn[2050,inter,day,ELC,RL1,2050,RL]
1.638134199134199 V_FlowIn[2050,inter,day,GSL,TXG,2040,TX]
3.3628658008658006 V_FlowIn[2050,inter,day,GSL,TXG,2050,TX]
0.4929110625 V_FlowIn[2050,inter,day,HYD,E31,2020,ELC]
122.73485456249999 V_FlowIn[2050,inter,day,HYD,E31,2030,ELC]
199.0243427425 V_FlowIn[2050,inter,day,HYD,E31,2040,ELC]
21.527325988962875 V_FlowIn[2050,inter,day,HYD,E31,2050,ELC]
7.23246634787081 V_FlowIn[2050,inter,day,ethos,IMPDSL1,2030,DSL]
5.001 V_FlowIn[2050,inter,day,ethos,IMPGSL1,2030,GSL]
343.779434356463 V_FlowIn[2050,inter,day,ethos,IMPHYD,2030,HYD]
1.8987180224202431 V_FlowIn[2050,inter,night,DSL,RHO,2030,RH]
0.2812727272727273 V_FlowIn[2050,inter,night,DSL,TXD,2040,TX]
1.4352121212121212 V_FlowIn[2050,inter,night,DSL,TXD,2050,TX]
0.847448692152912 V_FlowIn[2050,inter,night,ELC,RHE,2040,RH]
1.22544869215291 V_FlowIn[2050,inter,night,ELC,RHE,2050,RH]
65.0 V_FlowIn[2050,inter,night,ELC,RL1,2050,RL]
0.8185757575757576 V_FlowIn[2050,inter,night,GSL,TXG,2040,TX]
1.6804242424242424 V_FlowIn[2050,inter,night,GSL,TXG,2050,TX]
0.2463076875 V_FlowIn[2050,inter,night,HYD,E31,2020,ELC]
61.3306141875 V_FlowIn[2050,inter,night,HYD,E31,2030,ELC]

99.4524760075 V_FlowIn[2050,inter,night,HYD,E31,2040,ELC]
10.757206088066031 V_FlowIn[2050,inter,night,HYD,E31,2050,ELC]
3.61520287090511 V_FlowIn[2050,inter,night,ethos,IMPDSL1,2030,DSL]
2.499 V_FlowIn[2050,inter,night,ethos,IMPGSL1,2030,GSL]
171.786603970566 V_FlowIn[2050,inter,night,ethos,IMPHYD,2030,HYD]
0.5628831168831169 V_FlowIn[2050,summer,day,DSL,TXD,2040,TX]
2.872147186147186 V_FlowIn[2050,summer,day,DSL,TXD,2050,TX]
195.0 V_FlowIn[2050,summer,day,ELC,RL1,2050,RL]
96.1176571875 V_FlowIn[2050,summer,day,FEQ,E21,2030,ELC]
1.638134199134199 V_FlowIn[2050,summer,day,GSL,TXG,2040,TX]
3.3628658008658006 V_FlowIn[2050,summer,day,GSL,TXG,2050,TX]
51.930296918149686 V_FlowIn[2050,summer,day,HCO,E01,2030,ELC]
0.4929110625 V_FlowIn[2050,summer,day,HYD,E31,2020,ELC]
122.73485456249999 V_FlowIn[2050,summer,day,HYD,E31,2030,ELC]
199.0243427425 V_FlowIn[2050,summer,day,HYD,E31,2040,ELC]
113.2052406875 V_FlowIn[2050,summer,day,HYD,E31,2050,ELC]
3.4350303030303
V_FlowIn[2050,summer,day,ethos,IMPDSL1,2030,DSL]
96.1176571875 V_FlowIn[2050,summer,day,ethos,IMPFEQ,2030,FEQ]
5.001 V_FlowIn[2050,summer,day,ethos,IMPGSL1,2030,GSL]
51.9302969181497
V_FlowIn[2050,summer,day,ethos,IMPHCO1,2030,HCO]
435.457349055 V_FlowIn[2050,summer,day,ethos,IMPHYD,2030,HYD]
0.2812727272727273 V_FlowIn[2050,summer,night,DSL,TXD,2040,TX]
1.4352121212121212 V_FlowIn[2050,summer,night,DSL,TXD,2050,TX]
0.912615740740728 V_FlowIn[2050,summer,night,ELC,E51,2020,ELC]
10.151990331469 V_FlowIn[2050,summer,night,ELC,E51,2030,ELC]
17.2402371254524 V_FlowIn[2050,summer,night,ELC,E51,2040,ELC]
65.0 V_FlowIn[2050,summer,night,ELC,RL1,2050,RL]
48.029999062499996 V_FlowIn[2050,summer,night,FEQ,E21,2030,ELC]
0.8185757575757576 V_FlowIn[2050,summer,night,GSL,TXG,2040,TX]
1.6804242424242424 V_FlowIn[2050,summer,night,GSL,TXG,2050,TX]
25.94957248519419 V_FlowIn[2050,summer,night,HCO,E01,2030,ELC]
0.2463076875 V_FlowIn[2050,summer,night,HYD,E31,2020,ELC]

61.3306141875 V_FlowIn[2050,summer,night,HYD,E31,2030,ELC]
99.4524760075 V_FlowIn[2050,summer,night,HYD,E31,2040,ELC]
56.568665562499994 V_FlowIn[2050,summer,night,HYD,E31,2050,ELC]
1.71648484848485
V_FlowIn[2050,summer,night,ethos,IMPDSL1,2030,DSL]
48.0299990625 V_FlowIn[2050,summer,night,ethos,IMPFEQ,2030,FEQ]
2.499 V_FlowIn[2050,summer,night,ethos,IMPGSL1,2030,GSL]
25.9495724851942
V_FlowIn[2050,summer,night,ethos,IMPHCO1,2030,HCO]
217.598063445
V_FlowIn[2050,summer,night,ethos,IMPHYD,2030,HYD]
5.720969795918368 V_FlowIn[2050,winter,day,DSL,E70,2020,ELC]
12.800641836943777 V_FlowIn[2050,winter,day,DSL,E70,2030,ELC]
17.300485714285717 V_FlowIn[2050,winter,day,DSL,RHO,2030,RH]
1.1254285714285712 V_FlowIn[2050,winter,day,DSL,TXD,2040,TX]
5.742571428571429 V_FlowIn[2050,winter,day,DSL,TXD,2050,TX]
7.72166999999995 V_FlowIn[2050,winter,day,ELC,RHE,2040,RH]
11.1658799999999 V_FlowIn[2050,winter,day,ELC,RHE,2050,RH]
650.0 V_FlowIn[2050,winter,day,ELC,RL1,2050,RL]
192.17765531249998 V_FlowIn[2050,winter,day,FEQ,E21,2030,ELC]
3.2752857142857144 V_FlowIn[2050,winter,day,GSL,TXG,2040,TX]
6.723714285714285 V_FlowIn[2050,winter,day,GSL,TXG,2050,TX]
4.714101459375001 V_FlowIn[2050,winter,day,HCO,E01,2020,ELC]
906.4543663312501 V_FlowIn[2050,winter,day,HCO,E01,2030,ELC]
0.9855264375 V_FlowIn[2050,winter,day,HYD,E31,2020,ELC]
245.3960829375 V_FlowIn[2050,winter,day,HYD,E31,2030,ELC]
397.9292947575 V_FlowIn[2050,winter,day,HYD,E31,2040,ELC]
226.3425718124997 V_FlowIn[2050,winter,day,HYD,E31,2050,ELC]
42.690097347148 V_FlowIn[2050,winter,day,ethos,IMPDSL1,2030,DSL]
192.1776553125 V_FlowIn[2050,winter,day,ethos,IMPFEQ,2030,FEQ]
9.999 V_FlowIn[2050,winter,day,ethos,IMPGSL1,2030,GSL]
911.168467790625
V_FlowIn[2050,winter,day,ethos,IMPHCO1,2030,HCO]
870.653475945 V_FlowIn[2050,winter,day,ethos,IMPHYD,2030,HYD]

8.648660592124173 V_FlowIn[2050,winter,night,DSL,RHO,2030,RH]
0.5628831168831169 V_FlowIn[2050,winter,night,DSL,TXD,2040,TX]
2.872147186147186 V_FlowIn[2050,winter,night,DSL,TXD,2050,TX]
3.65119305555556 V_FlowIn[2050,winter,night,ELC,E51,2020,ELC]
83.9774402777778 V_FlowIn[2050,winter,night,ELC,E51,2030,ELC]
68.9747406915101 V_FlowIn[2050,winter,night,ELC,E51,2040,ELC]
19.8892756942434 V_FlowIn[2050,winter,night,ELC,E51,2050,ELC]
3.86012879275651 V_FlowIn[2050,winter,night,ELC,RHE,2040,RH]
5.5819187927565 V_FlowIn[2050,winter,night,ELC,RHE,2050,RH]
130.0 V_FlowIn[2050,winter,night,ELC,RL1,2050,RL]
96.1176571875 V_FlowIn[2050,winter,night,FEQ,E21,2030,ELC]
1.638134199134199 V_FlowIn[2050,winter,night,GSL,TXG,2040,TX]
3.3628658008658006 V_FlowIn[2050,winter,night,GSL,TXG,2050,TX]
2.357757915625 V_FlowIn[2050,winter,night,HCO,E01,2020,ELC]
453.36316491875 V_FlowIn[2050,winter,night,HCO,E01,2030,ELC]
0.4929110625 V_FlowIn[2050,winter,night,HYD,E31,2020,ELC]
122.73485456249999 V_FlowIn[2050,winter,night,HYD,E31,2030,ELC]
199.0243427425 V_FlowIn[2050,winter,night,HYD,E31,2040,ELC]
113.2052406875 V_FlowIn[2050,winter,night,HYD,E31,2050,ELC]
12.0836908951546
V_FlowIn[2050,winter,night,ethos,IMPDSL1,2030,DSL]
96.1176571875 V_FlowIn[2050,winter,night,ethos,IMPFEQ,2030,FEQ]
5.001 V_FlowIn[2050,winter,night,ethos,IMPGSL1,2030,GSL]
455.720922834375
V_FlowIn[2050,winter,night,ethos,IMPHCO1,2030,HCO]
435.457349055 V_FlowIn[2050,winter,night,ethos,IMPHYD,2030,HYD]
0.182897384305835 V_FlowOut[2030,inter,day,DSL,RHO,2010,RH]
0.182897384305835 V_FlowOut[2030,inter,day,DSL,RHO,2020,RH]
2.65820523138833 V_FlowOut[2030,inter,day,DSL,RHO,2030,RH]
0.06668 V_FlowOut[2030,inter,day,DSL,TXD,2010,TX]
0.03334 V_FlowOut[2030,inter,day,DSL,TXD,2020,TX]
1.97177566666667 V_FlowOut[2030,inter,day,ELC,E51,2020,ELC]
46.0433652710594 V_FlowOut[2030,inter,day,ELC,E51,2030,ELC]
0.559944 V_FlowOut[2030,inter,day,ELC,RL1,2020,RL]

149.440056 V_FlowOut[2030,inter,day,ELC,RL1,2030,RL]
30.7576503 V_FlowOut[2030,inter,day,FEQ,E21,2030,ELC]
0.51677 V_FlowOut[2030,inter,day,GSL,TXG,2010,TX]
0.25005 V_FlowOut[2030,inter,day,GSL,TXG,2020,TX]
0.754482533 V_FlowOut[2030,inter,day,HCO,E01,2010,ELC]
0.754482533 V_FlowOut[2030,inter,day,HCO,E01,2020,ELC]
30.2853586962739 V_FlowOut[2030,inter,day,HCO,E01,2030,ELC]
0.15773154 V_FlowOut[2030,inter,day,HYD,E31,2020,ELC]
39.27515346 V_FlowOut[2030,inter,day,HYD,E31,2030,ELC]
4.75298701298701 V_FlowOut[2030,inter,day,ethos,IMPDSL1,2030,DSL]
96.1176571875 V_FlowOut[2030,inter,day,ethos,IMPFEQ,2030,FEQ]
3.3195670995671 V_FlowOut[2030,inter,day,ethos,IMPGSL1,2030,GSL]
99.3572617571059
V_FlowOut[2030,inter,day,ethos,IMPHCO1,2030,HCO]
123.227765625 V_FlowOut[2030,inter,day,ethos,IMPHYD,2030,HYD]
0.0914486921529175 V_FlowOut[2030,inter,night,DSL,RHO,2010,RH]
0.0914486921529175 V_FlowOut[2030,inter,night,DSL,RHO,2020,RH]
1.32910261569416 V_FlowOut[2030,inter,night,DSL,RHO,2030,RH]
0.03332 V_FlowOut[2030,inter,night,DSL,TXD,2010,TX]
0.01666 V_FlowOut[2030,inter,night,DSL,TXD,2020,TX]
0.186648 V_FlowOut[2030,inter,night,ELC,RL1,2020,RL]
49.813352 V_FlowOut[2030,inter,night,ELC,RL1,2030,RL]
15.3695997 V_FlowOut[2030,inter,night,FEQ,E21,2030,ELC]
0.25823 V_FlowOut[2030,inter,night,GSL,TXG,2010,TX]
0.12495 V_FlowOut[2030,inter,night,GSL,TXG,2020,TX]
0.377014967 V_FlowOut[2030,inter,night,HCO,E01,2010,ELC]
0.377014967 V_FlowOut[2030,inter,night,HCO,E01,2020,ELC]
15.1335955572862 V_FlowOut[2030,inter,night,HCO,E01,2030,ELC]
0.07881846 V_FlowOut[2030,inter,night,HYD,E31,2020,ELC]
19.62579654 V_FlowOut[2030,inter,night,HYD,E31,2030,ELC]
2.37636363636364
V_FlowOut[2030,inter,night,ethos,IMPDSL1,2030,DSL]
48.0299990625 V_FlowOut[2030,inter,night,ethos,IMPFEQ,2030,FEQ]

1.65878787878788
V_FlowOut[2030,inter,night,ethos,IMPGSL1,2030,GSL]
49.6488296602695
V_FlowOut[2030,inter,night,ethos,IMPHCO1,2030,HCO]
61.576921875 V_FlowOut[2030,inter,night,ethos,IMPHYD,2030,HYD]
0.06668 V_FlowOut[2030,summer,day,DSL,TXD,2010,TX]
0.03334 V_FlowOut[2030,summer,day,DSL,TXD,2020,TX]
0.657083333333333 V_FlowOut[2030,summer,day,ELC,E51,2020,ELC]
12.5564902254025 V_FlowOut[2030,summer,day,ELC,E51,2030,ELC]
0.559944 V_FlowOut[2030,summer,day,ELC,RL1,2020,RL]
149.440056 V_FlowOut[2030,summer,day,ELC,RL1,2030,RL]
30.7576503 V_FlowOut[2030,summer,day,FEQ,E21,2030,ELC]
0.51677 V_FlowOut[2030,summer,day,GSL,TXG,2010,TX]
0.25005 V_FlowOut[2030,summer,day,GSL,TXG,2020,TX]
0.754482533 V_FlowOut[2030,summer,day,HCO,E01,2010,ELC]
0.754482533 V_FlowOut[2030,summer,day,HCO,E01,2020,ELC]
65.0869260752642 V_FlowOut[2030,summer,day,HCO,E01,2030,ELC]
0.15773154 V_FlowOut[2030,summer,day,HYD,E31,2020,ELC]
39.27515346 V_FlowOut[2030,summer,day,HYD,E31,2030,ELC]
0.432987012987013
V_FlowOut[2030,summer,day,ethos,IMPDSL1,2030,DSL]
96.1176571875
V_FlowOut[2030,summer,day,ethos,IMPFEQ,2030,FEQ]
3.3195670995671
V_FlowOut[2030,summer,day,ethos,IMPGSL1,2030,GSL]
208.112159816451
V_FlowOut[2030,summer,day,ethos,IMPHCO1,2030,HCO]
123.227765625
V_FlowOut[2030,summer,day,ethos,IMPHYD,2030,HYD]
0.03332 V_FlowOut[2030,summer,night,DSL,TXD,2010,TX]
0.01666 V_FlowOut[2030,summer,night,DSL,TXD,2020,TX]
0.186648 V_FlowOut[2030,summer,night,ELC,RL1,2020,RL]
49.813352 V_FlowOut[2030,summer,night,ELC,RL1,2030,RL]
15.3695997 V_FlowOut[2030,summer,night,FEQ,E21,2030,ELC]

0.25823 V_FlowOut[2030,summer,night,GSL,TXG,2010,TX]

0.12495 V_FlowOut[2030,summer,night,GSL,TXG,2020,TX]

0.377014967 V_FlowOut[2030,summer,night,HCO,E01,2010,ELC]

0.377014967 V_FlowOut[2030,summer,night,HCO,E01,2020,ELC]

32.5239408642442 V_FlowOut[2030,summer,night,HCO,E01,2030,ELC]

0.07881846 V_FlowOut[2030,summer,night,HYD,E31,2020,ELC]

19.62579654 V_FlowOut[2030,summer,night,HYD,E31,2030,ELC]

0.216363636363636 V_FlowOut[2030,summer,night,ethos,IMPDSL1,2030,DSL]

48.0299990625 V_FlowOut[2030,summer,night,ethos,IMPFEQ,2030,FEQ]

1.65878787878788 V_FlowOut[2030,summer,night,ethos,IMPGSL1,2030,GSL]

103.993658744513 V_FlowOut[2030,summer,night,ethos,IMPHCO1,2030,HCO]

61.576921875 V_FlowOut[2030,summer,night,ethos,IMPHYD,2030,HYD]

0.42049128 V_FlowOut[2030,winter,day,DSL,E70,2000,ELC]

0.42049128 V_FlowOut[2030,winter,day,DSL,E70,2010,ELC]

1.68196512 V_FlowOut[2030,winter,day,DSL,E70,2020,ELC]

106.562340322399 V_FlowOut[2030,winter,day,DSL,E70,2030,ELC]

0.83325 V_FlowOut[2030,winter,day,DSL,RHO,2010,RH]

0.83325 V_FlowOut[2030,winter,day,DSL,RHO,2020,RH]

12.11034 V_FlowOut[2030,winter,day,DSL,RHO,2030,RH]

0.13332 V_FlowOut[2030,winter,day,DSL,TXD,2010,TX]

0.06666 V_FlowOut[2030,winter,day,DSL,TXD,2020,TX]

0.657083333333333 V_FlowOut[2030,winter,day,ELC,E51,2020,ELC]

15.1129166666667 V_FlowOut[2030,winter,day,ELC,E51,2030,ELC]

1.86648 V_FlowOut[2030,winter,day,ELC,RL1,2020,RL]

498.13352 V_FlowOut[2030,winter,day,ELC,RL1,2030,RL]

61.4968497 V_FlowOut[2030,winter,day,FEQ,E21,2030,ELC]

1.03323 V_FlowOut[2030,winter,day,GSL,TXG,2010,TX]

0.49995 V_FlowOut[2030,winter,day,GSL,TXG,2020,TX]

1.508512467 V_FlowOut[2030,winter,day,HCO,E01,2010,ELC]

1.508512467 V_FlowOut[2030,winter,day,HCO,E01,2020,ELC]

231.788722363601 V_FlowOut[2030,winter,day,HCO,E01,2030,ELC]

0.31536846 V_FlowOut[2030,winter,day,HYD,E31,2020,ELC]

78.52674654 V_FlowOut[2030,winter,day,HYD,E31,2030,ELC]

391.585308851698
V_FlowOut[2030,winter,day,ethos,IMPDSL1,2030,DSL]

192.1776553125 V_FlowOut[2030,winter,day,ethos,IMPFEQ,2030,FEQ]

6.63714285714286
V_FlowOut[2030,winter,day,ethos,IMPGSL1,2030,GSL]

733.767960305002
V_FlowOut[2030,winter,day,ethos,IMPHCO1,2030,HCO]

246.381609375 V_FlowOut[2030,winter,day,ethos,IMPHYD,2030,HYD]

0.416548792756539 V_FlowOut[2030,winter,night,DSL,RHO,2010,RH]

0.416548792756539 V_FlowOut[2030,winter,night,DSL,RHO,2020,RH]

6.05406241448692 V_FlowOut[2030,winter,night,DSL,RHO,2030,RH]

0.06668 V_FlowOut[2030,winter,night,DSL,TXD,2010,TX]

0.03334 V_FlowOut[2030,winter,night,DSL,TXD,2020,TX]

0.373296 V_FlowOut[2030,winter,night,ELC,RL1,2020,RL]

99.626704 V_FlowOut[2030,winter,night,ELC,RL1,2030,RL]

30.7576503 V_FlowOut[2030,winter,night,FEQ,E21,2030,ELC]

0.51677 V_FlowOut[2030,winter,night,GSL,TXG,2010,TX]

0.25005 V_FlowOut[2030,winter,night,GSL,TXG,2020,TX]

0.754482533 V_FlowOut[2030,winter,night,HCO,E01,2010,ELC]

0.754482533 V_FlowOut[2030,winter,night,HCO,E01,2020,ELC]

115.929132967333 V_FlowOut[2030,winter,night,HCO,E01,2030,ELC]

0.15773154 V_FlowOut[2030,winter,night,HYD,E31,2020,ELC]

39.27515346 V_FlowOut[2030,winter,night,HYD,E31,2030,ELC]

10.271787012987
V_FlowOut[2030,winter,night,ethos,IMPDSL1,2030,DSL]

96.1176571875 V_FlowOut[2030,winter,night,ethos,IMPFEQ,2030,FEQ]

3.3195670995671
V_FlowOut[2030,winter,night,ethos,IMPGSL1,2030,GSL]

366.994056354167
V_FlowOut[2030,winter,night,ethos,IMPHCO1,2030,HCO]

| | |
|---|---|
| 123.227765625 | V_FlowOut[2030,winter,night,ethos,IMPHYD,2030,HYD] |
| 0.182897384305835 | V_FlowOut[2040,inter,day,DSL,RHO,2020,RH] |
| 2.65820523138833 | V_FlowOut[2040,inter,day,DSL,RHO,2030,RH] |
| 0.03334 | V_FlowOut[2040,inter,day,DSL,TXD,2020,TX] |
| 0.260052 | V_FlowOut[2040,inter,day,DSL,TXD,2040,TX] |
| 2.30031733333334 | V_FlowOut[2040,inter,day,ELC,E51,2020,ELC] |
| 52.9072986666667 | V_FlowOut[2040,inter,day,ELC,E51,2030,ELC] |
| 43.4553279327243 | V_FlowOut[2040,inter,day,ELC,E51,2040,ELC] |
| 1.69489738430583 | V_FlowOut[2040,inter,day,ELC,RHE,2040,RH] |
| 180.0 | V_FlowOut[2040,inter,day,ELC,RL1,2040,RL] |
| 0.25005 | V_FlowOut[2040,inter,day,GSL,TXG,2020,TX] |
| 0.756818 | V_FlowOut[2040,inter,day,GSL,TXG,2040,TX] |
| 0.15773154 | V_FlowOut[2040,inter,day,HYD,E31,2020,ELC] |
| 39.27515346 | V_FlowOut[2040,inter,day,HYD,E31,2030,ELC] |
| 63.1705759031966 | V_FlowOut[2040,inter,day,HYD,E31,2040,ELC] |
| 5.32881326051549 | V_FlowOut[2040,inter,day,ethos,IMPDSL1,2030,DSL] |
| 4.35873593073593 | V_FlowOut[2040,inter,day,ethos,IMPGSL1,2030,GSL] |
| 320.635815322489 | V_FlowOut[2040,inter,day,ethos,IMPHYD,2030,HYD] |
| 0.0914486921529175 | V_FlowOut[2040,inter,night,DSL,RHO,2020,RH] |
| 1.32910261569417 | V_FlowOut[2040,inter,night,DSL,RHO,2030,RH] |
| 0.01666 | V_FlowOut[2040,inter,night,DSL,TXD,2020,TX] |
| 0.129948 | V_FlowOut[2040,inter,night,DSL,TXD,2040,TX] |
| 9.57649312384901 | V_FlowOut[2040,inter,night,ELC,E51,2040,ELC] |
| 0.847448692152913 | V_FlowOut[2040,inter,night,ELC,RHE,2040,RH] |
| 60.0 | V_FlowOut[2040,inter,night,ELC,RL1,2040,RL] |
| 0.12495 | V_FlowOut[2040,inter,night,GSL,TXG,2020,TX] |
| 0.378182 | V_FlowOut[2040,inter,night,GSL,TXG,2040,TX] |
| 0.07881846 | V_FlowOut[2040,inter,night,HYD,E31,2020,ELC] |
| 19.62579654 | V_FlowOut[2040,inter,night,HYD,E31,2030,ELC] |
| 31.566340568304 | V_FlowOut[2040,inter,night,HYD,E31,2040,ELC] |
| 2.66402567787679 | V_FlowOut[2040,inter,night,ethos,IMPDSL1,2030,DSL] |
| 2.17806060606061 | V_FlowOut[2040,inter,night,ethos,IMPGSL1,2030,GSL] |

160.22173615095 V_FlowOut[2040,inter,night,ethos,IMPHYD,2030,HYD]
0.03334 V_FlowOut[2040,summer,day,DSL,TXD,2020,TX]
0.260052 V_FlowOut[2040,summer,day,DSL,TXD,2040,TX]
0.657083333333333 V_FlowOut[2040,summer,day,ELC,E51,2020,ELC]
5.32006995298123 V_FlowOut[2040,summer,day,ELC,E51,2030,ELC]
2.83647760647682 V_FlowOut[2040,summer,day,ELC,E51,2040,ELC]
180.0 V_FlowOut[2040,summer,day,ELC,RL1,2040,RL]
30.7576503 V_FlowOut[2040,summer,day,FEQ,E21,2030,ELC]
0.25005 V_FlowOut[2040,summer,day,GSL,TXG,2020,TX]
0.756818 V_FlowOut[2040,summer,day,GSL,TXG,2040,TX]
0.754482533 V_FlowOut[2040,summer,day,HCO,E01,2010,ELC]
0.754482533 V_FlowOut[2040,summer,day,HCO,E01,2020,ELC]
35.7990790636086 V_FlowOut[2040,summer,day,HCO,E01,2030,ELC]
0.15773154 V_FlowOut[2040,summer,day,HYD,E31,2020,ELC]
39.27515346 V_FlowOut[2040,summer,day,HYD,E31,2030,ELC]
63.6877896776 V_FlowOut[2040,summer,day,HYD,E31,2040,ELC]
1.27009523809524
V_FlowOut[2040,summer,day,ethos,IMPDSL1,2030,DSL]
96.1176571875
V_FlowOut[2040,summer,day,ethos,IMPFEQ,2030,FEQ]
4.35873593073593
V_FlowOut[2040,summer,day,ethos,IMPGSL1,2030,GSL]
116.587637905027
V_FlowOut[2040,summer,day,ethos,IMPHCO1,2030,HCO]
322.2521083675
V_FlowOut[2040,summer,day,ethos,IMPHYD,2030,HYD]
0.01666 V_FlowOut[2040,summer,night,DSL,TXD,2020,TX]
0.129948 V_FlowOut[2040,summer,night,DSL,TXD,2040,TX]
60.0 V_FlowOut[2040,summer,night,ELC,RL1,2040,RL]
15.3695997 V_FlowOut[2040,summer,night,FEQ,E21,2030,ELC]
0.12495 V_FlowOut[2040,summer,night,GSL,TXG,2020,TX]
0.378182 V_FlowOut[2040,summer,night,GSL,TXG,2040,TX]
0.377014967 V_FlowOut[2040,summer,night,HCO,E01,2010,ELC]
0.377014967 V_FlowOut[2040,summer,night,HCO,E01,2020,ELC]

17.8888019556005 V_FlowOut[2040,summer,night,HCO,E01,2030,ELC]

0.07881846 V_FlowOut[2040,summer,night,HYD,E31,2020,ELC]

19.62579654 V_FlowOut[2040,summer,night,HYD,E31,2030,ELC]

31.8247923224 V_FlowOut[2040,summer,night,HYD,E31,2040,ELC]

0.634666666666667

V_FlowOut[2040,summer,night,ethos,IMPDSL1,2030,DSL]

48.0299990625

V_FlowOut[2040,summer,night,ethos,IMPFEQ,2030,FEQ]

2.17806060606061

V_FlowOut[2040,summer,night,ethos,IMPGSL1,2030,GSL]

58.2588496550015

V_FlowOut[2040,summer,night,ethos,IMPHCO1,2030,HCO]

161.0293978825

V_FlowOut[2040,summer,night,ethos,IMPHYD,2030,HYD]

18.7799380872745 V_FlowOut[2040,winter,day,DSL,E70,2030,ELC]

0.83325 V_FlowOut[2040,winter,day,DSL,RHO,2020,RH]

12.11034 V_FlowOut[2040,winter,day,DSL,RHO,2030,RH]

0.06666 V_FlowOut[2040,winter,day,DSL,TXD,2020,TX]

0.519948 V_FlowOut[2040,winter,day,DSL,TXD,2040,TX]

0.657083333333333 V_FlowOut[2040,winter,day,ELC,E51,2020,ELC]

15.1129166666667 V_FlowOut[2040,winter,day,ELC,E51,2030,ELC]

12.4129707303257 V_FlowOut[2040,winter,day,ELC,E51,2040,ELC]

7.72166999999995 V_FlowOut[2040,winter,day,ELC,RHE,2040,RH]

600.0 V_FlowOut[2040,winter,day,ELC,RL1,2040,RL]

61.4968497 V_FlowOut[2040,winter,day,FEQ,E21,2030,ELC]

0.49995 V_FlowOut[2040,winter,day,GSL,TXG,2020,TX]

1.513182 V_FlowOut[2040,winter,day,GSL,TXG,2040,TX]

1.508512467 V_FlowOut[2040,winter,day,HCO,E01,2010,ELC]

1.508512467 V_FlowOut[2040,winter,day,HCO,E01,2020,ELC]

290.065397226 V_FlowOut[2040,winter,day,HCO,E01,2030,ELC]

0.31536846 V_FlowOut[2040,winter,day,HYD,E31,2020,ELC]

78.52674654 V_FlowOut[2040,winter,day,HYD,E31,2030,ELC]

127.3373743224 V_FlowOut[2040,winter,day,HYD,E31,2040,ELC]

84.9076118614778
V_FlowOut[2040,winter,day,ethos,IMPDSL1,2030,DSL]
192.1776553125 V_FlowOut[2040,winter,day,ethos,IMPFEQ,2030,FEQ]
8.71485714285714
V_FlowOut[2040,winter,day,ethos,IMPGSL1,2030,GSL]
915.88256925 V_FlowOut[2040,winter,day,ethos,IMPHCO1,2030,HCO]
644.3109041325 V_FlowOut[2040,winter,day,ethos,IMPHYD,2030,HYD]
0.416548792756539 V_FlowOut[2040,winter,night,DSL,RHO,2020,RH]
6.05406241448692 V_FlowOut[2040,winter,night,DSL,RHO,2030,RH]
0.03334 V_FlowOut[2040,winter,night,DSL,TXD,2020,TX]
0.260052 V_FlowOut[2040,winter,night,DSL,TXD,2040,TX]
3.86012879275652 V_FlowOut[2040,winter,night,ELC,RHE,2040,RH]
120.0 V_FlowOut[2040,winter,night,ELC,RL1,2040,RL]
30.7576503 V_FlowOut[2040,winter,night,FEQ,E21,2030,ELC]
0.25005 V_FlowOut[2040,winter,night,GSL,TXG,2020,TX]
0.756818 V_FlowOut[2040,winter,night,GSL,TXG,2040,TX]
0.754482533 V_FlowOut[2040,winter,night,HCO,E01,2010,ELC]
0.754482533 V_FlowOut[2040,winter,night,HCO,E01,2020,ELC]
145.076212774 V_FlowOut[2040,winter,night,HCO,E01,2030,ELC]
0.15773154 V_FlowOut[2040,winter,night,HYD,E31,2020,ELC]
39.27515346 V_FlowOut[2040,winter,night,HYD,E31,2030,ELC]
63.6877896776 V_FlowOut[2040,winter,night,HYD,E31,2040,ELC]
10.5138255341574
V_FlowOut[2040,winter,night,ethos,IMPDSL1,2030,DSL]
96.1176571875 V_FlowOut[2040,winter,night,ethos,IMPFEQ,2030,FEQ]
4.35873593073593
V_FlowOut[2040,winter,night,ethos,IMPGSL1,2030,GSL]
458.07868075
V_FlowOut[2040,winter,night,ethos,IMPHCO1,2030,HCO]
322.2521083675
V_FlowOut[2040,winter,night,ethos,IMPHYD,2030,HYD]
2.65820523138833 V_FlowOut[2050,inter,day,DSL,RHO,2030,RH]
0.130026 V_FlowOut[2050,inter,day,DSL,TXD,2040,TX]
0.663466 V_FlowOut[2050,inter,day,DSL,TXD,2050,TX]

2.30031733333333 V_FlowOut[2050,inter,day,ELC,E51,2020,ELC]
52.9072986666667 V_FlowOut[2050,inter,day,ELC,E51,2030,ELC]
43.4553279327244 V_FlowOut[2050,inter,day,ELC,E51,2040,ELC]
12.5306016227488 V_FlowOut[2050,inter,day,ELC,E51,2050,ELC]
1.69489738430582 V_FlowOut[2050,inter,day,ELC,RHE,2040,RH]
2.45089738430582 V_FlowOut[2050,inter,day,ELC,RHE,2050,RH]
195.0 V_FlowOut[2050,inter,day,ELC,RL1,2050,RL]
0.378409 V_FlowOut[2050,inter,day,GSL,TXG,2040,TX]
0.776822 V_FlowOut[2050,inter,day,GSL,TXG,2050,TX]
0.15773154 V_FlowOut[2050,inter,day,HYD,E31,2020,ELC]
39.27515346 V_FlowOut[2050,inter,day,HYD,E31,2030,ELC]
63.6877896776 V_FlowOut[2050,inter,day,HYD,E31,2040,ELC]
6.88874431646812 V_FlowOut[2050,inter,day,HYD,E31,2050,ELC]
7.23246634787081 V_FlowOut[2050,inter,day,ethos,IMPDSL1,2030,DSL]
5.001 V_FlowOut[2050,inter,day,ethos,IMPGSL1,2030,GSL]
343.779434356463 V_FlowOut[2050,inter,day,ethos,IMPHYD,2030,HYD]
1.32910261569417 V_FlowOut[2050,inter,night,DSL,RHO,2030,RH]
0.064974 V_FlowOut[2050,inter,night,DSL,TXD,2040,TX]
0.331534 V_FlowOut[2050,inter,night,DSL,TXD,2050,TX]
0.657083333333333 V_FlowOut[2050,inter,night,ELC,E51,2020,ELC]
7.30943303865767 V_FlowOut[2050,inter,night,ELC,E51,2030,ELC]
4.13466774173368 V_FlowOut[2050,inter,night,ELC,E51,2040,ELC]
0.847448692152912 V_FlowOut[2050,inter,night,ELC,RHE,2040,RH]
1.22544869215291 V_FlowOut[2050,inter,night,ELC,RHE,2050,RH]
65.0 V_FlowOut[2050,inter,night,ELC,RL1,2050,RL]
0.189091 V_FlowOut[2050,inter,night,GSL,TXG,2040,TX]
0.388178 V_FlowOut[2050,inter,night,GSL,TXG,2050,TX]
0.07881846 V_FlowOut[2050,inter,night,HYD,E31,2020,ELC]
19.62579654 V_FlowOut[2050,inter,night,HYD,E31,2030,ELC]
31.8247923224 V_FlowOut[2050,inter,night,HYD,E31,2040,ELC]
3.44230594818113 V_FlowOut[2050,inter,night,HYD,E31,2050,ELC]
3.61520287090511
V_FlowOut[2050,inter,night,ethos,IMPDSL1,2030,DSL]
2.499 V_FlowOut[2050,inter,night,ethos,IMPGSL1,2030,GSL]

171.786603970566
V_FlowOut[2050,inter,night,ethos,IMPHYD,2030,HYD]
0.130026 V_FlowOut[2050,summer,day,DSL,TXD,2040,TX]
0.663466 V_FlowOut[2050,summer,day,DSL,TXD,2050,TX]
8.27830298859207 V_FlowOut[2050,summer,day,ELC,E51,2040,ELC]
195.0 V_FlowOut[2050,summer,day,ELC,RL1,2050,RL]
30.7576503 V_FlowOut[2050,summer,day,FEQ,E21,2030,ELC]
0.378409 V_FlowOut[2050,summer,day,GSL,TXG,2040,TX]
0.776822 V_FlowOut[2050,summer,day,GSL,TXG,2050,TX]
16.6176950138079 V_FlowOut[2050,summer,day,HCO,E01,2030,ELC]
0.15773154 V_FlowOut[2050,summer,day,HYD,E31,2020,ELC]
39.27515346 V_FlowOut[2050,summer,day,HYD,E31,2030,ELC]
63.6877896776 V_FlowOut[2050,summer,day,HYD,E31,2040,ELC]
36.22567702 V_FlowOut[2050,summer,day,HYD,E31,2050,ELC]
3.4350303030303
V_FlowOut[2050,summer,day,ethos,IMPDSL1,2030,DSL]
96.1176571875
V_FlowOut[2050,summer,day,ethos,IMPFEQ,2030,FEQ]
5.001 V_FlowOut[2050,summer,day,ethos,IMPGSL1,2030,GSL]
51.9302969181497
V_FlowOut[2050,summer,day,ethos,IMPHCO1,2030,HCO]
435.457349055
V_FlowOut[2050,summer,day,ethos,IMPHYD,2030,HYD]
0.064974 V_FlowOut[2050,summer,night,DSL,TXD,2040,TX]
0.331534 V_FlowOut[2050,summer,night,DSL,TXD,2050,TX]
65.0 V_FlowOut[2050,summer,night,ELC,RL1,2050,RL]
15.3695997 V_FlowOut[2050,summer,night,FEQ,E21,2030,ELC]
0.189091 V_FlowOut[2050,summer,night,GSL,TXG,2040,TX]
0.388178 V_FlowOut[2050,summer,night,GSL,TXG,2050,TX]
8.30386319526214 V_FlowOut[2050,summer,night,HCO,E01,2030,ELC]
0.07881846 V_FlowOut[2050,summer,night,HYD,E31,2020,ELC]
19.62579654 V_FlowOut[2050,summer,night,HYD,E31,2030,ELC]
31.8247923224 V_FlowOut[2050,summer,night,HYD,E31,2040,ELC]
18.10197298 V_FlowOut[2050,summer,night,HYD,E31,2050,ELC]

1.71648484848485
V_FlowOut[2050,summer,night,ethos,IMPDSL1,2030,DSL]
48.0299990625
V_FlowOut[2050,summer,night,ethos,IMPFEQ,2030,FEQ]
2.499 V_FlowOut[2050,summer,night,ethos,IMPGSL1,2030,GSL]
25.9495724851942
V_FlowOut[2050,summer,night,ethos,IMPHCO1,2030,HCO]
217.598063445
V_FlowOut[2050,summer,night,ethos,IMPHYD,2030,HYD]
1.68196512 V_FlowOut[2050,winter,day,DSL,E70,2020,ELC]
3.76338870006147 V_FlowOut[2050,winter,day,DSL,E70,2030,ELC]
12.11034 V_FlowOut[2050,winter,day,DSL,RHO,2030,RH]
0.259974 V_FlowOut[2050,winter,day,DSL,TXD,2040,TX]
1.326534 V_FlowOut[2050,winter,day,DSL,TXD,2050,TX]
0.657083333333333 V_FlowOut[2050,winter,day,ELC,E51,2020,ELC]
15.1129166666667 V_FlowOut[2050,winter,day,ELC,E51,2030,ELC]
12.4129707303257 V_FlowOut[2050,winter,day,ELC,E51,2040,ELC]
3.57935375421298 V_FlowOut[2050,winter,day,ELC,E51,2050,ELC]
7.72166999999995 V_FlowOut[2050,winter,day,ELC,RHE,2040,RH]
11.1658799999999 V_FlowOut[2050,winter,day,ELC,RHE,2050,RH]
650.0 V_FlowOut[2050,winter,day,ELC,RL1,2050,RL]
61.4968497 V_FlowOut[2050,winter,day,FEQ,E21,2030,ELC]
0.756591 V_FlowOut[2050,winter,day,GSL,TXG,2040,TX]
1.553178 V_FlowOut[2050,winter,day,GSL,TXG,2050,TX]
1.508512467 V_FlowOut[2050,winter,day,HCO,E01,2020,ELC]
290.065397226 V_FlowOut[2050,winter,day,HCO,E01,2030,ELC]
0.31536846 V_FlowOut[2050,winter,day,HYD,E31,2020,ELC]
78.52674654 V_FlowOut[2050,winter,day,HYD,E31,2030,ELC]
127.3373743224 V_FlowOut[2050,winter,day,HYD,E31,2040,ELC]
72.4296229799999 V_FlowOut[2050,winter,day,HYD,E31,2050,ELC]
42.690097347148
V_FlowOut[2050,winter,day,ethos,IMPDSL1,2030,DSL]
192.1776553125 V_FlowOut[2050,winter,day,ethos,IMPFEQ,2030,FEQ]
9.999 V_FlowOut[2050,winter,day,ethos,IMPGSL1,2030,GSL]

911.168467790625
V_FlowOut[2050,winter,day,ethos,IMPHCO1,2030,HCO]
870.653475945 V_FlowOut[2050,winter,day,ethos,IMPHYD,2030,HYD]
6.05406241448692 V_FlowOut[2050,winter,night,DSL,RHO,2030,RH]
0.130026 V_FlowOut[2050,winter,night,DSL,TXD,2040,TX]
0.663466 V_FlowOut[2050,winter,night,DSL,TXD,2050,TX]
3.86012879275651 V_FlowOut[2050,winter,night,ELC,RHE,2040,RH]
5.5819187927565 V_FlowOut[2050,winter,night,ELC,RHE,2050,RH]
130.0 V_FlowOut[2050,winter,night,ELC,RL1,2050,RL]
30.7576503 V_FlowOut[2050,winter,night,FEQ,E21,2030,ELC]
0.378409 V_FlowOut[2050,winter,night,GSL,TXG,2040,TX]
0.776822 V_FlowOut[2050,winter,night,GSL,TXG,2050,TX]
0.754482533 V_FlowOut[2050,winter,night,HCO,E01,2020,ELC]
145.076212774 V_FlowOut[2050,winter,night,HCO,E01,2030,ELC]
0.15773154 V_FlowOut[2050,winter,night,HYD,E31,2020,ELC]
39.27515346 V_FlowOut[2050,winter,night,HYD,E31,2030,ELC]
63.6877896776 V_FlowOut[2050,winter,night,HYD,E31,2040,ELC]
36.22567702 V_FlowOut[2050,winter,night,HYD,E31,2050,ELC]
12.0836908951546
V_FlowOut[2050,winter,night,ethos,IMPDSL1,2030,DSL]
96.1176571875 V_FlowOut[2050,winter,night,ethos,IMPFEQ,2030,FEQ]
5.001 V_FlowOut[2050,winter,night,ethos,IMPGSL1,2030,GSL]
455.720922834375
V_FlowOut[2050,winter,night,ethos,IMPHCO1,2030,HCO]
435.457349055 V_FlowOut[2050,winter,night,ethos,IMPHYD,2030,HYD]
0.657083333333333 V_StorageLevel[2030,inter,day,E51,2020]
14.4203917289406 V_StorageLevel[2030,inter,day,E51,2030]
0.657083333333333 V_StorageLevel[2030,inter,night,E51,2020]
15.1129166666667 V_StorageLevel[2030,inter,night,E51,2030]
2.55642644126418 V_StorageLevel[2030,summer,day,E51,2030]
0.657083333333333 V_StorageLevel[2030,summer,night,E51,2020]
15.1129166666667 V_StorageLevel[2030,summer,night,E51,2030]
0.657083333333333 V_StorageLevel[2040,inter,day,E51,2020]
15.1129166666667 V_StorageLevel[2040,inter,day,E51,2030]

| | |
|---|---|
| 12.4129707303258 | V_StorageLevel[2040,inter,day,E51,2040] |
| 0.657083333333333 | V_StorageLevel[2040,inter,night,E51,2020] |
| 15.1129166666667 | V_StorageLevel[2040,inter,night,E51,2030] |
| 2.83647760647682 | V_StorageLevel[2040,inter,night,E51,2040] |
| 9.79284671368543 | V_StorageLevel[2040,summer,day,E51,2030] |
| 0.657083333333333 | V_StorageLevel[2040,summer,night,E51,2020] |
| 15.1129166666667 | V_StorageLevel[2040,summer,night,E51,2030] |
| 12.4129707303257 | V_StorageLevel[2040,summer,night,E51,2040] |
| 0.657083333333333 | V_StorageLevel[2050,inter,day,E51,2020] |
| 15.1129166666667 | V_StorageLevel[2050,inter,day,E51,2030] |
| 12.4129707303257 | V_StorageLevel[2050,inter,day,E51,2040] |
| 3.57935375421298 | V_StorageLevel[2050,inter,day,E51,2050] |
| 7.80348362800898 | V_StorageLevel[2050,inter,night,E51,2030] |
| 8.27830298859206 | V_StorageLevel[2050,inter,night,E51,2040] |
| 3.57935375421298 | V_StorageLevel[2050,inter,night,E51,2050] |
| 7.80348362800898 | V_StorageLevel[2050,summer,day,E51,2030] |
| 3.57935375421298 | V_StorageLevel[2050,summer,day,E51,2050] |
| 0.657083333333333 | V_StorageLevel[2050,summer,night,E51,2020] |
| 15.1129166666667 | V_StorageLevel[2050,summer,night,E51,2030] |
| 12.4129707303257 | V_StorageLevel[2050,summer,night,E51,2040] |
| 3.57935375421298 | V_StorageLevel[2050,summer,night,E51,2050] |

# 6 References


[1] Verzijlbergh, R et al. (2017). Institutional challenges caused by the integration of renewable energy sources in the European electricity sector. [online] Available at: <https://www.sciencedirect.com/science/article/pii/S1364032116307651> [Accessed 8 January 2021].

[2] Department of Energy. (2019). “Integrated Resource Plan” Technical Report, March 2019.

[3] Eskom Holding SOC Ltd. (2018) "Comments on Draft IRP, Eskom", October 2018.

[4] Voith, K. Kruger et al. (2018). “Comparison of li-Ion batteries and pumped storage for bulk energy storage”, Webinar on Hydroworld, September 2018.

[5] Argonne. (2014). [online] Pumped Storage Hydropower: Benefits for Grid Reliability and Integration of Variable Renewable Energy Available at: <https://publications.anl.gov/anlpubs/2014/12/106380.pdf> [Accessed 7 January 2021].

[6] Email Correspondence, Frans Louwinger (head of hydropower at Eskom in 2009), July 18, 2018.

[6A] www.world-nuclear.org. (n.d.). Nuclear Power in South Africa | South African Nuclear Energy - World Nuclear Association. [online] Available at: http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-africa.aspx [Accessed 18 Jan. 2021].

[7] Cer.org.za. (2017). [online] Available at: <https://cer.org.za/wp-content/uploads/2017/11/170804-Furtheranalysis-by-the-CSIR.pdf> [Accessed 7 January 2021].

[8] Barry, M. (2017). "Generation Expansion Plan (GEP) Study", Eskom.

[9] “The contribution of pumped storage schemes to energy generation in South Africa”- EE Publishers. (2018)

[online] Available at: http://www.ee.co.za/article/the-contribution-of-pumped-storage-schemes-to-energy-generationin-south-africa.html [Accessed 15 Aug. 2018].

[10] Interview and Email Correspondence, Rudolph Binneman and Gav Hurford, Simmerpan, Eskom, September 2018

[11] Palmiet Power Station. (2021). Palmiet Power Station. [online] Available at: <https://www.google.com/maps/place/Palmiet+Power+Station/@-30.2102971,20.9553937,7.01z/data=!4m5!3m4!1s0x1dcdcf9fcaca75a9:0x684c96b3eca0dae4!8m2!3d34.1972573!4d18.9743647> [Accessed 8 February 2021].

[12] Louwinger, F. (2016). South African Large Dams – A Century of Engineering Innovation. Johannesburg: South African National Committee on Large Dams (Sancold)

[13] Davidson, J.(2012). Electricity Generation: City of Cape Town. Cape Town: City of Cape Town.

[14] Eskom.co.za. (2021). Drakensberg Pumped Storage Scheme. [online] Available at: <https://www.eskom.co.za/Whatweredoing/ElectricityGeneration/PowerStations/Pages/Drakensberg_Pumped_Storage_Scheme.aspx> [Accessed 7 January 2021].

[15] Eskom Holdings, "Project Lima Pumped Storage Scheme", Business case report, Eskom, 2008.

[16] Kahla, C. (2019). Eskom's defective R29-billion power plant limits electricity output. [online] The South African. Available at: https://www.thesouthafrican.com/news/eskom-power-plant-defective-r29-billion/ [Accessed 14 Jun. 2019].

[17] SWECO. (2013). “Technical/Economic Feasibility Study on Kobong Pumped Storage Scheme”, Financial Evaluation Report. May, 2013.

[18] motebong lodge. 2021. Katse Dam Lesotho - Motebong Lodge. [online] Available at: <http://motebong.com/gallery/katse-dam-lesotho/> [Accessed 7 January 2021].

[19] Telephonic Discussion, Ceres Hydro Electrical, August 30, 2018.

[20] E. Barbour, et al. (2016) "A review of pumped hydro energy storage development in significant international electricity markets." Renewable and Sustainable Energy Reviews, 61. pp. 421-432. ISSN 1364-0321

[21] Water Power Magazine. (2019) "Pumping up Potential", March 2019, [p.10].

[22] Britannica. (2021). Nuclear Reactor - Three Mile Island And Chernobyl. [online] Available at: <https://www.britannica.com/technology/nuclear-reactor/Three-Mile-Island-and-Chernobyl> [Accessed 7
179
January 2021].

[23] National Hydropower Association. (2018). "Pumped Storage Report".

[24] Argonne (2014). "Modeling and Analysis of Advanced Pumped Storage Hydropower in the United States". US Department of Energy, June 2014.

[25] US Department of Energy. (2019). "Energy Storage Technology and Cost Characterization Report", Argonne National Laboratory, July 2019.

[26] Lazard. (2018). "Lazard's Levelised Cost of Storage Analysis-Version 4.0", Lazard, November 2018.

[27] Anl.gov. (2019). [online] Available at: https://www.anl.gov/sites/www/files/2019 05/Koritarov_PSH%20Valuation%20Guidance_EPRI_Apr2019.pdf [Accessed 14 Jun. 2019].

[28] P. Graham, J.Hayward, J.Foster, O. Story and L. Havas. (2018)."GenCost 2018 Updated projections of electricity generation technology costs", Csiro.

[29] T. Guo and V. Koritav. (2016). "Adjustable Speed Pumped Storage Hydro Generator PSH Evaluate by Plexos", Energy Exemplar.

[30] Department of Energy. (2016). “Integrated Resource Plan Update: Assumptions, Base Case Results and Observations (Revision 1). Technical Report November, Department of Energy (DoE).”

[31] Department of Energy. (2011). “Integrated Resource Plan:", Technical Report.

[32] Department of Energy. (2018). “Integrated Resource Plan”, Technical Report Update, August 2018.

[33] System Operator. (2018). "Ancillary Services Technical Requirements for 2019/20 – 2023/24", Eskom, November 2018.

[34] M. Kippie and W. Fuls. (2014). "Improvements to a key contributor of frequency control: The co-ordination of guide vane operation in a pumped storage plant", University of Cape Town.

[35] G. Chown. (2019) "Frequency Presentation", Stellenbosch University - Centre for Renewable and Sustainable Energy Studies.

[36] Springer, Cham. (2021). [online] Available at: <https://www.researchgate.net/publication/345866601_Transient_Stability_Assessment_of_Power_System_Incorporating_DFIM-Based_Pumped_Storage_Hydropower_and_Wind_Farm> [Accessed 7 January 2021].
transient

[37] Mararakanye1, N. Bekker, B. (2018). A methodology for assessing the impact of intermittent renewable energy systems into the grid. Johannesburg: PowerGen.

[38] “Eskom’s Woes Continue, This Time over World Bank Loan Penalties.” CityPress, 18 Aug. 2019, citypress.news24.com/News/world-bank-flags-eskom-project-20190817. Accessed 14 Nov. 2019.

[39] Science direct. 2019. Current Status and Perspective in the Use of Coal for Electricity Generation in the North

America Region . [online] Available at: < Capacity Factor - an overview | ScienceDirect Topics > [Accessed 7 January 2021].

[40] Transnet SOC Ltd. (2017). "LTPF 2017 Natural Gas Infrastructure Planning", Transnet.

[41] Clark, S., 2020. The Use of Natural Gas to Facilitate the Transition to Renewable Electric Power. PhD. Stellenbosch University. Page 134 Figure 67.

[42] Eskom Holdings. (2015). "MYPD 3 Re-opener of selective items (2015/16_2017/2018) OCGTs and STPPP", Eskom, April 2015.

[43] W. Cole, B. Frew, T. Mai, Y. Sun, J. Bistline, G. Blanford, D. Young, C. Marcy, C. Namovicz, R. Edelman and B. Meroney. (2017)."Variable Renewable Energy in Long-Term Planning Models: A Multi-Model Perspective. In NREL/TP-6A20-70528" National Renewable Energy Laboratory Golden, CO.

[44] John Andrews, N. J. (2017). Energy Science: Principles, Technologies and Impacts (Third Addition). Oxford: Oxford Press.

[45] Howells, M., Rogner, H., Strachan, N., Heaps, C., Huntington, H., Kypreos, S., Hughes, A., Silveira, S., DeCarolis, J., Bazilian, M., Roehrl, A., 2011. OSeMOSYS: The Open Source Energy Modeling System: An introduction to its ethos, structure and development. Energy Policy, 39 (10), pp. 5850-5870.