Carbon Footprint of Proposed Hauāuru mā raki Wind Farm

Prepared for Contact Wind Limited and

Contact Energy Ltd.

by
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February 2008

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CARBON FOOTPRINT OF PROPOSED HAUĀURU MĀ RAKI WIND FARM

EXECUTIVE SUMMARY

The goal of this project was to prepare a 'carbon footprint' of the Hauāuru mā raki Wind Farm (Hmr), proposed to be constructed by Contact Wind Limited (CWL), including the transmission plant necessary to connect Hmr to the National Grid proposed to be constructed by Contact Energy Limited. The ‘carbon footprint’ includes all greenhouse gas (GHG) emissions produced over the whole life cycle of the wind farm, as well as the energy required for construction and use of the farm over this same length of time. In addition, the amount of time it should take to recover the energy used in the construction of the farm has been calculated.

The functional unit of the study is the electricity produced at the Hmr over 20 years (a standard lifetime for wind farms). The wind farm scenario in this report is for up to 180 Vestas V90 3 MW turbines (total capacity 540 MW) on 100 m towers, and is assumed to provide 32,000 GWh electricity over 20 years.[1](Contact, 2007) This scenario is chosen because it is as close as possible to CWL’s maximum specifications for the wind farm for which consent is being sought.

The following life cycle stages of the wind farm have been included:

- Production of turbine parts and materials
- Transport of materials/parts from factory gate to building site
- Construction of access roads
- Construction process of wind turbines
- Construction of substation and all electrical equipment
- Maintenance
- Dismantling & disposal of wind turbines (included as a scenario)

No data for end of life scenarios were available. End of life is included as a scenario, with some assumptions made, as it is very difficult to predict the fate of the turbines in twenty years.

Table 1 shows the primary energy consumption and the GHG emissions of the proposed Hmr over its assumed lifespan of 20 years. The figures are broken up into the individual contributions from each component of the wind farm. This includes the wind turbines themselves, broken up into foundations, tower, nacelle and rotor. Additionally, figures for the electrical reticulation system and connection to the national grid, roading and excavation, and maintenance of the turbines over their lifetime have been included.

[1] As a decision on the type of turbine has not been finalised at the time of this report, it is assumed for the purposes of calculations, that the turbines are Vestas V90 3MW turbines, 100m hub height).

	GWP 100 in kg CO_2-Equiv.[2]	Energy in (GJ)
Foundations	11,305,738	112,023
Tower	100,227,318	1,318,895
Nacelle	29,451,861	346,480
Rotor	63,165,822	844,945
Electrical	105,152,743	1,286,236
Roads and Excavation	9,593,381	136,684
Maintenance	2,426,435	41,127
Total excluding EOL	**321,323,299**	**4,086,390**
Total including EOL	**355,032,594**	**4,496,884**

Table 1: GHG emissions and energy use of proposed Hauāuru mā raki wind farm over its whole life cycle (including and excluding end of life) in kg CO_2-Eq and GJ

Over 20 years the Hmr scenario would result in the emission of 321,323 tonnes of CO_2 equivalents and would have an energy input of 4.1 PJ, not including end-of-life scenarios (recycling and landfill). Including these scenarios, 355,032 tonnes of CO_2 equivalents would be emitted, and 4.5 PJ of energy would be required for construction and use. The Hmr would recover these amounts of energy in approximately 8.5 to 9.5 months of normal operation. This equates to between 3.5 % and 4 % of the wind farm's lifespan, using this 20 year scenario.

[2] GWP 100 (kg CO_2 equivalents) is the unit of measurement of global warming potential as used by the IPCC. The full term is 'Global warming potential over 100 years, measured in kilograms of CO_2 equivalents'. 100 years is used as a time frame because different gases remain in the atmosphere for different amounts of time. The 'kg CO_2 equivalents' is used because different gases contribute differently to global warming. For example methane has approximately 25 times the global warming potential of carbon dioxide (over 100 years). Therefore 1 kg of methane would be accounted for as 25 kg of 'CO_2 equivalents'. This way it is possible to add up the results of all emissions which contribute to the same environmental impact category.

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1 INTRODUCTION

1.1 Methodology

The study is based on Life Cycle Assessment (LCA) methodology as described in ISO standards 14040 and 14044. However, due to the data availability for the proposed wind farm and the restriction of the results to the greenhouse gas emissions and primary energy, the results do not fulfil the requirements of these standards. A more detailed study with further impact categories would be required to do this, but for the purposes of defining the order of effects under the Resource Management Act consenting process the methodology used is appropriate.

The following elements of an ISO-conforming LCA study have been included:

- Detailed goal and scope description, including functional unit, system boundaries, data quality
- Inventory analysis, including a description of the most significant material and energy inputs and outputs in terms of the contribution to GHG emissions and energy consumption
- Environmental impact assessment, (restricted to GHG emissions and primary energy consumption)
- Interpretation of the results.

1.2 Goal of the study

The goal of the project is to establish a 'carbon footprint' for Contact Wind Limited's (CWL's) proposed Hauāuru mā raki Wind Farm (Hmr). This report takes a 'scenario', in which the maximum total output and turbine height has been achieved (540 MW and 100 m respectively), and the scenario approaches the maximum number of turbines (specified maximum of 180). The 'carbon footprint' includes all GHG emissions from the incorporated materials/parts, the on-site construction as well as the related transportation. This report refers from here on to the total GHG emissions, which are expressed in kg CO_2 equivalents, instead of the 'carbon footprint'. Part of the study will involve calculating the estimated time it will take to recoup (through electricity generation) the energy used during the construction of the wind farm. The Wind Farm is located between Port Waikato and Raglan on the west coast of the North Island.

1.3 Functional unit

The functional unit of this study is the electricity produced at Hmr over 20 years.[3] The wind farm is comprised of 180 Vestas V90 3 MW turbines (540 MW total capacity) on 100 m towers (150 m total height), and is assumed to provide 32,000 GWh electricity (Contact, 2007) over 20 years.

The results are based on a calculation of one 3 MW Vestas V90 turbine and have then been scaled up to the size of the total wind farm. Following this, components such as on-farm electricity reticulation, connection to the national grid, substation construction, roading and maintenance have been included, as well as potential end-of-life scenarios.

1.4 System boundary and scope of the study

The following life cycle stages of the wind farm have been included:

- Production of the materials and parts of the wind turbines
- Transport of these materials/parts from the factory gate to the building site
- Construction of the access roads
- On-site construction process of the wind turbines
- All electrical equipment (cables, pylons, transformers, substation)
- Maintenance
- Dismantling & disposal (included as a scenario)

Data gaps and data quality

Data gaps within the information provided by CWL have been filled with data from previous life cycle inventory studies, turbine specifications and the literature. Site specific data was available, and used wherever possible. A more detailed description of data used can be found in the 'Inventory Analysis' section below.

1.5 Data collection

The data sources for the study are described below. Based on these sources a detailed list of materials has been compiled. Communication with CWL has resulted in a comprehensive list of materials; these and any data gaps are described below.

[3] 20 years is the lifetime assumption used by Vestas (Vestas 2005) in their studies and is a good 'worst case' scenario for turbine lifetime.

Data sources

The following data sources have been used for this project:

- Data from Hauāuru mā raki (WAIKATO WIND FARM) Project Description Report, Contact Wind Limited and Contact Energy Limited, 19 December 2007;
- Data from the Transportation Assessment Report, Traffic Design Group, December 2007;
- Data from the Construction Management Report, Beca Carter Hollings & Ferner Ltd (Beca), December 2007;
- The report “Life cycle assessment of offshore and onshore sited wind power plants based on Vestas V90-3.0 MW turbines”, 2005 [Vestas, 2005]
- Vestas data on V90 turbine specifications 2004-2006 [Vestas 2004-2006]
- LCA report “Life Cycle Assessment of offshore and onshore sited wind farms” by Vestas Wind Systems, 2004 [Elsam 2004] – study of a V80 turbine
- Life cycle inventory database ecoinvent v1.3 [ecoinvent]
- Life cycle inventory database and LCA software GaBi v4.2 [GaBi]

Specific data sources are clearly documented in the inventory analysis of this report (Chapter 2).

2 INVENTORY ANALYSIS

As a first step, an Input and Output analysis was established, which provides detailed material and energy balances over the system as identified under Section 1.4 'System Boundary' in the goal and scope definition. This means that a list of all significant quantities of material and energy inputs, such as concrete and diesel, was compiled. This Input and Output analysis was structured according to the life cycle stages of one turbine.

In the next step these inputs were linked to existing life cycle inventory (LCI) data. The input of diesel for example was connected to a refinery process, where all raw material inputs, such as crude oil as well as all related outputs as emissions to air, water, and soil, were listed.

In the following chapter the main life cycle stages of one Vesta's V90 3 MW turbine are described including detailed data used for the LCA model.

The inventory analysis is structured according to the following categories:

- Generic data (provision of power, model of trucks etc.)
- Foundation
- Tower
- Nacelle
- Rotor
- Electrical
- Access Roads & Other
- Maintenance
- End of life

2.1 Generic data

LCI data for the production of materials, provision of fuels, transport models (trucks and ships) are taken from the LCA software tool GaBi 4.2 [GaBi].

2.2 Foundation

The foundation of a turbine involves the excavation of earth, followed by the addition of concrete and reinforcing steel. The model also incorporates the transportation of the materials to the building site.

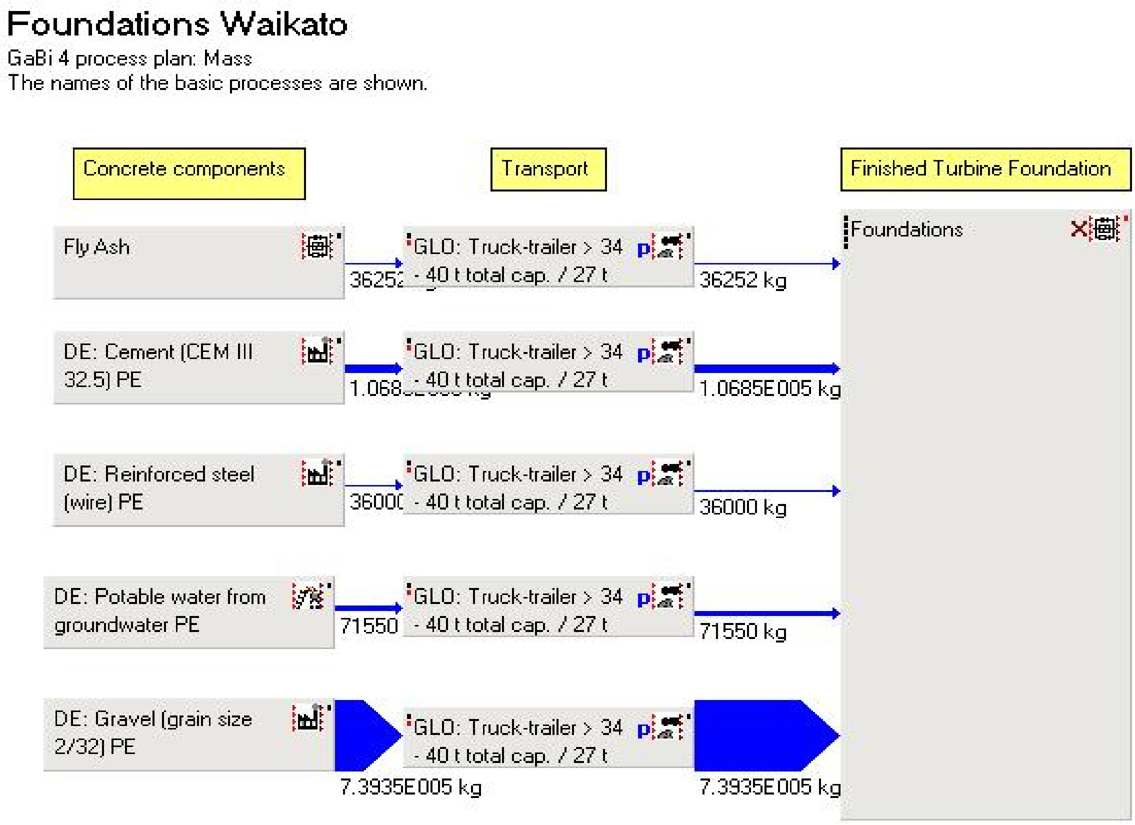

Figure 1: GaBi model of foundation used in proposed Hauāuru mā raki Wind Farm

Figure 1 above shows the GaBi model of foundations used in the Hauāuru mā raki Wind Farm. The following data has been used in the model:

Volume of concrete

The figure provided for the turbine foundation size at the Hauāuru mā raki Wind Farm was 400 m^3 per turbine.[4] This is for Vestas V90 turbines on 100 m towers. This results in the amount of 954 tonnes of concrete based on a density of 2,387 kg/m^3 (dataset "concrete for sole plate and foundation, B35/25, CEM III, 32.5" from [ecoinvent]). Volumes of concrete for each of the 3 substations and the switching station were also provided (2,350m^3 in total).[5] Additional volumes were calculated for the foundations for 33kV and 220kV steel monopoles and 220kV towers.

Components of concrete

The composition of the reinforced concrete foundation was based on a combination of CWL data and ecoinvent data [ecoinvent]. The following composition has been calculated and is a per turbine figure:

4 Hauāuru mā raki Project Description Report, Table 3.1
5 Hauāuru mā raki Project Description Report, Table 7.1

- 739 tonnes aggregate (based on ecoinvent concrete density, with water, fly ash and cement subtracted)
- 107 tonnes cement
- 36 tonnes fly ash
- 72 tonnes water
- 36 tonnes reinforcing steel

Transportation of materials to site

- Cement from nearest port (90 km by truck from Auckland – this is an assumption based on information provided by CWL)
- Aggregate from on-site source (35 km by truck)
- Fly ash from close-by source(35 km by truck)
- Water from closest source (35 km by tanker truck)
- Steel from Auckland to Site (90 km by truck,)

The distance figures for the transportation of different materials were assumptions, as the exact source of each material is not known yet. Information provided in the Contact Energy Project Description Report indicates there are a number of local quarries and aggregate sources within 35 km of the Hmr site.

2.3 Tower

The tower includes the production of steel sections, plus welding and coating, and shipping of the tower parts from Vietnam to Tauranga [Vestas, 2004-2006], followed by transport of the parts to the building site. The assumed end-of-life scenario includes disassembly, transport and recycling of the tower.

Materials, coating and assembly

A total of 250 tonnes of steel are required for the construction of the 100 m tower, as extrapolated from 80 m, 90 m and 105 m towers in Vestas product guides. [Vestas 2004-2006] This process actually starts with more steel than this, as a 5% loss is expected during the stamping and bending process, which is included. For the assembly 89.5 metres of welding line has been used, based on previous Scion experience and using the height & diameter figures [Vestas, 2004-2006] and amount of welds. The welding energy use is based on Ecoinvent. [ecoinvent]. For the epoxy resin coating a surface area of 1,002 m^2 has been calculated using height and diameter specifications. [Vestas, 2004-2006]. With a thickness of 1mm the total amount of epoxy would be 0.986 m^3. Epoxy resin has a density of 1,960 kg/m^3 resulting in a total mass of 1,964 kg of epoxy used[6].

Transportation

It is assumed that the tower sections are shipped from Vietnam to Tauranga. This results in a total shipping distance (Vietnam - Tauranga) of 10,000 km. A further 190 km transport by truck has been added for the transportation from the port to the building site.

2.4 Nacelle

The model of the Nacelle is based on the data shown in Table 2 and is described below.

Material	Mass (kg)	Data source
Gearbox (iron)	23,000	[Vestas, 2004-2006]
Transformer (steel)	7,975	[Vestas, 2004-2006]
Generator (steel)	8,000	[Vestas, 2004-2006]
Bedplate (iron)	8,500	[Vestas, 2004-2006]
Casing (Fibreglass/epoxy)	5,000	Estimation based on size
Other internal parts (steel)	8,814	Total mass minus gearbox/transformer/generator/ bedplate/individual metals
Control System (electronic component)	1,500	50/50 steel/plastic - weight taken from a V80 turbine - Elsam study [Elsam, 2004]
Zinc	2,090	[Vestas, 2005]
Manganese	1,810	[Vestas, 2005]
Aluminium	786	[Vestas, 2005]
Copper	525	[Vestas, 2005]
Lubricant	1,150	EcoInvent

Table 2: Input/output data for model of nacelle, including the data sources

The nacelle components are shown in Table 2, and come together to have a combined total weight of 68,000 kg. Materials in brackets indicate those materials that are being taken into account in the corresponding weight figure. Other materials are taken into account under their own category; for example the copper in the generator comes under ‘copper’ near the bottom of the table. The Nacelle is delivered as a complete unit, from Denmark to Tauranga by ship (approximately 22,000 km), followed by transport by truck to the site (190 km).

[6] Density based on: http://www.unitedlabequip.com/Downloads/Specifications/epoxy_spec.doc

2.5 Rotor

The model used for the rotor is based on data from Vestas and the LCA of a V90 turbine. [Vestas 2004-2006, Vestas, 2005] The quantity of each material is shown on the next page in Table 3. Each rotor has a total mass of approximately 40 tonnes, and is comprised of the blades, hub and nose cone. Figure 2 below shows the GaBi model of the rotor system at the proposed Hauāuru mā raki Wind Farm (for one turbine).

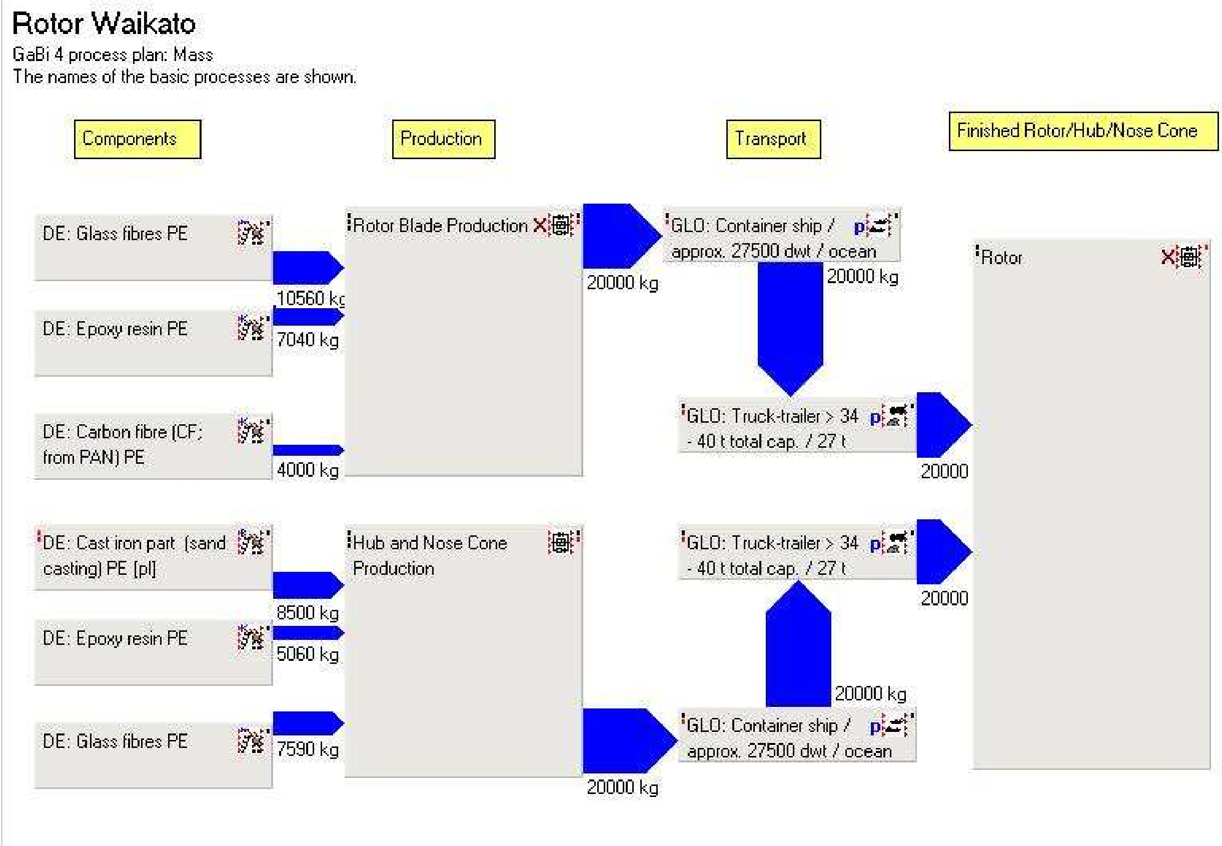

Figure 2: GaBi model of the rotor system at the proposed Hauāuru mā raki Wind Farm (one turbine)

All of the fibreglass and epoxy figures include 10% waste, as specified in the LCA report. [Vestas, 2005] The composite material that makes up the blades and the nose cone is called PrePreg, and consists of approximately 40% epoxy and 60% glass fibres by weight. [Vestas, 2005] For the blades, mass figures were used, and divided up amongst carbon fibre, epoxy and fibreglass. [Vestas, 2004-2006]

Transportation is, like the nacelle, by sea from Denmark to Tauranga, followed by transport to the site by truck.

Material	Amount (kg)	Data source
Blades (epoxy)	7,040	Vestas [2004-2006], [Vestas, 2005]
Blades (fibreglass)	10,560	Vestas [2004-2006], [Vestas, 2005]
Blades (carbon fibre)	4,000	Assumption of 20% by weight*
Hub (Cast iron)	8,500	Vestas [2004-2006]
Nose cone (fibreglass/epoxy)	12,650	Vestas [2004-2006], [Vestas, 2005]

Table 3: Input data for model of rotor, including the data sources

*The 20% (by weight) figure is to make sure that the impacts of carbon fibre are taken into account. No data were able to be obtained from Vestas as to the actual amount of carbon fibre in the blades.

2.6 Access roads and Excavation

The inputs and outputs from the diesel burning process in the excavator (including the emissions) are related to the volume of excavated soil [GaBi]. Figures for earthworks volumes for Hmr were provided. Total fuel use for the proposed project has not been provided but has been estimated on the basis of previous Scion experience. The total rock fill for roading was given as 260 tonnes. [TDG 2007] In addition, this report also notes a total of 300,000 m^3 of roading material and concrete aggregates and 2,500,000 m^3 of earthworks.

After calculating all other fuel use in the project that could be directly attributed to specific processes, extra fuel was added to bring the figure up to 3,000,000 litres. This figure is attributed to roading, cable trench digging and any other excavation on the site. Assuming a density of fuel of 0.9 kg/m3, a total mass of 2,700,000 kg of fuel was estimated.

2.7 Electrical Equipment & Substation

The on-site substation is of concrete construction with a steel roof. As no data on the control systems were available, these are omitted. However, the concrete for the foundations & walls was included, as well as steel for roofing. The quantities for these were calculated using dimensions data presented in the Project Description Report.

Details relating to the 220 kV cabling between the Limestone Substation and Orton Switching Station were included with exact specifications for the type of cable (ASCR

Codename 'Goat') to be used provided in the Contact Energy Project Description Report. The cables are comprised primarily from aluminium, with steel reinforcing. The total length of 220kV cabling was calculated as 68.7 km of cables between substations (22.9 km of single circuit, triple line) and 148.2 km between the Limestone substation and Orton (24.7 km of double circuit, six line). The total calculated length is therefore 216.9 km of 220kV cables.

The 33 kV lines for on-farm reticulation were calculated using data provided in the Project Description Report. Schematics for each substation provided cable lengths between turbines and from the last turbine to the substation. The height of the turbines was also added as additional lengths of cable. This ends up as a total cable length of 114.5 km of triple lines in the ground, plus 232 km of triple lines overhead[7] and a further 18 km to account for the cabling in 180 100m high towers of the turbines. The figures used were for single cables, and therefore were subsequently tripled as the cables are bunched in groups of three. A total of 1,094 km of 33kV cables was calculated. The specifications for the 33 kV cables were not provided (except for the fact that they were aluminium cables), so calculations were made using a single-core screened & PVC-sheathed aluminium cable made by Olex[8], with a nominal overall diameter of 50.8 mm. The fibre-optic cable for control of the turbines, which runs alongside these cables, is not taken into account, as its effect on overall results is expected to be negligible.

Cables to connect the substation to the transformers were not included, as material and cable type for these short cables was unable to be established.

The specifications for the two transformers used in each substation (six in total) were derived by Scion and made on the basis of previous Scion experience. The specifications only included the overall weight (10,100 kg each) and the amount of oil included. Therefore the composition of the transformers was assumed to be mostly steel, with some copper (assumed to be 100 kg, so that the environmental and energy impacts of copper are taken into account). The transport of these transformers from Malaysia to Tauranga has been taken into account.

2.8 Maintenance

Maintenance includes mainly the use of lubricants for the moving parts and epoxy for the steel tower. The total amount of lubricants needed for the whole life cycle was already accounted for in the model of the nacelle. It was assumed that another coat of

[7] For simplicity it is assumed that the cables from the last turbine plus 1 kilometre to the substation are overhead lines carried on steel mono poles.
[8] Specifications can be found at http://www.olex.com.au/Products/High-Voltage.html

epoxy will be applied once during the turbine's lifetime. This results in the use of an additional 1,964 kg of epoxy per turbine. Information provided by CWL states that there is not much traffic to be expected for servicing; therefore it is neglected in this study.

2.9 Dismantling and Recycling

The removal and disassembly of the wind farm is included as a scenario.
The following aspects have therefore been added to the model:

- Transportation of steel, aluminium and copper from the tower and electrical equipment to Auckland (90 km)
- Transportation of steel and aluminium from the nacelle to Auckland (90km)
- Recycling of steel, aluminium and copper (Auckland)
- Transport of remaining materials to landfill (assumed to be 90 km)

Demolition and transport of the foundations is not included as it is not a requirement of the landowners to remove the foundations after the wind farm has been decommissioned. The reinstatement of topsoil on top of the foundations may be required, however impacts of this process have been omitted due to the difficulty in predicting the nature and impacts of this process in 20 years.

The disassembly of the tower has not been taken into account as no data were available. The results include transportation to the recycling facilities, and the recycling processes, i.e. the energy required for the recycling processes of steel and aluminium itself (sorting, remelting, etc.).

The steel and aluminium in the nacelle are also assumed to be recycled, but no energy for the actual dismantling is taken into account, as this would be very difficult to predict (the dismantling techniques in 20 years may be different from those used today). It is likely that the environmental impacts of the transport to landfill or recycling plant and the recycling processes would far outweigh the dismantling processes.

Recycling or disposal to landfill is assumed to take place in Auckland (90km from the Hmr site.

3 GREENHOUSE GAS AND ENERGY ASSESSMENT

This assessment is restricted to the emissions of greenhouse gases and the overall consumption of primary energy.

The total amount of greenhouse gas emissions (or the 'carbon footprint') is expressed in kg CO_2 equivalents. The conversion factors for other greenhouse gases into kg CO_2 equivalents are based on the internationally accepted data provided by the IPCC (Intergovernmental Panel on Climate Change). Additionally the total primary energy use has been calculated and presented in GJ.

3.1 Individual Contributions – not including end-of-life

The results are presented for the full life cycle in order to provide an overview. The two impact categories displayed are global warming potential (GWP) and primary energy use.

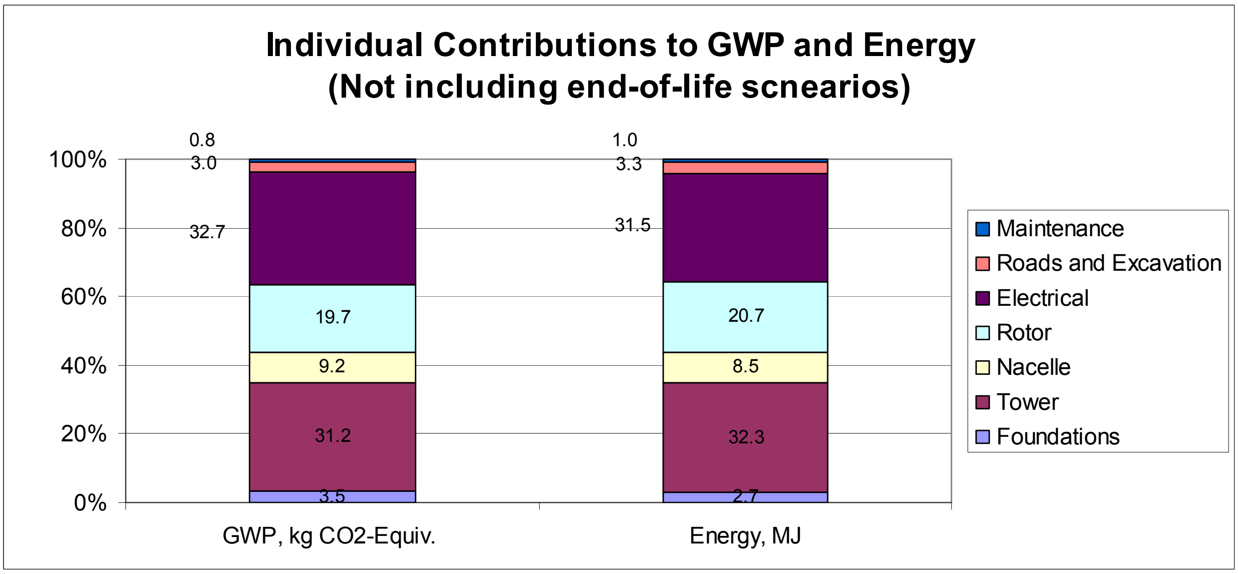

Figure 3: GHG emissions and primary energy use of proposed Hauāuru mā raki Wind Farm over its whole life cycle in % of the total

The main contributions are from the electrical equipment, the tower and the rotor. The electrical equipment is the biggest contributor to GWP and primary energy use with 31 – 33% of the total. This can be mainly attributed to steel in the pylons (monopoles and towers), substations and switching station and 220 kV cables, as well as aluminium and copper in the 220 kV and 33 kV cables. The concrete used for the tower, pole and substation foundations also contributes substantially to both GWP and energy use. The towers, each 100 m high and comprising of 250 tonnes of steel, contribute 31 - 32 % of the GWP and primary energy use. The production of this amount of steel obviously is very energy-intensive, and this is the reason that the tower contributes to these categories in such a way. The epoxy coating, welding and transport are relatively insignificant compared with the steel production. The rotors are the next biggest contributor to GWP and energy use, with around 20 % of the total. The rotor has 45 m long blades comprised of glass fibres, epoxy resin and carbon fibre. The carbon fibre figure in these rotors is an assumption, however even only at 20 % by weight it has a higher impact than glass fibre or epoxy resin. All three of these materials have a significant contribution to these impact categories.

The nacelles are the fourth-most significant contributor (8.5 % of the primary energy use, 9.2 % of the greenhouse gas emissions) due to the use of metals, such as steel, aluminium, manganese, zinc and copper. The large fibreglass casing also contributes to the environmental impact of the turbines. The nacelle itself contains approximately 56 tonnes of steel and iron, which are found in components such as the gearbox, generator, bedplate and transformer.

Roads and excavation contribute around 3 %, though fuel used for transport can account for around two-thirds of this figure. Foundations contribute to 2 - 3.5 %; this is due to the cement and reinforcing steel in the foundations. The aggregate production and subsequent transportation play a very minor role in energy use and GWP - the aggregate and water are to be sourced from nearby locations.

Maintenance on the wind farm plays a very minor role, contributing to less than 1.0 % of the total environmental effects, and this contribution is almost exclusively due to the environmental effects of epoxy production.

3.2 Individual Contributions – including end-of-life

Results for the end of life scenarios are shown in Figure 4, compared with the scenarios that do not include any end-of-life processes. Because it is not possible to predict exactly what will happen to the turbines in twenty years, assumptions have to be made. In this case, all accountable steel, aluminium and copper is recycled, except for reinforcing steel in the foundations. CEL advised that the foundations would remain on site and that all other waste is likely to be landfilled. The results include the transportation to the recycling facilities, and the recycling processes, i.e. the energy required for the recycling processes of steel, copper and aluminium (sorting, remelting, etc.). The relative impacts of each stage change slightly when these scenarios are taken into account.

The biggest change with end-of-life scenarios taken into account is the increased impact of the steel tower. This is due to the transport & more importantly the recycling of such a large amount of steel per turbine.

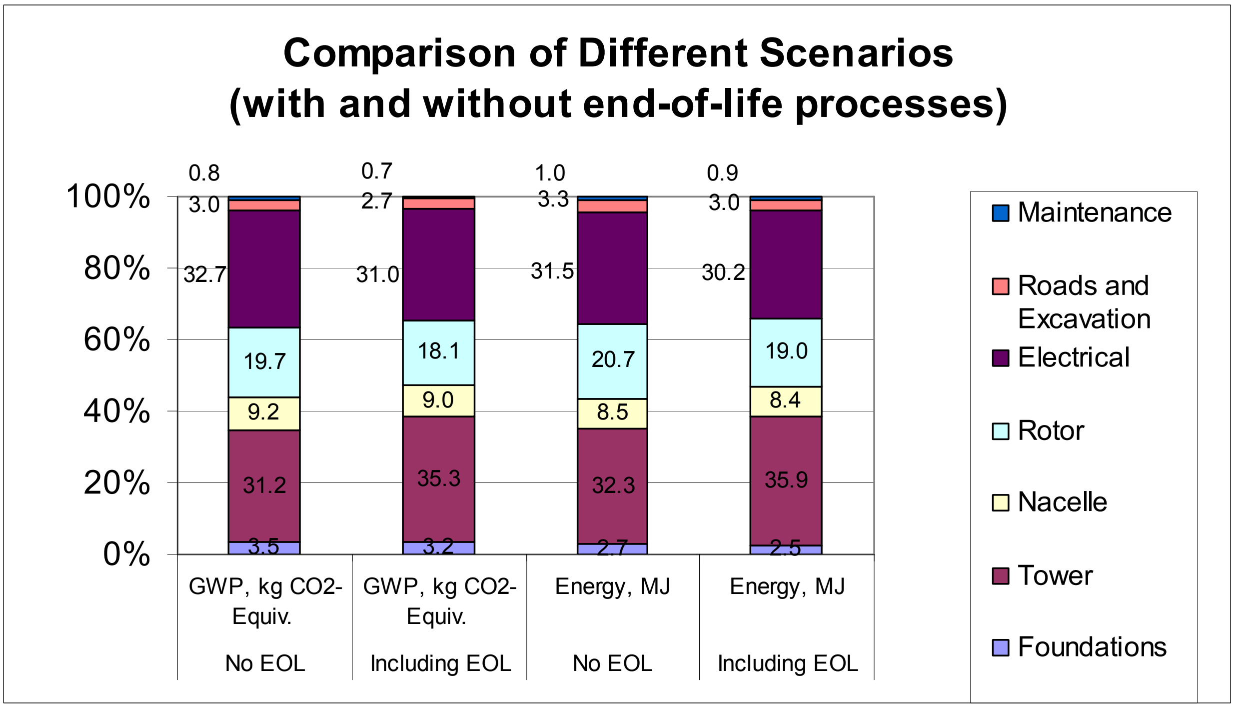

Figure 4: Comparison of the relative impact of each component of the proposed Hauāuru mā raki Wind Farm with and without end-of-life taken into account

All other components decrease in impact, which means their end-of-life processes have proportionally lower energy use and impact on GWP than the end of life disposal and recycling for the tower and foundations.

It should be noted that around 350 tonnes of recycled steel, 4 tonnes of recycled copper and 8 tonnes of recycled aluminium would be produced from these processes, *per turbine*. That amounts to a total of 63,000 tonnes of steel, 670 tonnes of copper, and 1500 tonnes of aluminium. Although the recycling of these materials is at a large energy cost, the opportunity to re-use metals should be noted as an important feature.

3.3 Total Contributions to GWP and Energy Use

The total impact on GWP has been calculated to 100 million kg CO_2 equivalents (excluding end of life processes) and 4.1 PJ of energy use over the 20 year life of the wind farm. The detailed data for the individual parts of the wind farm can be found in Table 4. This table is an alternative way of presenting the data from the previous two figures (Figure 3 and Figure 4), though this table displays the calculated contributions to each category. Table 5 shows the additional impacts caused by the end-of-life processes. EOL processes increase the contribution to GWP by 10.5 %, and increase primary energy use by about 10%.

	GWP 100 in kg CO_2-Equiv.	Energy in (GJ)
Foundations	11,305,738	112,023
Tower	100,227,318	1,318,895
Nacelle	29,451,861	346,480
Rotor	63,165,822	844,945
Electrical	105,152,743	1,286,236
Roads and Excavation	9,593,381	136,684
Maintenance	2,426,435	41,127
Total excluding EOL	**321,323,299**	**4,086,390**
Total including EOL	**355,032,594**	**4,496,884**

Table 4: Total GWP and energy use of proposed Hauāuru mā raki wind farm

	GWP 100 in kg CO_2-Equiv.[9]	Energy in (GJ)
EOL Foundations	0	0
EOL Tower	296,634,789	25,256
EOL Nacelle	29,712,588	2,544
EOL Rotor	11,104,489	974
EOL Electrical	73,041,654	4,934
EOL Roads and Excavation	0	0
EOL Maintenance	0	0
EOL Total	33,709,296	410,494

Table 5: GWP and Energy use of end-of-life scenarios for proposed Hauāuru mā raki wind farm.

Using the energy figures in Table 4, an energy payback time can be calculated. Because the energy produced by the wind farm is calculated in GWh, and the energy of production is shown in GJ, a conversion factor of 3,600 GJ to one GWh must be employed. This results in total primary energy use of 1,135 GWh excluding end-of-life scenarios, and 1,249 GWh including these scenarios. If the wind farm is assumed to generate 32,000 GWh over 20 years, this is an average of 1,600 GWh per year. Using

[9] GWP 100 in kg CO_2-Equiv. - 'Global warming potential over 100 years, measured in kilograms of CO_2 equivalents

this method, the wind farm should take 8.5 to 9.5 months (3.5 - 4 % of the assumed lifespan of the wind farm) to recoup the energy used for its production.

4 INTERPRETATION

This study provides an overview of the greenhouse gas emissions and the primary energy consumption of Hmr over an assumed life span of 20 years.

The results are based around information provided by CWL and therefore provide indicative results which are based on the maximum specifications for construction of Hmr. The end-of-life scenarios depicted in the results should be interpreted as possible outcomes, as the situation has the potential to change substantially in the next twenty years. Though all effort has been made to gather exact quantities for every material in this study, some assumptions have had to be made, the first of which was the use of Vestas V90 3MW turbines. Without exact specifications on rotor blade quantities, the amount of carbon fibre in the blades was estimated based on size. Likewise the amount of copper in the transformers was estimated. The on-farm 33 kV reticulation cable type was based on a standard type of 33 kV aluminium underground cable. Other data that was estimated and required a number of assumptions to be made include the following: the total mass of steel monopoles; the total mass of steel transmission towers; the total number of poles and towers required (details were provided in the Project Description Report to enable these estimates); total fuel use and types of vehicles used; total concrete volumes for all site construction; and Tauranga as an arrival port for imported components.[10]

The carbon footprint has been calculated for the Hmr in a scenario as close as is practicable to CWL's maximum scenario. The results show that the construction and use of the Hmr over 20 years would result in the emission of 321,323 tonnes CO_2-Equiv. and would have an energy input of 4.1 PJ, not including end-of-life scenarios. Including these scenarios, 355,032 tonnes of CO_2 equivalents would be emitted, and 4.5 PJ of energy would be required for construction and use. The Hmr would recover this amount of energy in approximately 8.5 to 9.5 months of normal operation.

[10] Auckland is an alternative arrival Port for imported components. The distance to Port Waikato from Auckland is approximately 90km compared to 190km from Tauranga to Port Waikato.

5 LITERATURE / DATA SOURCES

[Contact ,2007] Hauāuru mā raki (WAIKATO WIND FARM), Project Description, Contact Wind Limited and Contact Energy Limited, 19 December 2007.

[Beca, 2007] Hauāuru mā raki (WAIKATO WIND FARM), Construction Management Report, Beca, December 2007.

[TDG, 2007] Contact Wind Limited, Hauauru ma Raki, Waikato Wind Farm, Transportation Assessment, Transport Design Group, December 2007.

[ecoinvent] LCI Database, Version 1.3, Web: www.ecoinvent.com, access date: 15.05.2007

[Elsam, 2004] Life Cycle Assessment of Offshore and Onshore Sited Wind Farms. Elsam Engineering A/S, October 2004.

[GaBi] Gabi 4 Software-System and Databases for Life Cycle Engineering LBP, PE Stuttgart, Germany.

[Vestas, 2005] Life cycle assessment of offshore and onshore sited wind power plants based on Vestas V90-3.0 MW turbines. Vestas, 2005.

[Vestas, 2004-2006] Various product brochures and information sheets on the V90 turbine, released by Vestas.