goldenplains wind farm east

Greenhouse Gas Inventory Report – Life Cycle Assessment

Golden Plains Wind Farm - East

DOCUMENT HISTORY AND STATUS

The following table outlines the revisions made to this document.

Version	Date	Description	Prepared By	Reviewed By	Approved By
1	27/06/24	Modification made following CEFC's feedback.	Agnes	S Clifton	
2	18/10/24	Updated following Aurecon review – Draft to TagEnergy	N Palairet A Salter	A Dilger	
3	10/02/25	Scope 1/2/3 table added to appendix, final comments resolved following TagEnergy review	N Palairet A Salter	A Dilger	
4	16/05/25	Public Release (Confidental)	S Clifton	P.Villiers	P.Villiers

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KEY SUSTAINABILTY FIGURES

Wind plant carbon footprint (Global Warming Potential)

7.2
gCO_2e/kWh
excl. recycling credits

5.1
gCO_2e/kWh
incl. recycling credits

Whole-of-life wind plant GWP per MW

438
tCO_2e/MW

Wind plant specification	
Wind farm	Golden Plains Wind Farm East
WTG	122 * V162-6.2MW
Lifetime	30 years
Hub height	149 metres
Rotor diameter	162 metres
Mean wind speed	8.28 m/s
Access Tracks length	102 km
33kV UG Cable	180 km
Project size	756MW
Project location	Rokewood, Victoria, Australia

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TERMS AND ABBREVIATIONS

Abbreviation	Definition
CH_4	Methane
CO_2e	Carbon dioxide equivalent
COD	Commercial Operation Date
EPD	Environmental Product Declaration
gCO_2e	grams of greenhouse gas emissions expressed in equivalent carbon dioxide emissions
GHG	Greenhouse Gas
GWh	Gigawatt hour
GWP	Global Warming Potential
HFCs	Hydrofluorocarbons
ISC	Infrastructure Sustainability Council
km	kilometre
kWh	kilowatt-hour
LCA	Life Cycle Assessment
MLF	Marginal Loss Factor
MW	Megawatt
N_2O	Nitrous oxide
PFCs	Perfluorocarbons
SF_6	Sulphur hexafluoride
tCO_2e	tonnes of greenhouse gas emissions expressed in equivalent carbon dioxide emissions
WTG	Wind Turbine Generator

1 Executive Summary

1.1 Introduction

This Life Cycle Assessment (**LCA**) report evaluates the environmental impact of Golden Plains Wind Farm - East (**GP1** or the **Project**), a 756MW onshore wind farm with 122 EnVentus V162-6.2MW turbines located in Rokewood, Victoria, Australia.

Table 1-1 below provides an overview of the key Project specifications.

Table 1-1: Project Specification

Project Specification	
Wind farm	Golden Plains Wind Farm - East
Wind Turbine Generators (WTG)	122 * V162-6.2MW
Lifetime	30 years
Hub height	149 metres
Rotor diameter	162 metres
33kV UG Cable	180 km
Access Tracks length	102 km
Annual energy production	2492 GWh
Plant size	756 MW
Plant location	Rokewood, Victoria, Australia

1.2 Scope and methodology

The LCA considers all lifecycle phases of GP1: construction, operation and decommissioning with the goal of determining the cradle-to-grave carbon footprint (i.e. product, construction, use and end-of-life stages).

Key components of the wind farm included in this LCA are wind turbine generators, foundations, site cabling and the collector station[1]. The functional unit for this LCA study is defined as 1 kWh of electricity delivered to the grid by a 756 MW wind power plant.

1.3 Environmental Impact

The environmental impact assessed in this LCA is Global Warming Potential (GWP). This is provided as the carbon footprint per functional unit, which is **7.2 gCO_2e/kWh** for GP1 when accounting for a cradle-to-grave perspective, and **5.1 gCO_2e/kWh** when including the benefit of recycling turbine elements at the end of life. The construction phase of the wind farm, particularly the extraction of raw materials and production of components, is identified as the primary contributor to these emissions.

1.4 Environmental Benefits

Golden Plains Wind Farm East (GP1) will produce 65,419 GWh of clean energy over its lifetime. Victorian electricity generation is predominantly from brown coal (lignite) fired power stations, averaging 66% of generation over the past 12 months[2]. Electricity generated from brown coal is highly carbon intensive, especially when compared to renewables. GP1 will support Australia's transition to renewable energy and contribute to the reduction in the National Electricity Market's (NEM's) carbon emissions intensity over time; however, given the complexity of the NEM and the standards governing avoided emission calculations, it is beyond the scope of this study to quantify the magnitude of this direct benefit, nor attribute direct causal effects.

[1] The Cressy Terminal Station (CRTS) and Golden Plains Terminal Station (GPTS) has been excluded from the LCA, as they are owned and controlled by the Australian grid.

[2] https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/data-nem/data-dashboard-nem, 18 October 2024

GP1's cradle-to-grave carbon intensity of 7.2 gCO_2e/kWh is approximately 100 times lower than the carbon intensity of the electricity generated in Victoria and supplied to the NEM. Although not perfectly comparable to the grid itself, GP1, projects like it, and other projects that support the development of renewables (such as storage and transmission) all work to decarbonise the grid. On an indicative basis, GP1's cumulative emissions per kWh of energy generated reduces beyond the grid average within the first year of operations. This helps demonstrate the strong benefits of GP1 to decarbonise the grid, especially in conjunction with wider system changes.

1.5 Conclusion

GP1 demonstrates substantial environmental benefits through its low specific carbon footprint and rapid carbon payback period. While the LCA focuses on GWP, future assessments could consider additional environmental indicators such as the depletion of non-renewable resources (abiotic depletion potential), contribution to acid rain (acidification potential), or the nutrient (nitrogen and phosphorous) load on waterways (eutrophication potential). These assessments would provide a more comprehensive understanding of GP1's environmental footprint.

2 Introduction

2.1 Goal and Background

TagEnergy was created in 2019 to accelerate the energy transition with the objective of building large-scale renewable generation or storage infrastructure and manage how this supplied energy is commercialised.

The Golden Plains Wind Farm – East (hereafter GP1 or 'the Project') includes the construction of 122 Vestas V162-6.2 turbines with an installed capacity of 756 MW on 11,029 hectares of land to the west, south, and south-east of Rokewood. Rokewood is a small rural town in the Shire of Golden Plains located approximately 60 km north-west of Geelong. As well as the turbines and their towers, the project will include foundations, overhead powerlines, underground cabling, electricity collection stations, a terminal station, access tracks and other associated works.

TagEnergy aims to assess and quantify the greenhouse gas emissions associated with the Project through a Life Cycle Assessment (LCA). The purpose of this report is to provide an estimate of global warming potential (GWP) of the greenhouse gas emissions resulting from the construction, operation and eventual decommissioning of GP1.

Further goals are to understand the most significant sources of greenhouse gas (GHG) emissions, identify areas for improvement and actions that could be implemented to reduce the environmental impact of future projects. In addition, this LCA will serve as a template for future wind energy projects. It is not intended to be a comparative assertion of impacts and is primarily intended for business-to-business communication, rather than direct communication to the public as per the ISO 14040/44 standards for LCA. The assessment has been conducted in alignment with the ISO 14040/44 standards, as well *EN 17472:2022 Sustainability of construction works – sustainability assessment of civil engineering works,* noting that this assessment is only assessing the global warming potential, also known as the carbon emissions of this project.

2.2 Project Description

The Project started construction in November 2022 with the commercial operations date (COD) scheduled for October 2025. The Project's operational life span is 30 years.

Table 2-2 outlines the key project details and specifications that are applied to this assessment. Figure 2-1 illustrates the Project layout including all Wind Turbine Generators (WTGs), access tracks and underground cables.

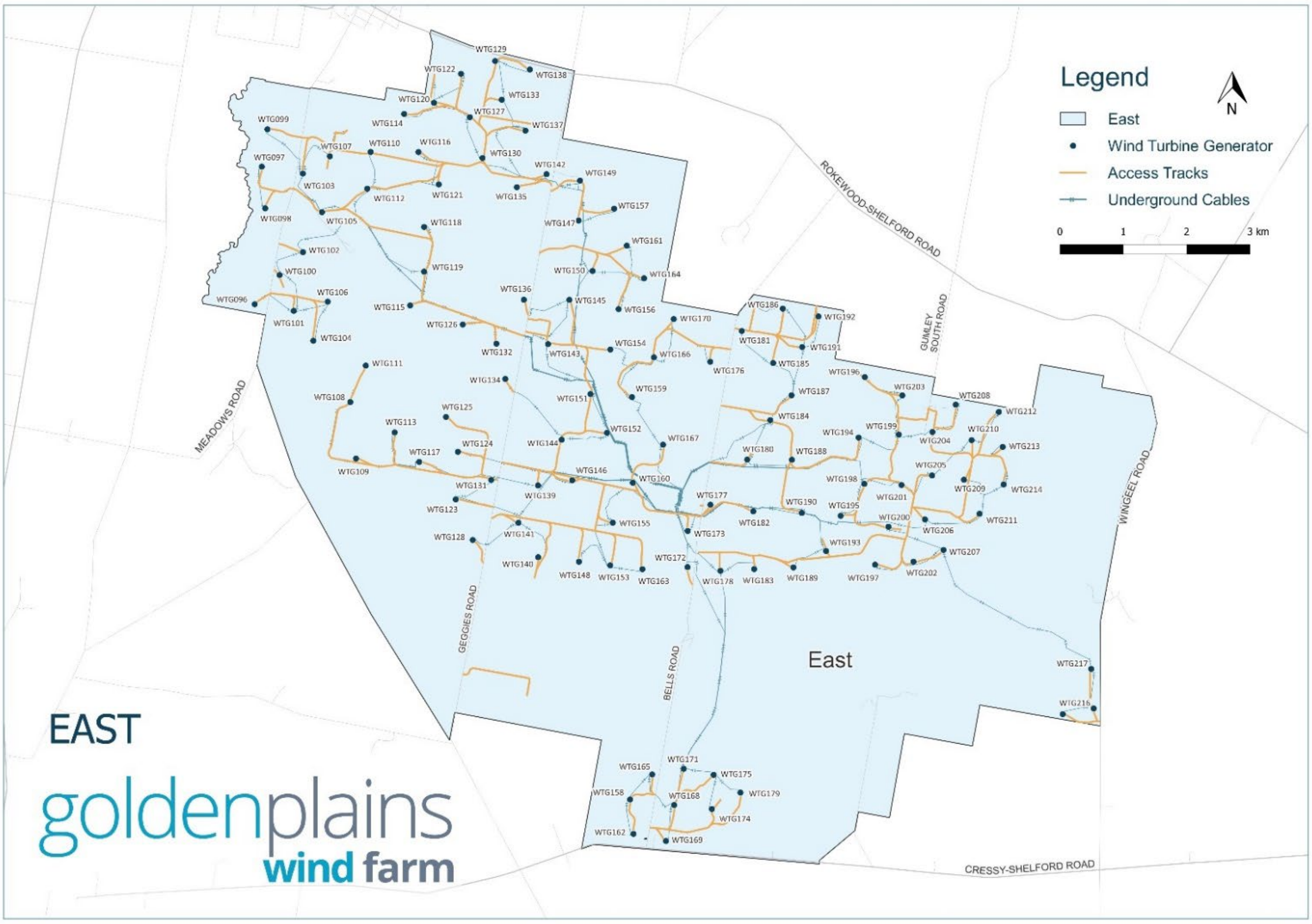
Table 2-1: Key Project Details

Characteristics	Details
Name	Golden Plains Wind Farm - East
Wind Farm Capacity	756.4 MW
Wind Turbine Generators	122 x Vestas EnVentus V162-6.2MW
Lifetime	30 years
Mean wind speed	8.28 m/s[3]
Length of access tracks	102 km
Length of 33kV UG Cable	180 km
Collector Station	Golden Plains Eastern Collector Station
Lifetime	30 years

[3] Golden Plains Wind Farm: Wind Resource and Energy Assessment, Revision 2, 2022-11-10, Aurecon

Rating per turbine	6.2 MW
Generator type	Permanent magnet synchronous, medium-speed geared
Number of turbines	122
Plant rating	756.4 MW
Hub height	149 meters
Rotor diameter	162 meters
Tower type	Standard steel
Total energy production	65,419 GWh
Wind plant location	Rokewood, Victoria, Australia

Figure 2-1: Project Overview



2.3 Scope of the study

This study conducts an LCA focusing exclusively on assessing the Global Warming Potential (GWP) to detail the full life cycle GHG emissions. 'Cradle-to-grave' refers to all lifecycle stages from Module A (Product Stage) to Module C (End-of-Life Stage), and 'cradle-to-cradle' refers to all modules, including Module D (Benefits and loads beyond the project boundary).

A0 Pre-construction phase

This phase includes all activities related to the project prior to tender, such as flights taken by design as project personnel.

A1-A3 Product Phase

This phase evaluates the GHG emissions generated during the production of raw materials for wind plant components such as: foundations, towers, nacelles, blades, cables and materials used for the access tracks, based on bill of quantity information.

A4-A5 Construction

This phase includes transporting wind plant components to site, using trucks and dedicated sea vessels. On-site construction activities to install the entire wind farm are also considered such as access track building and turbine assembly.

B1-B7 Use Phase (Site Operation)

Site operation involves the ongoing operation of the wind farm to generate electricity. Activities include fugitive sulphur hexafluoride (SF_6) emissions, oil changes, replacement of component parts over the lifetime of the wind plant, transportation for maintenance, electricity use by the site itself, and the end-of-life treatment of replaced parts.

C1-C4 End-of-life

This phase involves dismantling the wind farm, including transport of components, considering contractual obligations. It also evaluates the end-of-life treatment of the landfilled components.

D Benefits and Loads Beyond the System Boundary

Module D includes credits for component recycling where this is likely to occur, calculated as the net difference between recycling processes and new virgin material production.

3 System description

The Project includes the wind turbines, foundations, access tracks, cabling (connecting the individual wind turbines to the transformer station) and the transformer station (up to the point of existing grid) and the collector station Golden Plain Eastern Collector (GPEC). The Golden Plains Terminal Station (GPTS) and Cressy Terminal Station (CRTS) have been excluded from this life cycle assessment, as shown in Figure 3-1. Figure 3-3 presents a detailed reference value-chain of a wind farm aligned to the EN 17472 standard, and the boundary for this assessment.

Figure 3-1: Pictorial schematic of the physical assessment boundary

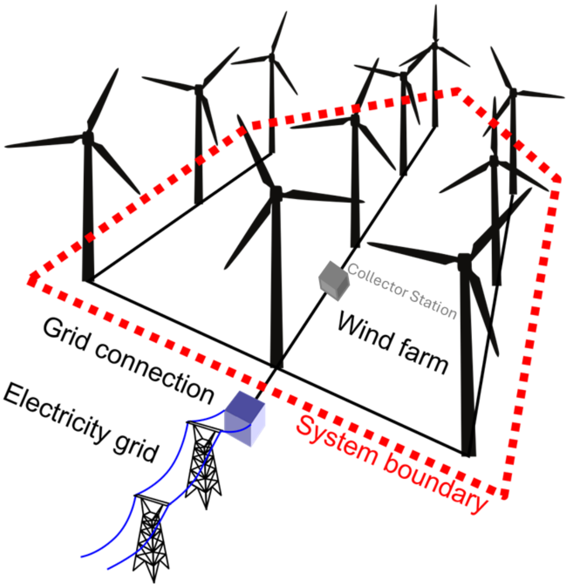


Figure 3-2: LCA value-chain reference system diagram and assessment boundary

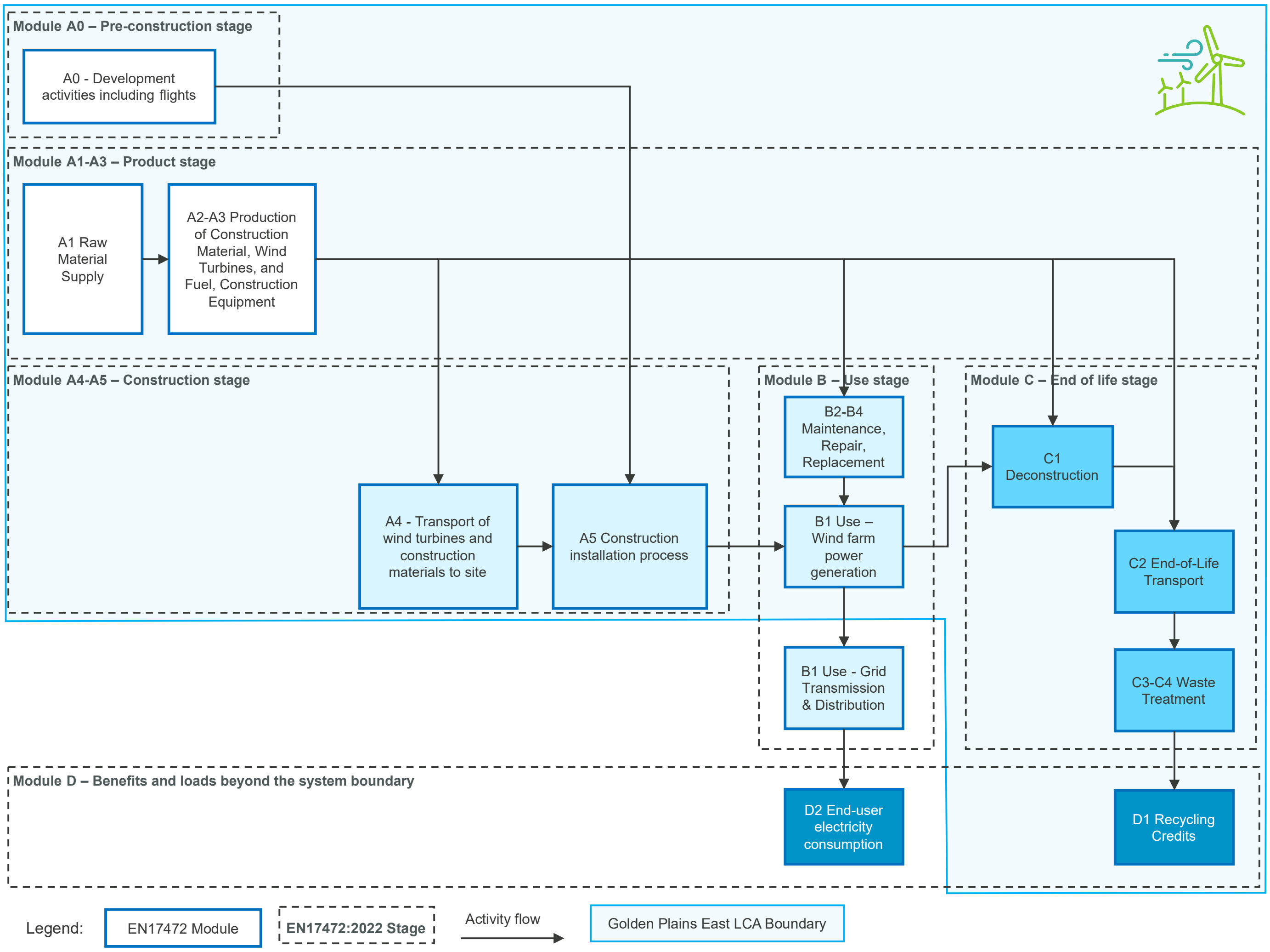


Table 3-1: Scope boundary inclusions under EN 17472

Stage	Module	Module Name	Boundary inclusions
Pre-construction	A0	Land and associated fees/advice	*None – considered below 1% cut-off level*
Product	A1-A3	Raw material supply, transport, manufacturing	Materials & component production
Construction	A4	Transport	Transportation of materials to site
Construction	A5	Construction - installation process	On-site fuel use and land change
Use	B1	Use	Fugitive emissions
Use	B2	Maintenance	Fuel use
Use	B3	Repair	*None - included as part of B2 maintenance & B4 replacement, matches existing Vestas LCA methodology*
Use	B4	Replacement	Gearboxes, blades, oil
Use	B5	Refurbishment	*None - no refurbishment planned*
Use	B6	Operational energy use	Operational electricity use
Use	B7	Operational water use	*None - GHG impact considered immaterial*
Use	B8	User's utilisation	*None - outside assessment boundary*
End-of-life	C1	De-construction	All on-site activities during deconstruction
End-of-life	C2	Transport	Transportation to disposal
End-of-life	C3	Waste processing for reuse, recycling, recovery	Fugitive SF_6 emissions during end-of-life
End-of-life	C4	Disposal	Landfill of materials not recycled, inert
Benefits	D1	Net flows from reuse, recycling, recovery	Recycling of WTG materials
Benefits	D2	Exported utilities	*None - avoided emissions considered separately*

4 Methodology

4.1 Functional unit

The functional unit for this LCA study is defined as 1 kWh of electricity delivered to the grid by a 756MW wind power plant. The functional unit is based on the design lifetime of GP1 (30 years), along with the total electricity produced over the lifetime, accounting for losses in transformers and the grid.

4.2 Data collection

Data used for the calculations includes data from the construction phase of the Project; from TagEnergy and its partners Vestas, CPP, and MPK. This includes estimates and forecast data for the completion of GP1.

The accuracy of the GHG modelling is relevant to the data available at the time of modelling, including mapping of materials against modelled emissions factors, and projections to finish the GP1 project. Further development of the bill of quantities with actual data on completion of GP1 may result in changes in the modelling outcomes.

To determine the carbon footprint, the 2023 National Green House Accounts (NGA) factors, published to support individuals and organisations estimating their GHG emissions, and the Infrastructure Sustainability Council Materials Calculator have been used.

4.2.1 Data Sources

Primary data for the turbines themselves have been provided by the manufacturer Vestas in the form of a published LCA. This provides a materials breakdown, which has been remodelled using data for Chinese production. Although the masses of the turbines are the same, the published LCA models a European-produced turbine operating in local conditions, and therefore needs to be changed so that it is relevant for the Australian market that GP1 operates in. For other data sources, local data has been selected, such as relevant options from the IS Materials Calculator (including from Environmental Product Declarations, [EPDs]) and other data sources such as background datasets from the LCAfE/GaBi databases.

Table 4-1 Overview of data sources

	Data	Data sources
Activity Data	**Material quantities – WTG**	Vestas LCA & REMPD (turbine composition) Tag Energy (number of turbines)
	Material quantities – Civil	Calculated by Tag Energy
	Material quantities – Electrical	Calculated by Tag Energy
	Construction fuel use	Calculated by Tag Energy
	Operational fuel use	Calculated by Tag Energy
	Construction electricity use	Calculated by Tag Energy
	Operational electricity use	Calculated by Tag Energy
	SF6 leakage	Adapted from Vestas LCA
	Land clearing	Calculated by Tag Energy
	Transportation distances	Calculated by Tag Energy, Aurecon
Emission factors	**Materials & Production - WTG**	Refer to Appendix A
	Materials & Production - Civil	ISC Materials Calculator
	Materials & Production - Electrical	ISC Materials Calculator
	Fuel	National Greenhouse Accounts Factors 2022
	Electricity (GreenPower), scope 3	IPCC AR5 and NEM composition
	SF_6	National Greenhouse Accounts Factors 2022
	Land clearing	Transport for NSW Carbon Estimate and Reporting Tool

	Transportation	WTG: Container Ship, modified 50-200kT DWT, Sphera LCAfE/GaBi Other: ISC Materials Calculator

4.3 Carbon accounting and characterisation methodology

Carbon emissions are generally reported in a mass of CO_2-equivalent emissions, which accounts for the differing warming potentials of gases in addition to carbon dioxide (CO_2) itself. This is known as Global Warming Potential or GWP. This assessment uses emission factors from a number of different sources including the IS Materials Calculator, academic literature, industry reports (including from the turbine manufacturer Vestas), and the most recent 2023 Managed Licensed Content database for the software package LCA for Experts (LCAfE, formerly known as GaBi), published by Sphera. For simplicity, this report refers to this source as "LCAfE/GaBi".

This assessment has been conducted using the latest CML2001 Aug. 2016 characterisation methodology. This aligns with the emission factors used in the Intergovernmental Panel on Climate Change's (IPCC's) Sixth Assessment Report (AR6) and the United Nations Framework Convention on Climate Change (UNFCCC) Reporting Guidelines. An example of GHG's included in this calculation include:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous dioxide (N_2O)
- Sulphur hexafluoride (SF_6)
- Perfluorocarbons (PFCs)
- Hydrofluorocarbons (HFCs)

4.3.1 Allocation

All input and output flows are allocated to a single product system, except for the input/output flows within Module D. For end-of-life allocation, materials are assigned specific landfill and recycling processes relevant to their modelled subtype. Impacts resulting from treating waste materials, such as landfilling are allocated to Module C4. Once a material has reached the end-of-life state, any impacts associated with further processing (such as recycling processes), as well as their benefits where secondary rather than primary products are used, are allocated to Module D.

4.3.2 Cut-off Criteria

The cut-off criteria used for this study is in alignment with a 99% rule, meaning that impacts that constitute less than 1% of the total are excluded. This follows the methodology conducted by Vestas in developing their own LCA for the EnVentus 162 6.2MW turbine, which is a key source of data used in this study.

4.4 Data Quality

4.4.1 Geographical Coverage

Geographical coverage was ensured by selecting local suppliers for materials that are procured locally, such as concrete and reinforcing steel. Internationally-procured elements such as turbines have been modelled so that they represent local production in China.

4.4.2 Technological Coverage

Primary datasets from EPDs have been used where possible, such as for local reinforcing steel production. Where detailed information was not available, datasets representative of these manufacturing technologies have been included instead, considering temporal and geographic coverage of the product being assessed.

4.4.3 Temporal Coverage

Construction of GP1 began in 2022 and will be commissioned in 2025. The reference year for the study is 2024, the year in which this LCA has been conducted. The study uses the most up-to-date datasets available at the time of assessment, and projects emission factors out over the 30-year lifespan of the wind farm asset where appropriate.

4.4.4 Precision

The majority of the data come directly from primary sources such as key vendors, design partners, and the wider project team. Whilst there is an undetermined uncertainty in this primary data, the authors consider these sources to be high quality. Precision is therefore likely to be high for this data. Where variations occur, averages have been used to represent information as accurately as possible.

4.4.5 Completeness

Foreground data has been provided by the project team, and (outside the noted scope exclusions) no data has been knowingly excluded from assessment. As a result, completeness is considered high for this data. Excluded items have been noted in this report.

4.4.6 Consistency

All primary data has been collected with the same level of detail and analysis, with background data sourced as so to match assessment methodologies. Where this could not be verified, life cycle inventory data has been remodelled with known emission factors to ensure consistency.

4.4.7 Data Quality Requirements

The selection of foreground and background datasets to complete the LCA was guided by the EN 17472 standard criteria. These include considerations of how current the data is and its temporal relevance, its technological relevance, and the geographic relevance to GP1. Where proxy data must be used, it has been conservatively selected, so that it is a reasonable representation of the project itself.

4.5 Interpretation method

The interpretation phase was conducted in accordance with the ISO 14044:2006 Environmental management — Life cycle assessment — Requirements and guidelines standard, including considerations of assessment precision, completeness and consistency, as set out in Table 4-2 below.

Table 4-2:LCA Interpretation methods

Criteria	Requirements for foreground data	Requirements for background data
Precision	Inputs to be calculated to two (2) decimal places or three (3) significant figures	The sensitivity of the results to key assumptions should be tested, particularly for those life cycle stages that have a significant contribution to the overall results
Completeness	Inputs to cover all life cycle phases and elements within system boundary. Excluded inputs must meet cut-off criteria.	Each material and process should be modelled with the most complete dataset. Where no dataset is available a similar substitute should be used.
Consistency	Inputs must be reflective of the project being assessed; where assumptions are made, they are consistent across both the Reference and Design Case.	Background data should be representative of the study.

5 GHG Emissions Assessment

5.1 Summary of total emissions

The total net global warming potential for the project is **331,000 tCO_2e**. Figure 5-1 illustrates the significance of the product emissions, primarily from the turbines themselves, compared to the emissions from other life cycle stages. Table 5-2 provides a breakdown of emissions across the EN 17472 modules, rounded to 3 significant figures.

Figure 5-1: GP1 life cycle emissions (GWP) across EN17472 modules (tCO_2e)

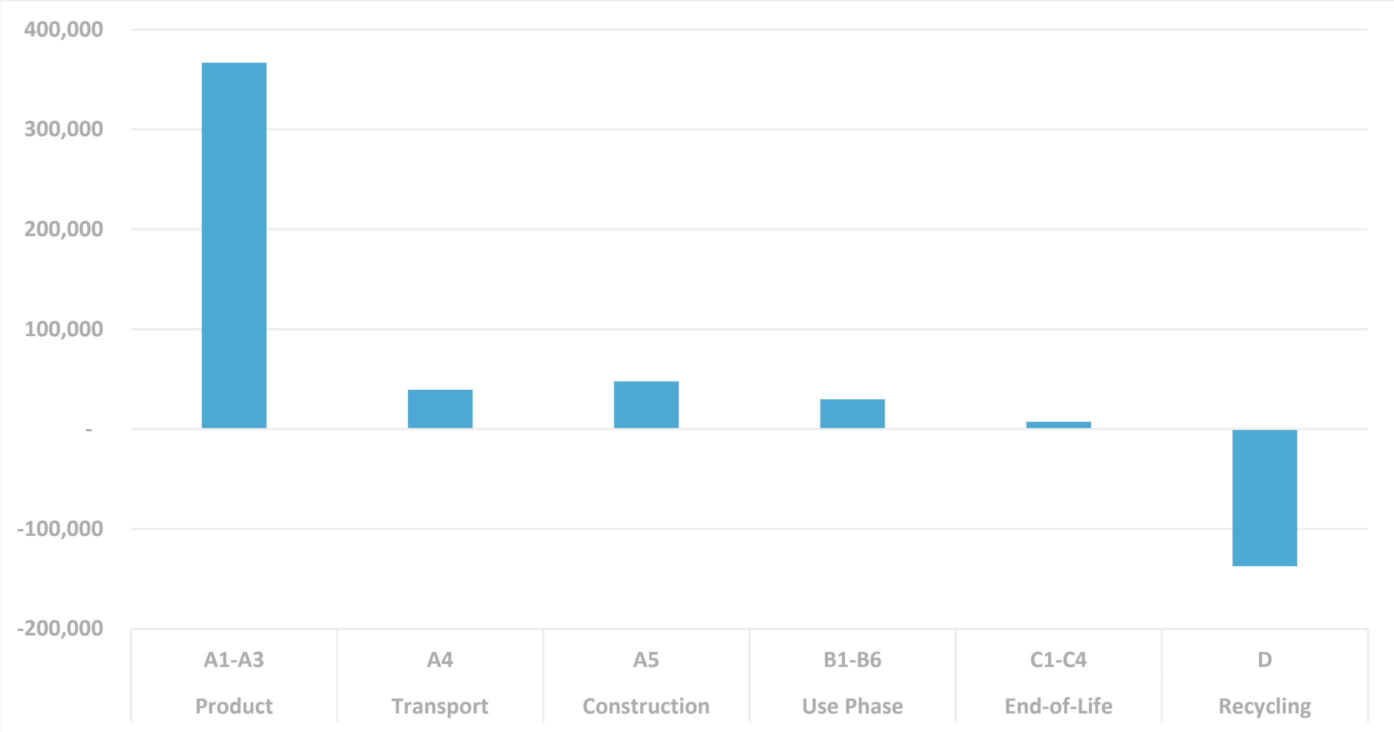


Table 5-1: GP1 life cycle emissions (GWP) across EN17472 modules (tCO_2e)

Stage	GWP (tCO_2e)	Percentage (of total A-C emissions)
A0 Pre-construction	-	0%
A1-A3 Product	367,000	78%
A4-A5 Construction	64,000	14%
B1-B7 Use	29,000	6%
C1-C4 End of life	8,000	2%
D Benefits	-137,000	-29%
Total (excl. D)	468,000	
Total	**331,000**	

Table 5-2 - Project GHG emissions of each EN 17472 module, rounded to 3 significant figures.

Stage	Module	Module Name	Boundary inclusions	GWP (tCO_2e)	Percentage (of total A-C emissions)
Pre-construction	A0	Land and associated fees/advice	*None – GHG impact considered immaterial*	-	0%
Product	A1-A3	Raw material supply, transport, manufacturing	Materials production cradle-to-gate	367,000	78%
Construction	A4	Transport	Transportation of materials to site	39,000	8%
Construction	A5	Construction - installation process	On-site fuel use & land change	25,000	5%
Use	B1	Use	Fugitive emissions	1,000	0%
Use	B2	Maintenance	Fuel use	2,000	0%
Use	B3	Repair	*None - included in B2 maintenance*	-	0%
Use	B4	Replacement	Gearboxes, blades, oil	26,000	6%
Use	B5	Refurbishment	*None - no refurbishment planned*	-	0%
Use	B6	Operational energy use	Operational electricity use	-	0%
Use	B7	Operational water use	*None - GHG impact considered immaterial*	-	0%
Use	B8	User's utilisation	*None - outside assessment boundary*	-	0%
End of life	C1	De-construction	All on-site activities during deconstruction	2,000	0%
End of life	C2	Transport	Transportation to disposal	3,000	1%
End of life	C3	Waste processing for reuse, recycling, recovery	Fugitive SF6 emissions during end-of-life	2,000	0%
End of life	C4	Disposal	Landfill of materials not recycled, inert	1,000	0%
Total (excl. benefits)				**469,000**	
Benefits	D1	Net flows from reuse, recycling, recovery	Recycling of WTG materials	-137,000	-29%
Benefits	D2	Exported utilities	*None - avoided emissions considered separately*	-	0%
Total				**331,000**	

5.2 Module A: Product and Construction Stage Emissions

The greenhouse gas (GHG) emissions inventory encompasses the emissions associated with all construction activities undertaken to date, as well as projections for future construction phases until completion. Modelling has been conducted in Microsoft Excel in conjunction with supporting LCA software, such as LCAfE/GaBi, and its linked databases, published by Sphera. This life cycle assessment includes:

- All fuel consumed during the construction of GP1.
- All travel emissions associated with TagEnergy management.
- Emissions resulting from land use changes and clearing activities.
- The GHG impacts of all materials and components used in GP1, such as turbines, cables, foundations, transformers, and materials used for constructing access tracks.

Modelling of the products used to construct the GP1 wind farm has included collecting information on the materials makeup of turbines, the total use of construction elements such as aggregates for access roads, elements used in site cables, and elements used for the onsite collector station. These elements are expanded on below.

5.2.1 Summary of Module A

The total emissions associated with the production and construction of GP1, including materials used, have been broken down by various construction activities. These estimates are based on a design and construction period of approximately 36 months.

3 provides a summary of these emissions, showing that the total emissions during the construction phase amount to 431,000 t CO_2-e, representing 92% of the total cradle-to-grave emissions of GP1 (excluding Module D).

Emissions associated with materials were estimated to be **367,000 tCO_2e**, representing **78%** of the total LCA cradle-to-grave emissions and are the primary contributors to emissions during the construction phase and the entire life-cycle. Steel accounted for the largest portion at **227,000 tCO_2e** (for turbines only, reinforcing steel for foundations makes up a further **28,600 tCO_2e**) followed by composites and polymers at **37,700 tCO_2e,** aluminium with **18,000 tCO_2e** and ready-mix concrete at **2,111 tCO_2e**.

Table 5-3: Total Carbon Emissions for the product and construction stages (Module A).

Activity	Lifecycle emissions (tCO_2e)	**Percentage (of total A-C emissions)**
Construction material, including turbines	367,000	78%
Wind turbine generators	285,000	
Construction Materials and Electrical Balance of Plant	82,000	
Transport	39,000	8%
Onsite fuel consumption (incl. oil)	8,000	2%
Vegetation clearing	17,000	4%
Total	431,000	92%

5.2.2 A1-A3 Wind Turbine Generators (WTGs)

The EnVentus V162 6.2MW turbines produced by Vestas are the primary element for the GP1 project. The existing LCA published by Vestas has been used as the key source of information to develop this life cycle inventory, with specific emissions factors modelled to match local production in China. Table 5-4 provides a summary of the mass breakdown for a single turbine. Further details on how these elements are modelled are provided in Appendix A.

Table 5-4: Mass and emissions breakdown of EnVentus V162 6.2MW turbine generator

Item	Mass of Component (t)	A1-A3 Emissions for one WTG (tCO_2e/WTG)	A1-A3 Emissions - GP1 (t CO_2e)	Percentage (of total A-C emissions)
Steel	**693**	**1,862**	**227,000**	**69%**
Low-Alloy Steel Components	536			
High-Alloy Steel Components	61			
Cast Iron	95			
Aluminium	**9**	**147**	**18,000**	**5.4%**
Aluminium + alloys	9			
Copper	**5**	**22**	**2,670**	**0.8%**
Copper	5			
Other	**98**	**309**	**37,700**	**11%**
Polymer - Hybrid	38			
Carbon Fibre	2			
Glass Fibre	4			
SF6	0.01			
NdFeB Magnet	1			
Electronics	2			
Electrics	5			
Lubricants	1			
Coolant	0			
Other	5			
Total	**804**	**2,340**	**285,000**	

5.2.3 A1-A3 Construction Materials and Electrical Balance of Plant

The remaining elements have been modelled on a whole-of-plant basis with data provided by the contractor MPK. These include elements such as roads & hardstands, turbine foundations, cable trenching, cables themselves, and transformers. These elements have been modelled using datapoints from the Australian IS Materials Calculator, as summarised in **Error! Reference source not found.**. Please note that elements may not add perfectly due to rounding. Further details on how these elements are modelled are provided in Appendix A.

Table 5-5: Material and emissions summary for site construction & balance of plant

Item	Amount Required (t or m^3)	A1-A3 Emissions (tCO_2e)	Percentage (of total A-C emissions)
Roads & Hardstands		**11,120**	**3.4%**
Asphalt	294 t	20	
Aggregates	1,200,000 t	11,100	
Concrete	2.75 m^3	2	
Turbine Foundations		**30,200**	**9.1%**
Concrete	100,000 m^3	1,700	
Steel	14,400 t	28,600	
O&M Considerations		**2,750**	**0.8%**
Steel	66 t	2,750	
GPEC & cable trenches		**1,340**	**0.4%**
Aggregates	45,000 m^3	286	
Concrete	1,060 m^3	459	
Steel	300 t	594	

Cables		**33,100**	**10%**
Aluminium (HV Cables)	1,650 t	33,000	
Copper	45 t	117	
Transformers		**2,960**	**0.9%**
Glass fibre reinforced plastic	21t	193	
Steel	879 t	2,400	
Copper	146 t	373	
Total		**81,500**	

5.2.4 A4-A5 Construction Stage Emissions

The construction stage of the assessment covers the emissions from the transportation of materials to site, both by ship internationally and truck, and the construction activities that occur onsite. These activities include producing and combusting the fuels used for all site equipment, including cranes and vehicles, along with the quantity of fuel used by generators to produce electricity for the site offices. Additionally, emissions from changes in land use are included without accounting for any compensating measures taken to offset biodiversity loss. This includes land use changes for foundations and access tracks. TagEnergy's travel for project management throughout the construction phase is also included. This includes flights from Sydney to Melbourne and project management visits to site two days per week.

The emissions associated with the transport of materials (A4) and onsite construction activities (A5) together amount to 64,900 tCO_2e, representing 14% of the cradle-to-grave LCA as shown in Table 5-6.

Table 5-6: Construction (A4-A5) activities emissions

	Item	Lifecycle emissions (tCO_2e)	Percentage (of total A-C emissions)
A4 - Transport	International shipping	32,800	7%
	Trucking	6,630	1%
	Subtotal A4	**39,500**	**8%**
A5 – Construction	Fuel Use	8,076	2%
	Oil and grease	2	<0.01%
	Land use and clearing	17,302	4%
	Management travel	25	0.01%
	Subtotal A5	**25,403**	**5%**

5.2.4.1 A4 Transport of Materials

Transport distances and methods for key materials are provided in Table 5-7.

Table 5-7: Transport of wind plant components to the site

Component	Truck (km)	Ship (km)	Details
Turbines	90	11,000	Truck from Vestas factory in Tianjin, China to port Specific turbine transport ship from Tianjin to Geelong Truck from Geelong to site
Site Cables	90	11,000	Truck from factory in China to port Ship from China to Geelong Truck from Geelong to site
Foundation materials - Steel	90	11,000	Truck from factory in China to port Ship from China to Geelong Truck from Geelong to site

Foundation materials - Concrete	5	N/A	Locally procured, specific distance dependent on material
Other materials	10-260		Precast concrete elements, steel framing, specialty aggregate & recycled ballast all from local area

The turbine ships have been modelled specifically using capacity factors from publicly available data, as outlined below in Table 5-8. Shipping wind turbine components has unique characteristics as compared to standard shipping data. Turbine shipments are generally volume-constrained, whereas standard shipping emissions data models container ships, which are generally mass-constrained. This means the vessel is less-efficient for each tonne-km of freight shipped on a mass basis, as shown in Table 5-9.

Table 5-8: Derivation of shipping utilisation factor from actual ships used by GP1

Ship Name	Gross Tonnage	Summer Deadweight Tonnage (DWT)	Load of 10x Turbines	Mass-based Utilisation Factor	Source
Da Xin	21,828	29,565	8,475	28.7%	Maritime Optima
Da Gui	21,992	28,000	8,475	30.3%	Maritime Optima
				29.9%	Project Cargo Journal

Table 5-9: Indicative comparison of turbine transport ship versus standard container ship

Element	Emission Factor ($kgCO_2e/tkm$)	Details
LCAfE/GaBi Datapoint	0.02750	Container ship, 5-200kt dwt, deep sea. Modified with 29.9% utilisation factor for mass as above.
IS Materials Calculator Emissions Factor	0.00889	Default process used by IS, unmodified from average container ship operations
Difference	**3.09x greater**	

5.3 Module B: Operations Stage

The site-operation phase is the general running of the wind turbine plant as it generates electricity. Within the Carbon footprint analysis of this phase, several key factors have been considered:

- B1: Use Phase - Release of sulphur hexafluoride gas (SF6)
- B2: Maintenance - Travel
- B4: Replacement Components
- B6: Onsite electricity use

5.3.1 Summary of Module B

The total emissions associated with operation have been broken down by various operation activity in Table 5-10. Total emissions are 29,647 tCO_2e, representing 6.3% of the total LCA of GP1, excluding recycling credits.

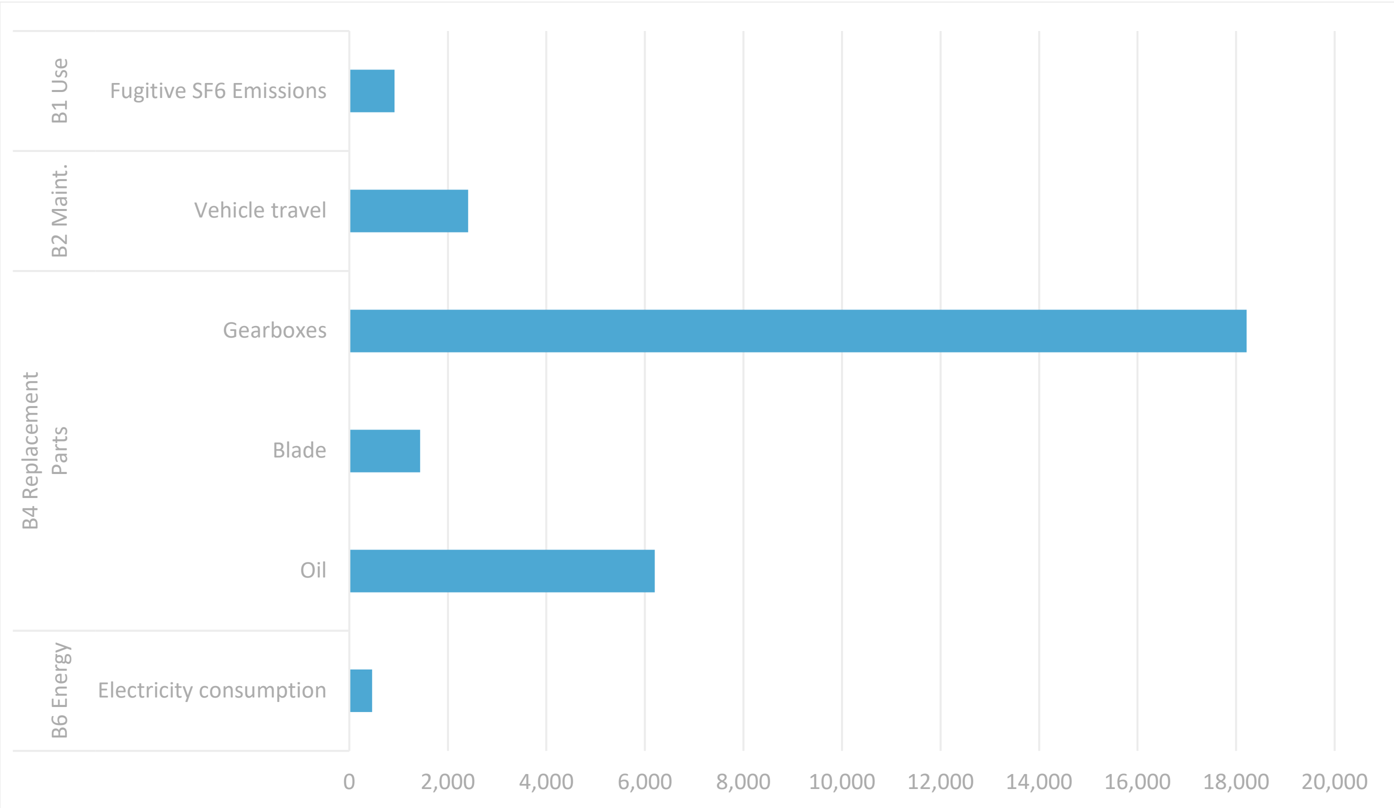
Table 5-10: Operation emissions

Activity	Material (tCO_2e)	Transport (tCO_2e)	End-of-Life (tCO_2e)	Total	Percentage (of total A-C emissions)

B1: SF_6 Release				919	0.2%
B2: Maintenance travel		2,410		2,410	0.5%
B4: Replacement Gearboxes	17,080	1,180	-48	18,210	0.3%
B4: Replacement Blades	1,340	95	17	1,440	3.9%
B4: Oil Changes	3,720	178	2,300	6,200	1.3%
B6: Electricity usage, maintenance facility & operations room				464	0.1%
Total	**22,100**	**3,860**	**2,270**	**29,700**	**6.3%**

Figure 5-2 highlights that the most significant activities within operations come from gearbox replacement and oil replacement (including treatment at end-of-life), and regular maintenance routines.

Figure 5-2: Module B emissions from operation and use, tCO_2e



5.3.2 B1 Switchgear insulating gas SF6

Sulphur hexafluoride (SF_6) is a highly potent GHG, with a global warming potential of 23,500 times greater than carbon dioxide over a 100-year period. To estimate the quantity of SF_6 loss through leakage, reference is made to the LCA conducted by Vestas for the same turbine type. According to the LCA, during normal operation, the turbine HV switchgear may potentially release up to 0.1% of the total SF_6 charge per year. This equals to 3% by weight released over 30 years of operation. The potential effect of a failure is not considered in this LCA, with sensitivity analysis in the Vestas study showing that a blowout would only represent a 0.1% increase in emissions. Table 5-11**Error! Reference source not found.** shows the total SF_6 leakage emissions during operations.

Table 5-11: Fugitive SF_6 emissions

Item	Quantity SF_6 (t)	SF_6 Loss per year (% weight)	Lifecycle Emissions (tCO_2e)	Percentage (of total A-C emissions)
122 x WTG Switchgear	1.3	0.1	919	0.2%

5.3.3 B2: Maintenance - Transportation of crew

Assumptions have been made for the transportation to and from the site for maintenance crew. Three maintenance vehicles scenarios have been developed for the 30 year maintenance period with resulting GHG emissions shown in Table 5-12:

- Gasoline-powered 4x4 vehicle with a fuel efficiency of 7 km/L
- Diesel-powered 4x4 vehicle with a fuel efficiency of 10 km/L
- Electric vehicle using renewable electricity program such as GreenPower[4], with an efficiency of 0.2 kWh/km

Table 5-12 – Life Cycle Emissions of the maintenance travel – three scenarios

Item	Distance Travelled (km/year)	Gasoline-powered vehicle (tCO_2e)	Diesel-powered vehicle (tCO_2e)	Electric vehicle (tCO_2e)
Transportation of the maintenance crew on site	27,720	345	282	4
Transportation of the maintenance crew to the site	166,320	2,068	1,689	23
	Total	**2,410**	**1,970**	**27**

In the final LCA result, shown in Table 5-13, the scenario involving maintenance conducted using gasoline-powered 4x4 vehicles was considered to ensure a conservative result. However, chargers for electric vehicles are already planned and it is highly likely that maintenance vehicles will electrify over the coming 30 years.

Table 5-13 - Maintenance emissions

	Life Cycle Emissions (tCO_2e)	Percentage (of total A-C emissions)
Maintenance Travel	2,410	0.5%

5.3.4 B4: Replacement of components

During the GP1 operations phase, oil changes and parts replacement will be required. Table 5-14 represent a list of the main components that may need to be changed or repaired during the operation phase of GP1. In the LCA, the annual gearbox oil changes and the replacement of all gearboxes and some blades have been considered. These have been modelled using proxy data from the NREL REMPD database, and account for both the transport of replacement items, their end-of-life, and recycling credits for the replaced items where appropriate. The REMPD data does not provide detail at the subcomponent level, so the nacelle model has been scaled by mass to approximate a 30 tonne gearbox.

[4] https://www.greenpower.gov.au/

Table 5-14 - Replacement parts

Item	Quantity	Material emissions (tCO_2e)	Transport emissions (tCO_2e)	End-of-Life emissions (tCO_2e)	Total emissions (tCO_2e)	Percentage (of total A-C emissions)
Blade	11x	1,330	95	17	1,440	0.3%
Gearbox	122x	17,000	1,180	-48	18,200	3.9%
Gear Oil	900 L	3,720	178	2,300	6,200	1.3%
Total replaced components		**22,100**	**1,450**	**2,270**	**25,900**	**5.5%**

5.3.5 Electricity consumption for the O&M Buildings

During the operational phase of the wind farm, electricity is consumed in the operations and maintenance (O&M) building. The amount of electricity consumed has been estimated, and the use of 100% GreenPower renewable energy has been assumed, reducing the impact compared to if this electricity had been procured from the grid. The emissions are shown in Table 5-15. Note that whilst GreenPower has zero emissions in a Scope 1 and 2 business GHG inventory, it does retain emissions associated with the infrastructure, due to the program mechanism operating through the purchase and surrender of LGC's. These emissions have been determined from the current NEM renewable energy grid mix.

Table 5-15: Electricity consumption of O&M Buildings

Item	Electricity consumption (MWh)	Lifecycle Emissions (tCO2e)	Percentage (of total A-C emissions)
Electricity consumption using 100% Greenpower	20,100	464	0.1

5.3.6 Net energy production

The net energy production after curtailment but before applying the marginal loss factor (MLF) is utilised to determinate the net energy production of the wind farm over its 30-year operational period. Net energy production accounts for all assumed losses, including wake, availability, electrical efficiency, etc. The net energy production over the lifespan of GP1 totals 65,420 GWh.

5.4 Module C: Decommissioning/End-of-Life Phase Life Cycle Inventory

The GP1 Development Approval specifies that all infrastructure must be removed at the end-of-life, including: access tracks, hardstand areas and wind turbines. All infrastructure between 0 and 0.5 m below ground level must be removed. Everything below 0.5m below ground level (such as foundations) may remain.

In the LCA, GHG emissions from the end-of-life treatment for major wind plant components are included (turbines, electrical components, road materials) with foundations below ground level assumed to remain in-situ. Most of the turbine mass is recycled, with Module C here accounting for diesel usage in decommissioning, dismantling, and transport to a recycling facility. Non-recycled components are modelled as inert materials on landfill. Additional elements included in Module C include fugitive SF_6 emissions at end-of-life waste treatment. Emissions associated with recycling are accounted for in Module D.

5.4.1 Summary of Module C

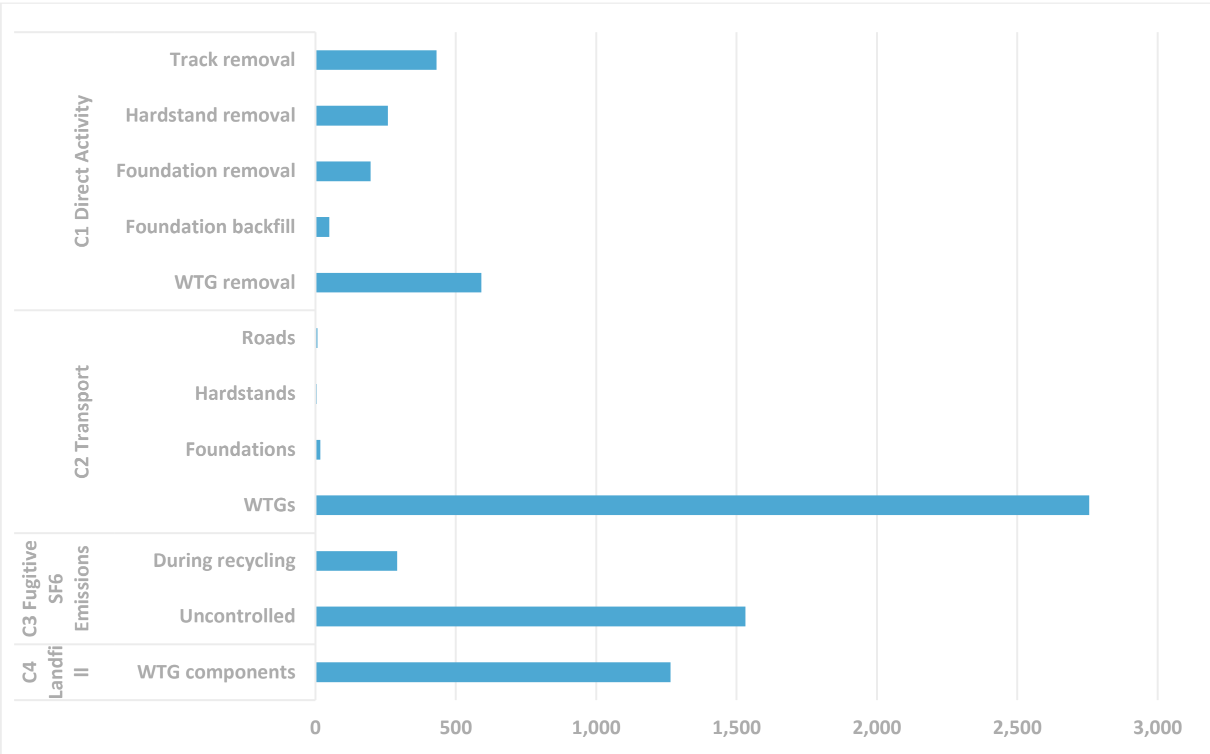
Table 5-16 details the emissions associated with the decommissioning phase of GP1, focussing on activities of the removal of various wind farm items and their transportation. In total, Module C makes up 1.6% of total emissions on a cradle-to-grave basis, excluding recycling credits. Decommissioning structures such as the O&M facility has been excluded from this analysis as it falls below the 1% cut-off rule.

The total carbon emissions for the decommissioning of GP1 is represented in Figure 5-3:, showing that transporting the WTGs to Melbourne is the most significant element, followed by fugitive SF_6 emissions and landfilling non-recycled WTG components.

Table 5-16 - Decommissioning activity and transport emissions

Item	Lifecycle Emissions (tCO_2e)	Percentage (of total A-C emissions)
C1 Deconstruction		**0.3%**
Removal of access tracks	432	
Removal of hardstand areas	258	
Removal of foundations	197	
Backfilling of foundations	49	
Removal of WTGs	591	
C2 Transport		**0.6%**
Road materials	7	
Hardstand area material	5	
Foundation materials	17	
WTGs components	2,760	
C3 Waste Processing		**0.4%**
Fugitive SF_6 Emissions – Recovered components	291	
Fugitive SF_6 Emissions – Non-recovered components	1,530	
C4 Disposal		**0.3%**
Landfill of non-recycled products	1,270	
Total	**7,400**	**1.6%**

Figure 5-3: Module C End-of-Life & Decommissioning Emissions (tCO_2e)



5.4.2 Module C on-site fuel consumption

Fuel consumption is determined based on assumed parameters as shown in Table 5-17 and Table 5-18, with fuel consumption figures provided by the contractor.

Table 5-17: Consumption of the different demolition plant and equipment

Machines	Consumption	Unit
Excavator	17	L/hr
Excavator with hammer	17	L/hr
Posi-track	8	L/hr
Truck	7	km/L
Backhoe loaders	17	L/hr
Main Crane	80	L/day
Support Crane	50	L/day

5.4.3 Module C2 transport

Table 5-18: Transport distances to recycling plants/landfills.

Components	Transport to	Distance from the site (km)
Roads and hardstand materials	Golden Plains Quarry	10
Foundation materials	Ballarat	45
WTG components	Melbourne	130

5.5 Module D: Benefits and loads beyond project boundary

At the end of the wind farm's life cycle, the components of the wind turbines are likely to be recycled. Module D assesses the benefits of recycling elements and applies these benefits in the form of an emissions credit using assumed end-of-life pathways. Metals have significant value at end-of-life and therefore there is a high likelihood that they will be recycled. This informs the use of an avoided-burden approach of modelling these credits, where virgin materials are assumed for upfront production, and recycled content is applied at the end of life.

Credits have been calculated from literature and from the LCAfE/GaBi database, using the most up to date production data where possible. These are defined as the net difference between the emissions of producing recycled material, and the reduction of impacts for an equivalent quantity of virgin material production that can be replaced with the recycled material.

The LCA methodology assumes current-state production technologies when applying these credits, but this is not guaranteed to be the case in 30 years' time. With a decarbonising electricity supply, there is potential that the environmental costs of recycling steel in an electric arc furnace are significantly decreased, for example. This could increase the benefits of recycling compared to current data. In contrast however, there could be new methods of manufacturing primary steel with renewables, using technologies such as direct electrolysis or hydrogen reduction. This means that the future virgin steel production that could be displaced by recycled steel could in fact be lower-emissions than current-state production, and the recycling credit could in fact be significantly reduced. We note this is a key sensitivity of this study, and is inherent within the current state, best-practice LCA methodology.

Table 5-19 outlines the assumed GHG emissions credit and recycling rate for each main component of the WTGs.

Table 5-19 - End-of-life treatment of turbine components

Material	Emissions Credit (tCO_2e/t)	Recycling Rate (via Vestas)	Total Recycling Credit (tCO_2e)
Low-alloy steel components	-1.7 t	92%	-104,000
High-alloy steel components	-2.0 t	92%	-13,800
Cast iron	-0.9 t	92%	-9,320
Aluminium + alloys	-8.2 t	92%	-7,960
Copper	-2.8 t	92%	-1,520
Polymer - hybrid	-	-	-
Carbon fibre	-	-	-
Glass fibre	-	-	-
SF6 gas	-	-	-
NdFeB magnet	-	-	-
Electronics - hybrid	-	-	-
Electrics - hybrid	-	-	-
Lubricants	-	-	-
Coolant	-	-	-
Other	-1.7 t	92%	-969

Recycling of blades and all roading materials (aggregates, rock) have not been considered in this LCA. Although TagEnergy plans to recycle them at the end-of-life, the technologies to do so for current-state blades are not yet mature, and there is uncertainty as to whether landowners would wish to keep the access roads on their land. As a conservative approach, these elements are assumed to be removed without recycling.

6 Specific carbon footprint

The specific carbon footprint of the Project can be determined by combining the LCA emissions of GP1 with the net energy production of the wind farm throughout its lifespan, generating an emissions factor per reference unit, in this case gCO_2e/kWh on the grid. There are two baseline factors for this figure; one that takes a cradle-to-grave perspective, and another that includes the emissions credits beyond the project boundary, where construction materials are recycled.

The former cradle-to-grave (Modules A-C) calculation result in GP1 having a carbon footprint of 7.2 gCO_2e/kWh, which is reduced by 41%, down to 5.1 gCO_2e/kWh overall, when Module D recycling credits are added.

$$\boldsymbol{Carbon\ Footprint_{Cradle\ to\ grave} = \frac{Total\ emissions\ (tCO_2e)}{net\ energy\ production\ (GWh)} = \frac{469,000}{65,400} = 7.2\ gCO2e/kWh}$$

$$\boldsymbol{Carbon\ Footprint_{Cradle\ to\ cradle} = \frac{Total\ emissions\ (tCO_2e)}{net\ energy\ production\ (GWh)} = \frac{331,000}{65,400} = 5.1\ gCO2e/kWh}$$

7 Indicative comparison between GP1 and the NEM grid

Avoided carbon emissions is a challenging metric to calculate for renewable energy projects. Wind power is an intermittent resource, and so is treated differently to thermal baseload generation; grid firming is achieved through network effects and other pieces of infrastructure such as grid-connected batteries. As a result, wind energy is not perfectly comparable to a perfectly dispatchable generator, and it would be incorrect to claim that energy generated by GP1 is directly reducing impacts from, say, thermal coal generation on a 1:1 basis.

The World Business Council for Sustainable Development (WBSCD) has a highly defined methodology to determine claims for avoided emissions, with a key concept being the definition of a suitable reference scenario where the project itself does not exist. This definition of a reference scenario determines what can be claimed by the GP1 project as direct benefits.

The latest 2024 AEMO Integrated System Plan (ISP) forecasts that through to 2030, wind projects will make up 70% of new utility-scale renewable generation. This demonstrates that GP1 is acting as part of a larger shift, and that projects like this will form the backbone of the energy transition over the coming years. Projects like GP1 are critical to this change, and collectively will help drive the reduction in emissions from Australia's grid emissions, increasing the share of renewables from 32% in 2021 up to 70% in 2027. Renewables will also supply the vast majority of the growth in total supply in the future. These factors combine in such a way that they are the de-facto default option for new energy projects, and cannot therefore be used to claim individual benefits.

Wind energy, such as that generated by GP1, is supporting the decarbonisation of the Australian national grid, and this can be illustrated using normalised emissions per unit of electricity generated, as shown in Figure 7-1 below. This is an indicative comparison only, and is not intended to be communicated as part of the life cycle assessment itself; it is not calculated to the same rigour due to the availability of data for the grid, and the difference between intermittent and thermal baseload generation as discussed above.

The figure broadly illustrates when the energy from GP1 will have reduced in emissions intensity such that is lower than the national grid average. It starts at almost the same emissions intensity as coal, where all the embodied emissions from construction are only allocated against the generation in the first year of operation. However, as total generation increases, these emissions rapidly decline, with the overall intensity matching during the first year of operation in 2025. The residual gas and coal in the grid, as well as the embodied emissions of new solar and wind projects both contribute to overall grid emissions, but the graph illustrates that energy from the GP1 project alone is lower-emissions than the sum total of the grid itself.

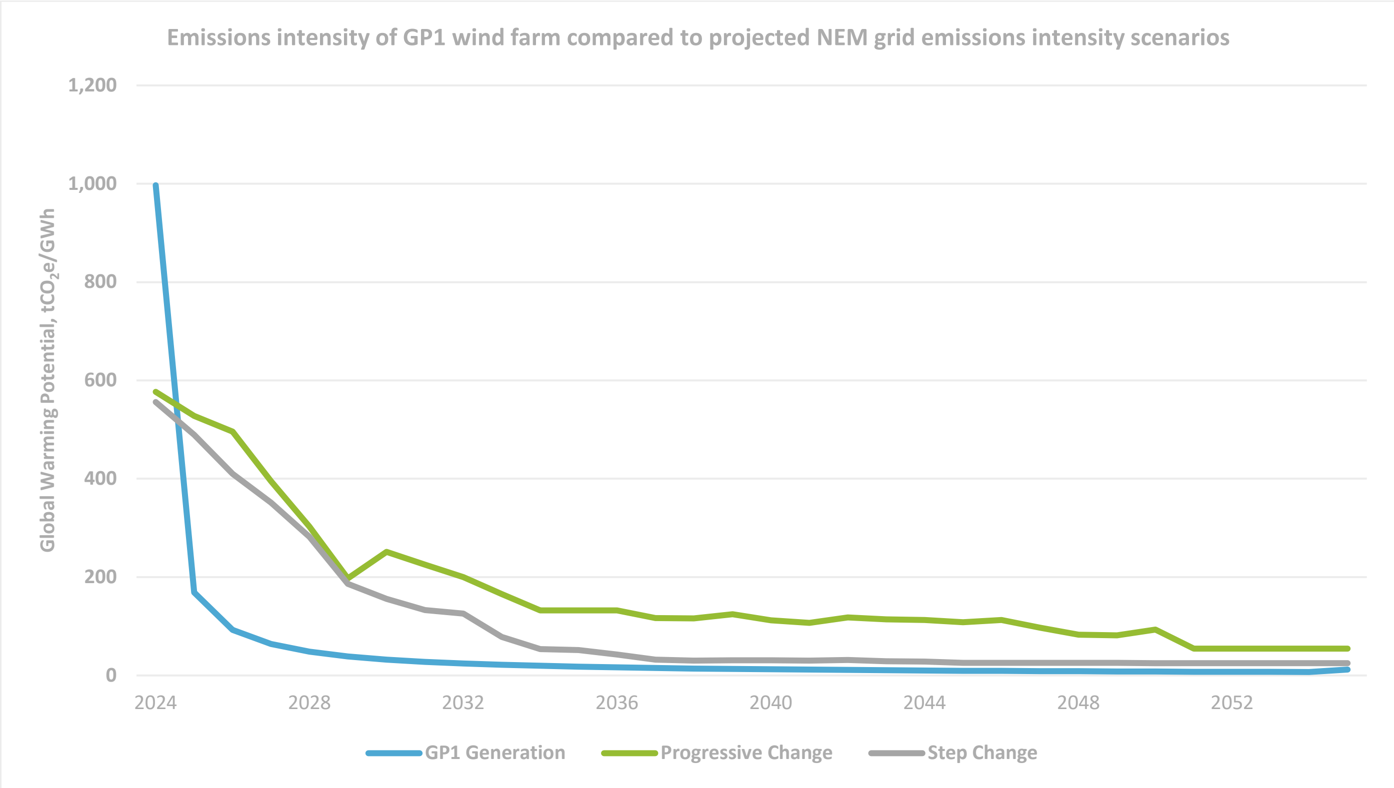


Figure 7-1: Illustrative comparison of Global Warming Potential of GP1 energy supplied to grid vs. AEMO projected grid averages, normalised via cumulative generation and cumulative emissions, tCO_2e/GWh

This calculation has been developed using the two main scenarios from the 2024 AEMO ISP report: the Progressive Change and the Step Change scenarios. It's notable that the "Slow Change" scenario in previous ISP reports has been excluded, showing the confidence the grid operator has in a decarbonising energy system. Annual generation averages have been converted to percentage figures, with high-level emissions intensity figures used to generate annual grid emissions factors. These figures include whole-of-life estimates, which is a notable difference from the emissions intensity figures used by AEMO themselves; figures that can be derived from the emissions intensity estimates provided in the ISP directly do not include embodied emissions from renewable generation, nor do they include upstream emissions from coal or gas production. As such, they cannot be compared with the life cycle carbon figures from reports such as this one.

Key sources used for these high-level estimates are summarised in Table 7-1 below. Note these figures are likely conservative for renewable generation, and that actual emissions are likely lower than this. Furthermore, they represent current-state and international production, meaning that future solar PV and wind plants with more efficient and decarbonised production processes will also be lower-carbon on an energy-delivered basis.

Table 7-1: Emissions summary and sources used for high-level embodied carbon estimate of the future electricity grid

Generation Type	Whole-of-life Emissions (g CO_2e/kWh)	Source
Lignite	1,360	LCAfE/GaBi, AU datapoint including upstream mining and fugitive CH_4 release
Hard Coal (Pulverised)	1,000	UN Economic Commission for Europe (2021)
Natural Gas	699	LCAfE/GaBi, AU datapoint including representative OCGT/CCGT mix, upstream extraction and fugitive CH_4 release
Hydropower	11	UN Economic Commission for Europe (2021)

Wind – Onshore	12	
Wind - Offshore	14	
Solar PV – Rooftop	37	
Solar PV – Utility	37	
Battery Storage – Lithium Iron Phosphate	8	Gutsch & Leker (2022)

8 Comparison against public Vestas EnVentus V162 6.2MW LCA

Although this GP1 LCA study is based on the same mass data for turbines as the LCA for the EnVentus V162 6.2MW conducted by Vestas, the top-line results are not directly comparable. Table 8-1 outlines the core differences between these wind plant studies, even though the turbines themselves have the same specifications. A key difference is that GP1 has an estimated operational lifespan 50% greater than the Vestas study, and is modelled as generating around 20% more electricity per turbine, per year. These two elements serve to decrease the emissions footprint when compared to the Vestas study. Conducting a high-level change to the operational lifespan of GP1 provides an additional comparison – decreasing total lifetime generation to match a 20 year lifespan and adjusting relative operational emissions demonstrates a significant increase in emissions on both an whole-of-life A-D basis and an A-C basis excluding recycling credits. There is minimal change to the emissions footprint on a nameplate per MW capacity, however. These changes are driven by the reductions in electricity generated by GP1 over the shorter lifespan.

Although the Vestas study models a European site and discusses European manufacturing sites, the transport distances as disclosed in the sensitivity analysis appears to suggest manufacturing in China. Their own sensitivity test, which considers a Western Australia-based site, increases total emissions by around 1%, although this does not assume any in-country land-based transport. In general, it is challenging to compare shipping assumptions between the GP1 study and the Vestas study. When comparing on a direct nameplate capacity level however, the two studies are very similar, with only 2% difference per MW.

Table 8-1 Comparison of the Vestas EnVentus 162 6.2MW LCA and the GP1 LCA using the same turbine model

Element	Unit	Vestas LCA	LCA of GP1	LCA of GP1 (adjusted to match Vestas' 20 year lifespan)
GWP of generated electricity (modules A-D)	gCO_2e/kWh	6.2	5.1	7.5
GWP of generated electricity (modules A-C)	gCO_2e/kWh	Not Disclosed	7.2	10.8
Whole-of-plant GWP per MW capacity (modules A-D)	tCO_2e/MW	430	438	434
Reference lifespan	years	20	30	20
Annual generation capacity per turbine	GWh	13.6	17.9	17.9

9 Future opportunities

Modelling conducted as part of this assessment has also provided insights into areas for improvement for future projects and assessments, in terms of the potential benefits for GWP reduction and the quality of assessment.

9.1 Reduction opportunities

Further opportunities to reduce GHG emissions can be considered for the Golden Plains Stage 2 Project including:

- Concrete
    - Use of SCMs in concrete designs. Using low carbon concrete designs with up to 65% supplementary cementitious materials (SCMs) such as flyash in concrete mixes can reduce up to **15,200 tCO_2e (3%)** of GP1 lifecycle carbon emissions when compared to standard ready-mix concrete.
- Shipping and construction
    - Targeting local suppliers and workforce to reduce transport distances, where appropriate.
    - If towers can be shipped from overseas in a format that is mass-limited rather than volume-limited (such as in a flat format, with rolling and spiral-welding conducted onsite), this could increase the efficiency of transport and lower the total emissions from this process. Furthermore, electrified equipment, either with battery-powered equipment or grid-powered equipment, could reduce the impact of diesel on construction and transport. As these sectors develop, new opportunities to decarbonise construction equipment are emerging.
- Use of electric vehicles during operation phase could reduce total emissions by **2,390 tCO_2e (1%)**.
- Ensuring that no SF_6 is leaked during the end-of-life stage could save an additional **1,800 tCO_2e (0.4%)**.
- Carbon offsets meeting the requirements of the Climate Active Carbon Neutral standard, used by major infrastructure projects in Australia can be purchased to offset up to 100% of the project, although this will not reduce the direct emissions from the project itself.

9.2 Data quality

Incorporating detailed, certified (by accredited quantity surveyors) Bills of Quantities into subcontractor contracts to boost transparency in the lifecycle of raw materials would improve data quality.

10 Conclusion

The Golden Plains Wind Farm - East (GP1) proposes the construction of 122 Vestas V162-6.2 turbines with a total capacity of 756MW on 11,029 hectares of land. The aim of this report was to model the global warming potential (GWP) across the life cycle of the project. The total GWP (including recycling credits) for the project are calculated to be **331,000 tCO_2e** based on the currently available bill of quantities, and using projected assumptions on the operation and decommissioning phases. When recycling credits (Module D using the EN 17472 standard) are excluded, this figure increases to **469,000 tCO_2e**.

The functional unit for this study is the delivery of 1kWh of energy to the grid. When normalising whole-of-life emissions against this figure, we obtain **7.2 g CO_2e/kWh** excluding recycling credits (Module D), and **5.1 g CO_2e/kWh** when these recycling credits are included. Although these figures are low when compared to other forms of energy, especially fossil energy, improvements to the carbon efficiency can still be made for future projects.

The Product Stage (Modules A1-A3) is the most significant across the project life cycle, accounting for 78% of total emissions (excluding recycling credits) at **367,000 tCO_2e**. This is where considerable improvements can be made, although this is reliant on partnership with turbine OEMs such as Vestas. One approach could be to rethink wind turbine design to reduce the use of steel, as steel accounts for 79% of the emissions associated with the turbines themselves. This could be done by using partial replacements in the tower with materials such as engineered timber, although careful consideration needs to be given to ensuring this does not impact the total lifespan. Additionally, recycled steel could also be used to lower the A1-A3 footprint; however, this would also reduce the recycling credit available at the end of life, minimising the emissions benefit over the whole life cycle.

For additional information, please feel free to contact TagEnergy at the following address: info@tag-en.com

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12 Photos of Golden Plains Wind Farm - East

Figure 12-1: Photo 1

Figure 12-2: Photo 2

Figure 12-3: Photo 3

Figure 12-4: Photo 4

Figure 12-5: Photo 6

Appendix

Appendix A Wind Turbine Generator Emissions Calculation Methodology

The V162 6.2MW EnVentus turbines have been modelled using the mass breakdowns as provided in the Vestas-supplied Life Cycle Assessment study. A previous version of the LCA conducted for the GP1 project used the IS Materials Calculator for emission factors, which has been updated to better reflect manufacturing practices and materials. Key datasets are outlined in Table 12-1 below. A key sensitivity is the choice of recycling credit use at Module D, especially for low-alloyed steel.

Table 12-1: Wind turbine generator emissions factor details

Vestas Model Material Categories		Emissions Factor Modelling Details	Sources
Steel & iron materials	Unalloyed, low-alloyed steel	Asia regional average steel plate production, plus allowance for welding. Module D recycling credit modelled as worldsteel global average credit.	worldsteel via. Sphera LCAfE/GaBi
	Highly alloyed steel	Chinese stainless steel production Module D recycling credit modelled as net between average Chinese recycled production and virgin production	WorldStainless via. Sphera LCAfE/GaBi
	Cast iron	Cast iron part modelled in LCAfE/GaBi using specific Chinese energy inputs, recycling credit standard LCAfE/GaBi factor	Sphera LCAfE/GaBi
Light alloys, cast & wrought alloys	Aluminium	International average for virgin aluminium production, plus an allowance for processing, recycling credit standard LCAfE/GaBi factor	International Aluminium Association via. Sphera LCAfE/GaBi,
Nonferrous heavy metals	Copper	Chinese copper wire supply, recycling credit standard LCAfE/GaBi factor	Sphera LCAfE/GaBi
Polymer materials	Polymers	Hybrid emission factor, epoxy resin and PET foam, using the REMPD to adjust proportions.	PlasticsEurope, Sphera LCAfE/GaBi, NREL REMPD
Other materials	Modified organic natural materials	Carbon fibre production including emissions from thermal treatment mass loss, as modelled by Prenzel et al.	Prenzel et al. (2024)
	Ceramic/glass	Borosilicate glass fibre production	Sphera LCAfE/GaBi
	SF_6 gas	Proxy datapoint using hydrogen fluoride dataset as primary precursor, plus thermal energy requirement (from natural gas) taken from literature data.	Sphera LCAfE/GaBi, Shiojiri et al. (2004)
	Magnets	NdFeB permanent magnet production using Chinese-sourced domestic rare earths from Bayan Obo mine.	Schreiber et al. (2018)
Electronics/ Electrics	Electronics	Hybrid emissions factor synthesising Environmental Product Declarations for ABB power equipment and electronics, scaled by mass.	ABB
	Electrics	Hybrid emissions factor synthesising Environmental Product Declarations for ABB power equipment and electronics, scaled by mass.	ABB
Lubricants & liquids	Lubricants	Oil-based lubricants at refinery	Sphera LCAfE/GaBi
Unspecified	Total Other	Asia regional average steel plate production, plus allowance for welding. Recycling credit standard LCAfE/GaBi factor.	worldsteel via. Sphera LCAfE/GaBi
		Custom model in LCAfE/GaBi from built-in data: injection-moulded part including Chinese electricity, 70% PA6 polymer and 30% glass fibres by mass.	Sphera LCAfE/GaBi

		Datapoint from LCAfE/GaBi database: moulded silicone part.	Sphera LCAfE/GaBi

Appendix B Organisational Emissions

The global warming potential figures calculated in this report take a whole-of-life perspective, and do not differentiate between levels of organisational or operational control within the value chain. This contrasts with footprinting methodologies such as the GHG Protocol, which sorts annual emissions along value chain lines into Scope 1, Scope 2 and Scope 3 emissions, generally on an annual basis.

Table 12-2 below outlines the whole-of-life emissions of the GP1 project split into these scopes. There are a few things to note with this way of categorising emissions, as it does not cleanly map to the EN 17472 standard. The first is that recycling credits are not permitted with these methodologies so emissions figures are only given using the Module A-C life cycle stages as presented in the body of the report. Scope 1 emissions are those that TAG Energy has direct operational control over, meaning that contracted companies are included as part of the Scope 3 inventory only. The only significant source of Scope 1 emissions is the fugitive release of SF_6 insulating gas that occurs over the lifespan of the asset.

Scope 2 emissions are those from purchased energy, and can be treated as zero-rated in the methodology with the purchase of GreenPower certifications, which TagEnergy has done. The whole-of-life model differs here by including the life cycle emissions from the renewable energy used to generate this energy. All remaining emissions across the life cycle are included in Scope 3.

Some Scope 3 emissions categories are not significant at construction as they are modelled from future estimates and requirements, including emissions from maintenance, producing spare parts, or decommissioning. Without a detailed construction programme to partition emissions into specific calendar years, the categories that are significant up to the completion of the project are also provided in this table.

Table 12-2: High-level alignment of project emissions against the GHG Protocol organisational emissions footprinting methodology. Elements have been rounded to match the high-level results in Table 5-2.

Emissions Scope	GHG Protocol Category	Source	Equivalent Module in EN 17472	Whole-of-Life GWP (tCO_2e)	As-Completed GWP (tCO_2e)
Scope 1	Fugitive Emissions	Fugitive SF_6 Release	B1 (Use)	1,000	
Scope 2	Emissions from Purchased Energy	Grid Electricity Usage	B6 (Energy Use)	500*	0*
Scope 3	1. Purchased Goods & Services	Construction, (including land clearing)	A5 (Construction)	25,000	25,000
		Maintenance & Spare Parts	B2-B4 (Maintenance)	28,000	
	2. Capital Goods	Turbines	A1-A3 (Materials) A4 (Transport)	317,000	317,000
		Foundations		32,000	32,000
		Construct. Materials & Balance of Plant		57,000	57,000
	5. Waste Generated in Operations	Decommissioning	C1-C4	8,000	
	6. Business Travel	Management Travel to Site	A5	25	25
Scope 3 Subtotal				467,000	431,000
Total				**468,500**	**431,000**