DNV·GL

HEPBURN SOLAR FARM

Solar resource and energy assesment

Hepburn Community Wind Park Co-Operative Ltd

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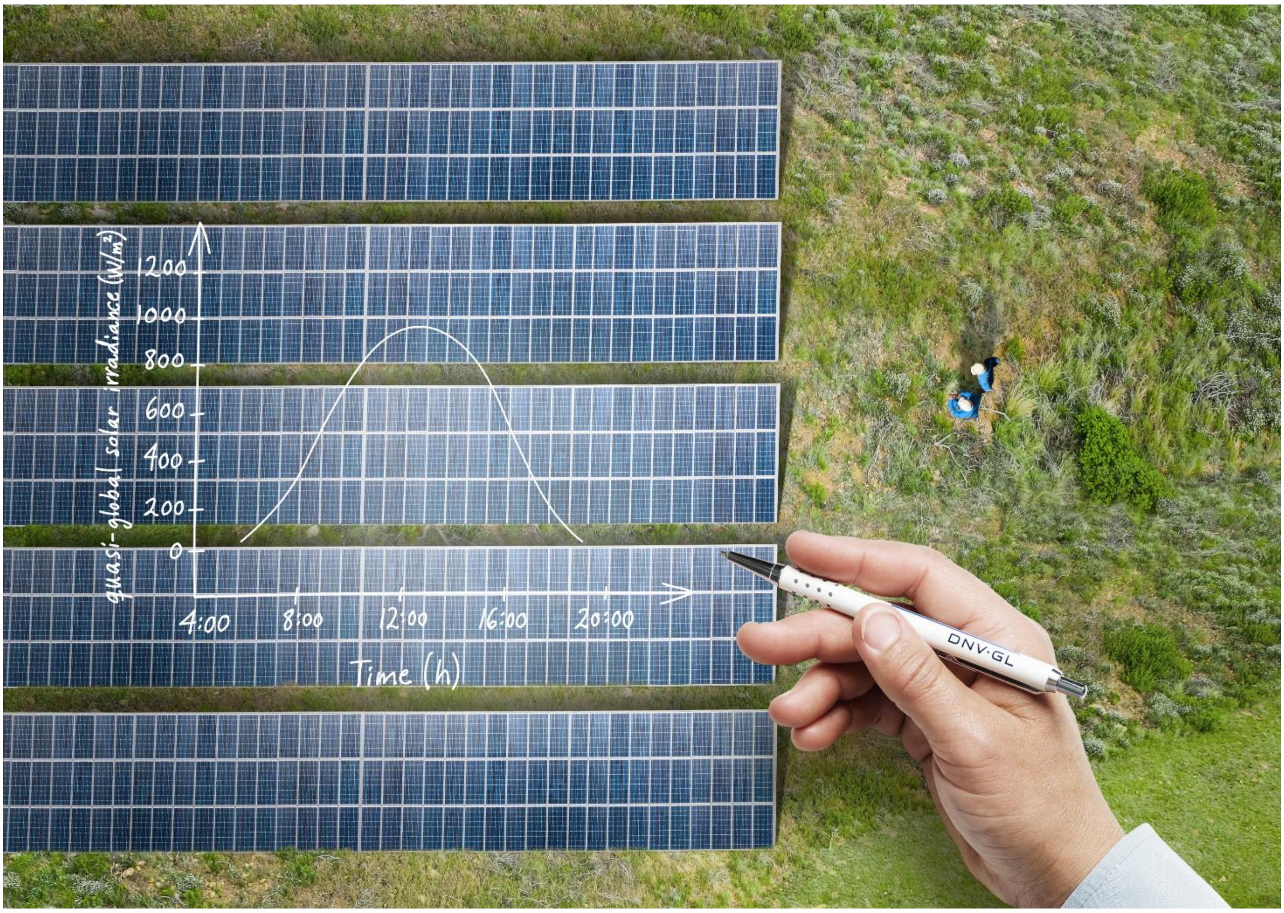

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Task and objective: Solar resource and energy assessment of Hepburn Solar Farm

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Reference to part of this report which may lead to misinterpretation is not permissible.

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A	20/06/2018	First issue	Christopher Smith	Jessica McMahon	Christian Peake
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1 EXECUTIVE SUMMARY

Hepburn Community Wind Park Co-Operative Ltd (the "Customer") has instructed DNV GL Australia Pty Ltd (DNV GL) to undertake an independent assessment of the long-term energy production of the proposed Hepburn Solar Farm (the "Project"). This summary report is issued to the Customer pursuant to a written agreement arising from DNV GL proposal L2C163726-AUME-SFA-001-C dated 18/05/2018.

DNV GL has conducted an independent solar resource and energy assessment for the proposed Hepburn Solar Farm. During analysis, DNV GL considered both single axis tracking and fixed tilt configurations of the proposed solar array.

The Project consists of 10,759 Yingli Solar YGE 335W polycrystalline silicon PV modules, each with a capacity of 335 Wp giving a total installed capacity of 3,604 kWp. The PV array utilises one SMA 2750 SC-EV central inverter giving a total AC capacity of 2,750 kW. As the inverter capacity is less than the panel capacity, high levels of inverter clipping are expected in the early year of operation. While this results in some energy losses, the high level of clipping is offset by the effects of degradation to some extent.

A summary of the energy, uncertainty and curtailment scenarios are presented in Table 1-1 and Table 1-2, which includes the uncertainty associated with degradation over the life of the project, the interaction of degradation with the different grid curtailment scenarios and consideration of energy production from the adjacent 4.1 MW wind farm.

Table 1-1 Summary of energy estimates including degradation, single axis tracking

Future Period	Annual production probability of exceedance [MWh/annum] Single axis tracking				
	P50	P75	P90	P95	P99
Single axis tracking [Uncurtailed]					
First 1 year	5,976	5,615	5,386	5,264	5,057
First 10 years	5,813	5,578	5,351	5,199	4,948
Lifetime – 30 years	5,505	4,989	4,434	4,172	3,905
Single axis tracking [4.5 MW Export Limit]					
First 1 year	5,715	5,367	5,146	5,027	4,826
First 10 years	5,585	5,357	5,137	4,990	4,748
Lifetime – 30 years	5,317	4,822	4,290	4,039	3,781
Single axis tracking [4.1 MW Export Limit]					
First 1 year	5,533	5,192	4,973	4,855	4,655
First 10 years	5,413	5,185	4,967	4,822	4,583
Lifetime – 30 years	5,164	4,681	4,164	3,920	3,666

Table 1-2 Summary of energy estimates including degradation, fixed tilt

Future Period	Annual production probability of exceedance [MWh/annum] Fixed tilt				
	P50	P75	P90	P95	P99
Fixed tilt [Uncurtailed]					
First 1 year	5,200	4,896	4,703	4,598	4,418
First 10 years	5,045	4,839	4,638	4,506	4,289
Lifetime – 30 years	4,753	4,301	3,817	3,588	3,353
Fixed Tilt [4.5 MW Export Limit]					
First 1 year	4,998	4,704	4,516	4,414	4,240
First 10 years	4,872	4,671	4,476	4,348	4,137
Lifetime – 30 years	4,613	4,177	3,711	3,491	3,264
Fixed Tilt [4.1 MW Export Limit]					
First 1 year	4,850	4,561	4,376	4,275	4,102
First 10 years	4,733	4,534	4,341	4,214	4,006
Lifetime – 30 years	4,491	4,066	3,613	3,398	3,175

2 INTRODUCTION

2.1 Project description

The proposed Hepburn solar facility will utilise 10,759 Yingli Solar YGE 335W polycrystalline silicon 335 Wp PV modules giving a total installed capacity of 3,604 kWp. The PV array utilizes one SMA 2750 SC-EV central inverter giving a total AC capacity of 2,750 kW. Table 2-1 describes the key characteristics of the proposed Hepburn Solar Farm.

DNV GL notes that the Hepburn Solar Farm is currently undergoing preliminary design and technical details including but not limited to tracker technology, fixed tilt angle and row spacing have not been finalised. DNV GL has based the energy assessment on design documentation provided by the Customer [1] [2] and pragmatic assumptions about the project design as necessary.

Table 2-1 Design characteristics of the Hepburn Solar Farm

	Single Axis Tracker Configuration	Fixed Tilt Configuration
Mounting Structure	Single axis tracker, E-W tilt	Fixed tilt
Tracker rotation limits [°]	+/- 60	N/A
Tilt Angle [°]	N/A	28
Row Spacing [m]	5.0	8.2
PV module type	Yingli YGE 335W	Yingli YGE 335W
PV module capacity (W_p)	335	335
Modules per string	29	29
Total number of strings	371	371
Total number of PV modules	10,759	10,759
DC Peak Power [kWp]	3,604	3,604
Inverter type(s)	SMA SC2750-EV	SMA SC2750-EV
Inverter maximum capacity at 25° [kW_{AC}]	2,750	2,750
Inverter maximum capacity at 50° [kW_{AC}]	2,500	2,500
Number of inverters	1	1
Total plant AC capacity at 25° [kW_{AC}]	2,750	2,750
Total plant AC capacity at 50° [kW_{AC}]	2,500	2,500

Regarding the fixed tilt configuration, DNV GL notes that a tilt angle optimised to achieve maximum energy yield only would be approximately 37 degrees, with a corresponding inter row spacing of greater than 12 m to minimise shading loss impacts. However, in lieu of further information regarding space constraints at the site, DNV GL has assumed that some space restrictions would apply and has therefore considered a tilt angle of 28 degrees in conjunction with an inter row spacing of 8.2 m.

DNV GL recommends that the fixed tilt configuration be investigated as part of a full cost-benefit analysis exercise considering all project physical and financial constraints. Such an analysis may also consider utilising a larger DC capacity for a fixed tilt design, given the lower energy yield relative to a tracking design.

3 SOLAR RESOURCE ASSESSMENT

3.1 Site Measurements

An onsite measurement campaign has been conducted at the proposed Hepburn Solar Farm commencing 2 May 2017. Table 3-1 describes the location and installation details of the solar monitoring station installed at the Hepburn Solar Farm site. Figure 3-1 shows the installed solar monitoring station.

Table 3-1 Installation details of the Hepburn solar monitoring station

Installation Details	
Datum	MGA Zone 55 GDA94
Easting	245,315 m
Northing	5,854,019 m
Installation Date	12/04/2017

Figure 3-1 Monitoring station at Hepburn Solar Farm

The following equipment is installed at the Hepburn solar monitoring station:

- 2 x Kipp & Zonen SMP11 Secondary Standard pyranometers; one mounted horizontally and one at a fixed tilt of 45 degrees oriented north

- 1 Vaisala HMP60 met sensor measuring temperature and humidity

DNV GL considers the instrumentation and data logging to be of good quality. DNV GL has confirmed that the calibration certificates provided match the pyranometers installed on site and notes that the Kipp & Zonen SMP11 pyranometers are smart pyranometers for which the calibration coefficients are applied to the device directly by the manufacturer. The measurements appear to have been provided in their raw data format.

DNV GL has been advised that the pyranometers are subject to weekly cleaning and alignment checks which is in line with best practice for maintaining the quality of measurements.

The meteorological data have been subject to a quality checking procedure by DNV GL to identify records which were affected by equipment malfunction and other anomalies such as soiling. The irradiance and temperature measurements were found to be of generally high quality. DNV GL notes that short periods of irradiance data were affected by condensation; these were either removed or found to have minimal impact on the data quality. Otherwise, no major problems were detected, however, DNV GL notes that without multiple horizontal pyranometers it can be difficult to identify all erroneous data; this has been considered in the uncertainty assessment.

3.2 Reference Datasets

Table 3-2 presents the long-term meteorological datasets used in the assessment of long-term meteorological conditions at Hepburn Solar Farm.

Table 3-2 Reference datasets considered for long-term assessment

Source	Location	Description of measurements	Measurement period	Data coverage [1]
Solargis	Hepburn SF Site (37.4256 °S, 144.1218 °E)	Satellite-derived data; hourly average GHI, diffuse irradiance and temperature	Jul 2006 to April 2018	100.00%
Bureau of Meteorology (BoM)	Hepburn SF Site (37.4256 °S, 144.1218 °E)	Satellite-derived data; hourly instantaneous GHI.	Jan 2006 to Jun 2017	97.25%
BoM Australian Weather Station (AWS)	Pyrenees (Ben Nevis) (37.23°S, 143.20°E) 2	Measured/ground-based data; hourly average temperature	Jan 2008 to April 2018	97.23%
BoM AWS	Wallan (Kilmore Gap) (37.38 °S, 144.97 °E) 2	Measured/ground-based data; hourly average temperature	Jan 2006 to April 2018	99.45%
BoM AWS	Smeaton (37.34 °S, 143.99 °E) 2	Measured/ground-based data; daily rainfall	Jan 2006 to April 2018	-

Notes: 1. Data coverage refers to the completeness of the dataset over the available period.
2. WGS84 datum.

DNV GL conducted consistency and correlation analysis for each source of GHI and temperature data included in Table 3-2 to ensure the integrity of the selected meteorological conditions used to represent Hepburn Solar Farm.

3.3 Long Term Meteorological Assessment

The analysis of the long-term meteorological conditions at the Hepburn site included consideration of the following parameters, which are used as inputs to energy production assessment:

- Global Horizontal Irradiance (GHI)
- Diffuse irradiance
- Ambient temperature
- Wind speed

Approximately 11 months of valid GHI and temperature data have been recorded at the Hepburn site. In order to extend the period of measured data to represent the long-term period at the site, the site measurements were correlated to selected reference datasets for each parameter.

The Solargis dataset was utilised in the assessment of the GHI and diffuse irradiance conditions, while the Wallan (Kilmore Gap) BoM Australian Weather Station was used in the long-term assessment of temperature conditions at the Hepburn site.

The resulting estimate of the long-term meteorological conditions at the Hepburn site are presented in Table 3-3

Table 3-3 Summary of long-term meteorological conditions at the site

Month	GHI [kWh/m²/day]	Diffuse [kWh/m²/day]	Temperature [°C]
Jan	7.37	2.04	17.33
Feb	6.29	1.99	16.40
Mar	4.69	1.60	14.33
Apr	3.13	1.30	10.91
May	2.07	1.00	7.80
Jun	1.63	0.87	5.42
Jul	1.90	1.02	4.89
Aug	2.70	1.40	5.89
Sep	3.99	1.86	7.95
Oct	5.48	2.18	10.20
Nov	6.38	2.41	13.53
Dec	7.36	2.45	15.19
Annual	**4.41**	**1.68**	**10.79**

4 ENERGY PRODUCTION ASSESSMENT

4.1 Methodology

The estimation of expected solar power generation is typically performed by DNV GL in several steps:

1) The climatic conditions - the global and diffuse irradiation on the horizontal plane and ambient temperature - are determined, as described in Section 3.3. The typical hourly dataset required for performing energy yield simulations has been synthetically generated based on these climatic conditions.

2) Irradiation on a tilted plane can be calculated by using the known global and diffuse irradiation on the horizontal plane. Transposition is the calculation of incident irradiance on a tilted plane, using horizontal irradiance data. Transposition is typically calculated using either the Hay model or the Perez model. For this study, DNV GL has used the Perez model. The transposition is separately calculated for each irradiance component: beam and diffuse. The reflected component is evaluated as a given fraction (the "albedo coefficient") of the global irradiance, weighted by the angle between the horizontal and the PV plane. DNV GL has assumed a generic albedo coefficient of 0.2 for this project, on account of the open field installation topology;

3) Irradiation losses (due to optical effects and usable irradiation) are calculated by using the proposed layout of the PV plant, site and surrounding topography, any nearby objects and standard assumptions regarding atmospheric properties and soiling;

4) The electrical simulation takes into account the properties of the PV modules, inverters, transformers and plant design (string configuration, cabling characteristics, etc.) in order to calculate the power delivered at the Connection Point on a time series basis; and

5) Production losses such as the power consumption of the Project and system availability are estimated to derive the long-term annual average energy production of the proposed PV plant.

The methodology used to estimate the uncertainty in both the irradiation data and the simulation models is presented in Section 5.

4.2 Plant Simulation

The PV plant simulation consists of an electricity production calculation corresponding to the site meteorological conditions in steps 2 to 4 described in Section 4.1 above.

The most commonly used simulation model within the PV industry is the "one-diode" model. The "one-diode" model is non-linear and implicit, and the required calculations must be performed with the aid of computational software. DNV GL utilised the commercial software, PVsyst, for simulation of the solar module energy conversion.

DNV GL has undertaken a simulation of the Project based on the layout, electrical configuration and components assumed by DNV GL as described in Table 2-1. DNV GL considers these assumptions for the energy modelling typical of current solar installations.

4.3 Loss Factors

The simulation software calculates irradiation in the plane of the array based on the climatic conditions defined at the site. The net energy produced by the PV plant is calculated through consideration of several loss factors, which are calculated or estimated during the simulation. These are described below.

Shading losses

There are two types of shading loss:

- **Far shading** - DNV GL has assessed the far shading effects attributed to the topography surrounding the proposed Hepburn Solar Farm. A representative horizon line was defined for the Project using satellite-derived digital elevation data procured from Meteonorm. Although no shading impacts were identified, DNV GL notes that the proposed solar farm site is located on the east flanks of a small hill. DNV GL recommends that further information about the site, including a horizon line photograph, is gathered via a site visit once the design is finalised.

- **Near shading** – This requires calculation which takes into account a detailed 3D description of the PV system and the surrounding area. A 3D model of the Hepburn PV plant was created for the computer simulation of near shading loss. The near shading loss takes into account the site topography and the inter-array shading. DNV GL has included a wind turbine in the shading model, located to the south-west of the solar farm, as per the design drawings provided.

  As the layout of the plant is currently considered preliminary, inverter stations were not considered in the shading model. DNV GL has also considered a flat slope for the PV array, noting the that the gentle easterly slopes seen at the site will have a negligible impact on energy production. DNV GL suggests that the shading model be revised once a detailed plant layout becomes available. DNV GL have assumed that trees or objects outside of the array blocks which may cause a shading impact will be removed during the construction phase of the Project.

Soiling losses

Soiling losses depend on the location of the PV system and on the frequency of rain events and cleaning. These losses are associated with dirt, dust and pollution which accumulate on the surface of modules and may result in PV cells receiving less irradiance. In other cases there may be non-uniformly distributed soiling, such as bird droppings; this type of soiling tends to produce significant partial shading on cells.

DNV GL has conducted modelling for soiling losses at the Hepburn site considering rainfall data obtained from the nearby Smeaton BoM station as described in Table 3-2 and the environmental attributes of the Hepburn region. DNV GL estimated an annual average energy loss of 1.1% attributed to soiling.

Reflection effects

The reflection effects, or incidence effect (the other typical designated term is IAM, for 'Incidence Angle Modifier'), corresponds to the weakening of irradiation actually reaching the PV cell surface, with respect to irradiation under normal incidence. In practice, this is commonly calculated using the ASHRAE-model, defined by the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE).

The Yingli Solar YGE 335W module considered is constructed with an anti-reflective coating which reduces the IAM loss; this has been integrated into analysis when defining the IAM loss curve.

Irradiance level losses

This loss is the difference between efficiency at 1,000 W/m² (irradiance under STC conditions) and actual irradiance within each hour.

Temperature losses

The temperature coefficient of power given for a PV module expresses the reduction of module output power with increasing module temperature. The temperature of the module is typically calculated from its thermal balance. The thermal behaviour of the field, which strongly influences electrical performance, is determined by a thermal balance between the ambient temperature and the cell heating, due to incident irradiation.

DNV GL has derived wind data to represent long-term conditions at the Hepburn site from DNV GL's in-house Virtual Meteorological Data (VMD) and the MERRA-2 satellite reanalysis databases. DNV GL has applied a power temperature coefficient of 0.42%/°C for the Yingli Solar YGE 335W module.

Module quality losses

It is common for as-delivered modules to vary slightly from their nameplate power. Module manufacturers provide power tolerance windows in which the actual module nameplate power will reside. It is unknown whether the actual averages of the modules delivered will match the nameplate, so DNV GL assumes that the module distribution will be centred at the lower quartile of the tolerance window. According to manufacturer specifications, the Yingli Solar YGE 335W module type is subject to a Nominal Power range at STC of 0/+1.5% of P_{max}. This results in an assumed distribution centre of 0.4% above nameplate for the Yingli Solar YGE 335W module proposed for Hepburn Solar Farm. This is one input for the module quality factor (MQF).

An additional 0.5% loss is incorporated into the MQF to account for non-ideal inverter maximum power point tracking. DNV GL then applies a modelling error adjustment to account for cases in which the module's modelled maximum power within the PVsyst PAN file deviates from the module nameplate power. In this case, a modelling error adjustment of 0.4% (loss) was applied for the Yingli Solar YGE 335W modules at Hepburn Solar Farm.

These attributes combine to produce an overall MQF gain of 0.5% (loss) for the Yingli Solar YGE 335W module type at Hepburn Solar Farm.

Module mismatching losses

Losses due to mismatch are related to the fact that the real modules in the array do not all have exactly the same current-voltage characteristics.

The estimation of mismatch loss is normally undertaken in accordance with typical module performance dispersion. In a series connection, the array mismatch loss can be kept low by using modules of the same type (with very similar currents) only.

DNV GL has estimated an annual average loss of 0.4% for the Yingli Solar YGE 335W module type based on the specifications of the module. The real figure will depend on the flash test results of the modules connected to the same string.

Ohmic wiring losses (DC)

The wiring resistance induces losses between the power available from the modules and that at the input of the inverter. The effective loss during a given period is calculated during the simulation. It is usually lower than the relative loss, when operating at Maximum Power Point (MPP).

Detailed electrical design information has not been provided for Hepburn Solar Farm therefore DNV GL has considered a generic DC ohmic loss assumption of 1.5% loss at STC conditions, resulting in a DC loss of 1.1% and 1.0% at normal operating conditions for tracker and fixed tilt configurations, respectively.

Inverter losses

The inverter losses include efficiency, other losses due both to the power and voltage threshold and operation above nominal power and voltage. This factor has been calculated using hourly simulations based on the technical information provided by the Customer.

Transformer losses

The customer has not provided specifications for the MV/LV transformer that will be used at the Hepburn Solar Farm facility. As such, DNV GL have assumed an appropriately sized generic first level transformer with expected fixed and variable losses incurred by a 3,000 kVA transformer.

DNV GL has calculated with these generic assumptions that a loss of 1.5% and 1.6% is expected for the tracker and fixed mounting structure configurations, respectively. DNV GL recommends that this loss be calculated based on the detailed design, once this becomes available.

No HV/MV second level transformer was considered during analysis of Hepburn Solar Farm, as it is understood that the plant will be connecting directly into the distribution network.

Wiring losses (AC network)

DNV GL has estimated an annual average loss of 0.4% attributed to AC side losses for the Hepburn Solar Farm for both single axis tracking and fixed tilt configurations, based on a default generic assumption of a 0.5% loss at maximum plant capacity. DNV GL recommends that this loss be calculated based on the detailed design, once this becomes available.

Auxiliary loads

DNV GL has assessed the station loads for both mounting configurations of Hepburn Solar Farm, inclusive of the power requirements for inverter cooling, monitoring system, control room operation and the tracker system. DNV GL has estimated an annual energy loss of 0.7% and 0.8% for single axis tracking and fixed tilt configurations, respectively.

System availability

DNV GL have used standard assumptions for availability based on mounting configuration, module technology and have assumed the plant will be monitored by on-site staff. Given these factors, DNV GL has considered a plant availability of 99.2% and 99.7% for single axis tracking and fixed tilt configurations, respectively. DNV GL has not included any grid availability loss factor as no site specific assessment of grid availability has been conducted at this stage.

Power limitation

DNV GL understands that the Hepburn Solar Farm will be subject to curtailment measures when aggregated with the adjacent 4.1 MW Hepburn Wind Farm. Hepburn has further advised DNV GL that the aggregated wind and solar export limitation has yet to be determined, however the likely aggregated curtailment scenarios will either be 4.1MW or 4.5MW. In order to determine the reduction in solar farm output due to curtailment, DNV GL undertook an analysis using measured production data taken from the adjacent wind turbines.

The Customer supplied DNV GL with over six years of production data from the two 2.05MW wind turbines over the period 08/2011 to 12/2017. To quantify the curtailed energy output on the Hepburn Solar farm, DNV GL estimated the average curtailed energy of the solar farm had both solar and wind farms been in production over this same period. This analysis was undertaken for both scenarios where a 4.1MW and 4.5MW aggregated wind and solar limitation would have been applied. This analysis was also conducted for two solar farm designs, fixed tilt and tracking.

The calculation of curtailment loss considers degradation of both the solar farm and wind farm, leading to a reduction in curtailment losses in the later years of operation.

4.4 Energy Yield

Table 4-1 presents the predicted long-term annual energy production for the Project, excluding the effects of system degradation. This value is the best estimate of the long-term P50 value to be expected from the proposed design.

Table 4-1 Long-term annual energy production and losses for Hepburn Solar Farm, Fixed Tilt

	Year 1 energy production	Fixed Tilt Configuration [Uncurtailed]	Fixed Tilt Configuration [4.5 MW Grid Limitation]	Fixed Tilt Configuration [4.1 MW Grid Limitation]
Basic Inputs	Global Irradiation on the Plane of Array [kWh/m²/year]	1,781	1,781	1,781
	Global Horizontal Irradiation (GHI) [kWh/m²/year]	1,599	1,599	1,599
	Fixed module/Tracking	Fixed	Fixed	Fixed
	DC Peak Power [kWp]	3,604	3,604	3,604
	AC Capacity at 25°C [kW]	2,750	2,750	2,750
	AC Capacity at 50°C [kW]	2,500	2,500	2,500
Losses	Far Shading/Horizon	0.00%	0.00%	0.00%
	Near Shading	2.90%	2.90%	2.90%
	IAM Factor	2.30%	2.30%	2.30%
	Soiling	1.10%	1.10%	1.10%
	Low-Irradiance fall-off	1.10%	1.10%	1.10%
	Temperature Loss	2.30%	2.30%	2.30%
	Module Quality Factor	0.50%	0.50%	0.50%
	Light induced degradation	2.00%	2.00%	2.00%
	Mismatch	0.40%	0.40%	0.40%
	DC Ohmic	1.00%	1.00%	1.00%
	Inverter Losses (PVsyst)	5.10%	5.10%	5.10%
	AC Ohmic	0.40%	0.40%	0.40%
	Transformer	1.60%	1.60%	1.60%
	Auxiliary Losses	0.80%	0.80%	0.80%
	Plant Controller	0.00%	0.00%	0.00%
	System availability	0.30%	0.30%	0.30%
	Windfarm Curtailment [4.1 MW Export Limit]	-	-	6.73%
	Windfarm Curtailment [4.5 MW Export Limit]	-	3.89%	-
Final Results	**Year 1 – P50 Yield Factor [kWh/kWp]**	**1,443**	**1,387**	**1,346**
	Year 1 – P50 Net Energy [MWh]	**5,200**	**4,998**	**4,850**
	Year 1 – Performance Ratio [%]	**81.00%**	**77.86%**	**75.56%**

Table 4-2 Long-term annual energy production and losses for Hepburn Solar Farm, single axis tracker

	Year 1 energy production	Single Axis Tracking Configuration [Uncurtailed]	Single Axis Tracking Configuration [4.5 MW Grid Limitation]	Single Axis Tracking Configuration [4.1 MW Grid Limitation]
Basic Inputs	Global Irradiation on the Plane of Array [kWh/m²/year]	2,080	2,080	2,080
	Global Horizontal Irradiation (GHI) [kWh/m²/year]	1,599	1,599	1,599
	Fixed module/Tracking	Tracking	Tracking	Tracking
	DC Peak Power [kWp]	3,604	3,604	3,604
	AC Capacity at 25°C [kW]	2,750	2,750	2,750
	AC Capacity at 50°C [kW]	2,500	2,500	2,500
Losses	Far Shading/Horizon	0.00%	0.00%	0.00%
	Near Shading	2.80%	2.80%	2.80%
	IAM Factor	1.70%	1.70%	1.70%
	Soiling	1.10%	1.10%	1.10%
	Low-Irradiance fall-off	0.80%	0.80%	0.80%
	Temperature Loss	3.20%	3.20%	3.20%
	Module Quality Factor	0.50%	0.50%	0.50%
	Light induced degradation	2.00%	2.00%	2.00%
	Mismatch	0.40%	0.40%	0.40%
	DC Ohmic	1.10%	1.10%	1.10%
	Inverter Losses (PVsyst)	6.60%	6.60%	6.60%
	AC Ohmic	0.40%	0.40%	0.40%
	Transformer	1.50%	1.50%	1.50%
	Auxiliary Losses	0.70%	0.70%	0.70%
	Plant Controller	0.00%	0.00%	0.00%
	System availability	0.80%	0.80%	0.80%
	Windfarm Curtailment [4.1MW Export Limit]	-	-	7.43%
	Windfarm Curtailment [4.5MW Export Limit]	-	4.38%	-
Final Results	**Year 1 – P50 Yield Factor [kWh/kWp]**	**1,658**	**1,586**	**1,535**
	Year 1 – P50 Net Energy [MWh]	**5,976**	**5,715**	**5,533**
	Year 1 – Performance Ratio [%]	**79.70%**	**76.24%**	**73.80%**

4.5 Performance ratio and energy yield

The Performance Ratio (PR) is an international measure for describing the level of utilisation for an entire PV system. The PR is the fraction of useful energy (at the feed-in point) in the nominally producible energy volume, which results from the module surface area, the module efficiency (according to the datasheet) and the irradiation incident on the module surface. The PR is non-dimensional and is a parameter that enables comparison between PV plants at different locations and orientations.

The PR is calculated during the simulation process, by multiplying the different factors described in Section 4.4. Given the overall PR factor, the total energy delivered is calculated, as follows:

$$E_{AC} = \frac{PR(\%) G_{INC} P_{STC}}{100 I_{STC}}$$

The yield factor Y_F is defined as the total energy produced in kWh per kW peak of installed capacity, i.e.

$$Y_F = \frac{E_{AC}}{P_{STC}} = \frac{PR(\%) G_{INC}}{100 I_{STC}}$$

In the formulae:

E_{AC} (kWh/year) is the system yield;

P_{STC} (kW) is the peak installed power (at STC);

G_{INC} (kWh/m^2) is the irradiation on the collector plane; and

I_{STC} (1 kW/m^2) is the irradiance (at STC).

5 UNCERTAINTY ANALYSIS

The uncertainty of the energy estimate is a result of the variation of solar radiation, the inaccuracies of the simulation procedure and uncertainties associated with external influences (e.g. shading, soiling, deviation of components from specification, inverter losses, cabling losses, etc.). In addition, the year to year variability in solar resource and other meteorological elements result in year to year variability in energy production at the Project. DNV GL has considered the uncertainty in the data and models used to determine the energy estimate, as well as the inter-annual variability, as described below.

5.1 Solar Resource Variability

DNV GL has based the assessment of solar resource variability at the Hepburn site on the annual plane of array (POA) irradiance derived from the Solargis model for both single axis tracker and fixed tilt configurations

5.2 Energy Yield Uncertainty

Model Uncertainties

To calculate overall downside risk, DNV GL considered several factors during analysis which are combined assuming the effects are independent. For this analysis DNV GL has approximated all effects, including that of resource variability as parametric distributions.

Both modelling and measurement uncertainties contribute to downside risk. To quantify these factors, DNV GL deconstructed the contributing model elements and estimated the P95 and P50 values for the following contributions:

- Solar resource variability
- Soiling variability
- Other variabilities including temperature and availability
- Resource uncertainty
- Plane of array transposition
- Loss factor assumptions
- Wind farm curtailment

Degradation

Long-term degradation is a slow and irreversible decline in output of a PV module's power output. DNV GL has conducted an extensive review of PV degradation rates, including the review of 135 papers on this topic in association with the National Renewable Energy Laboratory (NREL) [3]. This work indicates that half of crystalline PV system annual degradation rates vary within the interquartile range of 0.2% - 1.2% for systems that deploy multi-crystalline modules.

Given that the range of this rate is of similar magnitude to the rate itself, there is a high level of uncertainty associated with any presumed single value of degradation. Based on current industry leading summary of degradation research results and DNV GL's judgement, DNV GL recommends using a single-year P50 system-level degradation rate from approximately the middle of this range, or 0.64% per year. The expected probability distribution of system degradation rates are displayed in Table 5-1

Table 5-1 Confidence limits for degradation rate

Probability of exceedance	Annual degradation rate
P50	-0.64%
P75	-1.20%
P90	-1.82%
P90	-2.42%
P99	-3.46%

After analysis on the mitigating effects of inverter clipping and wind farm curtailment at Hepburn Solar Farm, the effective P50 degradation rate at progressive stages within the project lifetime are displayed in Table 5-4 to Table 5-9.

DNV GL notes that the assumed linear system degradation in Table 5-1 does not include elevated degradation rates associated with end-of-life failure mechanisms, due to the limited sample size and variable nature of late-life system performance. The results presented therefore assume that the solar farm is well managed over its remaining life and an increase in operational costs may be needed in the later years of operation to maintain the degradation rates included in this assessment.

5.3 Annual Energy Production

Table 5-2 presents the probability of exceedance levels for the net average energy production for the single axis tracking plant design at different future periods and export limitations. These probability of exceedance levels include the effects of degradation over the period considered.

Table 5-2 Summary of energy estimates including degradation for single axis tracking

Future Period	Annual production probability of exceedance [MWh/annum], single axis tracking				
	P50	P75	P90	P95	P99
Single axis tracking [Uncurtailed]					
First 1 year	5,976	5,615	5,386	5,264	5,057
First 10 years	5,813	5,578	5,351	5,199	4,948
Lifetime – 30 years	5,505	4,989	4,434	4,172	3,905
Single axis tracking [4.5 MW Export Limit]					
First 1 year	5,715	5,367	5,146	5,027	4,826
First 10 years	5,585	5,357	5,137	4,990	4,748
Lifetime – 30 years	5,317	4,822	4,290	4,039	3,781
Single axis tracking [4.1 MW Export Limit]					
First 1 year	5,533	5,192	4,973	4,855	4,655
First 10 years	5,413	5,185	4,967	4,822	4,583
Lifetime – 30 years	5,164	4,681	4,164	3,920	3,666

Table 5-3 presents the probability of exceedance levels for the net average energy production for the fixed tilt plant design at different future periods and export limitations. These probability of exceedance levels include the effects of degradation over the period considered.

Table 5-3 Summary of energy estimates including degradation for fixed tilt

Future Period	Annual production probability of exceedance [MWh/annum] Single axis tracking				
	P50	P75	P90	P95	P99
Fixed tilt [Uncurtailed]					
First 1 year	5,200	4,896	4,703	4,598	4,418
First 10 years	5,045	4,839	4,638	4,506	4,289
Lifetime – 30 years	4,753	4,301	3,817	3,588	3,353
Fixed Tilt [4.5 MW Export Limit]					
First 1 year	4,998	4,704	4,516	4,414	4,240
First 10 years	4,872	4,671	4,476	4,348	4,137
Lifetime – 30 years	4,613	4,177	3,711	3,491	3,264
Fixed Tilt [4.1 MW Export Limit]					
First 1 year	4,850	4,561	4,376	4,275	4,102
First 10 years	4,733	4,534	4,341	4,214	4,006
Lifetime – 30 years	4,491	4,066	3,613	3,398	3,175

5.3.1 Annual production of single axis tracker

Table 5-4, Table 5-5 and Table 5-6 present the energy estimates for years 1-30 for single axis tracking configurations. These numbers include the impact of uncertainty in modelling assumptions (including resource uncertainty, uncertainty in degradation assumptions, uncertainty in soiling estimates, etc.) as well as solar resource variability for a 1-year future period. The reduced variability associated with a average production over a longer future period (i.e. 10 or 30 years) is therefore not included in the yearly energy production estimates given.

Table 5-4 Annual production [MWh/year] including degradation effects (single axis tracking)

Year	P50 clipping adjusted degradation rate	Annual Production including degradation [MWh/annum] (tracking)				
		P50	P75	P90	P95	P99
1		5,976	5,615	5,386	5,264	5,057
2	-0.47%	5,948	5,585	5,354	5,228	5,013
3	-0.90%	5,923	5,555	5,315	5,178	4,942
4	-1.34%	5,896	5,521	5,268	5,114	4,844
5	-1.78%	5,870	5,483	5,213	5,036	4,725
6	-2.24%	5,843	5,442	5,152	4,964	4,648
7	-2.70%	5,815	5,398	5,084	4,886	4,566
8	-3.16%	5,787	5,352	5,012	4,803	4,482
9	-3.64%	5,759	5,303	4,935	4,716	4,394
10	-4.12%	5,730	5,253	4,855	4,626	4,304
11	-4.61%	5,701	5,200	4,772	4,533	4,211
12	-5.10%	5,671	5,146	4,686	4,438	4,116
13	-5.61%	5,641	5,091	4,598	4,340	4,020
14	-6.12%	5,611	5,034	4,508	4,240	3,921
15	-6.64%	5,580	4,976	4,417	4,139	3,821
16	-7.17%	5,548	4,917	4,324	4,036	3,720
17	-7.70%	5,516	4,857	4,229	3,932	3,617
18	-8.24%	5,484	4,796	4,134	3,826	3,513
19	-8.79%	5,451	4,734	4,037	3,719	3,408
20	-9.35%	5,418	4,671	3,939	3,612	3,301
21	-9.91%	5,384	4,607	3,840	3,503	3,194
22	-10.48%	5,350	4,543	3,740	3,393	3,086
23	-11.06%	5,316	4,478	3,640	3,283	2,977
24	-11.64%	5,281	4,413	3,538	3,171	2,867
25	-12.24%	5,245	4,346	3,436	3,059	2,756
26	-12.84%	5,209	4,279	3,334	2,946	2,644
27	-13.44%	5,173	4,212	3,230	2,832	2,532
28	-14.06%	5,136	4,144	3,126	2,718	2,419
29	-14.68%	5,099	4,075	3,021	2,603	2,305
30	-15.31%	5,061	4,006	2,916	2,488	2,190

Table 5-5 Annual production [MWh/year] including degradation effects (single axis tracking) [4.5 MW]

Year	P50 clipping adjusted degradation rate	Annual Production including degradation [MWh/annum] (tracking)				
		P50	P75	P90	P95	P99
1	0	5,715	5,367	5,146	5,027	4,826
2	-0.39%	5,693	5,343	5,119	4,997	4,789
3	-0.77%	5,671	5,317	5,085	4,953	4,724
4	-1.16%	5,648	5,287	5,043	4,894	4,634
5	-1.56%	5,626	5,253	4,994	4,823	4,524
6	-1.97%	5,603	5,217	4,938	4,757	4,453
7	-2.38%	5,579	5,178	4,876	4,685	4,378
8	-2.80%	5,555	5,137	4,810	4,609	4,300
9	-3.23%	5,530	5,093	4,739	4,529	4,219
10	-3.67%	5,505	5,047	4,665	4,446	4,135
11	-4.11%	5,480	4,999	4,589	4,359	4,049
12	-4.56%	5,454	4,950	4,509	4,271	3,961
13	-5.02%	5,428	4,900	4,428	4,180	3,872
14	-5.49%	5,401	4,848	4,344	4,087	3,780
15	-5.97%	5,374	4,795	4,259	3,993	3,687
16	-6.45%	5,346	4,741	4,173	3,897	3,593
17	-6.94%	5,318	4,686	4,085	3,800	3,497
18	-7.44%	5,290	4,630	3,996	3,702	3,400
19	-7.95%	5,261	4,573	3,906	3,602	3,302
20	-8.46%	5,231	4,516	3,815	3,501	3,203
21	-8.98%	5,201	4,457	3,723	3,400	3,103
22	-9.51%	5,171	4,398	3,630	3,297	3,002
23	-10.05%	5,140	4,339	3,536	3,194	2,900
24	-10.60%	5,109	4,278	3,441	3,090	2,797
25	-11.15%	5,078	4,217	3,346	2,985	2,694
26	-11.71%	5,046	4,155	3,250	2,879	2,589
27	-12.28%	5,013	4,093	3,154	2,773	2,484
28	-12.86%	4,980	4,030	3,056	2,666	2,378
29	-13.44%	4,947	3,966	2,958	2,558	2,272
30	-14.03%	4,913	3,902	2,860	2,450	2,164

Table 5-6 Annual production [MWh/year] including degradation effects (single axis tracking) [4.1 MW]

Year	P50 clipping adjusted degradation rate	Annual Production including degradation [MWh/annum] (tracking)				
		P50	P75	P90	P95	P99
1	0	5,533	5,192	4,973	4,855	4,655
2	-0.37%	5,512	5,170	4,949	4,828	4,621
3	-0.73%	5,492	5,146	4,917	4,786	4,560
4	-1.09%	5,472	5,118	4,878	4,731	4,476
5	-1.47%	5,451	5,087	4,831	4,665	4,371
6	-1.85%	5,430	5,053	4,779	4,602	4,304
7	-2.25%	5,408	5,017	4,721	4,534	4,233
8	-2.65%	5,386	4,978	4,658	4,462	4,159
9	-3.05%	5,364	4,937	4,591	4,386	4,082
10	-3.47%	5,341	4,894	4,521	4,307	4,003
11	-3.90%	5,317	4,849	4,449	4,225	3,922
12	-4.33%	5,293	4,803	4,373	4,141	3,838
13	-4.77%	5,269	4,755	4,296	4,055	3,753
14	-5.22%	5,244	4,706	4,216	3,966	3,666
15	-5.67%	5,219	4,656	4,135	3,876	3,577
16	-6.14%	5,193	4,605	4,053	3,785	3,487
17	-6.61%	5,167	4,553	3,969	3,692	3,396
18	-7.09%	5,140	4,500	3,884	3,598	3,304
19	-7.58%	5,113	4,446	3,798	3,503	3,210
20	-8.07%	5,086	4,391	3,711	3,407	3,115
21	-8.58%	5,058	4,336	3,623	3,309	3,020
22	-9.09%	5,030	4,280	3,534	3,211	2,923
23	-9.61%	5,001	4,223	3,445	3,112	2,825
24	-10.14%	4,972	4,165	3,354	3,013	2,727
25	-10.68%	4,942	4,107	3,263	2,912	2,628
26	-11.22%	4,912	4,048	3,171	2,811	2,528
27	-11.77%	4,881	3,989	3,078	2,709	2,427
28	-12.33%	4,850	3,929	2,985	2,606	2,326
29	-12.90%	4,819	3,868	2,891	2,503	2,223
30	-13.48%	4,787	3,807	2,797	2,399	2,121

5.3.2 Annual production of fixed tilt

Table 5-7, Table 5-8 and Table 5-9 present the energy estimates for years 1-30 for fixed tilt configurations. These numbers include the impact of uncertainty in modelling assumptions (including resource uncertainty, uncertainty in degradation assumptions, uncertainty in soiling estimates, etc.) as well as solar resource variability for a 1-year future period. The reduced variability associated with average production over a longer future period (i.e. 10 or 30 years) is therefore not included in the yearly energy production estimates given.

Table 5-7 Annual production [MWh/year] including degradation effects (fixed tilt)

Year	P50 clipping adjusted degradation rate	Annual Production including degradation [MWh/annum] (fixed tilt)				
		P50	P75	P90	P95	P99
1		5,200	4,896	4,703	4,598	4,418
2	-0.48%	5,175	4,870	4,674	4,566	4,380
3	-0.98%	5,149	4,839	4,636	4,518	4,313
4	-1.48%	5,123	4,805	4,591	4,458	4,224
5	-2.00%	5,096	4,769	4,540	4,386	4,115
6	-2.51%	5,069	4,730	4,482	4,319	4,044
7	-3.04%	5,042	4,688	4,419	4,247	3,969
8	-3.57%	5,015	4,644	4,352	4,171	3,892
9	-4.10%	4,987	4,598	4,282	4,092	3,812
10	-4.64%	4,959	4,551	4,208	4,010	3,730
11	-5.19%	4,930	4,502	4,133	3,925	3,646
12	-5.74%	4,902	4,452	4,054	3,839	3,560
13	-6.30%	4,873	4,401	3,975	3,750	3,472
14	-6.86%	4,843	4,348	3,893	3,661	3,384
15	-7.43%	4,814	4,295	3,810	3,569	3,294
16	-8.01%	4,784	4,241	3,727	3,477	3,202
17	-8.59%	4,754	4,186	3,642	3,383	3,110
18	-9.17%	4,723	4,130	3,556	3,289	3,017
19	-9.77%	4,692	4,074	3,469	3,193	2,923
20	-10.36%	4,661	4,017	3,381	3,097	2,828
21	-10.97%	4,630	3,959	3,293	3,000	2,732
22	-11.58%	4,598	3,901	3,204	2,902	2,636
23	-12.19%	4,566	3,843	3,114	2,804	2,539
24	-12.81%	4,534	3,783	3,024	2,705	2,441
25	-13.44%	4,501	3,724	2,933	2,605	2,343
26	-14.07%	4,468	3,664	2,842	2,505	2,244
27	-14.71%	4,435	3,603	2,750	2,405	2,144
28	-15.35%	4,402	3,543	2,658	2,303	2,044
29	-16.00%	4,368	3,481	2,565	2,202	1,943
30	-16.66%	4,334	3,420	2,472	2,100	1,842

Table 5-8 Annual production [MWh/year] including degradation effects (fixed tilt) [4.5 MW]

Year	P50 clipping adjusted degradation rate	Annual Production including degradation [MWh/annum] (fixed tilt)				
		P50	P75	P90	P95	P99
1	0	4,998	4,704	4,516	4,414	4,240
2	-0.44%	4,976	4,680	4,491	4,385	4,204
3	-0.89%	4,953	4,653	4,457	4,342	4,143
4	-1.35%	4,930	4,624	4,416	4,287	4,060
5	-1.81%	4,907	4,591	4,369	4,221	3,959
6	-2.28%	4,884	4,556	4,316	4,159	3,893
7	-2.76%	4,860	4,518	4,258	4,092	3,824
8	-3.24%	4,836	4,478	4,197	4,022	3,752
9	-3.73%	4,811	4,437	4,131	3,948	3,678
10	-4.23%	4,787	4,394	4,063	3,872	3,601
11	-4.73%	4,762	4,349	3,993	3,793	3,523
12	-5.24%	4,736	4,303	3,920	3,712	3,443
13	-5.75%	4,710	4,256	3,845	3,629	3,361
14	-6.27%	4,684	4,207	3,769	3,545	3,278
15	-6.80%	4,658	4,158	3,692	3,460	3,194
16	-7.33%	4,631	4,108	3,613	3,373	3,108
17	-7.87%	4,604	4,058	3,534	3,285	3,022
18	-8.42%	4,577	4,006	3,453	3,196	2,934
19	-8.97%	4,549	3,954	3,372	3,107	2,846
20	-9.53%	4,521	3,901	3,290	3,016	2,757
21	-10.10%	4,493	3,848	3,207	2,925	2,667
22	-10.67%	4,464	3,794	3,123	2,833	2,576
23	-11.25%	4,436	3,739	3,039	2,740	2,484
24	-11.84%	4,406	3,684	2,954	2,647	2,392
25	-12.43%	4,377	3,629	2,868	2,553	2,299
26	-13.03%	4,347	3,573	2,782	2,458	2,206
27	-13.63%	4,317	3,516	2,696	2,363	2,112
28	-14.24%	4,286	3,460	2,609	2,268	2,018
29	-14.86%	4,255	3,402	2,521	2,172	1,923
30	-15.48%	4,224	3,345	2,433	2,075	1,827

Table 5-9 Annual production [MWh/year] including degradation effects (fixed tilt) [4.1MW]

Year	P50 clipping adjusted degradation rate	Annual Production including degradation [MWh/annum] (fixed tilt)				
		P50	P75	P90	P95	P99
1	0	4,850	4,561	4,376	4,275	4,102
2	-0.42%	4,830	4,540	4,352	4,248	4,069
3	-0.84%	4,809	4,515	4,321	4,208	4,012
4	-1.28%	4,788	4,487	4,283	4,156	3,933
5	-1.72%	4,767	4,457	4,239	4,093	3,837
6	-2.16%	4,745	4,424	4,189	4,035	3,774
7	-2.62%	4,723	4,389	4,134	3,972	3,708
8	-3.08%	4,701	4,351	4,076	3,905	3,640
9	-3.55%	4,678	4,312	4,014	3,835	3,569
10	-4.02%	4,655	4,271	3,949	3,762	3,497
11	-4.50%	4,632	4,229	3,882	3,687	3,422
12	-4.99%	4,608	4,186	3,812	3,610	3,346
13	-5.48%	4,584	4,141	3,741	3,531	3,268
14	-5.98%	4,560	4,095	3,669	3,450	3,188
15	-6.49%	4,535	4,049	3,595	3,368	3,108
16	-7.00%	4,511	4,001	3,520	3,285	3,026
17	-7.52%	4,485	3,953	3,443	3,201	2,943
18	-8.05%	4,460	3,904	3,366	3,116	2,860
19	-8.59%	4,434	3,854	3,288	3,030	2,775
20	-9.13%	4,408	3,804	3,210	2,943	2,689
21	-9.67%	4,381	3,753	3,130	2,856	2,603
22	-10.23%	4,354	3,702	3,050	2,768	2,516
23	-10.79%	4,327	3,650	2,969	2,679	2,428
24	-11.36%	4,299	3,597	2,888	2,589	2,340
25	-11.93%	4,272	3,544	2,806	2,499	2,251
26	-12.51%	4,243	3,491	2,723	2,408	2,161
27	-13.10%	4,215	3,437	2,640	2,317	2,071
28	-13.69%	4,186	3,383	2,556	2,225	1,980
29	-14.29%	4,157	3,328	2,472	2,133	1,889
30	-14.90%	4,127	3,273	2,388	2,040	1,797

6 REFERENCES

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