AtkinsRéalis

Greenland Hydro Project – Site 07. e Energy Generation Study

Government of Greenland, The Ministry of Agriculture, Self-Sufficiency, Energy and Environment

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Greenland Hydro Project Site 07.e, Energy Generation Study

Final Report

Signatures

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EXECUTIVE SUMMARY

The Government of Greenland, through the Ministry of Agriculture, Self Sufficiency, Energy and Environment, has decided to expose the development of the two largest hydropower potential sites, the Tasersiaq (Site 07.e) and the Tarsartuup Tasersua (Site 06g) watershed areas in West Greenland, to public tender process for industrial use.

Prefeasibility studies for both sites were conducted in 2009 by AECOM, with the objective of providing electricity for a prospective aluminum reduction plant. The studies identified that the observed climate trend will lead to higher firm power potential. The main objective of the present study is to determine the firm power for different alternatives considered for Site 7.e. These studies were performed based on historical flow and taking into account climate trend changes based on available data.

AtkinsRéalis has been provided with hydrological data such as historical inflow series at the project intake site for a period of 42 years from 1980 to 2021, and annual inflow volume for future period corresponding to two periods. First, two initial climate change scenarios based on 20 years of annual inflow volume for future period 2031-2050, are presented. Second, the same analysis was performed for seven new climate change scenarios prepared by ASIAQ (2023) covering a longer period until 2100 and based on the latest relevant scientific information available.

To evaluate the impact of the revised methodology by ASIAQ (2023), firm power for the first cases previously analysed are reevaluated using the same inflow series for the period 2031-2050. The results obtained are slightly higher than the results of former study. The results of the new climate change scenarios allowed the qualification of the results obtained from the first climate change scenarios. It is assumed that all climate scenarios studied are equiprobable. The increase of the number of climate scenarios and the corresponding firm power analyses provides a better understanding of the potential range of installed capacity for this project, considering the uncertainties associated with the future inflows forecast.

The Table E-1 below presents the minimum, the maximum and the 50% probability of exceedance of the firm power based on the inflow scenarios available for the different period of analysis.

Table E-1: Site 07.e - Firm Power (100%) – Summary of the Results

Period	Number of scenarios	Firm Power (MW)		
		Minimum	50% probability of exceedance	Maximum
Historical	1	N/A	452	N/A
2031-2050	9	543	650	783 (1)
2031-2060	7	543	615	696
2051-2080	7	545	730	976
2071-2100	7	545	765	1136

(1) :Lowest firm power for the two reconstituted initial scenarios set of inflows for RCP 4.5

The main elements to consider:

- The trend of the firm power seems to increase for the future. For the 50% probability of exceedance, the increase in firm power is about 160 MW between the evaluation based on the historical data and the results for the period 2031-2060. It continues to increase for the period 2051-2080 and 2071-2100.

- The results for the period 2031-2050 are higher than the results for the period 2031-2060, since the two initial scenarios are considered only for the period 2031-2050 and the firm power for these scenarios are significantly higher than the others;

- The minimum firm power estimate for the different periods remains similar. It corresponds to the results of the scenario SSP126_ME_MAR. This scenario shows almost no increase of the annual volume of inflows in the future, which explains the almost constant value.

As mentioned previously, at this stage of the project, each climate change scenario is considered as equiprobable. It means that the choice of the firm power for a specific project must be based on the economic analysis of the project and account for the probability that the firm power will not be met during some years (or part of the year, i.e. until the next Spring flood occurs).

We recognize the difficulty to calibrate climate models and generate annual hydrographs for the study area, considering that most of the inflow comes from glacier melting which is a complex phenomenon. For these reasons, the firm power estimated must be considered with caution; the results are representative of the information available, but it is difficult to assess their confidence interval, even with nine scenarios. Furthermore, independent events, like a volcanic eruption, can have an impact on the climate and lead to changes in the conditions for one year or more. These impacts were excluded from the present study.

1. INTRODUCTION

1.1 Context

The Government of Greenland, through the Ministry of Agriculture, Self Sufficiency, Energy and Environment (The Ministry), has decided to expose the development of the two largest hydropower potential sites, the Tasersiaq (Site 07.e) and the Tarsartuup Tasersua (Site 06.g) watershed areas in West Greenland, to public tender process for industrial use.

Prefeasibility studies for both sites were conducted in 2009 by AECOM, with the objective of providing electricity for a prospective aluminum reduction plant. The studies identified a firm power potential of 432 MW at Site 07.e, based on historical flow data between 1958 and 2007. The study showed that observed climate trend will lead to higher firm power potential, estimating using synthetic projected series a firm power potential of 500 to 530 MW by 2020.

The main objective of the present study is to determine the firm power for different alternatives considered for Site 7.e. These studies were performed based on historical flow and considering climate trend changes based on available data.

When using the data from climate models to determine the trends in the future, it is a general practice to use an ensemble of climate model outcomes that also assists in assessing the uncertainty associated with the analysis. For example, a study performed by Zakrevskaya and Huard (Ref. 10) were using results from eleven climate models and four different scenarios to estimate the potential range of firm energy for a project in Northern Canada.

First, two initial climate change scenarios obtained in 2022 and based on 20 years of annual inflow volume for future period 2031-2050, were reviewed (Chapter 4). Following this first study, the same analysis was performed for seven new climate change scenarios prepared by ASIAQ (2023) covering a longer period until 2100 and based on the latest relevant scientific information available (Chapter 5).

1.2 Scope

The objective of the present study is to update the Site 07.e energy generation study, for the 2009 pre-feasibility study (PFS) proposed project characteristics, using updated flow series and revised hypothesis on the effect of future climate on the available flow at the site. The scope of work include:

- Collection of all available hydrological and meteorological data;
- Review of available data;
- Based on the daily data available and annual runoff volume, development of long-term daily flow series for different cases, including future climate scenarios;
- Simulation of energy generation, based on the general characteristics of the site layout developed in the 2009 PFS;
- Summary review of the PFS energy generation study hypothesis;

- Simulation of the energy generation for the different long-term flow scenarios (20-and 30-years);

- Sensitivity analysis of the effect of key site characteristics (e.g. operation levels, and 1-year deficit) on potential energy generation.

The scope of work does not include a review or modification of the 2009 PFS proposed project characteristics.

1.3 Site Description & Preliminary Layout

Site 07.e is located at the southwestern outlet of Lake Tasersiaq, in western Greenland. The site is located 120 km upstream of the settlement of Kangaamiut, 230 km north of Nuuk, as shown in Figure 1-1.

The layout of the proposed scheme, as established in the PFS study, is shown in Figure 1-2. Following the PFS scheme, Lake Tasersiaq would be dammed in two locations, and its level would be raised by about 24 m. The proposed conveyance structures include a 26.6 km long headrace tunnel, an air cushion surge chamber, underground powerhouse and a tailrace tunnel discharging in Evighedsfjord. The projected gross head at a maximum operating level of 714.0 m is 706 m, and the projected net head is about 697 m.

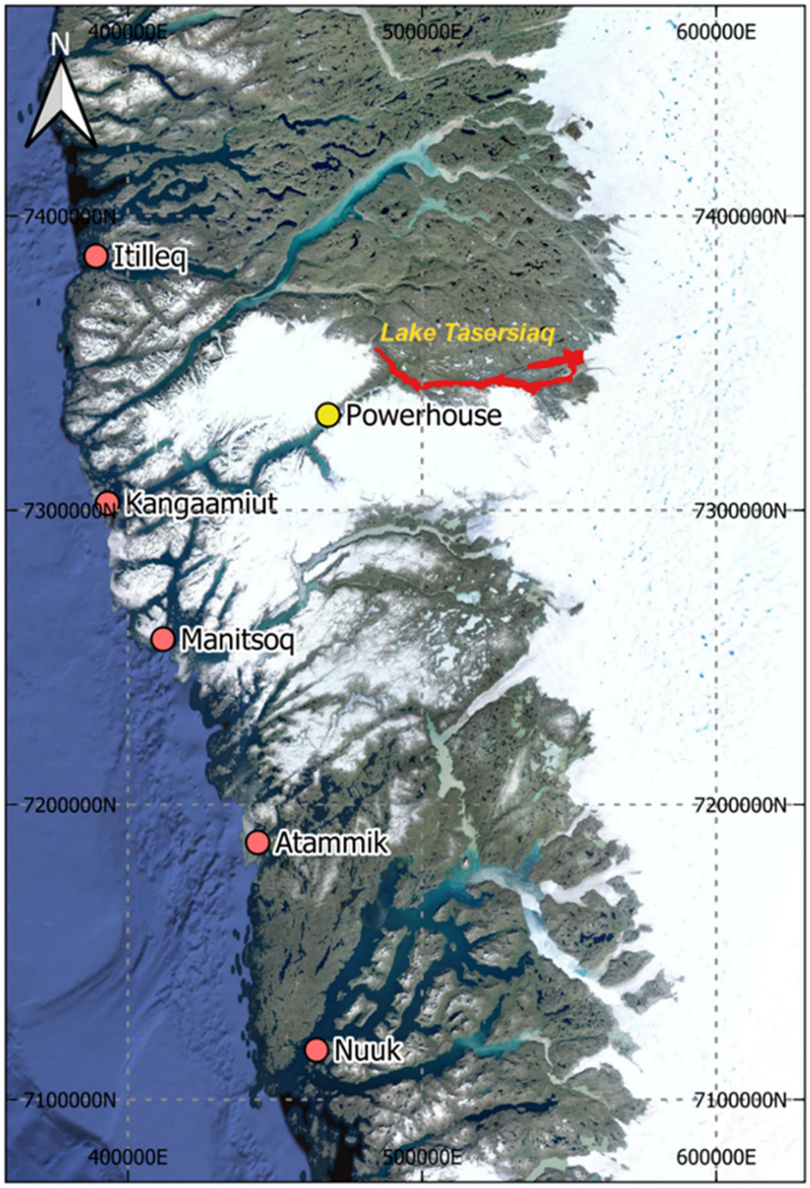

Figure 1-1 : Site 07.e - Project Location

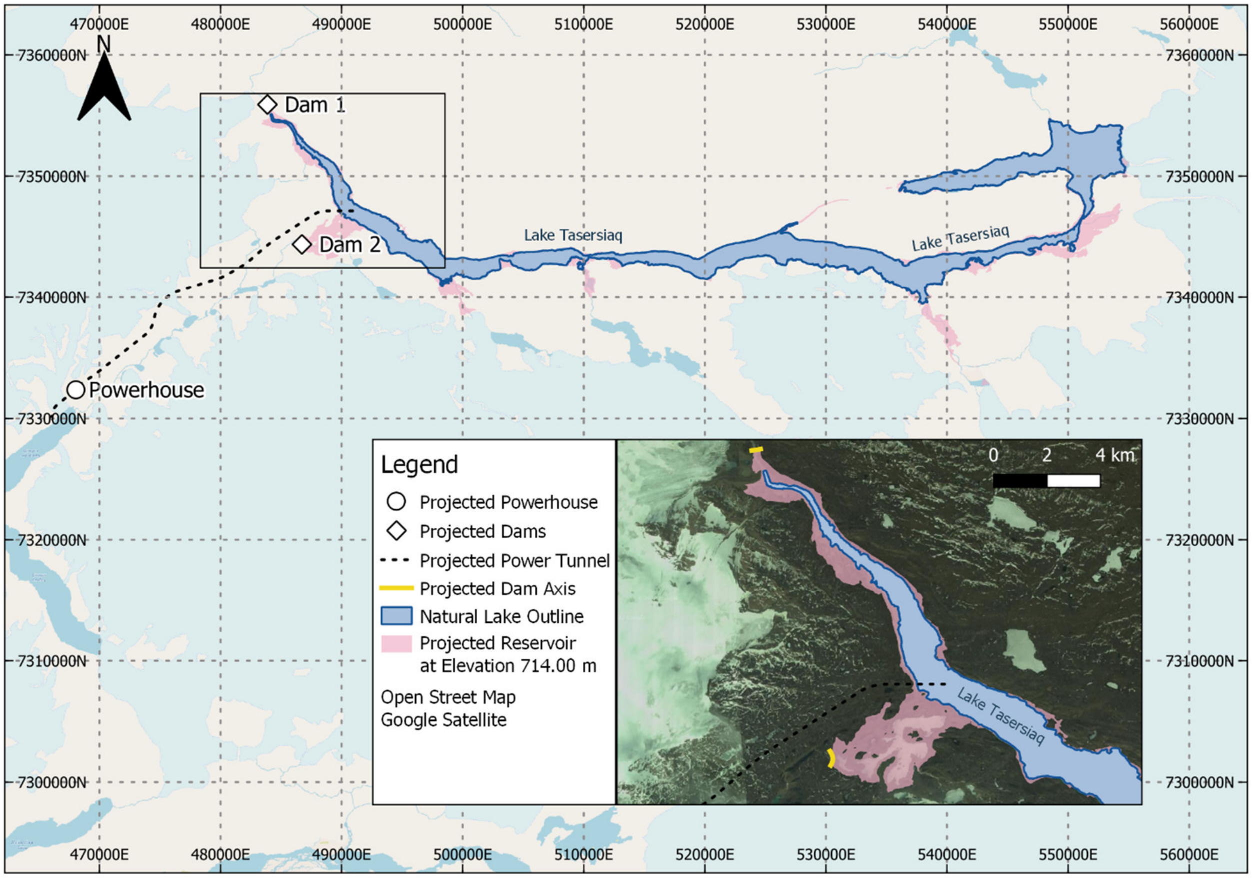

Figure 1-2 : Site 07.e - Project Layout (from AECOM, 2009)

The main characteristics of the scheme developed by AECOM are presented in Table 1-1. These characteristics were maintained in the present power generation study. However, some parameters were the object of a sensitivity analysis, and higher turbine capacity were selected for the inflow series allowing higher power generation, as described in Section 3.2.

Table 1-1: Site 07.e Main Project Characteristics (AECOM, 2009)

Water Levels	
Reservoir	
Maximum operating level	714 m*
Minimum operating level	680 m*
Downstream – Fjord	
Maximum tide level	2.6 m
Minimum tide level	-2.3 m
Headrace Canal	
Length	2 100 m
Flow velocity	0.65 m/s*
Headrace Tunnel	
Length	26.6 km
Diameter	8 m
Cross-sectional shape	Circular
Turbines	
Number of turbines	5
Type of turbines	Pelton
Level of turbine nozzles	8 m
Gross head (at max level)	706 m*
Net head (at max level)	697 m*
Unit discharge	17.4 m^3/s*

* Directly or indirectly the object of a sensitivity analysis in the present energy generation study.

2. SITE HYDROLOGY

The hydropower potential of 07.e is based on exploitation of the catchment of lake Tasersiaq. The total catchment area at Site 07.e is estimated to be 6,789 km², of which 78% are glacier covered. Majority of the inflow comes from glacier melting that occurs between June and October.

2.1 Data Availability

AtkinsRéalis has been provided by The Ministry with the following hydrological data:

- daily historical inflow series at the project intake site for a period of 42 years from 1980 to 2021. In the provided time series, some of the years has missing data. Figure 2-1 presents the availability of daily inflow data and the missing periods;
- annual inflow volume for historical period;
- annual inflow volume for future period corresponding to various Radiative Concentration Pathways (RCP) climate scenarios:
    - Two scenarios for the period (2031-2050);
    - Seven scenarios for the period (2023-2100).

The daily flow data provided to AtkinsRéalis was derived through a combination of observed flow data, water level data and HIRHAM climate model outputs [Ref 3]. The measured time series at catchment 07.e had 29 years overlapping with the HIRHAM5 ice runoff time series with a strong correlation ($R^2 = 0.90$). Applying this correlation, data derived from the climate model was used to provide data series from 1980 to 2021 [Ref 3].

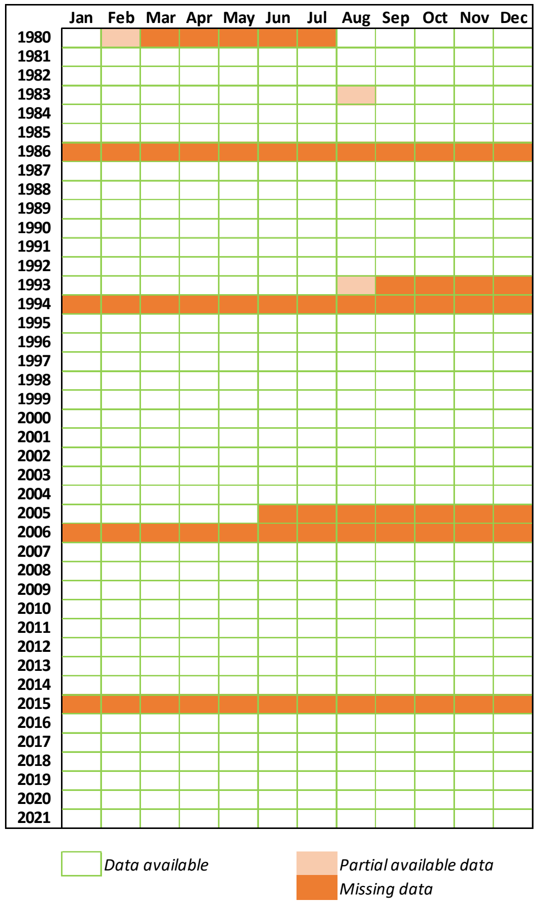

Figure 2-1 : Site 07.e – Daily Inflow Data Availability

The available daily inflow time series (with missing periods) is presented in Figure 2-2. The figure shows that every year flow peaks in mid-summer. Winter and autumn flows are minimal. The high flow is snowmelt / ice melt driven as significant part of the catchment is ice covered. The summary statistic of daily flow data is presented in Table 2-1. Mean flow is found to be about 18 times higher than the median flow and the time-series is positively skewed. Such a large difference between the mean and median of the data is reflective of large range of flow in the time series.

Table 2-1: Summary Statistics of Daily Inflow Data

Statistics	Flow (m^3/s)
Minimum	0.01
Maximum	1750
Mean	88.9
Median	4.87

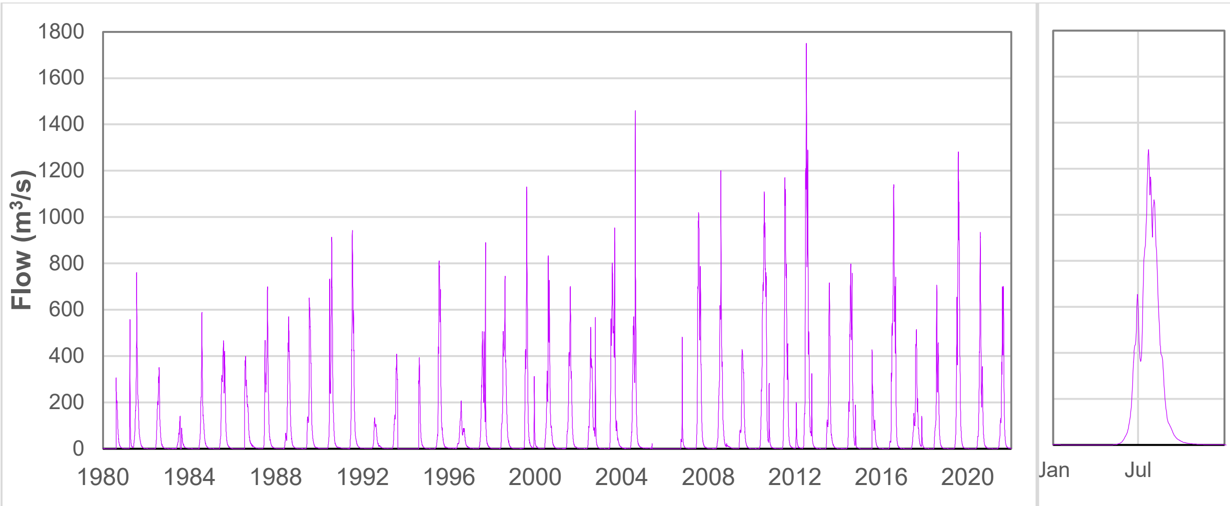

Figure 2-2: Daily Inflow Time Series with a Typical Year Hydrograph on Right Panel

The provided annual inflow volume data is presented in Figure 2-3. The plot also includes the mean annual temperature for Greenland [Ref 6]. Over the years a trend of increasing mean temperature is evident and the same trend is reflected in flow volumes too. Since the flows in the catchment primarily result from snow and ice melt, increase in mean temperature is resulting in higher flows over the years. Mann-Kendell statistical test applied on the annual inflow volume presents a significantly increasing trend in the data.

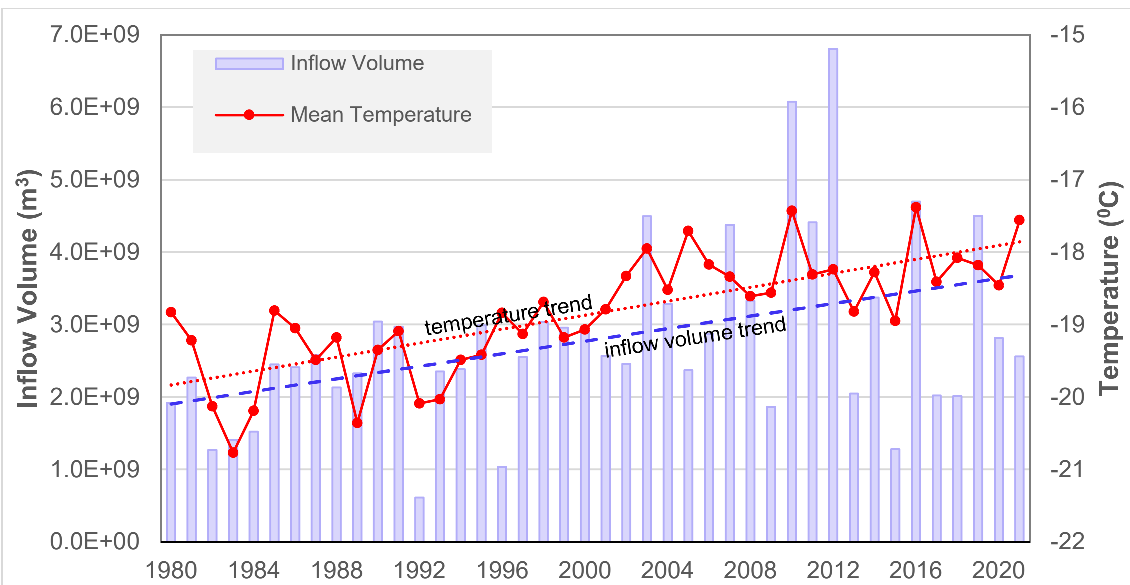

Figure 2-3: Annual Inflow Volume for Catchment 07.e and Mean Annual Temperature

2.2 Reconstitution of Flow Time Series

In order to build an appropriate power potential model, a daily flow time series is required which is reflective of the present and the changing hydrological conditions of the catchment. The provided flow series was reconstituted after performing the following operations on it:

a) **Data gap filling:** In order to effectively use the flow data for energy generation, it is important to fill the gaps in the provided daily flow series. Since there is no nearby station with same period of observed data, data gap filling was carried out applying statistical method. Two different approaches for gap filling are applied as described in later sections.

b) **Volume correction:** Since the annual inflow volume series was provided for each year, the generated time series, after gap filling, was corrected to match the annual volume. An attempt was made to minimize the corrections on the observed data.

c) **Trend correction:** As discussed earlier, an increasing trend in the annual flows has been observed in the historical data. Mean inflow volume over each decade is computed and the decadal trend is presented in Figure 2-4. With the increasingly warming climate, the trend observed in the water resources over the historical period is likely to continue in future. In order to estimate the hydropower potential for the catchment with minimum uncertainties, the trend in the annual inflow need to be diluted thus generating the time-series more representative of the present-day hydrological conditions.

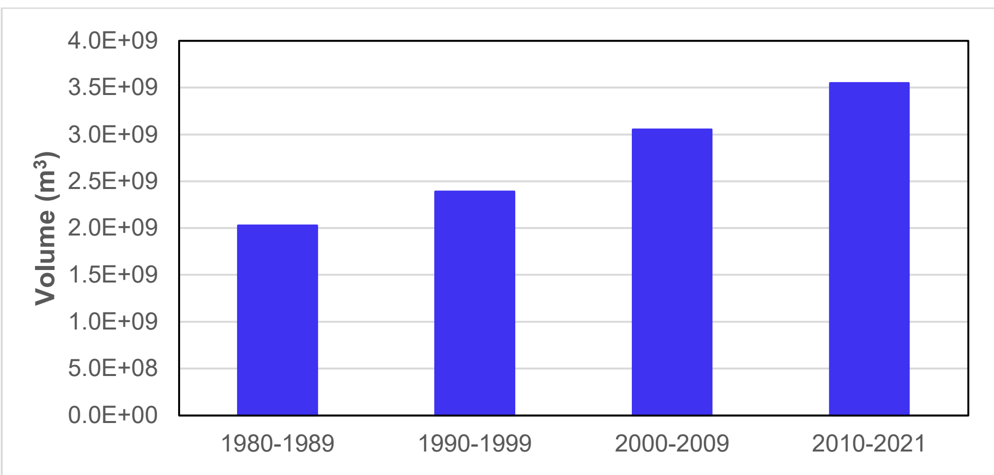

Figure 2-4: Trend for Mean Decadal Inflow Volume

To derive the flow series with no-trend two approaches were adopted. In both approaches, a factor was first derived on annual volume, which, when applied to the observed inflow volume, would eliminate the trend in the annual inflow volume series. The factor was then applied to the daily time-series.

Three set of reconstituted flow series were generated by applying the above procedure. First a historical series was derived by performing only two operations: filling the missing data and correcting for annual volume; the series is termed as Reconstituted Series-0 (RS0). Then two more data series were derived by performing all the three operations described above. In these series the increasing trend of annual flow over the years have been eliminated. These trendless series are termed as Reconstituted Series-1 (RS1) and Reconstituted Series-2 (RS2).

2.2.1 Reconstituted Series-0 (RS0)

As described above the reconstituted series was derived by applying the above operations:

- **Data gap filling:** The missing data for any given day was filled by taking the mean flow for that day, which is computed based on 42 years of available data.

- **Volume correction:** Since the annual inflow volume series was also available, the generated time series after gap filling was corrected to match the annual volume.

2.2.2 Reconstituted Series-1 (RS1)

As described above the reconstituted series was derived by applying all the above operations:

- **Data gap filling:** The missing data for any given day was filled by taking the mean flow for that day, which is computed based on 42 years of available data.

- **Volume correction:** Since the annual inflow volume series was also available, the generated time series after gap filling was corrected to match the annual volume.

- **Trend Correction:** It is considered that the beginning year of time series was lowest in trend and a year was selected till which the trend was assumed to have diminished. The volume was increased from beginning till the last selected year which was 2010. A linear variation of 2.52% per year was applied in the volume increment.

2.2.3 Reconstituted Series-2 (RS2)

Similar to the steps described above, another set of reconstituted series was derived:

- **Data gap filling:** In this approach, the time series imputation was carried out using an algorithm that seasonally decomposes the time series, fills the missing value by interpolation and later reintroduces the seasonality. The algorithm was implemented in R programing language using the function ‘*na_seadec*’.

- **Volume correction:** Since the annual inflow volume series was also available, the generated time series after gap filling was corrected to match the annual volume.

- **Trend Correction:** In this approach the annual volume is uniformly increased by 58% for each of the years from 1980 till 1999.

2.3 Comparison of Reconstituted Flow Series

Since the generation of reconstituted flow series involved various steps, comparison of different steps and the final series is presented here.

2.3.1 Data Gap Filling

Two different approaches of data gap filling were adopted in generating the reconstituted flow series (RS1 and RS2). Both approaches compare closely. As presented in **Figure 2-5** some differences in the estimated daily flow pattern are observed but the overall volume remains generally the same. In the plots Approach-1 and Approach-2 represent the method adopted to generate RS1 and RS2, respectively.

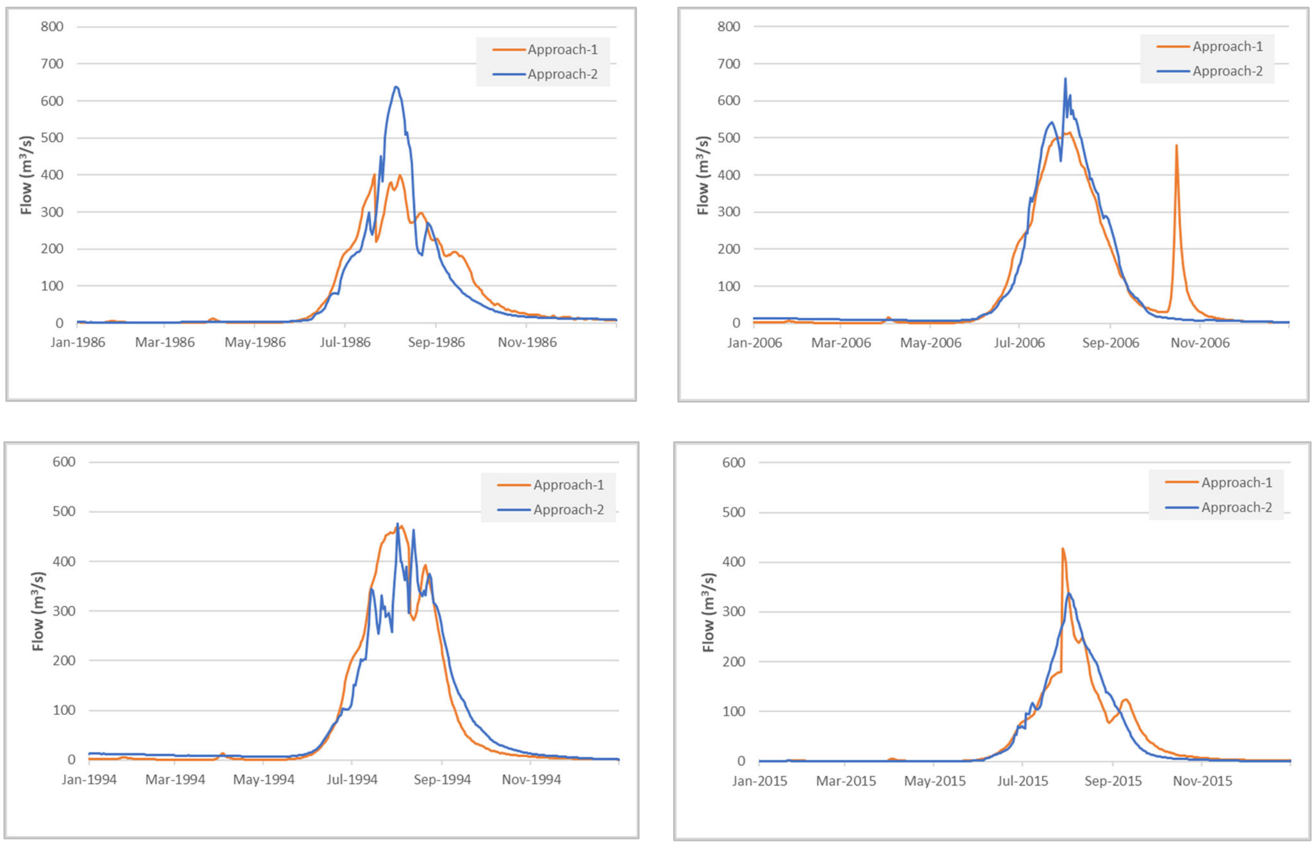

Figure 2-5: Comparison of Missing Years Flow Time Series after Gap Filling

As it will be shown with the energy analysis, the annual volume of water and the beginning of the melting season are the two most important factors for the energy analyses, since the reservoir is multi-annual, i.e. it takes more than one year to empty the reservoir when producing the firm power. Under these conditions, daily inflows patterns are less significant but sensitivity analysis have been done on both set of data.

2.3.2 Correction for Trend

Elimination of the trend in the flow time series has led to the increase in the mean annual volume in the trendless series. When compared to the observed series, the increase in volume is estimated to be about 22.5% and 20.5% in RS1 and RS2, respectively. The comparison of annual volume of observed and derived trendless series is presented in **Figure 2-6**. It can be seen from the plot that for some of the initial year RS1 has larger volume while RS2 has a large volume increment for the years 1997-1999. For some of the low flow years such as 1992 and 1996, which are more critical in power potential analysis, both approaches provide similar results.

The derived factors, for making the annual inflow series trendless, are then applied to the daily time series to generate final series for power potential analysis.

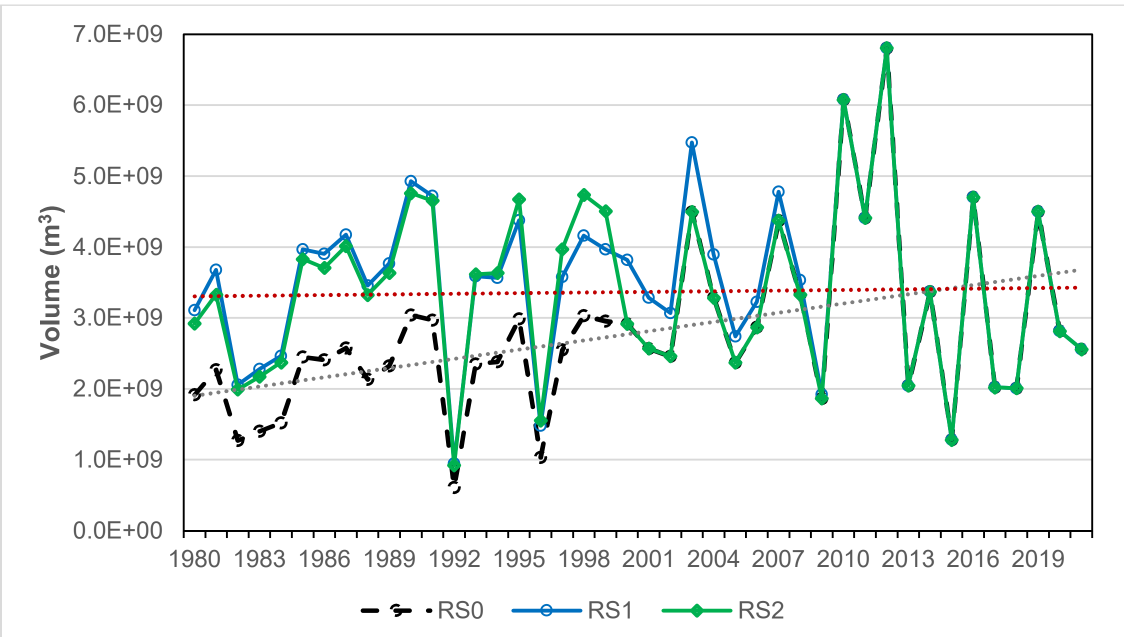

Figure 2-6: Comparison of Annual Inflow Volume

2.4 Final Flow Series

The reconstituted flow series are compared in terms of flow statistic and the summary plots presented here. As seen from **Figure 2-7**, the mean monthly flow for the two trendless series (RS1 and RS2) is almost identical. However, RS0 has lower overall flow volume, as described earlier. In this series inflows are mainly lower during peak flow months of July and August.

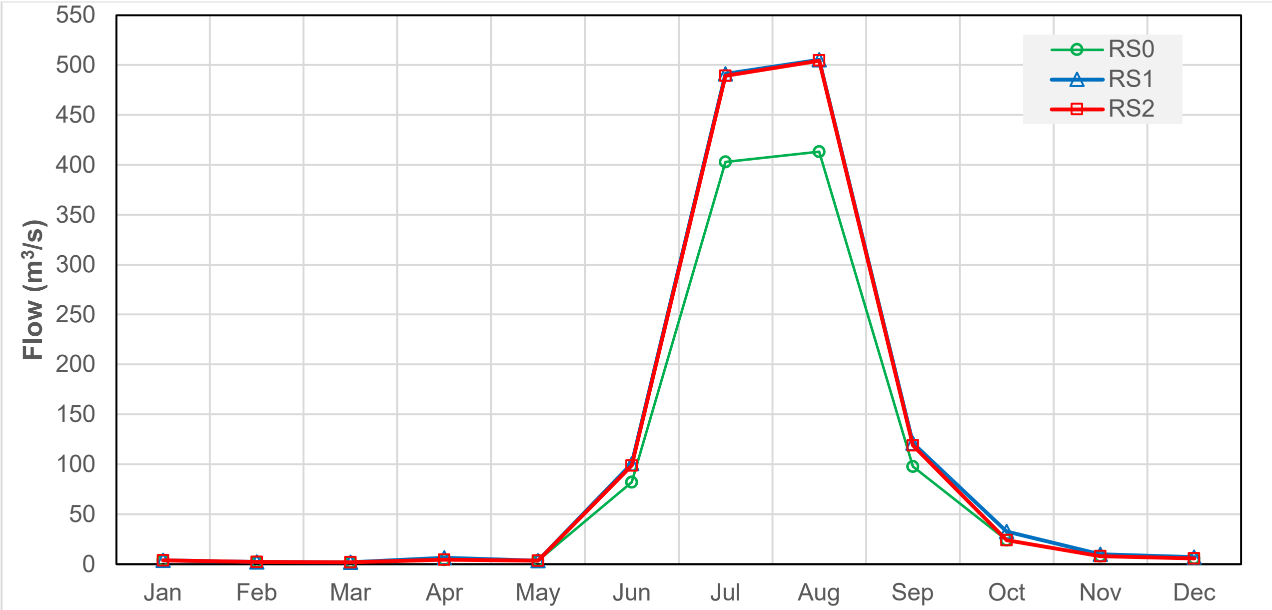

Figure 2-7: Comparison of Mean Monthly Flow

Mean flow and mean annual volume of time series RS0 are markedly lower than that of the other two series, as presented in Table 2-2. As described above the correction of trend has led to increase of volume in the latter two reconstituted series.

Table 2-2: Summary Statistics of Reconstituted Daily Flow Series

Statistics	Value		
	RS0	RS1	RS2
Daily Flow (m^3/s)			
Minimum	0.0	0.0	0.0
Maximum	1750.0	1750.0	1785.4
Mean	88.5	108.4	106.7
Median	6.05	6.23	6.16
Specific Flow ($m^3/s/Km^2$)			
	0.0130	0.0160	0.0157
Volume (x 10^6 m^3)			
Mean Annual	2757	3376	3324

Flow duration curve (FDC) is complementary to the cumulative distribution frequency of flows and is an important flow signature of a catchment. FDC's of the reconstituted series are also found to be mostly matching for the series RS1 and RS2 as reflected in Figure 2-8, while the high and mid-range flows are lower in RS0 than the other two series.

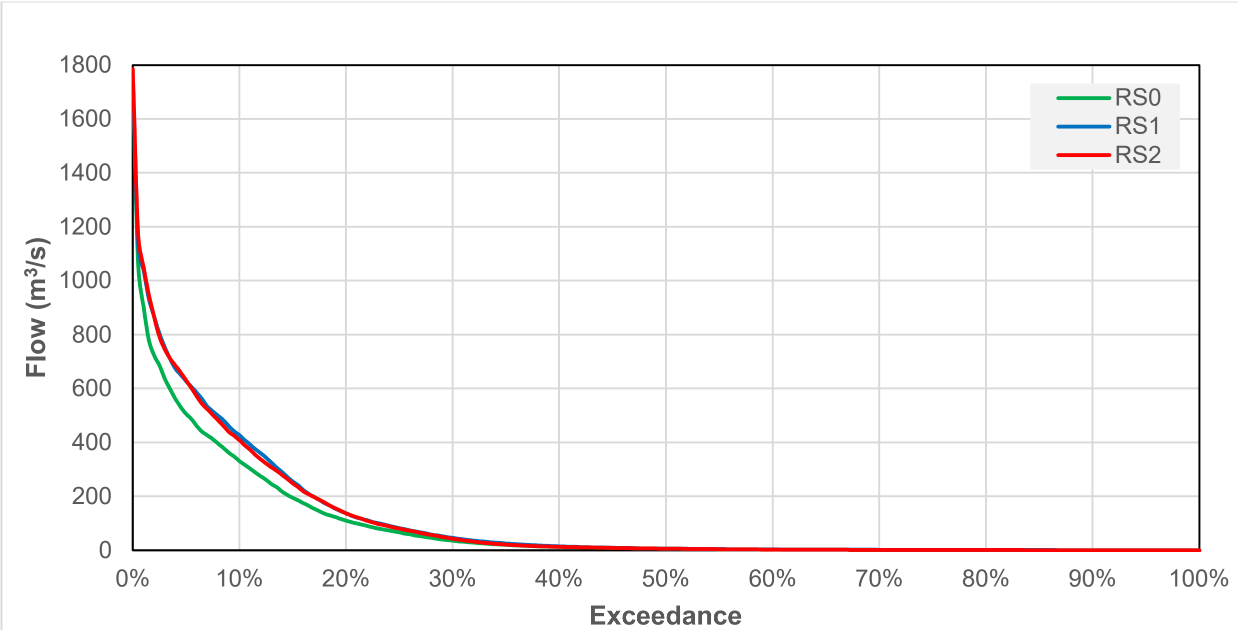

Figure 2-8: Flow Duration Curves for Reconstituted Inflow Series

The above comparison illustrates that both approaches of generating trendless series lead to the reconstituted flow series that have similar characteristics. The mean monthly flow corresponding to three sets of reconstituted flow time series (RS0, RS1 and RS2) are presented in Appendix A0, A1 and A2, respectively.

2.5 Climate Change Scenario

2.5.1 Climate Change 2031-2050 Period

AtkinRéalis (formerly SNC-Lavalin) [Ref 9] was provided with annual inflow volume for catchment 07.e for a future period from 2031-2050, based on meteorological characteristics observed for the period 1991-2010. The data provided was produced through modeling of future climate in Greenland according to two of the UN climate panel (IPCC) scenarios for the future level of greenhouse gasses in the atmosphere - RCP4.5 and RCP8.5 [Ref 7 and 8]. The results are the outcome of the HIRHAM regional climate model (RCM) run for the future time slice.

The annual water yield for catchment 07.e is projected to increase in the future climate scenario. Table 2-3 presents the comparison of mean annual inflow for the basin. It is evident from the comparison that the flow is projected to increase significantly during 2031-2050 period when compared to the historic period flow. The increase is projected to be higher for RCP4.5 scenario than for RCP8.5. In the table, the inflow volume for historic period is the mean of the inflow corresponding to the reconstituted series RS1 and RS2.

Table 2-3: Mean Annual Inflows

Scenario	Period	Volume ($\times 10^6$ m^3)	% change*
Historic	1980-2021	3350	…
	1991-2010	3364	…
RCP4.5	2031-2050	5106	51.8%
RCP8.5	2031-2050	4766	41.7%

* Change is with respect to the Historic period 1991-2021 for series RS1 and RS2

Figure 2-9 presents the provided annual inflow volume corresponding to RCP4.5 and RCP8.5 scenarios. The trend in annual water resources is found to be decreasing for RCP4.5 scenario while it is increasing for RCP8.5 scenario. The output from climate model is a result of a very complex systems with processes that can have opposite effects, thus the trend in each of the scenarios could be different.

It must be mentioned that the annual hydrograph from the climate model cannot be compared to the historical data for a specific year (ex. 2031 with 1991 or 2032 with 1992).

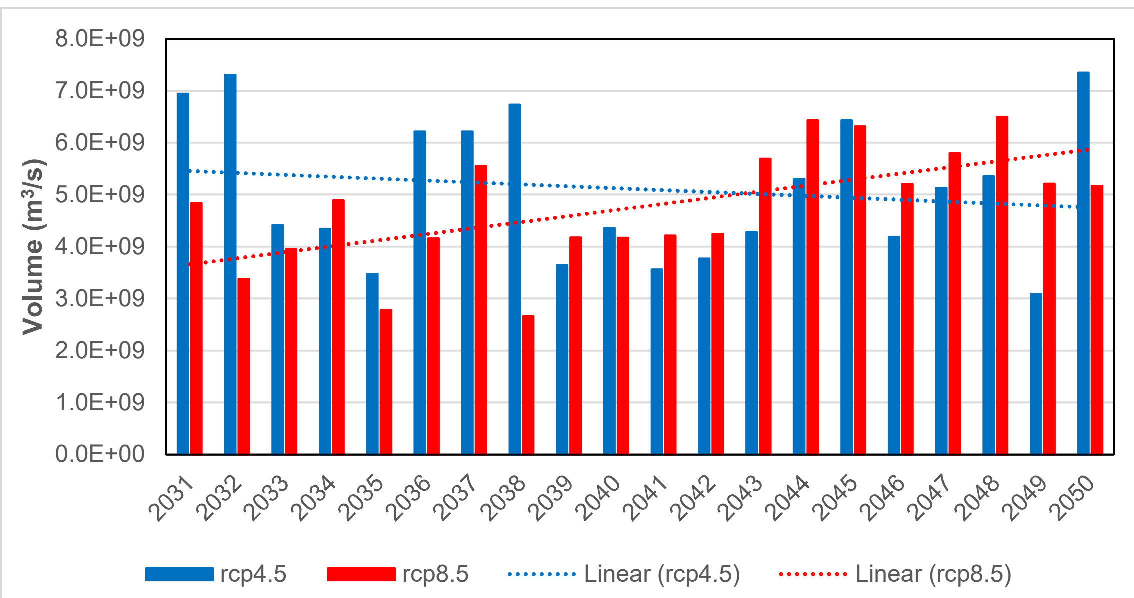

Figure 2-9: Projected Annual Inflows Volume for RCP4.5 and RCP8.5 Scenarios

2.5.2 Climate Change 2031-2100 Period

ASIAQ performed a study in 2023 [Ref 4] to evaluate new climate change scenarios at Site 07.e.

Figure 2-10 presents a comparison of the annual runoff of the two climate change scenarios 2031-2050 period considered in section 2.5.1 and the seven scenarios proposed by ASIAQ. Adjustment factors were used to calibrate the runoff provided by the models with the observed annual runoff. The blue bar corresponds to the adjustment based on the minimum adjustment factor and the orange bar corresponds to the adjustment based on the maximum adjustment factor, which means that the average runoff for the period 2031-2050 will be the average between these two adjustments. The figure shows that the annual average runoff for the new scenarios is generally lower than the annual average runoff for the two initial projection scenarios presented in **Figure 2-9**. More details are provided in the memo prepared by D. Petersen [Ref 5].

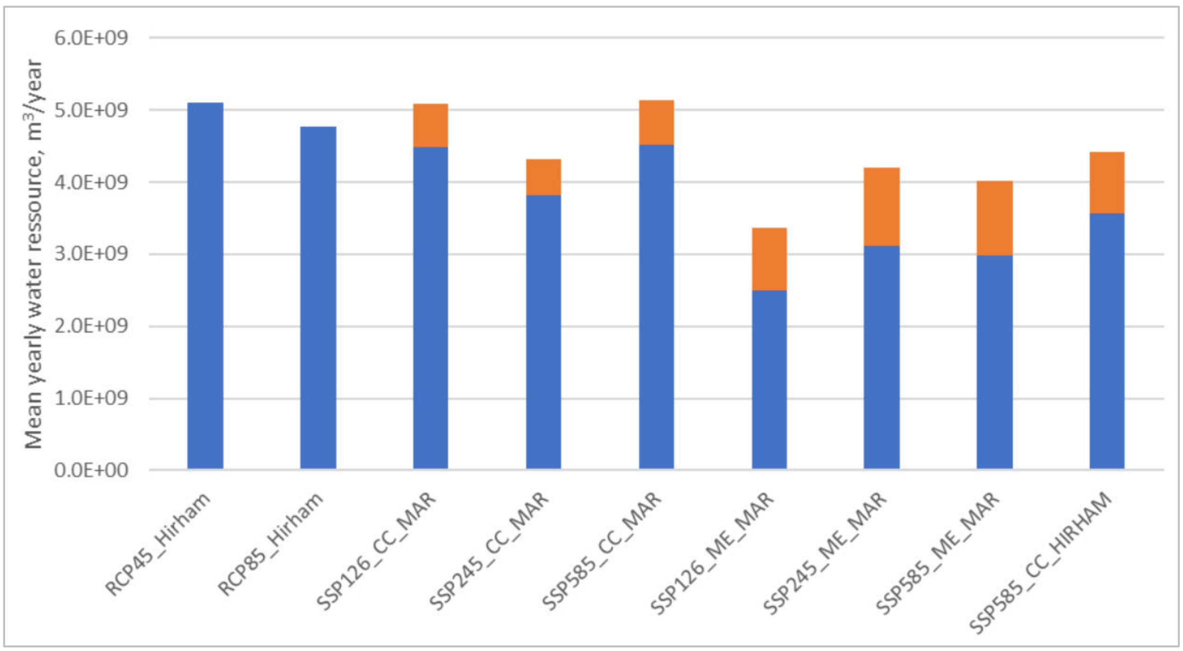

Figure 2-10: Site 07.e - Climate Change Scenario – Comparison of Average Annual Runoff – 2031-2050 (from Ref 4)

Figure 2.11 illustrates the annual runoff for the period 2023-2100 period for the seven scenarios based on an average adjustment factor. The annual runoff remains in the lower range between 2023 and 2060, followed by a noticeable to significant increase between 2061 and 2100. However, there are some exceptions, such as the scenario SSP126_ME_MAR, where the annual runoff between 2060 and 2100 remains unchanged compared to the period 2031-2060 period.

As recommended by ASIAQ [Ref 4], the monthly distribution for each year is based on the percentage of runoff per month extracted from the historical time series.

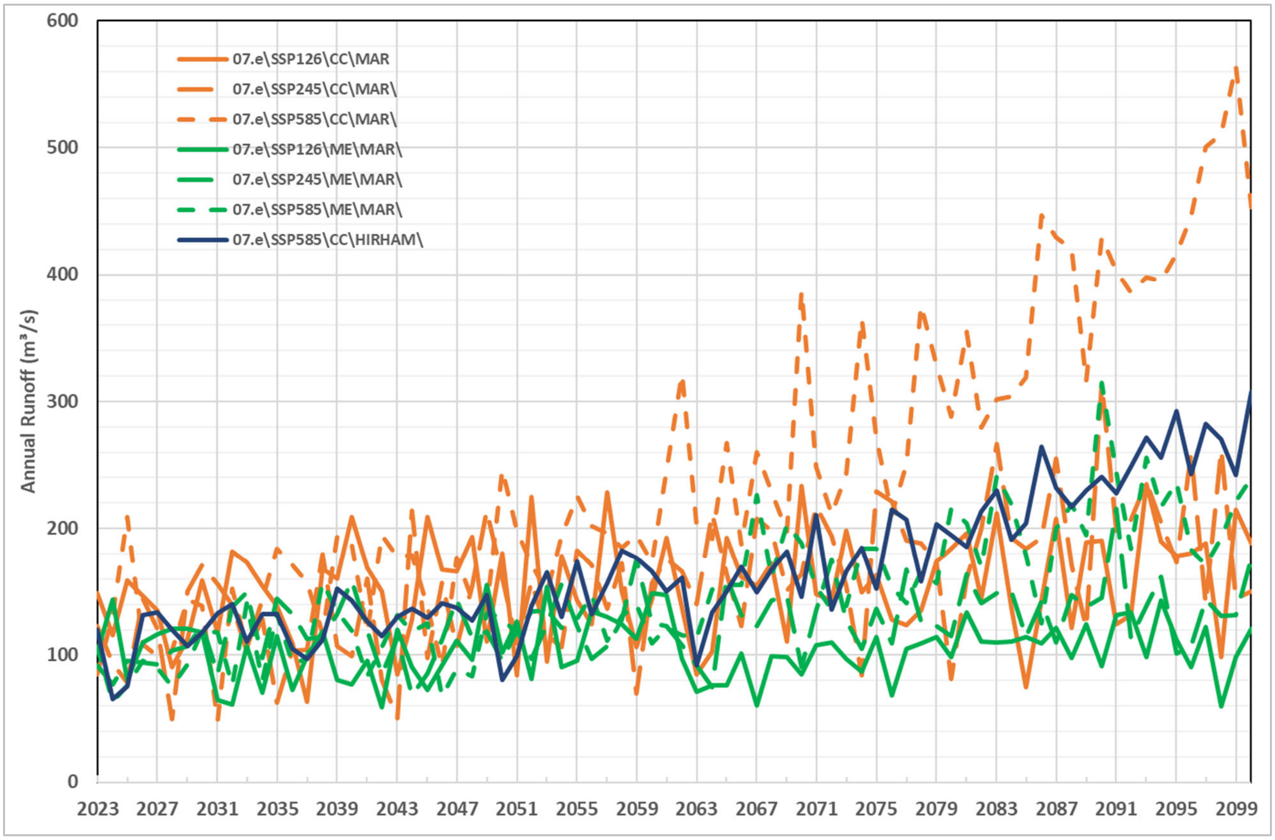

Figure 2-11: Climate Change Scenario – Annual Runoff (data adapted from ASIAQ [Ref 4])

3. ENERGY MODELING

Energy modeling was carried out for the hydropower scheme developed by AECOM in the 2009 pre-feasibility study [Ref 1]. The PFS modeling parameters and assumptions were maintained, when possible, but modifications were made to perform sensitivity analysis, or to increase the plant capacity under high-flow hydrology scenarios, as described below.

3.1 Model & General Methodology

Modeling was performed using an in-house spreadsheet-based energy model. Simulations were performed with a daily-time step. The use of daily-time step provides sufficient accuracy for the energy analysis, considering that the reservoir operation follows a multi-annual pattern.

The general modeling methodology can be described as follows:

- Daily inflows are routed through the reservoir using continuity equations and the reservoir storage curve (streamflow method);
- Outflows are function of the firm power target, which is constant in time. The outflow required to produce the firm power depends on the net head available;
- Water is released by the spillway when the reservoir level reaches the maximum operating level. The spillway capacity is considered sufficient to not exceed the maximum operation level;
- Generation is halted when the reservoir level reaches the minimum operating level (deficit).

The evaluation of the available firm power for a given scenario is a trial-and-error process. The firm power target is modified until the maximum target allowing for operating rules compliance is identified. The firm power target is assumed to be available at 100% at any time during the simulation period.

3.2 System Characteristics & Modeling Assumptions

3.2.1 Storage

The storage curve of the proposed reservoir is presented in Figure 3-1. As described by AECOM in the PFS report [Ref 1], the proposed location of the intake structure is separated from the upstream section of Lake Tasersiaq by shoals at an approximate elevation of 688 m. To use the total volume of the reservoir below elevation 688 m would require dredging the shoals, shown in **Figure 3-2**. Therefore, two storage curves are presented in Figure 3-1, the complete reservoir storage, that would require dredging to be used for generation, and the storage with a limitation to the intake sector for elevation under 688 m. The curves were extracted from AECOM's PFS report and validated using available bathymetric and topographic data provided by The Ministry.

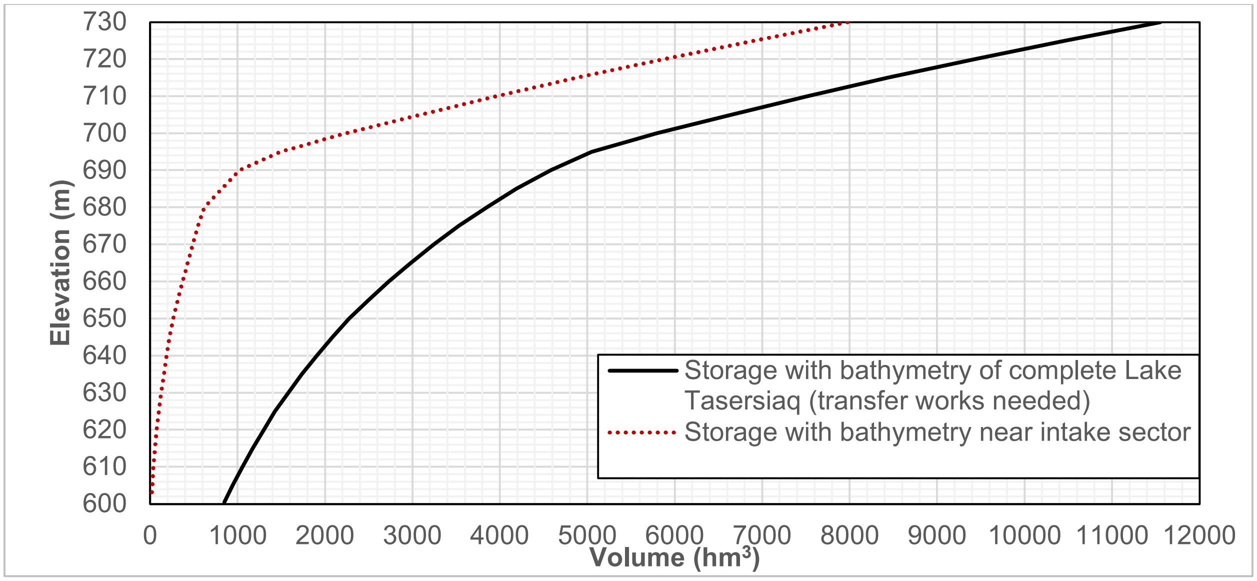

Figure 3-1: Site 07.e - Lake Tasersiaq Storage Curves (AECOM [Ref 1])

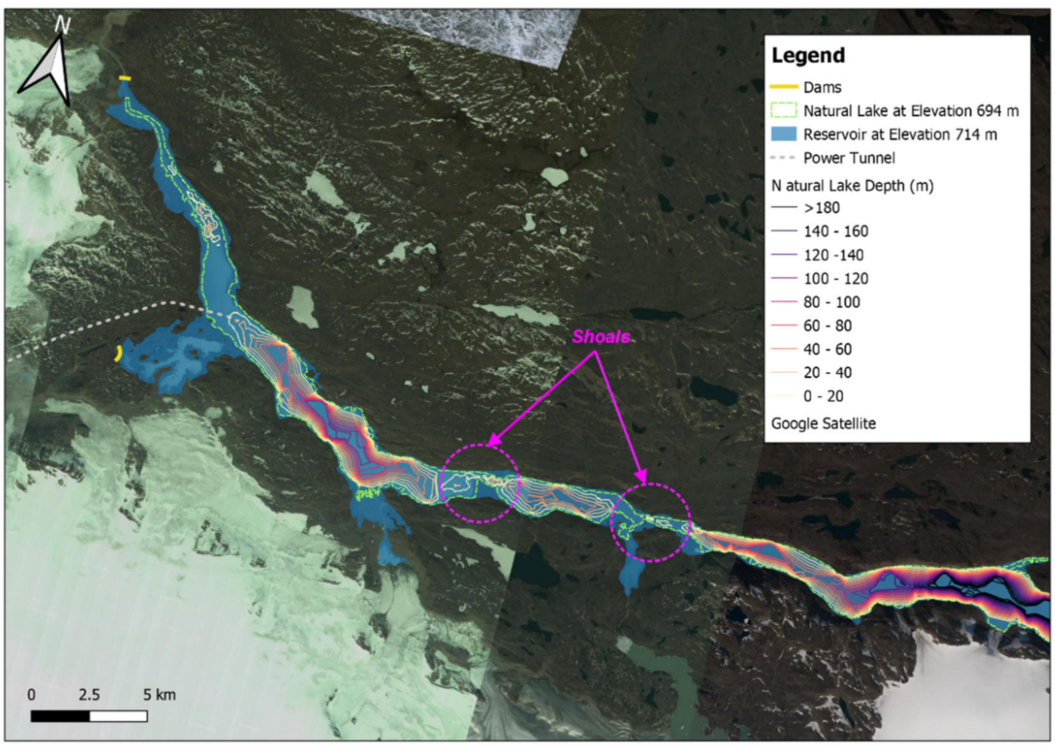

Figure 3-2: Lake Tasersiaq Bathymetry near the Projected Intake

3.2.2 Operating Levels

The PFS minimum and maximum operating level (680 m and 714 m, respectively) [Ref 1] were selected for the base case of the energy generation simulations. Additional scenarios were also considered, as described in Table 3-1.

Table 3-1: Site 07.e - Operating Level Scenarios

Reservoir Level (m)	Storage (hm^3)	
	Intake Sector Only	Complete Lake Tasersiaq
Minimum Operating Level Scenarios		
680 (base case)	620	3,860
690	1,020	4,580
700	2,230	5,790
Maximum Operating Level Scenarios		
714 (base case)	4,690	8,250
717	5,270	8,840
720	5,880	9,440
723	6,500	10,060
726	7,130	10,690

3.2.3 Generation Devices

Following the scheme proposed in the PFS [Ref 1], the powerplant was modeled with five (5) Pelton turbines, with nozzle elevation of 8.0 m. However, the turbine capacity was adapted to the hydrological scenario to allow for high firm power target, up to 35 m^3/s. No calculations were performed to determine the optimal number of units and their capacity, as it was outside of the objectives of the present study.

The adopted efficiency curve of the Pelton turbines is presented in **Figure 3-3**. The curve was extracted from the RETSCREEN software and adjusted to match the efficiency considered by AECOM (91.9%) [Ref 1]. A 98.6% generator efficiency was considered, and a 0.055% loss was added to consider the potential impact of a high velocity oxygen fuel (HVOF) coating.

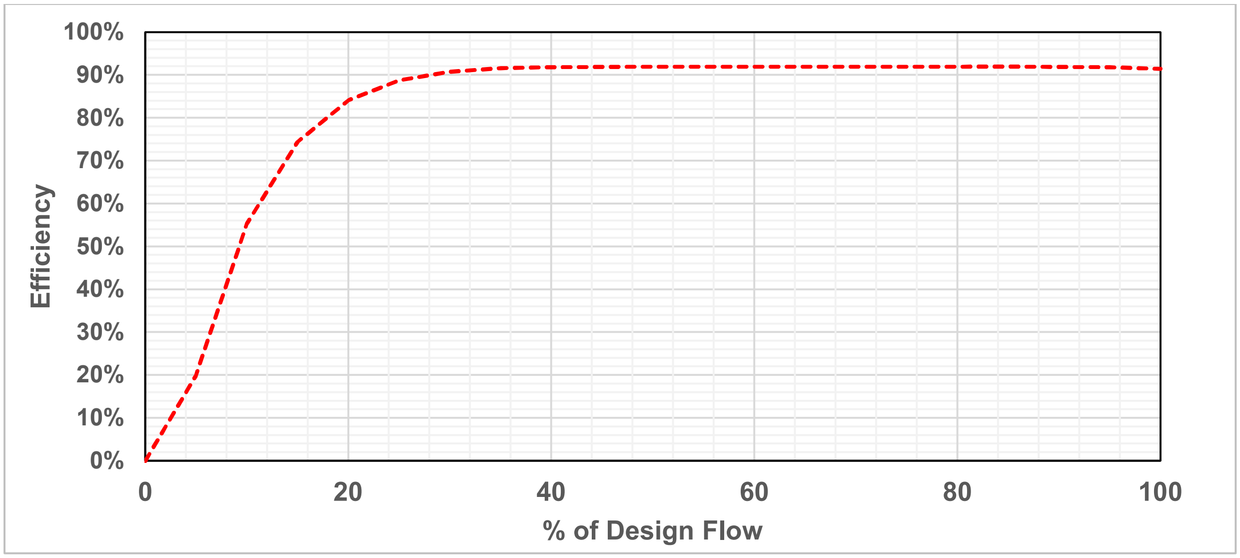

Figure 3-3: Site 07.e - Efficiency Curve for a Single Pelton Turbine

3.2.4 Head Losses

A simplified head loss relationship was defined, to match the net head values published by AECOM for typical operating conditions [Ref 1]. The adopted curve is presented in Figure 3-4. No optimization work was done on the intake or power canal geometry to allow for lower losses at higher discharge values, as the scheme optimization was outside of the objectives of the present study.

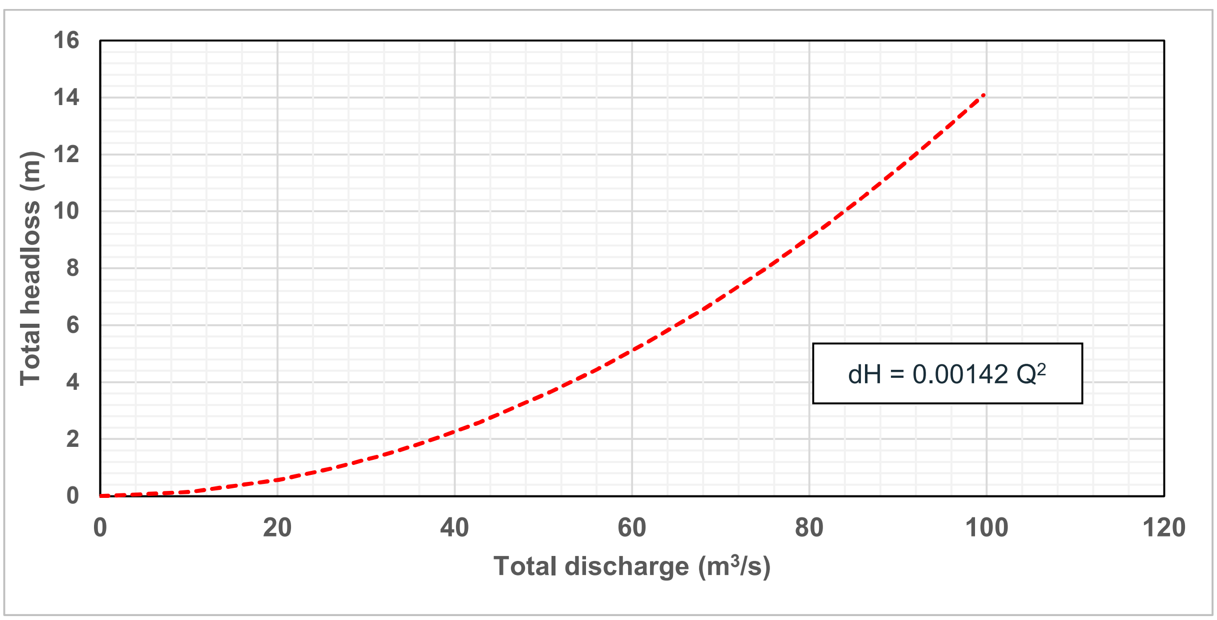

Figure 3-4: Site 07.e - Adopted Total Headlosses Curve

3.2.5 System Power & Other Losses

A power station energy requirement of 3 MW was considered, same as the value used in the PFS study [Ref 1]. Therefore, this value is subtracted from the firm power target to obtain the net firm power available for each modeled scenario.

Transmission losses were not considered, as the location of potential users is unknown.

3.2.6 Outages

No outage (planned or unplanned) was modeled. The net firm power published for each scenario is conditional to having five units available during the complete modeled period.

Maintaining the firm power target during planned or unplanned outages would require additional power units, to provide redundancy.

3.3 Scheme Optimization

No optimization study of the proposed layout was performed. Optimization work would require updated cost estimates, which is outside of the objectives of the present study.

3.4 Sensitivity Analysis

Sensitivity analyses were performed on the following parameters:

- Maximum and minimum operating levels (see Section 3.2.2);
- Storage capacity (with or without dredging work in Lake Tasersiaq);
- Inflow series:
  - Historical period (1980-2021);
  - Trendless annual series (1980-2021);
  - Historical period (1991-2010);
  - Future climate scenario (2031-2050) for RCP4.5 and RCP8.5;.
  - Future climate scenario based on ASIAQ 2023 (2031-2050, 2031-2060, 2051-2080, 2071-2100).

An additional sensitivity analysis was performed by running scenarios allowing for a deficit in power generation for one of the modeled years.

4. Initial Climate Change Scenarios – Results Analyses

The analyses performed are described in Section 3.4. The results will be compared with the base case, i.e. considering a maximum operation level of 714 m, a minimum operation level of 680 m and a level-storage curve without dredging work in Lake Tasersiaq.

It is not possible to make any recommendation on the best alternative for the system, since an evaluation of the cost of the project and each potential alternative would have been required to determine an optimum solution.

4.1 Historical Data - ASIAQ 1980-2021

The first set of analyses were performed on the historical set of inflow data provided by ASIAQ [Ref 7] and subsequently reconstituted for the period 1980 to 2021, as described in Section 2.2. As mentioned in Section 2, two other sets of inflows were prepared to eliminate the strong trends observed on the historical set of data. Thus, the power potential analysis was performed using:

- RS0 – Data gap filling and correction of the inflows volume;
- RS1 - Data gap filling and correction of the inflows volume and trend correction for the period 1980 to 2021;
- RS2 - Data gap filling and correction of the inflows volume and trend correction for the period 1980 to 2021.

The last two sets of data are considered more representative of the situation observed over the last 10 to 20 years and should provide better indications of the actual firm energy of the system.

4.1.1 Historical data – Reconstituted Daily Inflows Series – 1980-2021 (RS0)

The first set of analyses were performed with the historical set of data using reconstituted series RS0. It will serve as a basis of comparison for the other analysis and will be used to determine the main trends related to different parameters. Table 4-1 presents the main results for the different analyses performed with the historical set of inflows.

For the base case (i.e. H_{max} = El. 714 m and H_{min} = El. 680 m with storage capacity corresponding to intake sector only) the firm power is estimated to be 418 MW which is in the same range that the firm power estimated by AECOM in the 2009 study [Ref 1]. For each analysis, the water level at the beginning of the simulation was set identical as the final level (iterative process) to guarantee that the total inflow to the system is equal to the total outflow at the end of the analysis.

Figure 4-1 illustrates the variation of the reservoir level for the period of analysis. For a constant power demand of 418 MW, the figure shows that the reservoir cannot be filled completely during the period 1980 to 1999 (even if it is almost full in 1981 and 1992). Since the reservoir was not completely filled before reaching the minimum level (1985), it is essential that the initial and final level in the simulation are the same. Similar conditions were observed for most of the cases analysed, except when the live storage is significantly reduced, such as the case where H_{min} = El. 700 m.

The Table 4-1 shows the difference of firm energy in comparison with the base case. The following trends have been noted:

- The increase of the minimum operation level (H_{min}) has a limited impact on the firm energy, i.e. a reduction of about 3% for H_{min} = El. 690 m and a reduction of about 17% if H_{min} = El. 700 m;

- The increase of H_{max} and the live storage has also a limited impact. i.e. between 3.5% and 9% for H_{max} varying from El. 717 m to El. 726 m;

- The dredging of the Tasersiaq Lake, i.e. maximizing the live storage available between elevation 680 m and 690 m, correspond to an increase of 10 MW on the firm energy of the system (about 2.4%);

- Accepting the possibility to have deficit of generation during a year over the period of analysis has also limited impact on the firm power. For the base case, the firm power is increased only by 11 MW, which is relatively limited (2.6%). It must be noted that the period of deficit in generation observed during the critical year (1985) is estimated to be about 65 days, i.e. that the reservoir is empty about two months before the beginning of the Spring flood the following year.

Table 4-1: Site 07.e – RS0 – Energy Analysis Results – 1980-2021

Hmax El. (m)	Hmin El. (m)	Firm Power (MW) [1]	Difference with base case (MW)	Firm Energy (GWh/y)	Average Energy (GWh/y)	Secondary Energy (GWh/y)
Intake Sector only – Firm at 100%						
714	680	418 [2]	-	3662	3712	50
714	690	405	-13 (-3%)	3552	3616	64
714	700	347	-71 (-17%)	3040	3186	146
717	680	433	+15 (+4%)	3790	3827	37
720	680	440	+22 (+5%)	3856	3889	33
723	680	448	+30 (+7%)	3924	3952	28
726	680	455	+37 (+9%)	3991	4016	25
Reconstituted daily inflows series – Complete Tasersiaq Lake – Firm at 100%						
714	680	428.0	+10 (+2%)	3749	3788	39
Reconstituted daily inflows series – Intake Sector only – 1 Year with deficit						
714	680	429	+11 (+3%)	3747	3787	40
714	690	425	+7 (+2%)	3699	3745	46
714	700	351	-67 (-16%)	3072	3212	140

(1) Values rounded at the nearest MW

(2) Firm power for the base case.

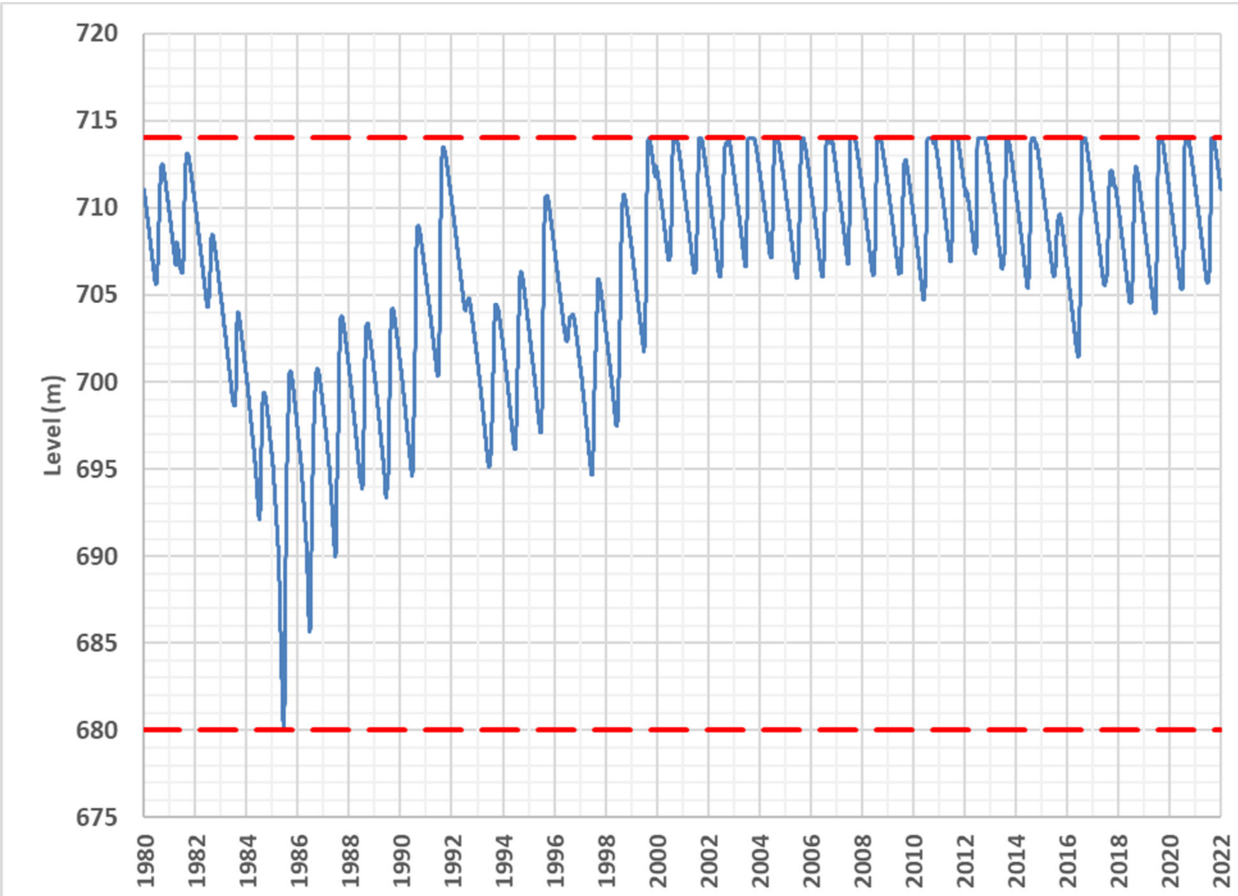

Figure 4-1: Site 07.e - Base Case – Water Levels for the Period 1980-2021, Firm Power Available of 418 MW

4.1.2 Historical data – Trendless inflows series

As mentioned previously, two “trendless” series have been reconstituted to “minimize” the trend observed on the historical annual runoff volume. Since the critical period for the historical data was observed during the 1980’s, it is expected that the impact on the firm energy generation will be significant.

Table 4-2 and Table 4-3 present the results of the energy analysis for these two inflows series, RS1 and RS2.

Table 4-2: Site 07.e – RS1 – Energy Analysis Results – 1980-2021

Hmax El. (m)	Hmin El. (m)	Firm Power (MW) (1)	Difference with base case (MW) (2)	Firm Energy (GWh/y)	Average Energy (GWh/y)	Secondary Energy (GWh/y)
Intake Sector only – Firm at 100%						
714	680	557	+139 (+33%)	4879	4897	18
714	690	517	+99 (+23%)	4529	4580	51
714	700	390	-28 (-7%)	3416	3632	216
717	680	573	+155 (+37%)	5021	5032	11
720	680	583	+165 (+39%)	5110	5132	23
723	680	592	+174 (+42%)	5190	5207	17
726	680	602	+184 (+44%)	5272	5286	14
Complete Tasersiaq Lake – Firm at 100%						
714	680	567	+149 (+36%)	4968	4980	12
Intake Sector only – 1 Year with deficit						
714	680	559	+141 (+34%)	4896	4913	17
714	690	543	+125 (+30%)	4747	4775	28
714	700	442	+24 (+6%)	3852	3991	139

(1) Values rounded at the nearest MW.

(2) Base case as defined on Table 4-1

The results for RS1 (Table 4-2) show an increase in firm power of about 30% for most of the cases. For the system parameters of the base case, the firm power is 557 MW, i.e., an increase of 33% in comparison of the firm power based on the initial set of inflows (418 MW for RS0). These values are slightly higher than the results presented by AECOM for their synthetic projected series (i.e., between 500 MW to 530 MW) [Ref 1].

Figure 4-2 illustrates the water levels in the reservoir for this case. The critical period occurs now between 1991 and 1993, instead of the 1980's for the base case presented in **Figure 4-1**. It should be also noted that the reservoir level is relatively low in 2016 and 2019, which appears to be more representative of the hydrological conditions observed recently.

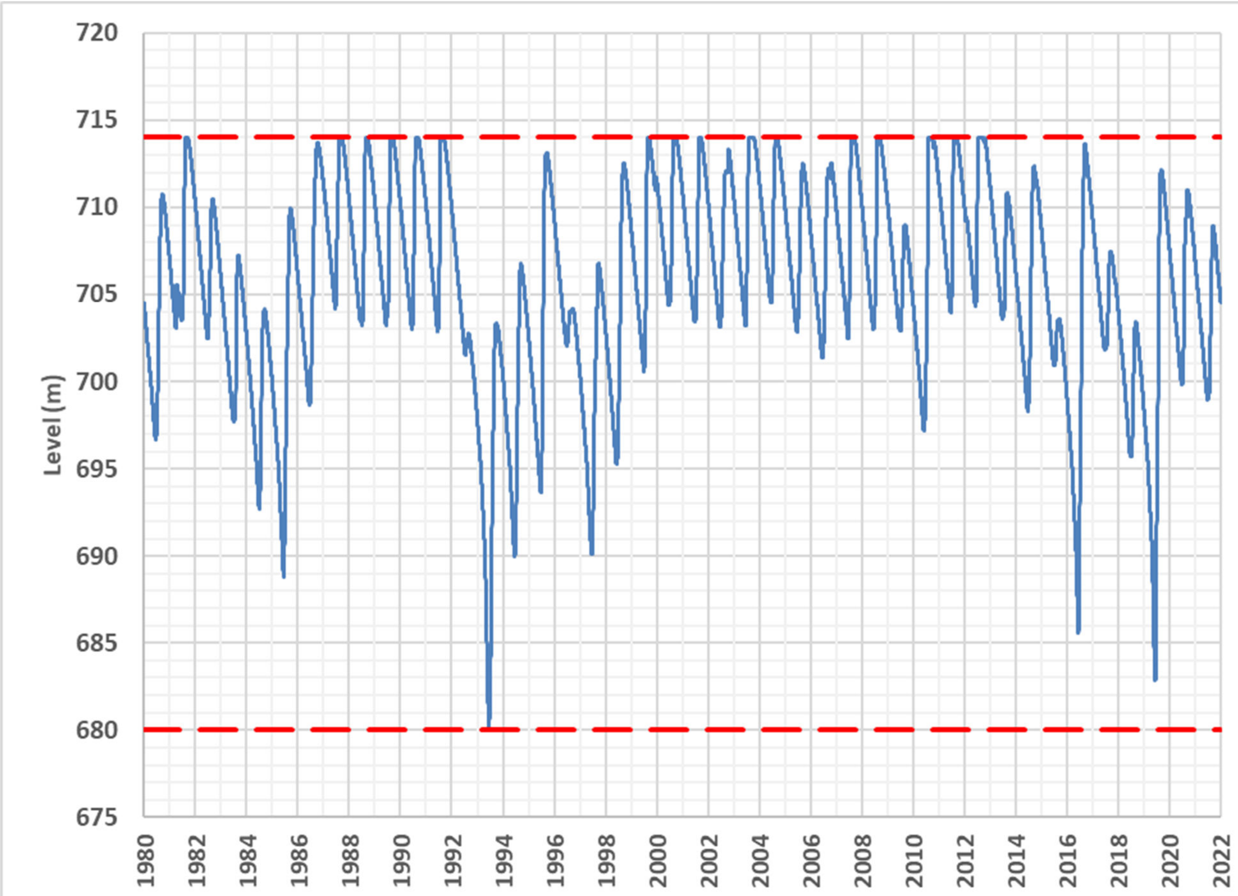

Figure 4-2: Site 07.e – RS1 – Water Levels for the Period 1980-2021 - Firm Power Available of 557 MW

The results for RS2 (Table 4-3) show a similar trend as the RS1 series but around 2% to 3% lower. The firm power is 545 MW for the system parameters of the base case, i.e. an increase of 30% in comparison of the firm power based on the initial set of inflows (418 MW). Figure 4-3 presents the variation of the water level for this case. The critical period occurs between 1981 and 1985, but the reservoir level is also low in 1993. It can be explained by the fact that the correction on the annual volume of runoff was less important on the first years of the period in comparison with the RS1 series. It also shows that the firm energy depends on the pattern of annual volume on the drainage area, but the range of firm energy observed is quite similar for the "trendless" inflows series and the results will not change a lot for the period 2010 and 2021.

Table 4-3: Site 07.e – RS2 – Energy Analysis Results – 1980-2021

H_{max} El. (m)	H_{min} El. (m)	Firm Power (MW) [1]	Difference with base case (MW) [2]	Firm Energy (GWh/y)	Average Energy (GWh/y)	Secondary Energy (GWh/y)
Intake Sector only – Firm at 100%						
714	680	545	+127 (+30%)	4776	4798	22
714	690	517	+99 (+24%)	4529	4573	44
714	700	390	-28 (-7%)	3416	3624	208
717	680	556	+138 (+33)	4876	4893	17
720	680	566	+148 (+35)	4958	4988	30
723	680	575	+157 (+38)	5037	5063	26
726	680	584	+166 (+40)	5116	5138	22
Complete Tasersiaq Lake – Firm at 100%						
714	680	550	+132 (+32)	4821	4840	19
Intake Sector only – 1 Year with deficit						
714	680	556	+138 (+33)	4853	4870	17
714	690	550	+132 (+32)	4806	4825	19
714	700	442	+24 (+6)	3853	3981	128

(1) Values rounded at the nearest MW.

(2) Base case as defined on Table 4-1

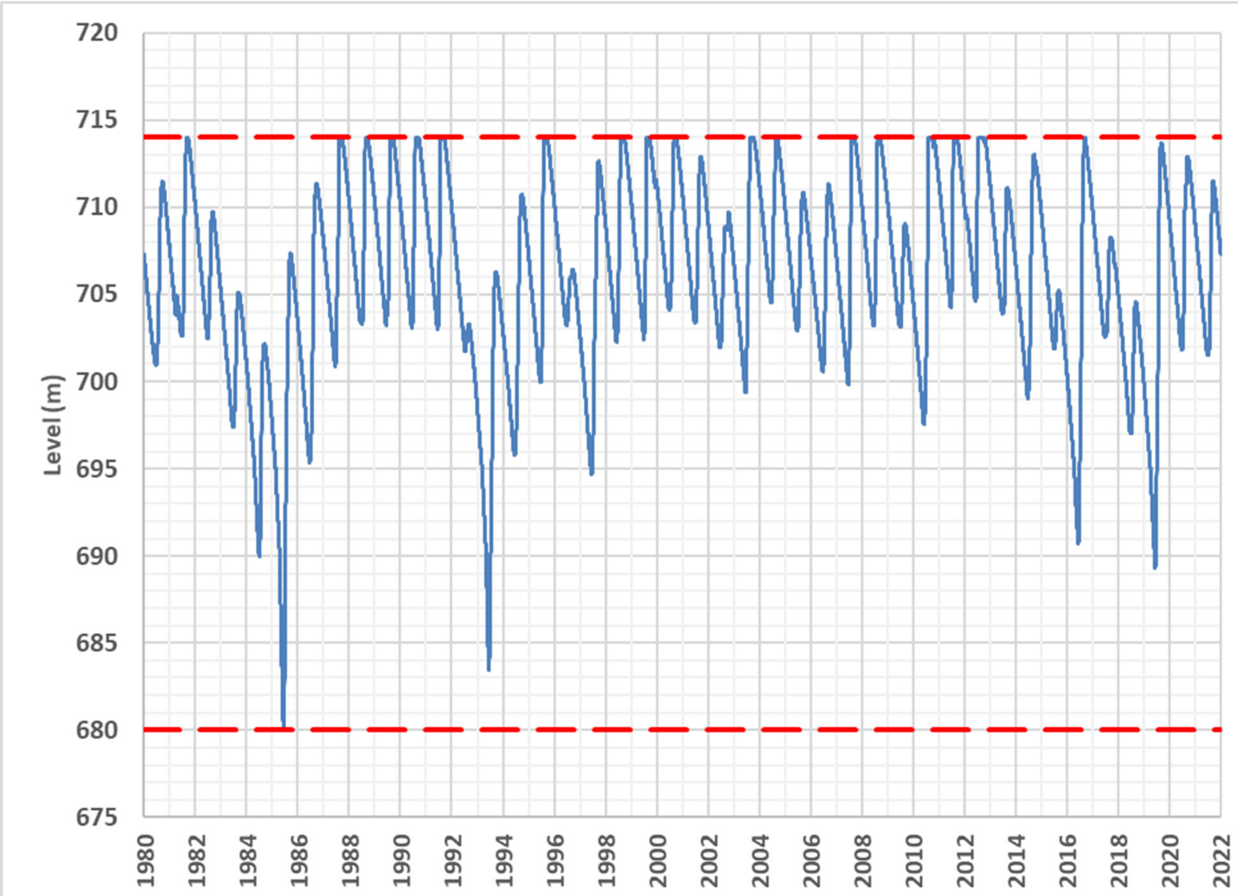

Figure 4-3: Site 07.e – RS2 – Water Levels for the Period 1980-2021 - Firm Power Available of 545 MW

4.2 Climate Change – 2031-2050 – RCP4.5 and RCP8.5

The present section describes the results of the evaluation of the firm energy based on the annual runoff volume estimated by ASIAQ for the period 2031-2050 [Ref 7]. The following points have been considered in the analysis:

- The climate change series are shorter than the initial series (20 years instead of 42 years (1981-2020)). The series is also shorter than what is normally used for this type of analysis (30 years and more), however this was the only information available at that moment. Furthermore, the critical periods for the 1981-2020 series were in the 1980's, period not covered by the present sample. To determine the impact of the shorter period of analysis, the following approach was used:
    - The firm power was evaluated for the historical data for the period 1991-2010. The results of power generation for this period will be compared to the results obtained for the period 1981-2020 to evaluate the impact of the shorter period on the firm energy.

- The results for the different climate change conditions will be compared to the results obtain for the historical period 1991-2010 to determine the potential impact in the future.

- Two sets of annual inflows have been provided by ASIAQ for each climate change scenarios (RCP4.5 and RCP8.5). Both sets will be analysed to determine the potential impact on the firm power available.

- The reconstitution of the annual runoff volume is based on the observed conditions between 1991 to 2010, but it doesn't mean that the runoff will follow the same annual pattern. For example, the annual runoff for the second year of the 1991-2010 series was low, but it doesn't mean it will be similar to the second year of the 2031-2050 series.

- In the future, the daily flow pattern will probably be slightly different since the melting period will probably start earlier and will end later because of the increase in temperature. However, this aspect was not covered in the GEUS 2021 study [Ref 3]. For the energy analyses, the annual hydrographs were based on the shape of the observed hydrographs for the period 1991-2010 (ex. 1991 was used to reconstitute 2031, and so on) and the inflows have been corrected to obtain the annual volume provided by ASIAQ [Ref 7][Ref 8]. This assumption is conservative since the beginning of the Spring flood will be the same as the observed conditions.

4.2.1 Historical data – Reconstituted Daily Inflows Series – 1991-2010

The firm power available based on the historical data for the period 1991-2010 is presented in Table 4-4. For the base case, the firm power is estimated to be 446 MW instead of 418 MW for the period 1980-2021 (see Table 4-1). The difference is 28 MW (+7%), which is not critical, but shows the impact of the shorter period of analysis. For the other case, the firm energy follows the same pattern as the results for the period 1980-2001. The results are slightly higher but in the same range.

It should be noted that firm energy considering one year with deficit is much higher than the results obtained for the period 1980-2021. It seems to be caused by the hydrological series since the critical period is not the same. Furthermore, the number of days with deficit exceeds four months for the base case instead of the period of two months observed previously. The probability related to such event is 5% (1 in 20 years) instead of 2.4% (1 in 42 years) for the period 1980-2021.

Figure 4-4 illustrates the variation of the water level in the reservoir over the period of analysis.

Table 4-4: Site 07.e - ASIAQ - Historical Data – Energy Simulation Results – 1991-2010

H_{max} El. (m)	H_{min} El. (m)	Firm Power (MW) [1]	Difference with base case (MW)	Firm Energy (GWh)	Average Energy (GWh)	Secondary Energy (GWh)
Intake Sector only – Firm at 100%						
714	680	446 [2]	-	3907	4067	160
714	690	434	-12	3802	4004	202
714	700	351	-95	3075	3494	419
717	680	466	+20	4082	4208	126
720	680	487	+41	4266	4365	99
723	680	506	+60	4433	4515	82
726	680	523	+77	4581	4623	42
Complete Tasersiaq Lake – Firm at 100%						
714	680	456	+10	3995	4136	141
Intake Sector only – 1 Year with deficit						
714	680	477	+31	4095	4207	112
714	690	459	+13	3955	4102	148
714	700	396	-50	3434	3750	316

(1) Values rounded at the nearest MW.

(2) Firm power for the base case (period 1991-2010)

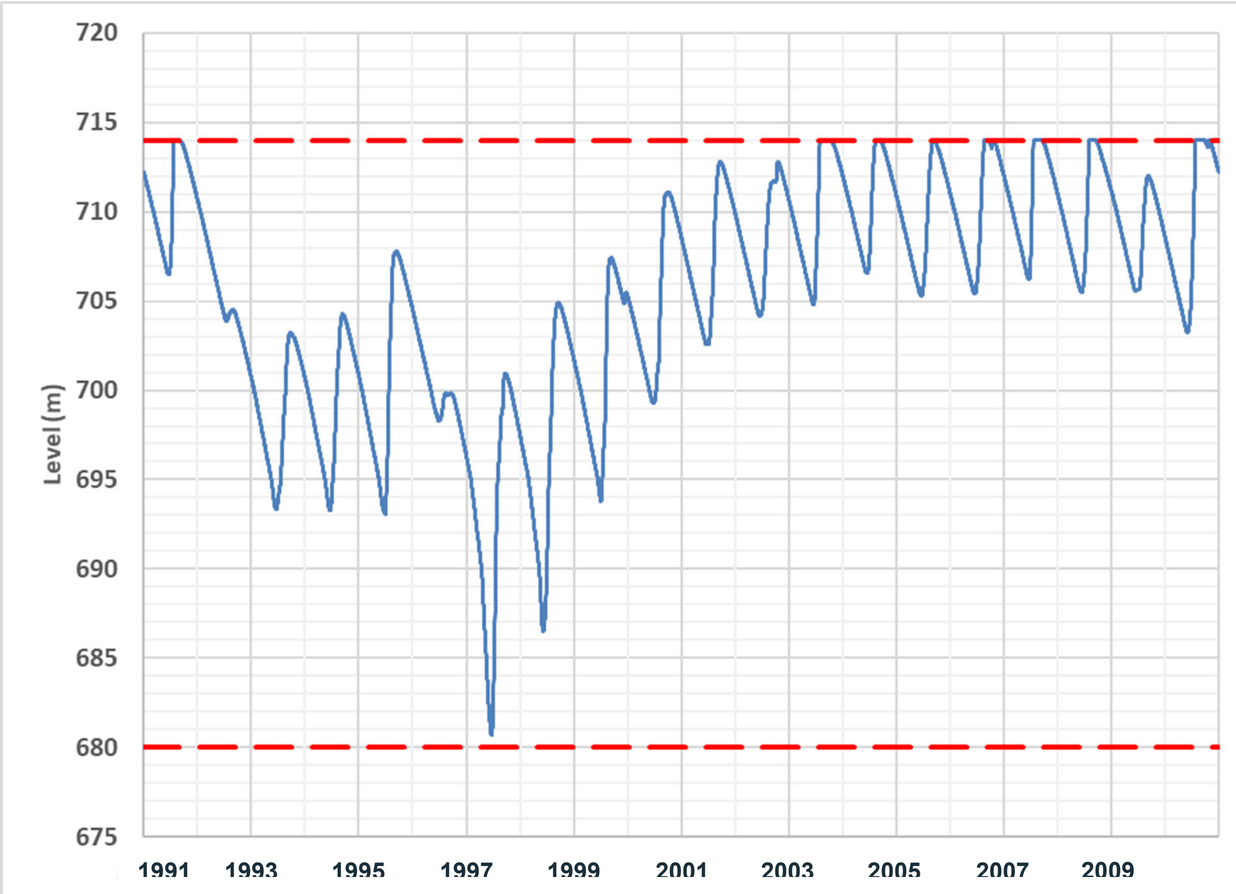

Figure 4-4: Site 07.e - Historical Inflows – Water Levels for the Period 1991-2010, Firm Power Available of 446 MW

4.2.2 Climate Change - First Reconstituted Series – 2031-2050

As mentioned previously, ASIAQ provided two sets of annual runoff volume representing climate conditions for the period 2031-2050 based on the conditions observed for the period 1991-2010. Figure 4-5 shows the annual volume for three series:

- For the historical period 1991-2010 (purple column);
- For the period 2031-2050 considering RCP4.5 (blue line);
- For the period 2031-2050 considering RCP8.5 (brown line).

The linear trends are presented with the dotted lines. It occurs that the trend observed for the two series representing climate change are different. The trend observed for the RCP8.5 is similar to the trend of the historical data (increasing), while the trend for the RCP4.5 series is going in the other direction (decreasing).

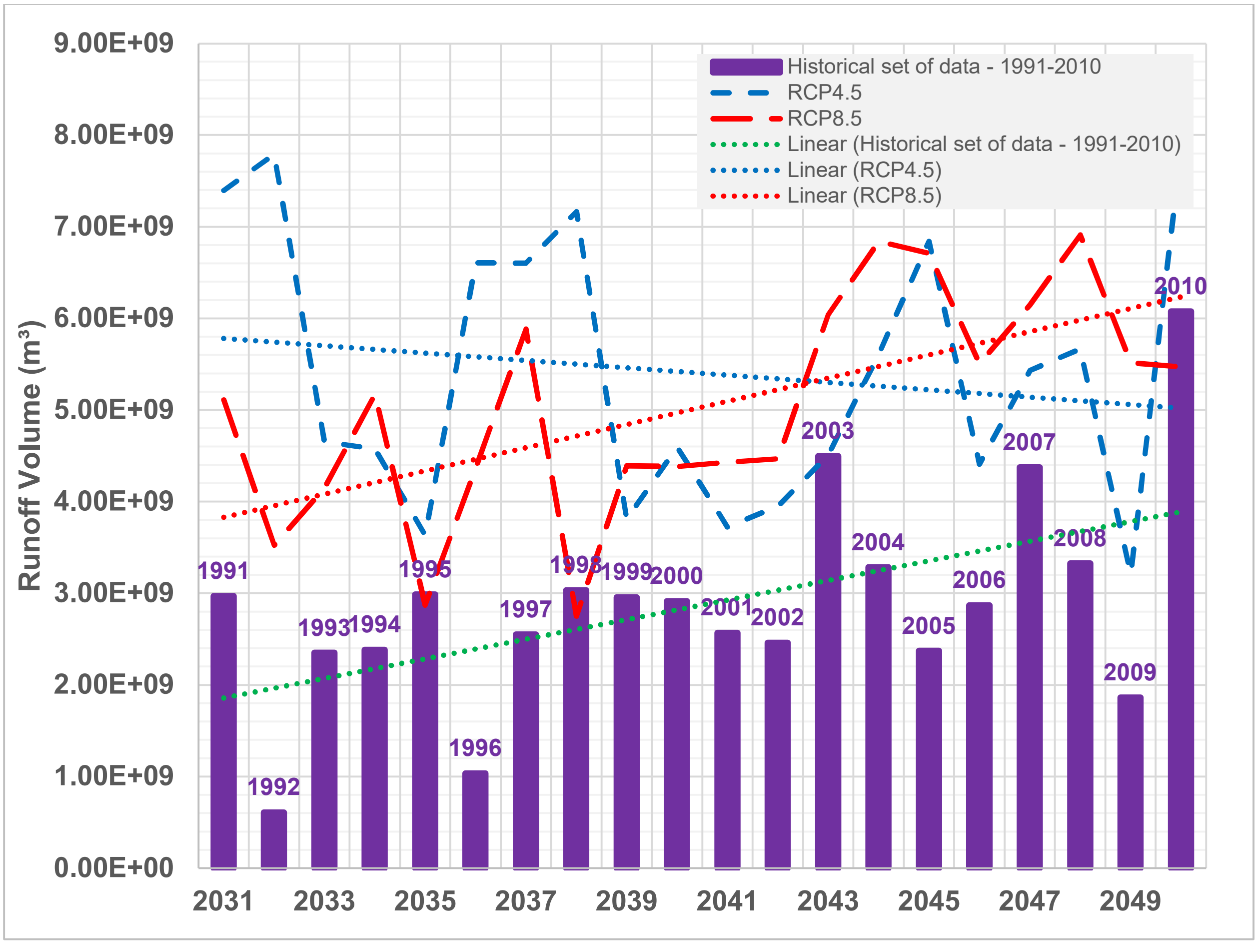

Figure 4-5: Site 07.e - Climate Change – First Reconstitution – RCP4.5 and RCP8.5

Table 4-5 presents the firm available power for both series (i.e. RCP4.5 and RCP8.5). It shows:

- A significant increase of the firm energy for most of the cases;
- For the base case, the increase is about 79% for the first set of inflows (799 MW for RCP4.5) and 66% for the second one (742 MW for RCP8.5);
- For most of the cases, the firm energy exceeds 700 MW;
- The critical period is shorter, and the reservoir is full at the end of the flood season for most of the years (see Figure 4-6).

These increases can be explained by the fact that the annual runoff volume is in general significantly higher than the historical values. Furthermore, there is no long period of low annual runoff, which is important since the reservoir is multi-annual.

Table 4-5: Site 07.e - ASIAQ – Climate Change – First Series – 2031-2050

Hmax El. (m)	Hmin El. (m)	RCP4.5		RCP8.5	
		Firm Power (MW) (1)	Difference with base case (MW) (2)	Firm Power (MW) (1)	Difference with base case (MW) (2)
Intake Sector only – Firm at 100%					
714	680	799	+353 (+79%)	742	+296 (+66%)
714	690	785	+339 (+76%)	704	+258 (+58%)
714	700	652	+206 (+46%)	582	+136 (+30%)
717	680	823	+377 (+84%)	800	+354 (+79%)
720	680	847	+401 (+90%)	815	+369 (+83%)
723	680	868	+422 (+94%)	828	+382 (+85%)
726	680	889	+443 (+99%)	839	+393 (+88%)
Complete Tasersiaq Lake – Firm at 100%					
714	680	810	+364 (+81%)	773	+227 (+51%)
Intake Sector only – 1 Year with deficit					
714	680	818	+372 (+83%)	786	+240 (+54%)
714	690	786	+340 (+76%)	759	+313 (+70%)
714	700	665	+219 (+49%)	636	+190 (+42%)

(1) Values rounded at the nearest MW.
(2) Difference with firm power for the base case (1991-2010).

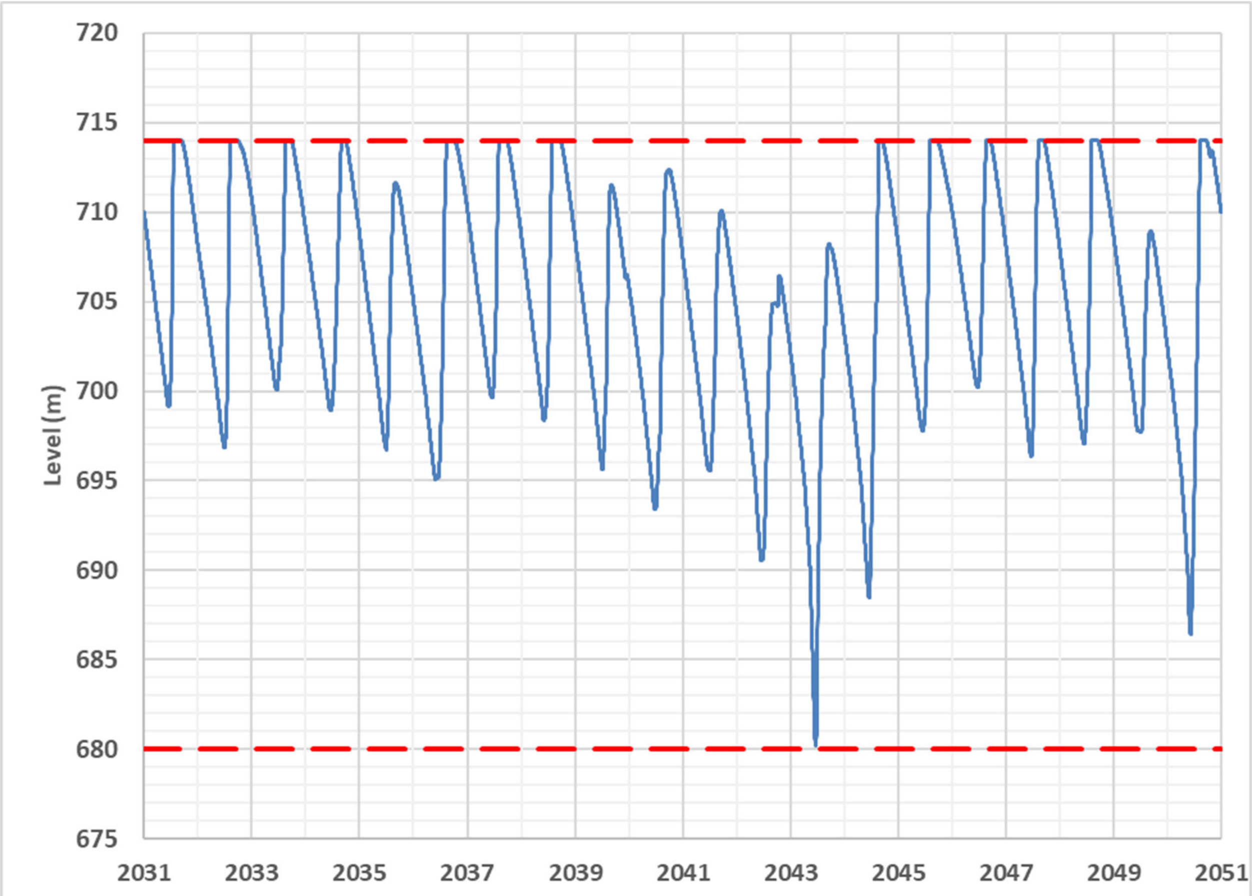

Figure 4-6: Site 07.e - First Reconstitution – RCP4.5 – Water Levels for the Period 2031-2050 - Firm Power Available of 799 MW

4.2.3 Climate Change - Second Reconstituted Series – 2031-2050

The second set of reconstituted annual runoff volumes follows the same trends than the ones presented previously, but the annual runoff volume are slightly lower. The results for these set of data are presented on Table 4-6. As expected, the firm power available follows the same trend that the previous results but are about 20 MW lower. For the base case, the firm power is estimated to be 772 MW for RCP4.5 and 732 MW for RCP8.5.

Table 4-6: Site 07.e - ASIAQ – Climate Change – Second Series – 2031-2050

Hmax (m)	Hmin (m)	RCP4.5		RCP8.5	
		Firm Power (MW) (1)	Difference with base case (MW) (2)	Firm Power (MW) (1)	Difference with base case (MW) (2)
Intake Sector only – Firm at 100%					
714	680	772	+326 (+73%)	732	+286 (+64%)
714	690	758	+312 (+70%)	693	+247 (+55%)
714	700	648	+202 (+45%)	572	+126 (+28%)
717	680	795	+349 (+78%)	770	+324 (+72%)
720	680	818	+372 (+83%)	785	+339 (+76%)
723	680	839	+393 (+88%)	797	+351 (+78%)
726	680	860	+414 (+93%)	808	+362 (+81%)
Complete Tasersiaq Lake – Firm at 100%					
714	680	782	+336 (+75%)	761	+315 (+70%)
Intake Sector only – 1 Year with deficit					
714	680	791	+345 (+77%)	758	+312 (+70%)
714	690	771	+325 (+73%)	747	+301 (+67%)
714	700	652	+206 (+46%)	624	+178 (+40%)

(1) Values rounded at the nearest MW.
(2) Difference with firm power for the base case (1991-2010).

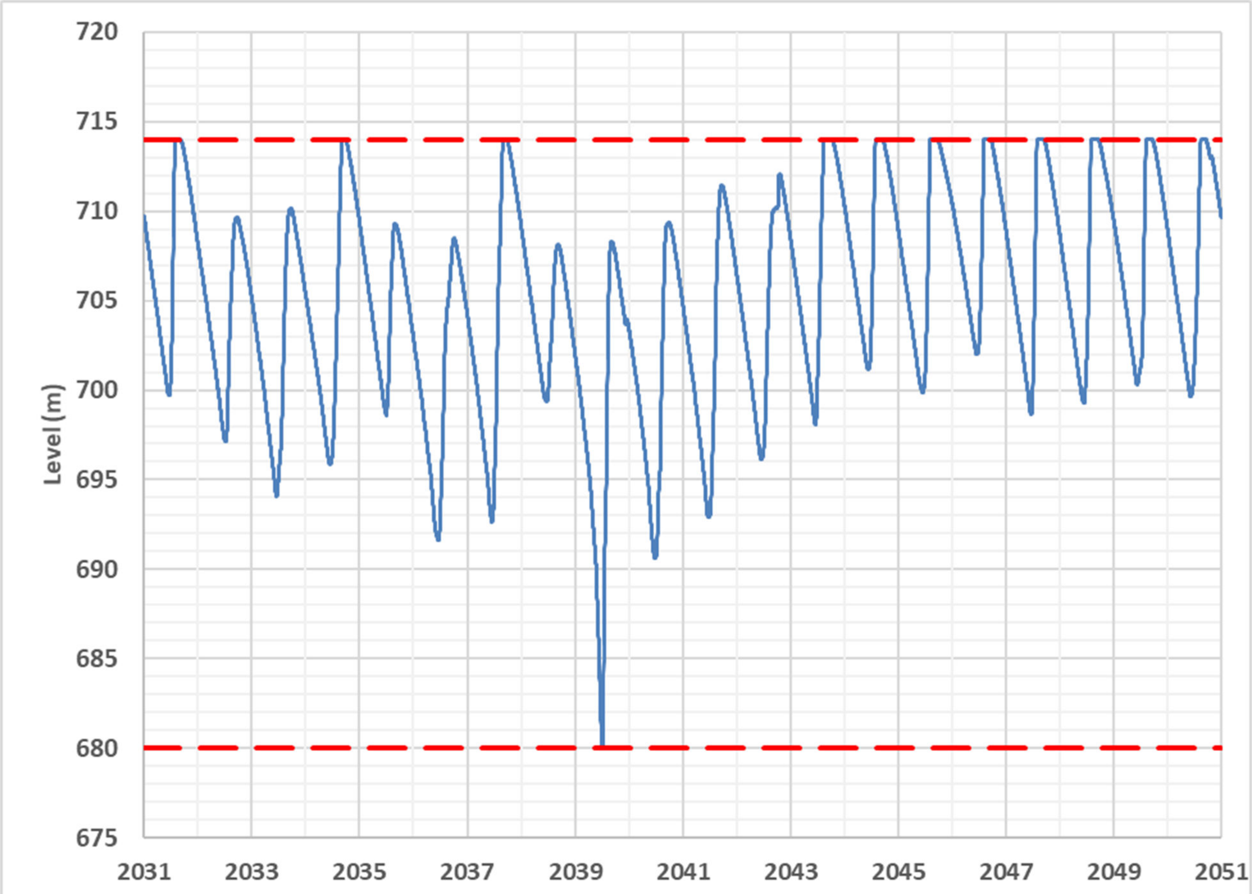

Figure 4-7: Site 07.e - Second Reconstitution – RCP8.5 – Water Levels for the Period 2031-2050 - Firm Power Available of 732 MW

4.3 Comments on the Results

Based on the main trends observed about the annual runoff volume in Greenland and other regions of the world with similar conditions, we think there is a general consensus that the historical runoff data are not representative of the future conditions expected over the next 30 years.

The annual runoff volume should remain higher than the average historical values (particularly the period 1980 to 2000), but the trend is not clear (as shown for RCP4.5 and RCP8.5) and the annual runoff volume variability is also a factor difficult to qualify. For example, independent event (volcanic eruption or other) can have an impact on solar radiation on the ground and ice melt, which will reduce the annual runoff on one or more consecutive years.

Furthermore, the duration of the climate change sample is short, only 20 years, for this type of study. The sensitivity analysis performed on the period 1991-2010 with the historical data shows a difference, an increase of 7% of the firm power. This emphasizes the importance of eliminating the bias of carrying out analyses with insufficiently long time series and their impact on the confidence in the obtained results.

A firm power of 418 MW for the period 1980-2021 appears realistic. The trendless series (RS1 and RS2) on the same period give a firm power of about 550 MW, which seems more representative of the present conditions considering the second half of the historical series.

About the climate change scenarios for the period 2031-2050, the results are in line with the annual volume of water available at the site, since it is based on a detailed study performed by GEUS [Ref 3]. However, there are many factors and unknowns to consider in such a study and the firm energy estimated for the period 2031-2050 must be considered with caution. Analyses of other climate change scenarios can help understanding the range and the risk related to the choice of installed capacity and firm power for the system.

5. New Climate Change Scenarios – Results Analyses

ASIAQ was mandated in 2023 to prepare new climate change scenarios covering a longer period until 2100 and based on the latest relevant scientific information available [Ref 4].

This section presents the main results of the firm power evaluation performed considering the new climate change scenarios. The main characteristics of the climate change scenarios prepared by ASIAQ were presented in Section 0. This section presents the methodology used for the energy study and elaborates on the validation of the model. The results of the firm power analyses are presented with an analysis of the potential risk related to the determination of the firm power at Site 07.e.

5.1 Methodology

The methodology applied for the energy analysis of the new scenarios is similar to the methodology described in the Section 3.1. However, some modifications have been performed:

- Based on ASIAQ recommendations, the same monthly pattern distribution (in %) is used for each year. Previously, historical monthly flow patterns have been used over the period of analysis;

- ASIAQ presented two sets of annual runoffs for each studied climate change scenario, i.e. with minimum and maximum adjustment factor. For the present study, an average adjustment factor is used for each scenario (as mentioned in Section 0);

- The daily discharge during each month is assumed to be constant. In the previous study an arbitrary daily distribution was adopted to mimic a typical hydrograph. Considering the size of the reservoir (multi-annual storage capacity), it is not considered required to use an arbitrary pattern for the daily inflows;

- Considering the total duration of the new inflow scenarios, analysis periods of 30 years are used instead of the 20 years periods used for the first two scenarios (which corresponded to the total length of the available series). A period of 30 years is considered more appropriate for energy analysis to assess the impact of hydrological trends on the power generation;

- Analyses are performed with the characteristics of the base case considered for the first two scenarios, which are:

  - Reservoir: Intake sector only of Lake Tasersiaq;
  - Maximum reservoir level: El. 714 m;
  - Minimum reservoir level: El. 680 m;
  - Maximum drawdown: 34 m;
  - Number of units: 5.

Analyses are performed on four different periods to evaluate the impact of the climate change trends over time and for comparison purposes with the results obtained for the first two scenarios. These periods are:

- 2031-2050 (comparison with the results of the first two scenarios);
- 2031-2060;
- 2051-2080;
- 2071-2100.

The period 2023 to 2030 is not considered since it is unlikely that a future project will be fully operational before 2030.

5.2 Validation

To evaluate the impact of the revised methodology, firm power for the cases previously analysed (Section 4) have been estimated using the same inflow series for the period 2031-2050. The results are presented in Table 5-1.

Table 5-1: Site 07.e Comparison of Firm Power (100%) – Initial Methodology vs. Updated Methodology

Climate Change Scenario	Period	Initial approach	Updated approach	Difference	
		(MW)	(MW)	(MW)	%
Historical Data (Base Case)	1991-2010	446	452	+6	+1.3 %
RCP 4.5 – reconstitution 1	2031-2050	799	811	+13	+1.5%
RCP 8.5 – reconstitution 1	2031-2050	742	782	+40	+5.1%
RCP 4.5 – reconstitution 2	2031-2050	772	783	+11	+1.5%
RCP 8.5 – reconstitution 2	2031-2050	732	767	+35	+4.5%

The results obtained are slightly higher than the results presented in Section 4.2. The difference is about 1.5% except for the two cases with RCP 8.5 which are about 5% higher. For these two cases, the critical period is shorter (2 years) than the critical period of the cases with RCP 4.5 (5 years). Thus, the difference in the flow pattern (monthly and daily distributions) and the length of the critical period can explain the impact on the evaluation of firm power.

Taking into account the uncertainties associated with the assumptions made in both climate change studies, the results are considered in a similar range. The updated methodology is therefore compatible with the initial methodology used for the two initial scenarios for the period 2031-2050 and could be applied in the present study based on extended future annual runoff series covering the period 2031-2100.

5.3 Results

Table 5-2 presents the firm energy for each scenario and analysis period. The main aspects to consider from this table are presented below:

1. For the period 2031-2050, the firm power estimated for the new scenarios are significantly lower than the firm power estimated for the first two climate change scenarios. The difference varies between 50 MW and 270 MW depending on the scenarios. Different causes can explain these differences, such as:

   - The average runoff for the new scenarios is lower for the same analysis period;
   - The variability of the annual runoff for the new scenarios, such as:
     - longer duration of a dry period; or
     - driest critical period.

   Figure 5-1 illustrates the difference between the annual runoff for two scenarios, i.e. one initial scenario (in green) and one new scenario (in blue).

2. The firm power estimated for the 2031-2050 period and the 2031-2060 period are the same, except for the SSP585_CC_HIRHAM scenario (firm power of 696 MW for 2031-2060 instead of 720 MW). It means that the critical period observed for the majority of the new scenarios occurred in the first 20 years of the series (2031-2050).

3. It is expected that the firm power will increase (sometimes significantly) after 2050 as shown by the results for period 2051-2080 (increase of 30 MW to 320 MW, 6% to 72%) and 2071-2100 (increase of 50 MW to 480 MW, 11% to 107%). However, there are some exceptions such as the results for the SSP126_ME_MAR scenario where the firm power remains almost constant due to a critical period between 2060 and 2080.

Figure 5-2 illustrates the probability of exceedance, based on the number of climate scenarios, of the firm power for different periods. This figure illustrates the quantification of the risk related to the selection of the firm power for a future project. Analyses performed on the 2031-2060, 2051-2080 and 2071-2100 periods provide the expected range for the firm power based on the available scenarios. The 2031-2050 trend differs from the other periods since it includes the initial results for the RCP 4.5 and RCP 8.5 scenarios (only one of the two reconstitution is used). Since these two values are higher than the results obtained for the new scenarios, the results of the first half of the curve are higher than the results obtained for the 2031-2060 period. As Figure 5-2 illustrates, the main risk of deficit will be in the first 20 years, which therefore is the most critical period for a new project.

Figure 5-3 illustrates the correlation between the average annual runoff for the period of analysis and the firm power. Results for the three periods of analysis have been combined to increase the number of points for the analysis. There is a good correlation between these two variables ($R^2 = 0.88$), even though the average runoff does not take directly into account the annual variability of the inflows. The good correlation can be explained by the fact that the system is multi-annual and it takes more than one year to empty the reservoir if the system is operating at the firm power.

Table 5-2: Site 07.e - Firm Power (100%) for Different Climate Change Scenarios Intake Sector Only

Climate Change Scenario	Period	Average Runoff	Firm Power	Difference with base case	
		(m³/s)	(MW)	(MW)	(%)
Historical Data (Base Case) *	1991-2010 (20 years)	91.1	452	---	---
RCP 4.5 – reconstitution 1 *	2031-2050 (20 years)	171.2	811	359	+80%
RCP 8.5 – reconstitution 1 *		159.5	782	330	+73%
RCP 4.5 – reconstitution 2 *		161.8	783	331	+73%
RCP 8.5 – reconstitution 2 *		151.0	767	315	+70%
ASIAQ 2023 - SSP126_CC_MAR		151.7	685	233	+52%
ASIAQ 2023 - SSP245_CC_MAR		128.9	602	150	+33%
ASIAQ 2023 - SSP585_CC_MAR		153.0	652	200	+44%
ASIAQ 2023 - SSP126_ME_MAR		93.1	543	91	+20%
ASIAQ 2023 - SSP245_ME_MAR		115.9	617	165	+37%
ASIAQ 2023 - SSP585_ME_MAR		110.8	606	154	+34%
ASIAQ 2023 - SSP585_CC_HIRHAM		126.5	720	268	+59%
ASIAQ 2023 - SSP126_CC_MAR	2031-2060 (30 years)	150.4	685	233	+52%
ASIAQ 2023 - SSP245_CC_MAR		131.9	602	150	+33%
ASIAQ 2023 - SSP585_CC_MAR		165.1	652	200	+44%
ASIAQ 2023 - SSP126_ME_MAR		102.0	543	91	+20%
ASIAQ 2023 - SSP245_ME_MAR		119.0	617	165	+37%
ASIAQ 2023 - SSP585_ME_MAR		116.3	606	154	+34%
ASIAQ 2023 - SSP585_CC_HIRHAM		135.1	696	244	+54%
ASIAQ 2023 - SSP126_CC_MAR	2051-2080 (30 years)	152.3	716	264	+58%
ASIAQ 2023 - SSP245_CC_MAR		160.4	728	276	+61%
ASIAQ 2023 - SSP585_CC_MAR		239.1	976	524	+116%
ASIAQ 2023 - SSP126_ME_MAR		104.1	545	93	+21%
ASIAQ 2023 - SSP245_ME_MAR		125.5	664	212	+47%
ASIAQ 2023 - SSP585_ME_MAR		149.8	749	297	+66%
ASIAQ 2023 - SSP585_CC_HIRHAM		161.7	789	337	+75%
ASIAQ 2023 - SSP126_CC_MAR		162.1	736	284	+63%

Climate Change Scenario	Period	Average Runoff	Firm Power	Difference with base case	
		(m^3/s)	(MW)	(MW)	(%)
ASIAQ 2023 - SSP245_CC_MAR	2071-2100 (30 years)	193.6	764	312	+69%
ASIAQ 2023 - SSP585_CC_MAR		359.1	1136	684	+151%
ASIAQ 2023 - SSP126_ME_MAR		107.7	545	93	+21%
ASIAQ 2023 - SSP245_ME_MAR		136.7	757	305	+68%
ASIAQ 2023 - SSP585_ME_MAR		193.1	888	436	+97%
ASIAQ 2023 - SSP585_CC_HIRHAM		219.6	937	485	+107%

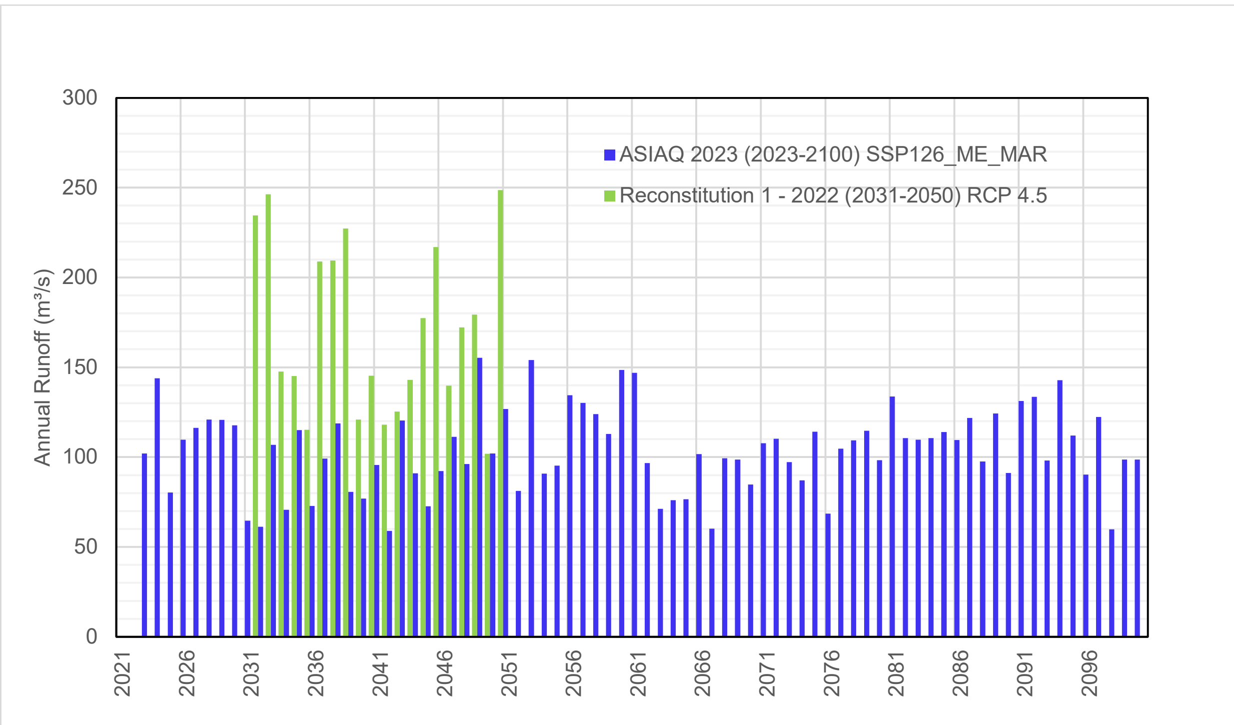

Figure 5-1: Site 07.e - Comparison of Annual Runoff for an Initial Scenario (green) and a New Scenario (blue)

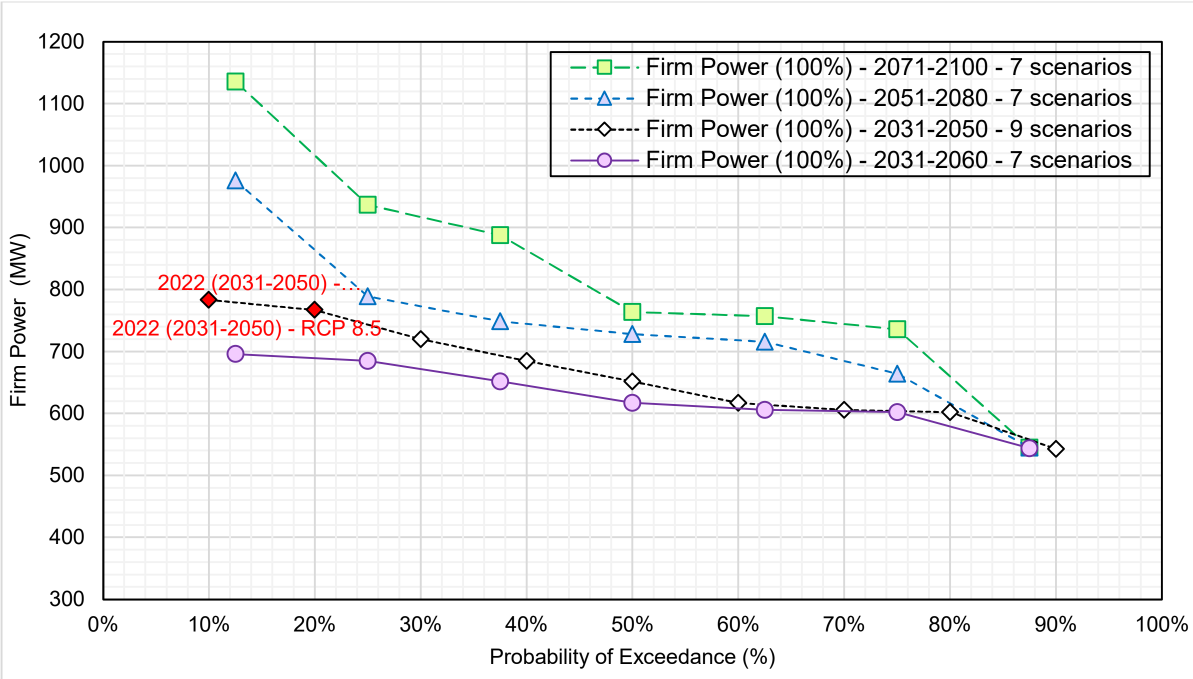

Figure 5-2: Site 07.e - Probability of Exceedance of Firm Power (100%) vs Period of Analysis

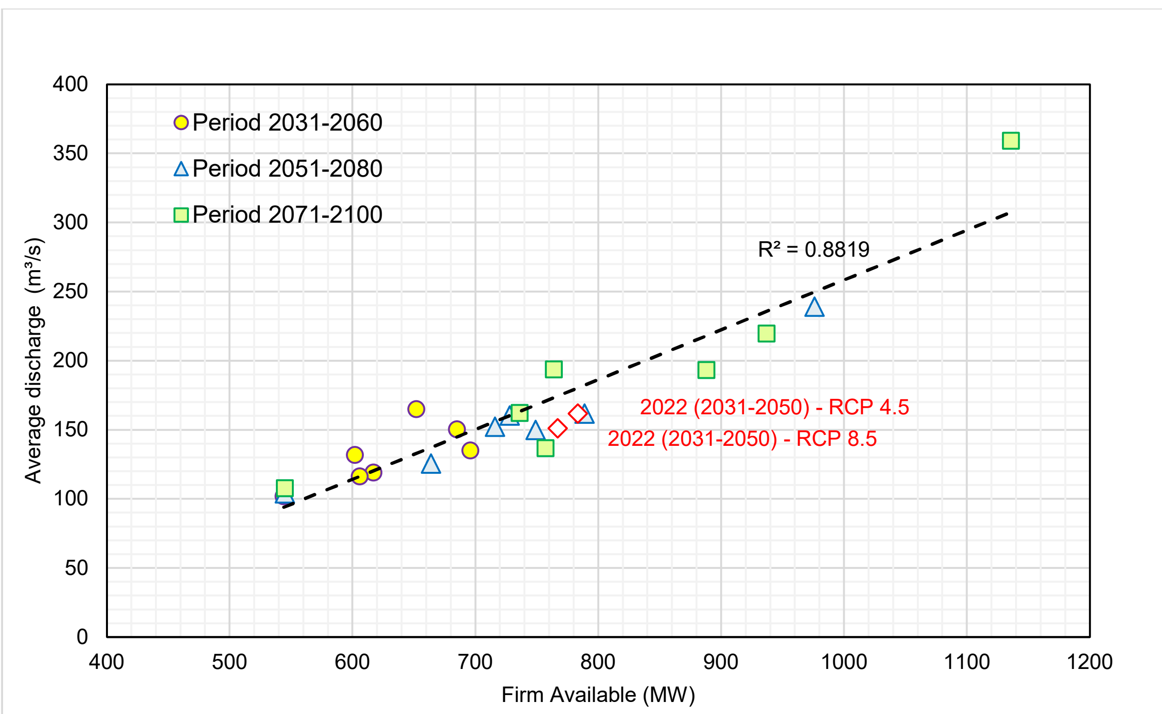

Figure 5-3: Site 07.e - Firm Power (100%) vs Average Runoff Period 2031-2060, 2051-2080, 2071-2100

Appendix C presents the results of a sensitivity analysis performed for two alternatives considered in the initial study, which are:

- Using the total volume of Lake Tasersiaq as reservoir instead of the intake sector only;
- Considering one year of deficit over the period of analysis (20- or 30-years period).

The sensitivity analysis was performed for the same periods. The trend of the firm power is similar to the trend observed for the cases presented in this section.

Figure 5-4 shows the probability of exceedance of the firm power for the 2031-2050 period for the firm power at 100% considering the intake sector only and for the two alternatives mentioned hereabove. The trends are similar for each alternative and the difference of firm power with the initial series varies between a few MW to 80 MW. The choice of the best "firm power" to be installed will be based on the results of an economic analysis for a specific project.

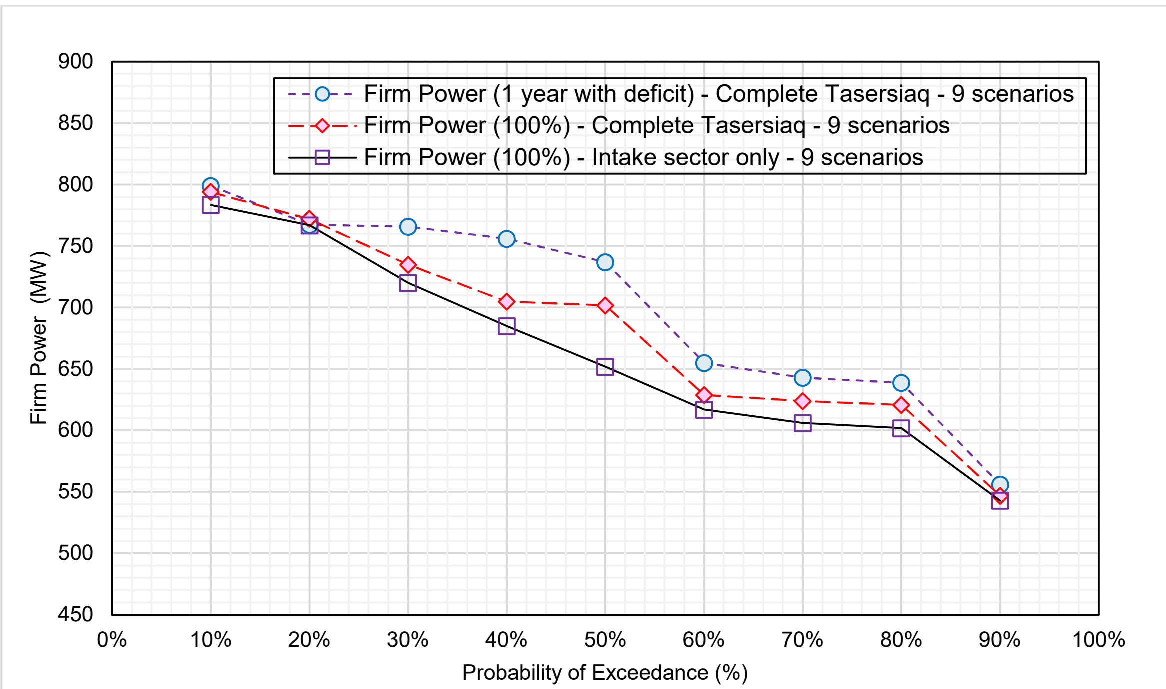

Figure 5-4: Site 07.e - Probability of Exceedance of Firm Power Based on Different Assumptions - Period 2031-2050

5.4 Comments on the Results

The energy analyses based on the two initial scenarios (as presented in Section 4.2) concluded that the firm power for the base case was exceeding 730 MW for the 2031-2050 period. The results based on the new climate change scenarios indicate that this estimate was "optimistic" for that period. Adding the two 2023 scenarios to the new scenarios, the firm power for the period 2031-2050 based on a 50% level of exceedance (scenario presenting median results) is estimated to be about 650 MW with range in the results between the studied climate scenarios from -17% to +20%. Analyses performed on the periods 2031-2060, 2051-2080 and 2071-2100 indicate that the firm power based on a 50% level of exceedance (median results) is estimated to be around 615 MW (range -12% to 13%), 730 MW (range -25% to 34%) and 765 MW (range -29% to 49%), respectively.

The results of the new climate change scenarios allowed the qualification of the results obtained with the initial climate change scenarios. The increase of the number of climate scenarios and the corresponding firm power analyses provide a better understanding of the potential range of installed capacity for this project, considering the uncertainties associated with the future inflows forecast.

Results have shown a good correlation between the average annual inflows of each scenario on a 30-years period and the firm power of the system – based on the assumptions considered in the Section 5.1. This approach can help to quickly estimate the potential impact of new climate change scenarios in the future.

As mentioned in Section 4.3, the firm power estimated for the near future (ex. period 2031-2050) must be considered with caution since the results are representative of the information available. The results presented in this section are based on extended data and give a better understanding of the confidence interval on the firm power of the system. However, it is noted that uncertainties about the impact of climate change in the future remain. Furthermore, independent events (such as a volcanic eruption) can have an impact on the climate and impact the runoff volumes conditions for one year or more as it was already recorded in the past. The impacts of such an event are not considered in the present study.

6. Conclusions and Recommandations

The main objective of the present report consists of determining the firm power available at Site 07.e taking into account the uncertainties in the future inflows mainly caused by climate change. For these purposes, different climate change scenarios have been analysed to assess the impact on the firm power over different periods of analysis.

The study was divided in two phases, a first one based on two inflows scenarios for the period 2031-2050 and a second one taking into account seven new inflows scenarios covering the period 2023-2100. The analyses were performed on a period of 20 or 30 years depending on the duration of the inflows series and to evaluate the impact of climate change on the firm power over the years. A period of 30 years is normally considered as the minimum duration considered for this type of study to take into account the variability of the hydrology in the system.

At this stage of the project, each climate change scenario is considered as equiprobable. It means that the choice of the firm power for a specific project must be based on the economic analysis of the project and take into account the probability that the firm power will not be met during some years (or part of the year, i.e until the next Spring flood occurs).

Table 6-1 presents the minimum, the maximum and the 50% probability of exceedance (median scenario) of the firm power based on the inflows scenarios available for the different period of analysis.

Table 6-1: Site 07.e - Firm Power (100%) – Summary of the Results

Period	Number of scenarios	Firm Power (MW)		
		Minimum	50% probability of exceedance (median results)	Maximum
Historical	1	N/A	452	N/A
2031-2050	9	543	650	783 (1)
2031-2060	7	543	615	696
2051-2080	7	545	730	976
2071-2080	7	545	765	1136

(1) :Lowest firm power for the two reconstituted initial scenarios set of inflows for RCP 4.5

The main elements to consider from this table:

- The trend of the firm power seems to increase for the future. For the 50% probability of exceedance (corresponding to the median results), the increase in firm power is about 160 MW between the evaluation based on the historical data and the results for the period 2031-2060. It continues to increase for the period 2051-2080 and 2071-2100;

- The results for the period 2031-2050 are higher than the results for the period 2031-2060, since the two initial scenarios are considered only for the period 2031-2050 and the firm power for these scenarios are significantly higher than the others;

- The minimum firm power estimate for the different periods remains similar. It corresponds to the results of the scenario SSP126_ME_MAR. This scenario shows almost no increase of the annual volume of inflows in the future, which explains the almost constant value.

We recognize the difficulty to calibrate climate models and generate annual hydrographs for the study area, considering that the majority of the inflow comes from glacier melting which is a complex phenomenon. For these reasons, the firm power estimated must be considered with caution; the results are representative of the information available, but it is difficult to assess their confidence interval, even with nine scenarios. Furthermore, independent events (such as volcanic eruption) can have an impact on the climate and changes the conditions for one year or more, impact not considered in the present study.

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APPENDIX A :
SITE 07.E
INITIAL SCENARIOS
MEAN MONTHLY INFLOWS

Table A-1: Mean Monthly Inflow in Reconstituted Flow Series-0 (RS0)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1980	0.7	1.4	8.5	16.6	25.2	54.4	217.3	290.9	86.6	14.0	4.1	2.0	**60.1**
1981	1.4	1.2	19.2	123.3	7.0	45.3	330.9	256.0	52.4	13.1	4.0	1.4	**71.3**
1982	0.6	0.3	0.1	0.1	0.1	24.8	197.5	211.0	31.7	7.1	2.2	0.9	**39.7**
1983	0.8	1.1	1.0	1.0	1.4	39.6	181.2	223.3	53.0	13.9	7.1	4.1	**44.0**
1984	0.9	0.5	0.3	0.0	0.0	15.7	249.7	231.1	53.6	12.7	4.4	1.8	**47.6**
1985	0.9	0.5	0.1	0.1	1.9	121.7	356.7	334.1	83.5	14.3	5.4	2.0	**76.8**
1986	1.9	1.7	2.1	2.6	3.7	48.2	288.7	396.8	105.8	28.8	13.9	10.9	**75.4**
1987	5.0	2.6	1.8	1.3	1.4	94.5	309.3	448.7	76.2	18.1	6.3	3.1	**80.7**
1988	1.5	0.7	0.9	0.7	3.2	45.0	249.7	395.4	81.3	14.6	5.1	2.4	**66.7**
1989	1.1	0.7	0.5	0.4	0.8	84.0	365.1	344.9	54.0	12.9	5.3	3.5	**72.8**
1990	1.7	1.0	0.6	0.7	2.1	168.4	422.5	461.2	61.2	12.9	6.4	4.8	**95.3**
1991	2.6	1.6	1.0	0.7	0.5	82.4	655.5	305.9	42.5	12.7	5.2	2.9	**92.8**
1992	2.5	1.7	1.1	0.8	0.6	4.1	75.1	93.0	29.5	11.1	6.5	3.0	**19.1**
1993	2.2	1.9	2.2	1.6	2.1	72.7	264.1	382.1	101.9	27.5	14.6	10.9	**73.6**
1994	12.3	10.6	8.9	7.8	8.2	60.3	262.5	359.9	128.5	26.8	8.6	3.0	**74.8**
1995	0.9	0.5	0.3	0.2	2.6	38.2	575.7	409.4	66.0	15.5	5.9	3.9	**93.3**
1996	2.4	2.4	2.2	2.0	8.6	34.5	143.9	86.3	73.8	21.8	7.9	4.2	**32.5**
1997	2.6	1.7	0.9	0.7	2.5	64.5	362.7	301.7	193.9	19.5	6.9	3.0	**80.1**
1998	1.5	1.2	1.0	0.7	2.5	120.4	443.5	443.7	96.5	20.5	6.0	2.3	**95.0**
1999	1.2	1.0	0.8	0.5	0.6	4.4	297.9	636.0	59.7	12.9	4.9	86.5	**92.2**
2000	11.3	4.1	1.9	1.0	0.9	41.2	223.8	603.6	156.8	38.4	9.2	3.3	**91.3**
2001	1.8	1.1	0.7	0.5	0.8	39.2	264.2	482.4	143.9	19.6	7.1	3.4	**80.4**
2002	1.8	0.9	0.8	0.5	1.2	59.9	326.0	298.6	86.0	133.8	10.9	3.2	**77.0**
2003	1.4	0.9	0.5	0.3	0.4	127.1	619.1	538.3	308.2	69.1	20.5	7.8	**141.1**
2004	3.6	2.1	1.7	1.7	3.0	110.7	450.7	556.1	77.9	14.7	6.5	3.9	**102.7**
2005	2.1	2.3	2.5	1.8	5.1	56.6	326.1	348.3	97.8	19.5	15.4	13.4	**74.3**
2006	13.2	11.4	9.5	8.1	7.9	58.3	408.9	435.4	102.0	12.2	7.2	4.3	**89.9**
2007	2.3	1.6	1.1	1.0	0.9	80.0	835.3	567.6	124.3	16.4	6.2	3.1	**136.7**
2008	1.4	0.8	0.5	0.4	7.2	123.6	550.1	450.3	76.0	15.9	14.3	8.9	**104.1**
2009	4.8	2.2	1.1	0.7	0.9	57.8	261.0	299.4	56.5	10.7	3.4	1.5	**58.3**
2010	0.9	0.7	0.4	0.3	11.2	245.5	765.0	859.8	297.1	81.0	19.8	5.2	**190.6**
2011	2.4	1.6	1.0	0.7	0.5	72.4	834.1	562.2	156.6	14.2	5.7	3.0	**137.9**
2012	50.4	22.3	4.6	2.6	6.5	366.9	1171.2	718.2	108.1	91.1	12.1	4.1	**213.2**
2013	1.7	0.8	0.4	0.2	0.1	42.2	236.1	417.8	48.0	13.0	4.6	2.3	**63.9**
2014	1.3	0.7	0.5	0.4	1.0	63.4	441.2	575.7	123.3	48.9	5.5	2.9	**105.4**
2015	0.9	0.8	0.5	0.3	0.6	24.8	170.5	223.0	51.0	5.6	1.7	0.7	**40.0**
2016	0.7	0.3	0.1	0.1	14.7	228.9	786.2	615.6	105.7	9.4	3.0	1.0	**147.1**
2017	0.5	0.2	0.1	0.1	2.4	55.0	144.0	377.7	112.6	20.8	40.5	7.1	**63.4**
2018	1.9	0.9	0.4	0.1	0.1	44.0	322.0	319.2	52.9	8.5	2.6	1.0	**62.8**
2019	0.6	0.3	0.1	0.2	5.4	234.9	823.5	561.8	51.8	7.7	2.2	1.0	**140.8**
2020	0.5	0.3	0.2	0.3	1.8	46.2	501.7	347.7	135.9	15.1	5.3	2.1	**88.1**
2021	1.3	0.5	0.2	0.4	1.9	40.2	215.7	584.4	98.2	11.1	3.8	2.2	**80.0**
Mean	**3.6**	**2.2**	**2.0**	**4.4**	**3.6**	**82.0**	**403.0**	**413.2**	**97.7**	**24.0**	**8.0**	**5.8**	**87.4**

Table A-2: Mean Monthly Inflow in Reconstituted Flow Series-1 (RS1)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1980	1.3	1.3	1.7	4.8	3.4	103.2	498.2	477.7	140.4	23.3	7.3	3.6	**105.5**
1981	2.4	2.0	33.3	213.4	12.0	78.3	572.7	443.1	90.7	22.6	6.9	2.4	**123.3**
1982	1.0	0.4	0.2	0.1	0.2	42.3	336.9	359.8	54.0	12.1	3.8	1.6	**67.7**
1983	0.7	1.0	0.9	0.9	1.2	33.6	176.5	604.7	44.9	11.8	6.0	3.5	**73.8**
1984	1.5	0.8	0.4	0.1	0.0	25.9	412.3	381.7	88.5	20.9	7.3	3.0	**78.5**
1985	1.4	0.7	0.2	0.2	3.2	198.4	581.4	544.6	136.1	23.3	8.8	3.3	**125.1**
1986	4.0	2.2	1.8	5.0	3.5	107.6	454.0	490.1	270.4	73.0	29.0	16.2	**121.4**
1987	7.9	4.2	2.8	2.0	2.3	149.2	488.6	708.8	120.4	28.6	9.9	4.9	**127.5**
1988	2.3	1.2	1.4	1.1	5.0	70.0	388.1	614.6	126.4	22.7	8.0	3.7	**103.7**
1989	1.7	1.0	0.8	0.6	1.3	128.5	558.4	527.4	82.6	19.8	8.1	5.4	**111.3**
1990	2.6	1.5	1.0	1.0	3.1	253.3	635.5	693.6	92.1	19.3	9.6	7.2	**143.3**
1991	3.8	2.4	1.5	1.1	0.7	121.9	969.4	452.4	62.8	18.8	7.7	4.3	**137.2**
1992	3.6	2.5	1.6	1.1	0.8	5.9	109.2	135.2	42.9	16.1	9.5	4.3	**27.7**
1993	2.3	2.1	2.4	1.7	3.2	97.9	322.4	527.9	216.2	58.7	17.3	11.9	**105.3**
1994	3.8	2.1	1.7	4.7	3.3	102.5	494.6	503.2	112.5	18.4	6.5	2.6	**104.7**
1995	1.2	0.7	0.4	0.3	3.6	52.7	793.3	564.1	90.9	21.4	8.1	5.3	**128.5**
1996	3.2	3.3	3.0	2.7	11.7	46.6	194.6	116.7	99.8	29.5	10.7	5.7	**44.0**
1997	3.4	2.3	1.2	0.9	3.4	85.6	481.6	400.5	257.4	25.9	9.2	3.9	**106.3**
1998	1.9	1.5	1.2	0.9	3.2	156.8	577.6	577.9	125.7	26.7	7.8	3.0	**123.7**
1999	1.5	1.3	1.0	0.7	0.8	5.6	380.5	812.3	76.2	16.5	6.2	110.5	**117.8**
2000	14.1	5.1	2.4	1.3	1.1	51.6	280.2	755.8	196.3	48.0	11.6	4.1	**114.3**
2001	2.2	1.3	0.9	0.6	1.0	48.1	324.2	591.8	176.6	24.1	8.7	4.2	**98.6**
2002	2.1	1.1	0.9	0.6	1.4	72.0	391.7	358.8	103.3	160.7	13.1	3.9	**92.5**
2003	1.7	1.0	0.6	0.4	0.5	149.5	728.3	633.2	362.5	81.3	24.1	9.1	**166.0**
2004	4.2	2.4	2.0	1.9	3.4	127.4	518.9	640.1	89.6	16.9	7.5	4.5	**118.2**
2005	3.0	3.4	3.6	2.5	6.5	80.7	389.4	385.9	91.1	24.7	7.3	5.0	**83.6**
2006	3.3	1.8	1.5	4.1	2.9	88.0	424.5	420.7	99.9	120.2	14.9	4.3	**98.8**
2007	2.4	1.8	1.2	1.1	1.0	86.0	898.5	610.5	133.7	17.7	6.6	3.4	**147.0**
2008	1.5	0.9	0.5	0.4	7.5	129.8	577.8	473.0	79.9	16.7	15.0	9.3	**109.4**
2009	4.9	2.3	1.1	0.8	0.9	59.3	267.6	307.0	58.0	10.9	3.5	1.5	**59.8**
2010	0.9	0.7	0.4	0.3	11.2	245.5	765.0	859.8	297.1	81.0	19.8	5.2	**190.6**
2011	2.4	1.6	1.0	0.7	0.5	72.5	834.1	562.2	156.7	14.2	5.7	3.0	**137.9**
2012	50.4	22.3	4.6	2.6	6.5	366.9	1171.2	718.2	108.1	91.1	12.1	4.1	**213.2**
2013	1.7	0.8	0.4	0.2	0.1	42.2	236.1	417.8	48.0	13.0	4.6	2.3	**63.9**
2014	1.3	0.7	0.5	0.4	1.0	63.4	441.2	575.7	123.3	48.9	5.5	2.9	**105.4**
2015	1.1	0.6	0.5	1.3	0.9	28.6	166.5	182.5	79.4	14.3	4.1	1.7	**40.1**
2016	0.7	0.3	0.1	0.1	14.7	228.8	785.8	615.3	105.6	9.4	3.0	1.0	**147.1**
2017	0.5	0.2	0.1	0.1	2.4	55.0	143.9	377.4	112.6	20.8	40.4	7.1	**63.4**
2018	1.9	0.9	0.4	0.1	0.1	44.1	322.5	319.7	53.0	8.5	2.6	1.0	**62.9**
2019	0.6	0.3	0.1	0.2	5.4	234.9	823.3	561.6	51.8	7.7	2.2	1.0	**140.8**
2020	0.5	0.3	0.2	0.3	1.8	46.2	501.7	347.8	136.0	15.1	5.3	2.1	**88.1**
2021	1.3	0.5	0.2	0.4	1.8	39.5	211.9	574.1	96.5	10.9	3.7	2.2	**78.6**
Mean	**3.7**	**2.0**	**2.0**	**6.3**	**3.3**	**100.6**	**491.2**	**505.4**	**121.2**	**32.5**	**9.7**	**6.9**	**107.1**

Table A-3: Mean Monthly Inflow in Reconstituted Flow Series-2 (RS2)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1980	0.7	1.4	8.5	16.6	25.2	85.9	343.3	459.6	136.8	14.0	4.1	2.0	**91.5**
1981	1.4	1.1	19.2	123.3	7.0	71.5	522.8	404.5	82.8	13.1	4.0	1.4	**104.3**
1982	0.6	0.3	0.1	0.1	0.1	39.2	312.1	333.3	50.0	7.1	2.2	0.9	**62.2**
1983	0.8	1.1	1.0	1.0	1.4	62.6	286.3	352.8	83.7	13.9	7.1	4.1	**68.0**
1984	0.9	0.5	0.3	0.0	0.0	24.7	394.5	365.1	84.7	12.7	4.4	1.8	**74.1**
1985	0.9	0.4	0.1	0.1	1.9	192.3	563.6	527.9	131.9	14.3	5.4	2.0	**120.1**
1986	1.9	1.6	2.1	2.6	3.7	76.1	456.1	627.0	167.1	28.8	13.9	10.9	**116.0**
1987	5.0	2.6	1.8	1.3	1.4	149.3	488.7	709.0	120.4	18.1	6.3	3.1	**125.6**
1988	1.5	0.7	0.9	0.7	3.2	71.1	394.5	624.8	128.5	14.6	5.1	2.4	**104.0**
1989	1.1	0.6	0.5	0.4	0.8	132.7	576.9	544.9	85.3	12.9	5.3	3.5	**113.8**
1990	1.7	0.9	0.6	0.7	2.1	266.1	667.6	728.6	96.7	12.9	6.4	4.8	**149.1**
1991	2.6	1.6	1.0	0.7	0.5	130.2	1035.8	483.4	67.1	12.7	5.2	2.9	**145.3**
1992	2.5	1.7	1.1	0.8	0.6	6.4	118.7	146.9	46.7	11.1	6.5	3.0	**28.8**
1993	2.2	1.8	2.2	1.6	2.1	114.9	417.3	603.8	161.0	27.5	14.6	10.9	**113.3**
1994	12.3	10.2	8.9	7.8	8.2	95.3	414.7	568.7	203.1	26.8	8.6	3.0	**114.0**
1995	0.9	0.5	0.3	0.2	2.6	60.4	909.6	646.8	104.2	15.5	5.9	3.9	**145.9**
1996	2.4	2.4	2.2	2.0	8.6	54.4	227.3	136.3	116.6	21.8	7.9	4.2	**48.8**
1997	2.6	1.7	0.9	0.7	2.5	101.9	573.1	476.7	306.4	19.5	6.9	3.0	**124.6**
1998	1.5	1.1	1.0	0.7	2.5	190.2	700.7	701.1	152.5	20.5	6.0	2.3	**148.3**
1999	1.2	1.0	0.8	0.5	0.6	6.9	470.7	1004.8	94.3	12.9	4.9	86.5	**140.4**
2000	11.3	4.1	1.9	1.0	0.9	41.2	223.8	603.6	156.8	38.4	9.2	3.3	**91.3**
2001	1.8	1.1	0.7	0.5	0.8	39.2	264.2	482.4	143.9	19.6	7.1	3.4	**80.4**
2002	1.8	0.8	0.8	0.5	1.2	59.9	326.0	298.6	86.0	133.8	10.9	3.2	**77.0**
2003	1.4	0.9	0.5	0.3	0.4	127.1	619.1	538.3	308.2	69.1	20.5	7.8	**141.1**
2004	3.6	2.1	1.7	1.7	3.0	110.7	450.7	556.1	77.9	14.7	6.5	3.9	**102.7**
2005	2.1	2.3	2.5	1.8	5.1	56.6	326.1	348.3	97.8	19.5	15.4	13.4	**74.2**
2006	13.2	11.0	9.5	8.1	7.9	58.3	408.9	435.4	102.0	12.2	7.2	4.3	**89.8**
2007	2.3	1.6	1.1	1.0	0.9	80.0	835.3	567.6	124.3	16.4	6.2	3.1	**136.7**
2008	1.4	0.8	0.5	0.4	7.2	123.6	550.1	450.3	76.0	15.9	14.3	8.9	**104.1**
2009	4.8	2.2	1.1	0.7	0.9	57.8	261.0	299.4	56.5	10.7	3.4	1.5	**58.3**
2010	0.9	0.7	0.4	0.3	11.2	245.5	765.0	859.8	297.1	81.0	19.8	5.2	**190.6**
2011	2.4	1.5	1.0	0.7	0.5	72.4	834.1	562.2	156.6	14.2	5.7	3.0	**137.9**
2012	50.4	22.3	4.6	2.6	6.5	366.9	1171.2	718.2	108.1	91.1	12.1	4.1	**213.2**
2013	1.7	0.8	0.4	0.2	0.1	42.2	236.1	417.8	48.0	13.0	4.6	2.3	**63.9**
2014	1.3	0.7	0.5	0.4	1.0	63.4	441.2	575.7	123.3	48.9	5.5	2.9	**105.4**
2015	0.9	0.8	0.5	0.3	0.6	24.8	170.5	223.0	51.0	5.6	1.7	0.7	**40.0**
2016	0.7	0.3	0.1	0.1	14.7	228.9	786.2	615.6	105.7	9.4	3.0	1.0	**147.1**
2017	0.5	0.2	0.1	0.1	2.4	55.0	144.0	377.7	112.6	20.8	40.5	7.1	**63.4**
2018	1.9	0.9	0.4	0.1	0.1	44.0	322.0	319.2	52.9	8.5	2.6	1.0	**62.8**
2019	0.6	0.3	0.1	0.2	5.4	234.9	823.5	561.8	51.8	7.7	2.2	1.0	**140.8**
2020	0.5	0.3	0.2	0.3	1.8	46.2	501.7	347.7	135.9	15.1	5.3	2.1	**88.1**
2021	1.3	0.5	0.2	0.4	1.9	40.2	215.7	584.4	98.2	11.1	3.8	2.2	**80.0**
Mean	**3.6**	**2.1**	**2.0**	**4.4**	**3.6**	**98.8**	**489.3**	**504.5**	**118.8**	**24.0**	**8.0**	**5.8**	**105.4**

APPENDIX B:
SITE 07.E
ANNUAL INFLOWS
ALL SCENARIOS

Table B-1: Annual Inflow (m^3/s) of Climate Change Scenarios - 2023-2100 – ASIAQ (2023)

		Reconstitution 1 - 2022 (2031-2050)		Reconstitution 2 - 2022 (2031-2050)		ASIAQ 2023 (2023-2100)						
Year	Historical 1980-2014 (1991-2010)	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	SSP126_CC_MAR	SSP245_CC_MAR	SSP585_CC_MAR	SSP126_ME_MAR	SSP245_ME_MAR	SSP585_ME_MAR	SSP585_CC_HIRHAM
1991	94.2											
1992	19.3											
1993	74.5											
1994	75.6											
1995	94.7											
1996	32.7											
1997	80.8											
1998	96.2											
1999	93.8											
2000	92.2											
2001	81.4											
2002	78.0											
2003	142.6											
2004	103.8											
2005	75.2											
2006	91.0											
2007	138.7											
2008	105.2											
2009	59.1											
2010	192.7											
2011												
2012												
2013												
2014												
2015												
2016												
2017												
2018												
2019												
2020												
2021												
2022												
2023						*148.7*	*122.7*	*85.0*	*102.1*	*92.3*	*106.4*	*120.2*
2024						*115.7*	*93.1*	*131.2*	*143.9*	*76.8*	*63.1*	*65.1*
2025						*159.0*	*78.2*	*209.4*	*80.2*	*95.3*	*76.6*	*75.5*
2026						*146.8*	*144.4*	*108.6*	*109.7*	*94.2*	*95.3*	*131.8*
2027						*135.4*	*120.8*	*99.4*	*116.2*	*93.1*	*89.9*	*134.0*
2028						*90.4*	*50.0*	*103.6*	*121.0*	*103.6*	*75.4*	*120.2*
2029						*112.9*	*150.3*	*143.5*	*120.7*	*107.2*	*92.6*	*107.3*
2030						*158.5*	*171.2*	*139.0*	*117.6*	*123.8*	*119.5*	*118.1*
2031		234.6	162.1	220.2	153.4	*118.1*	*155.9*	*48.4*	*64.7*	*84.8*	*117.6*	*133.2*
2032		246.4	111.5	231.0	106.8	*182.1*	*139.6*	*152.4*	*61.2*	*137.7*	*76.2*	*139.9*
2033		147.6	131.5	140.1	125.3	*173.3*	*102.9*	*105.9*	*106.9*	*149.4*	*141.1*	*111.0*
2034		145.1	164.0	137.8	155.2	*154.3*	*128.6*	*143.8*	*70.7*	*97.8*	*79.8*	*132.4*
2035		115.2	91.1	110.3	88.0	*138.4*	*62.3*	*184.1*	*114.9*	*144.8*	*132.9*	*131.9*
2036		209.0	138.2	196.6	131.4	*109.6*	*103.7*	*170.8*	*72.7*	*132.5*	*93.3*	*105.0*
2037		209.4	186.5	197.0	176.0	*62.9*	*104.0*	*157.3*	*99.1*	*113.0*	*97.2*	*97.2*
2038		227.3	87.2	213.5	84.5	*168.4*	*179.6*	*117.0*	*118.8*	*114.3*	*157.4*	*112.3*
2039		120.9	139.3	115.5	132.4	*160.5*	*107.0*	*193.1*	*80.7*	*132.1*	*134.3*	*152.4*
2040		145.3	138.6	138.0	131.8	*209.3*	*99.3*	*187.2*	*76.8*	*158.7*	*119.2*	*142.8*
2041		118.1	140.5	112.9	133.6	*168.5*	*160.3*	*117.6*	*95.6*	*119.1*	*83.7*	*126.8*
2042		125.4	141.7	119.6	134.6	*150.1*	*80.5*	*194.9*	*59.0*	*84.5*	*106.4*	*114.8*
2043		143.0	191.6	135.8	180.6	*84.8*	*50.1*	*177.6*	*120.3*	*113.5*	*131.4*	*130.0*
2044		177.4	216.4	167.5	203.4	*127.8*	*213.8*	*179.1*	*90.9*	*68.0*	*118.6*	*136.8*
2045		216.9	212.8	203.9	200.2	*208.8*	*97.5*	*138.1*	*72.6*	*85.3*	*124.8*	*129.4*
2046		139.8	174.6	132.9	165.0	*167.1*	*157.6*	*90.7*	*92.3*	*111.8*	*67.4*	*141.0*
2047		172.2	195.0	162.8	183.7	*165.7*	*106.5*	*177.1*	*111.3*	*143.6*	*89.3*	*137.5*
2048		179.2	218.6	169.2	205.4	*193.1*	*154.2*	*143.7*	*96.1*	*113.5*	*83.2*	*127.3*
2049		101.8	175.0	97.9	165.3	*111.0*	*213.9*	*135.6*	*155.2*	*118.3*	*133.2*	*147.6*

Table B-1: Annual Inflow (m^3/s) of Climate Change Scenarios – 2023-2100 – ASIAQ (2023) (continued)

		Reconstitution 1 - 2022 (2031-2050)		Reconstitution 2 - 2022 (2031-2050)		ASIAQ 2023 (2023-2100)						
Year	Historical 1980-2014 (1991-2010)	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	SSP126_CC_MAR	SSP245_CC_MAR	SSP585_CC_MAR	SSP126_ME_MAR	SSP245_ME_MAR	SSP585_ME_MAR	SSP585_CC_HIRHAM
2050		248.5	173.5	233.0	164.0	180.6	161.1	246.4	101.9	95.6	129.2	80.7
2051						84.3	109.6	198.2	126.8	120.2	116.5	99.3
2052						225.0	158.3	171.7	81.1	97.2	134.4	139.0
2053						95.1	116.1	149.8	154.1	124.3	134.8	165.5
2054						178.2	106.2	194.2	90.8	156.0	121.1	130.0
2055						142.7	182.3	225.3	95.3	123.2	128.7	173.9
2056						124.6	170.8	202.1	134.4	96.8	147.7	132.2
2057						228.8	136.4	196.3	130.2	106.9	111.3	157.0
2058						150.5	172.2	184.9	124.0	127.8	130.6	182.5
2059						106.2	69.9	194.9	112.9	175.0	139.8	176.9
2060						143.4	156.5	173.5	148.5	125.4	109.3	166.2
2061						192.8	176.1	245.6	147.0	122.7	121.6	150.3
2062						137.0	166.0	321.9	96.7	107.8	115.7	160.9
2063						85.0	140.5	202.9	71.2	92.3	113.8	92.1
2064						102.5	212.2	191.6	76.1	74.9	151.5	133.6
2065						192.5	163.6	267.5	76.6	160.9	155.5	150.1
2066						162.0	122.9	187.4	101.6	131.3	154.9	169.8
2067						154.6	207.4	259.9	60.2	123.2	226.4	149.4
2068						172.5	198.4	229.1	99.3	142.9	161.8	167.3
2069						110.4	150.9	197.7	98.6	146.7	203.4	181.9
2070						233.4	163.8	386.9	84.8	90.8	188.0	145.7
2071						148.2	218.0	248.3	107.7	135.1	153.6	210.6
2072						142.8	193.7	211.6	110.2	175.0	135.8	136.1
2073						198.5	154.3	242.9	97.2	127.3	138.4	165.8
2074						149.8	84.2	364.7	87.0	104.6	184.2	184.9
2075						163.0	229.1	271.4	114.2	136.4	183.6	152.4
2076						127.9	221.0	211.2	68.6	108.9	154.0	214.9
2077						123.5	190.4	250.8	104.6	167.4	141.1	206.7
2078						134.9	188.4	375.8	109.4	126.2	165.2	158.4
2079						173.8	172.8	328.5	114.6	122.9	156.8	203.3
2080						183.9	81.1	287.8	98.3	114.8	215.4	194.5
2081						196.1	160.0	355.1	133.7	163.8	204.4	185.5
2082						144.1	199.6	279.2	110.5	141.1	169.3	213.4
2083						212.1	266.7	301.4	109.7	148.6	241.6	229.7
2084						137.2	192.3	303.9	110.5	150.4	219.3	190.8
2085						74.7	183.6	319.2	114.0	114.2	179.0	203.7
2086						142.9	192.5	447.1	109.6	142.5	125.4	264.1
2087						207.9	255.1	429.7	121.8	109.7	199.5	232.1
2088						121.1	170.9	420.6	97.6	147.7	219.3	216.8
2089						189.0	121.8	316.3	124.3	137.8	194.5	229.6
2090						190.1	313.9	429.7	91.2	144.9	314.7	241.0
2091						124.5	198.3	402.7	131.3	215.8	244.5	228.0
2092						131.7	206.8	385.8	133.6	113.7	183.9	248.6
2093						235.1	236.2	398.0	98.1	138.4	255.7	271.8
2094						189.5	204.7	394.8	142.9	161.6	217.1	255.4
2095						177.9	173.5	417.0	111.9	101.6	236.7	292.4
2096						180.1	259.2	445.9	90.3	107.4	183.3	242.5
2097						188.0	140.3	501.0	122.4	143.6	171.2	282.1
2098						98.5	262.2	510.5	59.8	130.8	192.5	270.3
2099						214.8	144.4	564.4	98.6	131.8	221.2	242.4
2100						214.8	144.4	564.4	98.6	131.8	221.2	242.4

APPENDIX C:

SENSITIVITY ANALYSIS - FIRM POWER FOR COMPLETE TASERSIAQ AND FOR ONE YEAR WITH DEFICIT

Table C-4: Site 07.e - Firm Power (100%) for Different Climate Change Scenarios Complete Tasersiaq

Climate Change Scenario	Period	Firm Power (MW)	Difference with base case (MW)	Difference with base case (%)
Historical Data (Base Case) *	1991-2010 (20 years)	462	+ 10	+2%
RCP 4.5 – reconstitution 1 *	2031-2050 (20 years)	822	+370	+82%
RCP 8.5 – reconstitution 1 *		803	+351	+78%
RCP 4.5 – reconstitution 2 *		794	+342	+76%
RCP 8.5 – reconstitution 2 *		772	+320	+71%
ASIAQ 2023 - SSP126_CC_MAR		705	+253	+56%
ASIAQ 2023 - SSP245_CC_MAR		624	+172	+38%
ASIAQ 2023 - SSP585_CC_MAR		702	+250	+55%
ASIAQ 2023 - SSP126_ME_MAR		547	+ 95	+21%
ASIAQ 2023 - SSP245_ME_MAR		629	+177	+39%
ASIAQ 2023 - SSP585_ME_MAR		621	+169	+37%
ASIAQ 2023 - SSP585_CC_HIRHAM		735	+283	+63%
ASIAQ 2023 - SSP126_CC_MAR	2031-2060 (30 years)	704	+252	+56%
ASIAQ 2023 - SSP245_CC_MAR		624	+172	+38%
ASIAQ 2023 - SSP585_CC_MAR		691	+239	+53%
ASIAQ 2023 - SSP126_ME_MAR		549	+97	+22%
ASIAQ 2023 - SSP245_ME_MAR		629	+177	+39%
ASIAQ 2023 - SSP585_ME_MAR		621	+169	+37%
ASIAQ 2023 - SSP585_CC_HIRHAM		716	+264	+58%
ASIAQ 2023 - SSP126_CC_MAR	2051-2080 (30 years)	736	+284	+63%
ASIAQ 2023 - SSP245_CC_MAR		741	+289	+64%
ASIAQ 2023 - SSP585_CC_MAR		1001	+549	+121%
ASIAQ 2023 - SSP126_ME_MAR		555	+103	+23%
ASIAQ 2023 - SSP245_ME_MAR		679	+227	+50%
ASIAQ 2023 - SSP585_ME_MAR		758	+306	+68%
ASIAQ 2023 - SSP585_CC_HIRHAM		808	+356	+79%

Climate Change Scenario	Period	Firm Power (MW)	Difference with base case (MW)	Difference with base case (%)
ASIAQ 2023 - SSP126_CC_MAR	2071-2100 (30 years)	768	316	70%
ASIAQ 2023 - SSP245_CC_MAR		795	343	76%
ASIAQ 2023 - SSP585_CC_MAR		1184	732	162%
ASIAQ 2023 - SSP126_ME_MAR		605	153	34%
ASIAQ 2023 - SSP245_ME_MAR		776	324	72%
ASIAQ 2023 - SSP585_ME_MAR		907	455	101%
ASIAQ 2023 - SSP585_CC_HIRHAM		960	508	112%

* Initial scenario

Table C-2: Site 07.e – Firm Power – One Year with Deficit – Intake Sector Only

Climate Change Scenario	Period	Firm Power (MW)	Difference with base case (MW)	Difference with base case (%)
Historical Data (Base Case) *	1991-2010 (20 years)	483	+31	+7%
RCP 4.5 – reconstitution 1 *	2031-2050 (20 years)	828	+376	+83%
RCP 8.5 – reconstitution 1 *		790	+338	+75%
RCP 4.5 – reconstitution 2 *		799	+347	+77%
RCP 8.5 – reconstitution 2 *		767	+315	+70%
ASIAQ 2023 - SSP126_CC_MAR		766	+314	+70%
ASIAQ 2023 - SSP245_CC_MAR		655	+203	+45%
ASIAQ 2023 - SSP585_CC_MAR		756	+304	+67%
ASIAQ 2023 - SSP126_ME_MAR		556	+104	+23%
ASIAQ 2023 - SSP245_ME_MAR		643	+191	+42%
ASIAQ 2023 - SSP585_ME_MAR		639	+187	+41%
ASIAQ 2023 - SSP585_CC_HIRHAM		737	+285	+63%
ASIAQ 2023 - SSP126_CC_MAR	2031-2060 (30 years)	766	+314	+70%
ASIAQ 2023 - SSP245_CC_MAR		655	+203	+45%
ASIAQ 2023 - SSP585_CC_MAR		756	+304	+67%
ASIAQ 2023 - SSP126_ME_MAR		557	+105	+23%
ASIAQ 2023 - SSP245_ME_MAR		643	+191	+42%
ASIAQ 2023 - SSP585_ME_MAR		639	+187	+41%
ASIAQ 2023 - SSP585_CC_HIRHAM		721	+269	+60%
ASIAQ 2023 - SSP126_CC_MAR	2051-2080 (30 years)	760	308	+68%
ASIAQ 2023 - SSP245_CC_MAR		783	331	+73%
ASIAQ 2023 - SSP585_CC_MAR		1035	583	+129%
ASIAQ 2023 - SSP126_ME_MAR		558	106	+23%
ASIAQ 2023 - SSP245_ME_MAR		729	277	+61%
ASIAQ 2023 - SSP585_ME_MAR		760	308	+68%
ASIAQ 2023 - SSP585_CC_HIRHAM		792	340	+75%

Climate Change Scenario	Period	Firm Power (MW)	Difference with base case	
			(MW)	(%)
ASIAQ 2023 - SSP126_CC_MAR	2071-2100 (30 years)	829	+377	+83%
ASIAQ 2023 - SSP245_CC_MAR		783	+331	+73%
ASIAQ 2023 - SSP585_CC_MAR		1139	+687	+152%
ASIAQ 2023 - SSP126_ME_MAR		613	+161	+36%
ASIAQ 2023 - SSP245_ME_MAR		773	+321	+71%
ASIAQ 2023 - SSP585_ME_MAR		908	+456	+101%
ASIAQ 2023 - SSP585_CC_HIRHAM		955	+503	+111%

* Initial scenario

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