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Comparing The Environmental Impacts Of Diesel Generated Electricity With Hybrid Diesel-Wind Electricity For Off Grid First Nation Communities In Ontario : Incorporating A Life Cycle Approach

Jade Schofield
Ryerson University

COMPARING THE ENVIRONMENTAL IMPACTS OF DIESEL GENERATED ELECTRICITY WITH HYBRID DIESEL-WIND ELECTRICITY FOR OFF GRID FIRST NATION COMMUNITIES IN ONTARIO

INCORPORATING A LIFE CYCLE APPROACH

By

Jade Schofield

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Author: Jade Schofield

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Abstract

The cost of diesel is rapidly increasing and the environmental impacts associated with diesel fuel combustion are substantial. Hybrid diesel-wind energy was found to be a feasible energy alternative for off-grid electricity production in seven First Nation communities of Ontario. Based on calculating the wind energy potential for a proposed 250 KW wind turbine and determining the amount of diesel that the wind turbine could replace hybrid diesel-wind has the potential to reduce diesel consumption and environmental impacts associated with the current diesel energy systems by 12- 46 % depending on the wind energy potential. Results of a life cycle analysis comparing the environmental impacts of the proposed hybrid diesel-wind system to the diesel system through the use of GaBi software show that global warming potential is the largest impact for both energy systems, but hybrid diesel-wind can significantly reduce the overall environmental impact caused by off grid diesel electricity generation.

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Chapter 1: Background

Ontario is the most populated province in Canada and currently has an installed electricity capacity of 35,485MW (Independent Electricity System Operator, 2010). Ontarians use more than 152,000,000 MWh of electricity a year (Independent Electricity System Operator, 2010). Installed renewable energy in Ontario consists of hydro totaling 23% and wind energy 3% (Independent Electricity System Operator, 2010). Only 0.3% of the total electricity is produced by other renewable sources such as biomass and solar power (Independent Electricity System Operator, 2010).

Ontario currently has the largest capacity of installed wind energy in Canada (Independent Electricity System Operator, 2010). The annual energy capacity factor produced by wind for the period March 2006 through October 2007 averaged 27 per cent of the total installed generation capacity (Independent Electricity System Operator, 2010) this power is currently generated from ten wind farms across Ontario. Large scale plans are set to further increase the current wind energy capacity in Ontario. The Ontario Power Authority's Integrated Power System Plan currently calls for 4600 MW of wind energy by 2020 (Canadian Wind Energy Association, 2008). An expansion of the electricity grid is already being implemented to allow more wind farms and hydro plants to be connected in Northern Ontario. The expansion is operated by Hydro One, a major electricity supplier of Ontario and is set to be completed by 2013 (Hydro One, 2009).

The Ontario Government has also initiated plans designed to encourage renewable energy production by encouraging the general public and businesses to implement small scale renewable energy technologies that feed into the grid. The program was introduced by the Ontario Power Authority (OPA) and is known as the Feed in Tariff (FIT) program. The program incorporates a twenty year fixed rate payment for electricity production. The main reason for implementing this scheme is to enable Ontario to phase out coal fired power plants (Ontario Power Authority, 2009).

Most towns and cities in Ontario, gain their electricity through the national grid. So far the Ontario grid is increasing its renewable energy sources, but this is not the case for the electricity that supplies communities through off-grid sources. Many remote communities that produce electricity through off-grid sources rely solely on energy produced by diesel generators. These diesel generators account for a large usage of fossil fuels which in turn leads to pollution being emitted.

In Ontario there are 25 remote communities are not connected to the national grid (Hydro One, 2009). Nineteen communities are currently supplied electricity by Hydro One, 15 of which are First Nations Communities. The other communities supply themselves with diesel fuel energy (Ret Screen, 2009). Only three of the First Nation communities have renewable energy sources installed and each of these renewable energy sources installed only partially supports their electricity needs. Wind energy supports energy production for the communities of Kasabonika and Big Trout Lake and a small hydro set is installed at Deer Lake (RET Screen, 2009). These communities with installed renewable sources still rely on diesel to supply some of their electricity demands. Those communities without renewable energy systems rely on diesel to produce 100% of their electricity needs. The Hydro One supplied diesel generators are currently using a total of 14-17 million liters of fuel per year (Hydro One, 2009). In addition to large amount of fossil fuel being consumed, twelve of these communities are not accessible by year-round road and can be accessed only by aircraft, by winter road or, in case of one community, by barge as well (Natural Resources Canada, 2010). The isolation of Hydro One's service territory for electricity also means that the transportation of staff, fuel, and equipment is a factor in the increased energy costs (Hydro One, 2009). Currently costs for fuel in the remote off-grid communities are up three times more expensive than fuel prices elsewhere in Canada and this is mainly due to transportation costs (Natural Resources Canada, 2010).

The small-scale diesel generators (50–100 kW) in remote communities of Ontario are only 25–35% efficient (Thompson and Duggirala, 2009). Since costs for fuel in the remote off-grid communities, with diesel generation and freight costs, are three times more expensive than fuel prices elsewhere in Canada due to transportation costs, renewable energy technologies may make more economic and social sense in remote off-grid communities (Thompson and Duggirala, 2009).

The lack of renewable energy implementation has not been overlooked by the federal government. The reduction of diesel fuel consumption in remote communities was stated as a goal of the government of Canada's Department of Indian and Northern Affairs (INAC) 'Aboriginal and Northern Community Action Program' from 2003–2007 (Indian and Northern Affairs Canada, 2007) and the subsequent 'ecoENERGY for Aboriginal and Northern Communities Program' launched in 2007 (Weis and Illinca 2010). The Eco Energy grant provides a subsidy of one cent per kilowatt-hour for up to 10 years for wind energy production (Eco Action, 2010). This is designed financially help remote communities and the stakeholders to support renewable energy developments as this grant provides security for long term sustainable energy production (Eco Action, 2010). If the reasons behind the lack of uptake of renewable energy are not due to lack of government support or financial assistance then the issue lies within restriction in the availability of energy that can be harnessed for electricity production or limitation of environmental benefits.

1.1 Thesis Statement

Very few off-grid communities in Ontario have installed renewable energy systems to support their electricity demand. The viability of renewable energy as an alternative to diesel fuel for the production of energy requires an in depth assessment. If a renewable energy source can be deemed viable, than an evaluation of the environmental benefits of that renewable energy source can be compared to the current diesel systems in off-grid communities. This will ensure that these communities are able to lower their fossil fuel dependence in a way that promotes environmental protection.

Chapter 2: Literature Review

A literature search is conducted to determine the previous work that has been completed on the impacts of diesel generated electricity for remote off-grid applications in Ontario. This search will determine in depth, the reasons behind why diesel generated electricity is an environmental issue, as well as determining whether other potential energy alternatives have been considered as a suitable alternative for replacing the current diesel systems.

The literature search covers a large range of information that was gathered from primary and secondary sources. The information found to be of significance to the issue are analyzed and the findings and the impact of these findings will have on the issue brought forward is included in the literature review.

For the ease of understanding, the literature review is organized by the categories:

- The impacts of off-grid diesel energy on human health and the environment.

Reviewing the previous works on the environmental impacts created through the use of diesel generated electricity will highlight the major problems that lie within using diesel as an energy source. The works included are those that focus on diesel generated electricity in remote communities. By defining the contributions to the issue occur provides the parameters for the direction in which this study will follow.

- The success of implementation of different renewable energy technologies for northern off-grid communities.

Examining the success of different renewable energy resources will provide insight into the technologies available for off-grid energy production. The literature review defines how different types of renewable energy technologies function, the strengths and weaknesses of each technology and their applicability for off-grid use for remote communities through the understanding of current case studies.

- Potential methods for evaluating the benefits of renewable energies taking into account the site location.

Based on the literature available, physical methods for examining the environmental impacts of energy technologies are established. Evaluating the different methods that have been applied will provide a foundation for comparing the optimum renewable energy technology to the diesel generated electricity systems already in place in the remote communities of Ontario. This method of evaluation can further support future energy choices before a renewable energy technology is installed. This will ensure that the optimum technology is fully investigated before implemented.

The outcomes of the literature review will allow an objective for the study to be formed. They also support decisions as to what methods should be used to fulfill these objectives.

2.1 Diesel as an Energy Source in Remote Communities

For off-grid small scale diesel electricity generation, diesel fuel is combusted in an engine to produce mechanical energy which can be used to generate electricity. Diesel is composed of about 75% saturated hydrocarbons, and 25% aromatic hydrocarbons (Agency for Toxic Substances and Disease Registry, 1995).

Many remote communities in Ontario, gain electricity through the operation of diesel fuelled generator sets. Many of these communities have three engines, one or two of which will be operating at any given time, with the third acting as a standby engine for periods when the others require servicing (Hydro One, 2009). The generators are sized to meet the electrical peak load (maximum demand) of the community with the standby capable of supplying the critical loads of the community. During normal operation two engines operate, each at part load, so as to provide the reliability and load following flexibility necessary for the community (Natural Resources Canada, 2006).

The cost of diesel fuel is becoming a major weakness in diesel generated electricity. Hydro One has stated that the fuel cost increase totaled $3,744,000 which equals 21% of the total cost in 2009, in comparison to 2006 (Hydro One, 2009). The Energy Information Administration (EIA) predicts that the cost of diesel fuel will continue to rise, making it more expensive to produce electricity from this source (Energy Information Administration, 2009). This is due to the increase in the amount of diesel in demand which reduces the available supply and drives up the cost (Indian and Northern Affairs Canada, 2010). The cost of diesel fuel is also being impacted by global warming. The shorter the winters, the less time the ice roads are available for transportation, therefore the amount of diesel being transported by air is increasing, which raises the cost of fuel (Indian and Northern Affairs Canada, 2010). The delivered cost of diesel fuel has increased by 70% since 2004 compared to the costs in 2008 (Hydro One, 2009). In 2008 Hydro One required an additional $42,500 to pay for the increases in diesel and operating costs for remote communities of Ontario (Hydro One, 2009). This means that the remote communities are required to find the extra finances to pay for the increased cost of diesel to Hydro One. The high cost of diesel generated energy deters economic growth in these northern regions as new businesses are put off by the high energy cost (Indian and Northern Affairs Canada, 2010).

In addition to the economic implications, diesel energy produces social impacts. Diesel generated electricity is noisy which can be disruptive in quiet remote locations (Indian and Northern Affairs Canada, 2010). Due to the remote location of these communities blackouts often occur due to generator break down. This can be very dangerous in the winter when the temperatures are very low (Indian and Northern Affairs Canada, 2010).

Unfortunately the production and use of diesel fuel leads to many emissions being released into the environment. These emissions have implications on human health and the environment. Cackette and Lloyd (2001) list the emissions produced during the combustion of diesel as:

- Carbon Dioxide (CO_2)
- Carbon Monoxide (CO)
- Methane (CH_4)
- Nitrous Oxides (NO_x)
- Particulate Matter (PPT)
- Sulphur Oxides (SO_x)
- Volatile Organic Compounds (VOCs)
- Heavy Metals (HM)

It can be summarized that effluents from the combustion of diesel contribute to many cancer and non-cancer health effects in humans and living species as well as contributing to soil, water and atmospheric degradation (Cackette and Lloyd, 2001). The severity of these emissions is high and each has a negative impact on humans and the environment.

In addition to the many emissions produced through the combustion of diesel, other effluents are produced during diesel engine manufacturing, as well as the production, storage and distribution

(Cackette and Lloyd, 2001). Figure 1 shows the sources that emissions are produced throughout the use of diesel fuel.

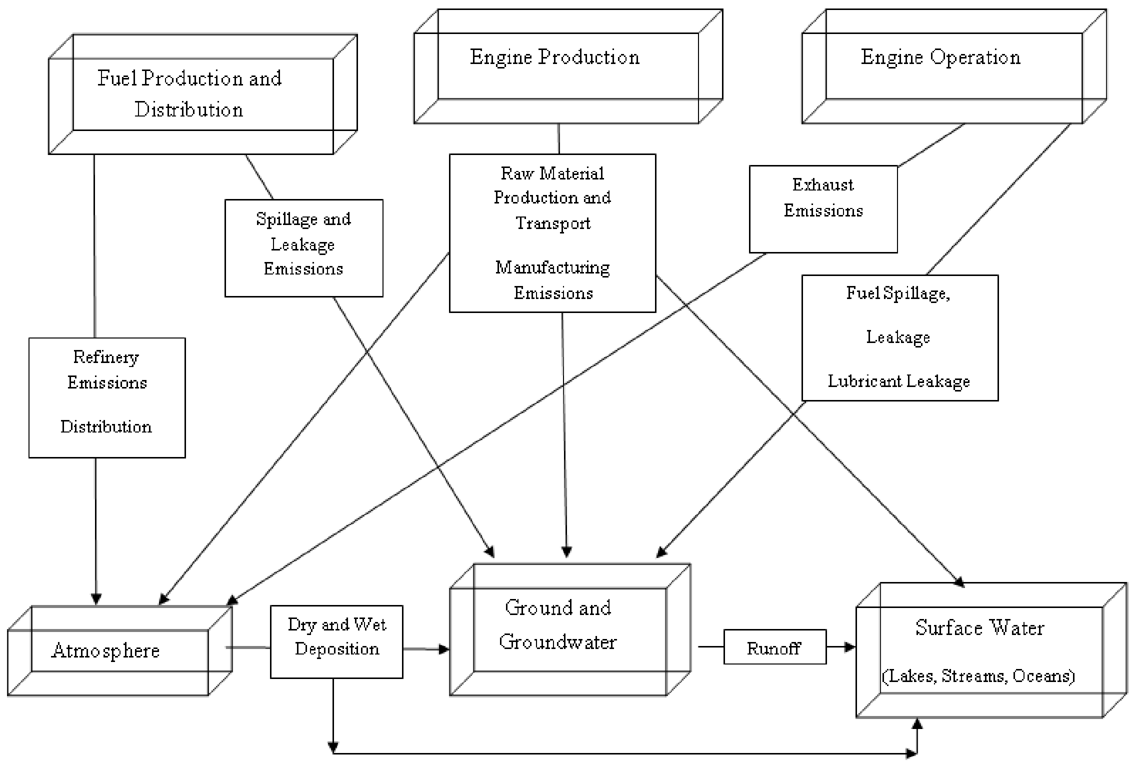

Figure 1 The emissions sources produced through the use of diesel fuel (Cackette and Lloyd, 2001)

Hydro One (2009) states that fuel spills also have major environmental implications in remote communities. Diesel spills lead to soil contamination. When a spill occurs action must be taken. This includes removing the contaminated soil or implementing mitigation methods to prevent future accidents (Hydro One, 2009). In 2008 environmental expenses associated with the clean up, investigation and monitoring of a large fuel spill at the Kingfisher station cost $263,000 (Indian and Northern Affairs Canada, 2010).

Nonetheless, diesel fuelled generators provide a suitable energy source for use in off-grid communities due to its low cost in comparison to connecting the community to an existing grid (Nayer, 2011). Cost is often the main driver in decision making when it comes to deciding the energy technologies to be installed (Verbruggen et al., 2009). Diesel is also the least flammable in comparison to other combustion fuels such as gasoline and propane, making this type of fuel safer for transportation and storage (Verbruggan et al., 2009).

There are some benefits associated with diesel generated electricity. Diesel fuelled generator systems are small in size when in comparison to other energy technologies. They also require little planning for installation (Nayar, 2011). This is due to their ability to operate in any location providing there is a diesel fuel supply. Diesel availability is stable, and many suppliers operate delivery systems, making diesel fuel fully accessible (Nayer, 2011). A major benefit of using diesel generator systems is its ability to meet the electricity demand at any given time. The amount of electricity a diesel fuelled generator can produce can be controlled and therefore the electricity output fluctuates depending how much energy a user requires (Vebruggan et al., 2009). This prevents over use of diesel fuel and a secure method for providing electricity as it is demanded (Natural Resources Canada, 2006).

It can be concluded that diesel generated electricity provides a stable electricity source that meets the individual demands of the remote communities (Nayer, 20011; Natural Resources Canada, 2006). Diesel generators are small in size require little planning for implementation. Although there are benefits to using diesel generated electricity as it is a reliable fuel source, as well as easy to operate technology, using diesel generated electricity produces many economical, environmental and social impacts (Indian and Northern Affairs Canada, 2010). Unfortunately, diesel emissions degrade human health and the environment. In addition, cost for this electricity is rising due to increasing diesel costs and restrictions in transportation. The restrictions to transportation refer to ice roads in particular, where the period in which they are open is decreasing yearly as a result of warmer winters, which results in more diesel fuel having to be transported by plane or boat. A suitable alternative to the electricity source needs to be determined that meets the strengths of diesel generated electricity but mitigates the weaknesses caused by diesel generated electricity. This leads to the following requirements that need to be obtained by a replacement electricity source:

- Meets the energy demands of the individual remote community
- Provides a reliable electricity source
- Can operate in cold climates

- Reduces cost by limiting the need for fuel delivery
- Reduces emissions that have harmful effects on human health and the environment.
- Reduces the potential environmental impacts associated with spillage

2.2 Renewable Energy Technologies in Remote Communities

This section of the literature review evaluates hydro, solar and wind renewable energy for implementation in off-grid communities in Ontario. These energy sources have been selected for evaluation as they do not require a fuel for electricity production, and will mitigate the need to transport fuels to the remote communities. It can be considered that the renewable energy technologies discussed are the most feasible alternatives for electricity generation.

2.2.1 Hydro Generated Electricity

Hydro generated electricity is a renewable electricity source produced by the movement of water (Hinrichs and Kleinbach, 2006).

In Canada, small hydro generated electricity generally refers to hydroelectric projects with between 100 kW and 50 MW in installed capacity (Natural Resources Canada, 2009). Small hydro is often used for off-grid applications and has been applied in off-grid locations (Natural Resources Canada, 2009).

Hydro generated electricity is commended for its ability to produce a steady amount of electricity providing the water supply is constant (Natural Resources Canada, 2006; Paish, 2002). This is an important factor for remote communities which need a reliable source of electricity. For off-grid locations, hydro electricity technology contains a speed control which allows the adjustment of power production to meet the electricity demands of the community it is serving (Paish, 2002). Hydro generated electricity does not produce emissions during its lifespan making it a preferred option over fossil fuel based electricity sources (Paish, 2002). The technology itself also has a long life span between 25-50 years (Ministry of Natural Resources 2011; Natural Resources Canada, 2006). Another major benefit to hydro produced electricity is that it does not require a large amount of maintenance which reduces operating costs (Ministry of Natural Resources, 2011). This is particularly beneficial to those remote communities of Ontario where transportation and maintenance costs are a major cost factor.

In 1999, Yukon and Northwest Territories had the largest amount of installed off-grid hydro generated electricity in Canada (You and Leng, 1999). The provinces of Alberta, Saskatchewan and Manitoba did not have any installed hydroelectricity. You and Leng (1999) state that, "hydro generated electricity is playing an important role in electricity generation in remote communities of Canada especially in the Yukon". This is because hydro generated electricity has a life span of fifty years and is been increasingly developed by independent power producers who have been able to negotiate a long term contract to sell power to the local utility (You and Leng, 1999).

In Ontario, INAC and Hydro One funded the implementation of the off-grid 490 kW hydroelectric plant for the remote community of Deer Lake, Ontario (Environment Canada, 2010). This is currently the only off-grid hydro plant operating in Ontario. The small hydro plant, implemented in 1998, harnesses 3.4 m of hydraulic head to support the community's energy needs (Natural Resources Canada, 2009). A programmed control system integrates the hydroelectric plant with the Deer Lake’s existing diesel generation system in order to meet peak energy requirements (Natural Resources Canada, 2009). Although the hydro energy plant is not capable of producing the entirety of Deer Lake’s energy demands, it has been able to reduce the amount of diesel consumed by 30%. Between years 1999-2000, $400,000 was saved due to the reduction of diesel fuel required for electricity production (Environment Canada, 2010). During 1999-2000 the hydro plant at Deer Lake prevented 1,300,000 kg of CO_2, 25,500 kg of $NO_{x,}$ and 2,500 kg of SO_x being released into the environment (Environment Canada, 2010).

Other potential off-grid hydro generating electricity sites have been identified in Ontario. According to the Ontario Water Power Association (2006) there is potential for more First Nation communities located in Northern Ontario to gain their some or all of their electricity needs from hydro technology. These communities include:

- Bearskin Lake: Four potential sites that could produce 1-9.9 MW of electricity
- Fort Severn: One potential Site that could produce 10-49.9 MW of electricity
- Gull Bay: One potential site that could produce 1-9.9 MW of electricity
- Maarten Falls: Two potential sites, one with a potential greater than 100 MW, the other between 1-9.9 MW
- Wapekeka: One potential site that could produce 1-9.9 MW of electricity

- Wunnummin Lake: One potential site that could produce 10-49.9 MW of electricity.

The literature does not suggest if or when that future implementation of hydro electricity may occur. This may be due to a number of reasons but the main barrier is the cost of implementing hydroelectricity generating technology. Smaller hydro generated electricity sites are often a result of the existence of a low hydro head. Economic feasibility is currently the most important factor in the development of a low head site as lower hydro head means lower power output per unit of flow (Ministry of Natural Resources, 2008). A low or ultra-low head system costs $2,000-9,000 per kilowatt, installed. This price estimate does not include transportation or implementation costs (Ministry of Agriculture and Rural Affairs, 2011). Due to the remote locations of these communities it is presumed that the cost for installing hydro electric would be much higher, further restricting the economical viability of hydro electric power in remote communities.

Weather conditions are a major consideration for small hydro generated electricity developments. In cold climates there is a risk that small waterways may freeze which prevents electricity from being produced (ABS Alaskan, 2008). Precautions need to be taken to protect the hydro turbine during winter freeze and spring thaw; the entire assembly may need to be removed from a river during surface-freezing. After the ice has formed completely, a hole can be cut in the ice to accommodate the re-installation of the generator and mounting assembly. In spring, the generator should be removed when thaw begins, and re-installed once the surface ice has disintegrated to the point of not posing a structural threat to the assembly (ABS Alaskan, 2008). If a winter is particularly cold there is risk that the entire water body could freeze (particularly on hydro dams with low head); this would prevent electricity production (Ettema et al.,2009). This would require the remote communities to gain their electricity supply from a secondary source. Fluctuations in water levels created by seasonal temperature changes also create a barrier: if a summer is long and dry it is likely that water levels will drop lowering the head of the hydro dam and lowering its potential electricity capacity (Gleick, 1992;Smakhtin, 2001). The restrictions created by seasonal changes may impact the ability for remote communities to gain a steady supply of electricity. Remote communities' peak electricity demand occurs in the winter (Hydro One, 2009); if hydro generated electricity is restricted by the freezing of water then it does not provide a reliable electricity supply.

Major ecological impacts are caused by hydropower projects in all of the four habitats associated with the projects, the reservoir catchment, the artificially created lake, the downstream reaches of the dammed river, and any estuary into which the river flows (Gleick, 1992; Abassi and Abassi, 2000). Hydro dams create elevated sediment movement in the water body, which can increase the availability of heavy metals such as mercury (Abbasi and Abbasi, 2000). This poses environmental and social risk. If mercury is released from the sediment it increases the amount available to form volatile substances such as methyl mercury (MeHg) (Mailman et al., 2006). Evidence proves that there are effects on fish reproduction when their food contains MeHg concentrations that are in or near the range found in new hydroelectric reservoirs (Wiener, et al.,2003). During the construction of the hydro electric plant dams, a temporary dam must be put in place to allow construction to commence. This temporary dam results in flooding of the lands surrounding the proposed hydro electric site. This can create many environmental concerns as flooding the surrounding area distributed the water body's sediment transporting mercury onto the land (Mailman et al., 2006). The sediment is deposited on the land which poses a risk for contaminating soils and vegetation People are exposed to MeHg by eating fish, contaminated vegetation, or animals that have eaten contaminated fish and vegetation (Richardson et al., 1995). In humans, MeHg can cause the loss of sensation in skin, loss of coordination of the muscles, disorders in articulation, deafness, death, and effects to offspring (Clarkson, 1990). This is of particular risk to those remote communities in northern Ontario where many rely on their land or fish to sustain their diet (Natural Resources Canada, 2009). Hydro electricity has also proven to have severe impacts on the movement of aquatic species within the water body (Johansson and Burnham, 1993).

Social impacts are often created with hydro electricity development. The need to flood land for dam construction creates the risk of flooding homes resulting in the relocation of individuals and, in extreme cases, entire communities. Hydro electricity can restrict the availability of water for other uses (Gleick, 1992). Many remote communities rely on surface waters within close proximity for drinking, if the water is dammed for hydro electricity usage this may prevent drinking water access (Natural Resources Canada, 2009).

In summary, the findings show that hydro energy technology does have the potential to produce electricity for some off-grid remote communities of Ontario (Environment Canada, 2009; You and Leng, 1999, Ontario Waterpower Association, 2007). Hydro generated electricity could provide a better energy alternative to diesel generated electricity, as no emissions are created through its lifespan (Paish, 2002). When operating, this type of technology produces a steady amount of electricity. However issues with icing in cold temperatures effect the reliability of this technology during the remote community's peak demand times (Ettema et al., 2009; ABS Alaskan, 2008; Smakhtin, 2001). The necessity to have a reliable electricity source provided by hydro generated electricity in winter may be made vulnerable hydro generated electricity does have a negative impact on the environment, including land degradation and contamination of aquatic species (Gleick, 1992; Abassi and Abassi, 2000; Mailman et al., 2006; Natural Resources Canada, 2009).

2.2.2 Solar Energy

Solar energy may be used to produce electricity by extracting light energy from sunlight and converting it into electrical energy (Hinrichs and Kleinbach, 2006). Photovoltaic cells (PV) are the most common technology used to convert the sunlight into electricity (Hinrichs and Kleinbach, 2006; Thomas, 2009). According to Hinrichs and Kleinbach (2006) energy conversion efficiency of sunlight to electricity can be as high as 30%.

Electricity generated by PV is becoming more economically feasible in part due to the increase of fossil fuel prices (CanSIA, 2011; Ayoub and Dignard, 2008). PV does not require any fossil fuels for electricity production; the only energy source required is solar radiation. This lowers the cost of running PV technology as well as eliminating emissions created by fossil fuel electricity generation (Ayoub and Dignard, 2008). There has been a significant increase in material technology and the ability for PV technology to produce a greater electricity capacity (Ayoub and Dignard, 2008; Solar Energy International, 2004). These increasing benefits have provided the opportunity for electricity to be harnessed by PV technology, which has resulted in an increased into installed as well as proposed PV, produced electricity (Ayoub and Dignard, 2008).

McKenney et al. (2008) produced a map showing the variation of potential PV-generated energy across Canada in terms of seasonal solar radiation available and to determine feasible sites for grid connected, and off-grid PV (Natural Resources Canada, 2007). The outcome of this study shows that Canada has a PV potential averaging 1120 kWh/kW (McKenney et al., 2008). South of the Prairie Provinces particularly Regina, Saskatchewan has the highest potential for PV electricity production in Canada averaging 1300-1400 kWh/kW (McKenney et al, 2008). Other areas with high PV include southeast Ontario, southern Quebec and southwest Ontario.

The feasibility and benefits of PV electricity has resulted to the increase of installed solar power in Canada (CanSIA, 2011). Installed capacity for PV in Canada has grown by 27% annually since 1993, reaching 25.8 MW in 2007, of which 89% are in off-grid applications (Natural Resources Canada, 2009). In September 2010 the world's largest PV plant began operation in Sarnia, Ontario, with an installed capacity of 80 MW.

For smaller scale electricity generation PV panels can be attached to roofs of buildings, (Usher, 1994). Although PV is easily designed to produce electricity for off-grid use according to INAC (2010) there are currently no off-grid First Nation communities in Canada are relying only on PV technology to support electricity demands. The only communities utilizing PV technology are Beaver Lake Cree Nation, Alberta who implemented a PV wall to heat their community centre, and Wha-Ti community in the Northwest Territories who implemented PV to help heat their elder's complex (Indian and Northern Affairs Canada, 2007).

The lack of installed PV technologies in off grid First Nations communities is due to many reasons. In northern areas of Ontario the available sunlight is approximately 1000 kWh/kW (McKenney et al., 2008); this is significantly lower than those areas with high PV potential. The long winter periods and short hours of daylight prevent PV from being able to produce a secure amount of electricity (McKirdy, 1999; Nepetaypo et al., 2010; McKenney et al., 2008; Nepetaypo et al., 2010; Usher et al., 1994). This suggests that electricity produced by PV does not reflect the electricity demand of the off-grid First Nations of Ontario, as it is during the winter season the peak demand for electricity occurs (Nepetaypo et al., 2010). Seasonally fluctuating radiation and other adverse climatic factors have made the implementation of PV challenging in northern Canada (Usher et al., 1994).

In addition, storage methods are required for electricity produced during the daytime for use during the night (Thomas, 2009). In order to be cost-effective in the north, either form of seasonal storage or a back-up generator is required (Usher et al., 1994; McKirdy, 1999).

Weather conditions greatly impact the amount of electricity able to be produced. The amount of cloud cover affects the energy available to be harnessed by the PV technology (Sen, 2004; McKenney, et al., 2008). Another climatic factor to consider when utilising PV systems especially in northern Canada is snow accumulation on the PV panels (Usher et al., 1994). If snow covers the PV panel it prevents solar radiation from being absorbed (Usher et al., 1994; McKirdy, 1999). This is a major restriction of the use of PV technology in northern Ontario as this region experiences a significant amount of snowfall.

Through the use of new technologies and the development of cold climate expertise, many off-grid electricity applications in Canada are now being supplied cost effectively by small scale PV. With proven success of PV electricity production, this technology has the potential to support the electricity demands of off-grid First Nation communities of Ontario, but is not able to compete fully with diesel generators (McKirdy, 1999). Due to varying radiation available by sunlight, PV would not be able to provide an entire community with their electricity needs without the implementation of storage, or the provision of back up energy sources such as diesel generators, which would be heavily relied on during the long winter season and time of peak electricity demand (Nepetaypo et al., 2010; Usher et al., 1994). Even with electricity storage or back up electricity sources the total amount of storage required to sustain high energy demands during the winter periods may be large and would only slightly reduce the need for diesel generators (Nepetaypo et al., 2010). Based on the findings it can be concluded that PV power does not have the potential to replace diesel generators used in off-grid First Nation communities of Ontario.

2.2.3 Wind Energy

This section of the literature review will include an overview of how electricity is produced by wind; taking into account the common technologies used the benefits and the weaknesses of wind energy, and a detailed study as to whether it has the potential to be electricity source of remote communities.

Electricity is produced by the energy in the wind which is derived from kinetic energy available in masses of air. Through the use of wind turbine technology this kinetic energy is able to be harnessed and transformed into electrical energy (Mathew, 2006).

Wind energy is the fastest growing energy source. It is often favoured over fossil fuel electricity supplies as it produces no emissions during its use, it does not require a fuel to operate the technology just optimum wind speeds (Sesto et al., 1998). Wind energy technology requires little maintenance and has a lifespan of twenty years. Wind turbines are often implemented on farmland as it requires little land space, enabling farmers to utilize the land surrounding the towers base. Wind turbines are often argued to be the most economically feasible renewable energy source as the mechanisms of the turbines are fairly simple in design.

Today, a wind turbine produces 180 times more electricity; at less than half the cost per kWh than its equivalent 20 years ago (European Wind Energy Association, 2006). The increased wind turbine technology development has led to rising energy conversion efficiency. Wind energy is being noted for high reliability with the support of increasing detail of the planning process. This in turn with a drop in selling prices of machines has allowed wind energy to be an environmentally and economically viable energy resource (Sesto et al., 1998).

The wind turbine is a device able to tap some of the power of wind and has theoretical efficiency between about 35-40% (Sesto and Casale, 1998). Wind turbine technology has two general designs: horizontal and vertical axis (Pope et al., 2010). Horizontal axis wind turbines are the most common used and this is because they are able to achieve higher energy conversion efficiencies (Pope et al., 2010). Horizontal axis wind turbines generally consist of blades mounted on tall towers attached to a horizontal shaft. Wind turbines produce electricity when the wind blows. The wind causes the blades to turn a shaft. The shaft is attached to a generator located inside the head, or ‘nacelle’ of the turbine (Mathew, 2006). It is the generator which turns the kinetic energy into electrical energy (Canadian Wind Energy Association, 2010). This electricity can then be transported through cables for consumption or storage (Mathew, 2006). Wind turbines vary in size. The size of a wind turbine reflects the amount of energy that it is able to produce (Diamond and Plotnik, 2010; Hakim and Tafreshi, 2009). The larger the blades and nacelle, the higher amount of kinetic wind energy can be harnessed and converted into electrical energy (Diamond and Plotnik, 2010). The reason that the largest turbines are not implemented in all areas is simply due to efficiency and cost (Lindenburg, 2008; Hakim and Tafreshi, 2009).

Wind speed increases with elevation (Wen et al., 2009). The height of the wind turbine tower is important for extracting the necessary energy available from the wind for electricity production (Lindenburg, 2009). The wind turbine tower is the main structure which supports rotor, power transmission and control systems. The tower also elevates the rotating blades above the land surface (Negm and Malawi, 2000). Because wind velocity increases with distance to the ground, the tower height can assist with determining how much energy a wind turbine can produce (Hinrichs and Kleinbach, 2006). Wind turbines intended for smaller stand-alone use usually have rotor diameters of 10 m or less and would be mounted on towers of 50 m or less in height (American Wind Energy Association, 2009).

Cut in wind speed is the minimum wind speed that a wind turbine needs to produce electricity. These speeds range from 4 km/hr-18 km/hr (Wen et al., 2009). The cut in speed can affect the reliability of a wind turbine by affecting the load carrying capacity (ability to produce energy). The lower the cut in speed of a wind turbine the higher the load carrying capacity resulting in a better reliability (Wen at al., 2009). Cut out speed is the wind speed in which the wind turbine stops turning. If the wind blows higher than the turbine load capacity, the turbine will stop. This is mainly due to safety reasons. For optimal wind harnessing, a wind turbine will need to be elevated at a height where wind speeds exceed the cut in speed, yet are not higher that the cut out speed of the turbine.

Canada has a wind energy potential of approximately 28,000 MW (Independent Electricity System Operator, 2010), which represents a significant sustainable energy source. Canada is known for utilizing its large wind energy potential both for electricity through the grid and off grid applications (Islam et al., 2004). Off grid applications of wind energy in Canada have a potential to produce 616,900 KW of electricity, with 2900 KW being located in northern and remote areas (Canadian Wind Energy Association, 2010).

The community of Kasabonika is a remote off-grid community that is taking advantage of the available wind energy. In 2004 this First Nation community located in northern Ontario installed a 280 KW wind turbine to support their electricity needs (Johnson, 2009). Diesel generators are still used in Kasabonika to support the wind turbine when demand is high or when wind energy is not available (Johnson, 2009).

Weis and Illinca (2010) used Ret Screen software to determine whether the average wind speeds would allow for wind energy to be feasible energy source for the 150 remote communities across Canada. The results outlined that, eighty-nine remote off-grid villages have wind speeds identified as being at least 5.0 m/s. Therefore could be considered as candidates for economically sound remote wind energy applications. It has been estimated that remote communities of Canada could save $11,500,000 Cdn per year if diesel wind replaced traditional diesel generator energy sources (Weis and Illinca, 2010). The cost itself provides a large incentive for remote communities to switch their energy sources. If the 89 remote communities that were determined feasible for diesel wind systems, implemented wind turbines it would result in avoiding 7,600 tonnes of CO_2 emissions by displacing of 9.6 million liters of diesel annually (Weis and Illinca, 2010).

Weis and Illinca (2010) determined that only two remote communities Ontario were suitable for wind energy harnessing: Fort Severn and Webequie. Although other off-grid communities in Ontario were deemed to not have a large enough wind speed in their location, this can be argued. As previously mentioned wind speed increases with elevation. Weis and Illinca (2010) only established communities that have the potential to harness wind by establishing the wind speeds in each of these communities at a height of 25 m above ground level. If wind speeds were measured at a higher elevation, then more communities may be suitable for harnessing wind energy.

A major reason behind the slow implementation of wind energy in remote communities is due to the difficulty in determining the economic feasibility of wind energy is dependent on the technology installed and the wind resource (Blanco, 2009). The local wind resource is by far the most important factor affecting the profitability of wind energy investments and also explains most of the differences in the cost per kWh produced between individual wind projects (Blanco, 2009). In areas where a low energy concentration occurs, a wind turbine of significant power must be installed, or a large number of wind turbines may have to be used (Sesto and Casale, 1998). This increases capital cost of implementing wind energy but does not increase the profit made from the energy returned, meaning that the return rate is lower.

According to the 2006 global wind outlook report, the development of meteorological software to evaluate the profit margin of wind energy harnessing is now a major factor in determining location and installation of wind turbines (Global Wind Energy Council, 2006). The focus in meteorological modeling has taken away from the development of the wind turbine itself. The location for each individual wind turbine is now extensively researched to ensure maximum profit can be made, which ironically has lead to the increase of the cost for wind turbine installation (Blanco, 2009). By focusing on determining the optimal sites for locating wind turbine implementation has led to navigating away from improving the technology of wind turbines, where as if wind technology was improved at a faster rate it would be a greater viable energy resource for more locations (Blanco, 2009).

Financial funding by the government provides incentive for the further development of wind energy especially as costs are increasing due to rising planning and labor costs. A study conducted by Bolinger and Wiser (2009) shows that the cost of wind farm implementation increased in 2008 by 20% from the costs measure in 2007 (Bolinger and Wiser, 2009). To ensure that wind energy continues to be a feasible energy source, costs need to be minimal and incentives offered by the government which offer some relief and incentive to continue the growth of wind energy need to remain available. When wind energy can be used to reduce reliance on diesel generation, communities that are not connected to the electricity grid can achieve lower costs and greater independence (Natural Resources Canada, 2009). Wind energy is a sustainable power source and is becoming sustainable financially. In short, those companies investing in wind energy will be able to do well by doing good (Welch and Venkateswaran, 2009).

Although there are many benefits associated with wind energy it must be noted that electric power from wind energy is quite different from that of conventional fossil fuel resources. The fundamental difference is that the wind power is intermittent and uncertain. Therefore, it affects the reliability of power system in a different manner from that of the conventional electricity generators (Wen et al., 2009). It has to be recognized that there is low energy concentration of wind, and it is highly variable and random availability over time. Wind energy unfortunately cannot replace the entire energy source as it does not provide a steady rate of electricity (Johnson, 2009).

Another issue that lowers the efficiency in a wind turbine is during the energy conversion stage. The amount of electrical energy actually produced by the wind turbine is much lower than that of the energy available from the wind due to the loss of energy when kinetic energy is converted into electrical energy (Gipe, 2004). The maximum amount of electrical energy produced from the wind is approximately 49.3% of the wind's power (Gipe, 2004).

The environment in which the wind turbine is located is another important factor in the reliability of the wind turbine as an energy source. Weather can impact the maintenance needs. Northern communities of Ontario experience harsh weather particularly in the winter where cold climate can greatly affect a wind turbine's ability to produce power (Wen et al., 2009). Icing of the blades is a significant issue with wind turbine located in cold climates. Icing occurs when ice builds up on components of the wind turbine. A study conducted by Jasinski et al. (1998) proved that icing degraded the efficiency of a wind turbine by as much as by as much as 20% (Jasinski et al., 1998). Ice collects on both the rotating and non-rotating surfaces (Lacroix and Manwell, 2007). The most adverse effect of icing occurs on the rotor itself. Its consequences vary but mainly consist of:

- Interference with the speed control of moving components within a wind turbine
- Increased load on the rotor preventing it from turning freely due to the extra mass of the ice on the blades and rotor
- Off balancing the rotor causing it to wear, especially if ice buildup is not evenly spread
- Reduce the amount of energy the wind turbine is able to capture. (Lacroix and Manwell, 2000).

Changing the physical properties of the blade can prevent ice accumulation. The application of an anti-adhesive coating on the blade such as Teflon can prevent ice formation. Another method is the use of black coated blades which absorb heat and therefore restricts the ideal conditions of ice formation (Lacroix and Manwell, 2000). Heating of the blades is also a method used to de-ice the blades of the wind turbine unfortunately that does lead to increased energy consumption which can be up to 25% of the wind turbines energy production and is therefore not the most energy efficient method of de icing, but does provide a superior method of de icing in areas where Tethlon and dark coloured blades will not prevent icing.

Another factor affecting the implementation of wind energy is public concern. Although studies prove that the majority of public are in support of sustainable energy such as wind, when designs turn into development it often creates huge skepticism within the general public (Krohn and Damborgs, 1999). However, the literature is increasingly identifying the importance of distinguishing between public opinions of wind energy and opinions of wind farms (Bell et al., 2005). Many oppositions of wind farms are often against wind farm development due to sociological issues; these issues are often traits of NIMBY (not in my back yard), as shown in the results of Krohn and Damborgs (1999) study. While public opposition to wind energy projects is still an issue with respect to a minority of projects in Canada, such opposition is gaining a higher profile in light of the rapid expansion of the industry (Saidur et al., 2010). A Canadian questionnaire asked a representative group of Canadians if they would like to see their provincial power utility give a high priority to wind generated electricity in their province (Canadian Wind Energy Association, 1995). According to this survey 79% of the Canadians believe that wind generated electricity should have a high utility priority in Canada (Krohn and Damborg, 1999).

Public acceptance of wind energy in general is very. It has been proven that public acceptance does increase in the local area after the installation of the wind turbines (Krohn and Damborg, 1999). Krohn and Damborg (1999) compared studies conducted in the UK and in Holland comparing the public attitude of wind energy before implementation, during and after. Both studies showed the same trends, that public attitude towards wind energy becomes more negative losing approximately 40% of public support when a wind farm is being constructed within close proximity of public residence (Krohn and Dasburg, 1999), but regains public support after installation. It is also important to note that when the public is given the chance to be part of decision making, often public support is increased. This may be due to the planning process, but outlining the benefits that individuals may gain from support of such a development often out rules the opposition.

2.2.4 Hybrid Diesel-Wind Energy

Electricity for isolated communities needs to be a constant supply and due to wind's intermittency a wind turbine has to be supported by other energy sources. The obvious solution to the problem of using wind power capacity at a remote location is to compensate the variability of the wind by using a diesel generator (Hunter and Elliot, 1994) which can be used to supply the community with their energy needs if wind is not available. In order to ensure reliable electricity production the capacity of storage has to be chosen properly as a function of guaranteed service availability (Sesto and Casale, 1998). As discussed previously, diesel generators are one of the most popular methods of supporting wind systems in remote communities, mainly due to the high reliability of diesel and its ability to produce electricity on demand. Also most remote communalities are familiar with the diesel system. Alaska projects have demonstrated that wind–diesel technology can work in harsh climates and remote conditions given the right circumstances (American Wind Energy Association, 2007). This suggests that this type of system could be applied in remote communities of Ontario.

Incorporating a hybrid diesel-wind system is fairly simple. When the wind blows the effective load on the diesel generator is reduced. When there is no wind the load of the diesel generator increases (Hunter and Elliot, 1994).

The main issue with hybrid diesel-wind systems is that the wind turbine requires regulation since when a wind turbine is creating large amounts of power sometimes the energy demands of the community are not as high as the power being produced. This means that the excess power needs to be consumed or stored. This is known as 'power dumping'. According to Hunter and Elliot (1994) there are two main ways that power dumping can be achieved: power control, or machine control. Power control is when the excess power is put to a secondary use, such as battery storage or hot water heating. Machine control is when the actual rate power production from the wind turbine is controlled. This is where the speed in which the blades turned are slowed so that the amount of power produced is effectively smaller (Hunter and Elliot 1994). Both these systems work well but the cost of implementing power control to a hybrid diesel-wind systems greatly exceed those of power control, yet the maintenance that a machine control requires is higher due to the constant control of the operating speed of the wind turbine.

To overcome the issues of power dumping new hybrid diesel-wind systems have been specifically designed with a machine control power dumping method to control the speed of the wind turbine that can be achieved far away from the location of the wind turbine. For example, in Canada, Wind Energy Solutions, a manufacturer of wind turbines provides monitoring and power frequency control through the internet (Wind Energy Systems, 2010). This means that when wind speed is low, the power feeding the communities can be switched from wind to diesel via the monitoring that is located far from the wind turbine location.

The wind energy systems (WES) manufacturer currently produce two wind turbines for the use of hybrid diesel-wind system in remote communities the WES 30 and the WES 15. The WES 30 wind turbine is a 250 kW wind turbine that is able to produce 560,000 kWh / year. It has a life span of 20 years considering an average wind speed of 6.5 m/s. The towers are available at 31, 40 or 49 meters (Wind Energy Systems, 2010). The WES 15 wind turbine is an 80 kW wind turbine that is able to produce 193,000 kWh / year. This turbine has a life span of 20 years considering an average wind speed of 6.5 m/s. The towers available for WES 15 include 24 and 39 meter towers (Wind Energy Systems, 2010).

2.2.5 Summary of Findings

The literature suggests that none of the researched renewable energy technologies provide a secure energy source capable of being the sole supply for applications in remote communities, which is a result of the fluctuations in energy availability.

Hybrid diesel-wind systems however have the potential to produce a stable supply of electricity. Although the hybrid renewable technology does allow the coupling of diesel systems with hydro electric and solar energy, the renewable energy components of these systems have limitations when producing electricity in the winter. The largest energy demand by the remote communities occurs during the winter period and therefore hybrid diesel-hydro or hybrid diesel-solar is not likely to be feasible electricity systems for the remote communities.

Wind energy is not restricted during the winter season (providing there are icing mitigation methods implemented in the system) and is able to produce electricity all year round. By reducing the amount of diesel consumption through the use of hybrid diesel-wind it could allow a reduction in the amount of emissions produced by the current diesel generating systems. The literature therefore suggests that hybrid diesel- wind energy is a potentially valuable technology for use in many off-grid communities in Canada (Weis et al., 2008).

Determining the feasibility of a hybrid diesel-wind system mainly requires focus on the design of the wind turbine. For example, the WES wind turbines are designed to mitigate the significant weaknesses with wind energy harnessing in remote communities that have limited access to resources and cold climates. These types of wind turbines further support the feasibility of producing electricity from hybrid wind-diesel systems in remote communities of Ontario.

To determine whether a selected site is physically feasible for wind energy generation a preliminary assessment would need to be conducted. This would determine the factors that are likely to affect the efficiency of a wind system in these locations.

2.3 Method of Evaluating Energy Technology

The literature research suggests that the use of diesel-wind energy could provide a secure solution to reduce the use of diesel fuel and the emissions produced from electricity generation in remote communities of Ontario. To ensure that this energy technology is a suitable solution for these locations, methods to determine the overall environmental and economical impacts need to be evaluated. This section of the literature review evaluates methods used to determine the environmental impacts of hybrid diesel-wind systems.

2.3.1 Requirements for Assessing Proposed Wind Technology

The Environmental Assessment (EA) is designed to determine the ecological, cultural, economic and social impact of the project before construction begins during its use and at the end of its lifespan (McCraig, 2005; Ministry of Environment, 2010). Under the Canadian Constitution, provincial governments hold primary jurisdiction over most issues related to environment and health (McCraig, 2005). In 1975, Ontario was the first to implement an integrated assessment strategy at the policy level (Winfield et al., 2000). Conducting an EA is a key part of a planning process in Ontario to ensure compliance with the Environmental Assessment Act. The EA process is conducted before decisions are made to proceed on a project (Ministry of

Environment, 2010). The federal EA process is administered by the Canadian Environmental Assessment Agency (CEAA).

In Ontario, a wind developer may be required to perform either a provincial or a federal environmental assessment (EA). This will depend on the size of the project, the location of the project and the Federal government's involvement

In Ontario, a wind turbine project less than 2 MW will not require a provincial EA. However, if the project is located on Crown land and is less than 2 MW the Ministry of Natural Resources will complete an Environmental Screening Report (Gipe and Murphy, 2005). Federally, there is no requirement to perform an EA unless there is a financial or project contribution by the federal government or there is a specific issue of federal jurisdiction (Gipe and Murphy, 2005).

If the proposed wind project does not trigger an environmental assessment to be conducted then a preliminary site assessment will take place to ensure that the proposed project is environmentally and economically viable.

2.3.2 Preliminary Siting Assessment

Before a wind diesel system is installed a preliminary site assessment needs to be conducted in order to determine if this technology is suitable for the remote community. A preliminary site assessment will enable a decision to be made as to whether wind energy has the potential to produce energy as well as to assess site suitability from an environmental perspective (American Wind Energy Association, 2010).

In order to ensure hybrid diesel-wind systems are a feasible energy source, the location of the wind turbine must be sited to maximize wind energy capture (Ahmed, 2010). Most wind turbines are designed to be optimal at producing energy in areas where wind speeds average between 5 and 15 m/s (Ahmed, 2010). Before installing a wind turbine it is important to predict how much energy could be produced in a specific location. This is achieved by the gathering of wind speed data from the site location (Ahmed, 2010). There are many ways in which wind speed can be evaluated including physical measurement of wind speeds, historical climate data and using a wind atlas (Gipe, 2004).

Wind speed data can be measured using an anemometer located on the top of a pole that has the same height as the proposed wind turbine tower (Gipe, 2004). This method allows detailed measurement of the variation in wind speed in a given location. Although this measurement ensures accurate data is collected, it requires a substantial amount of time to collect the data (Gipe, 2004).

Other methods for evaluating wind speed in Canada include the use of the Canadian Wind Atlas. The Canadian Wind Atlas is an online geographical information system (GIS) that has incorporated the National Climate Data archive which represents data values measured over a period of 30 years. The model illustrates the annual and seasonal wind speeds in a given location. Using this GIS interface also allows the user to determine wind speeds that are 50 m and 80 m above ground level to allow the user to determine a suitable tower height for wind energy harnessing. Using the Canadian Wind Atlas allows the evaluation of wind speeds in a given location to be determined in a short amount of time, which can allow for a faster evaluation of wind as an energy source in remote communities of Ontario. There are limitations within the Canadian Wind Atlas, the weaknesses are listed as:

- Accuracy of wind speed decreases in areas with a low populations this is because the majority of weather stations are located in populated areas and therefore remote areas the wind data is measured from a further distance (True North, 2008).
- The Canadian Wind Atlas does not allow the user to produce an in depth load profile for a wind turbine in a particular location. This is because only annual and seasonal wind speed measurements are recorded and therefore a more in depth load profile cannot be produced (True North, 2008).

2.3.3 Calculating Wind Energy

Once the wind speed has been determined it is possible to calculate the potential energy production of a wind turbine. The potential electrical energy output the swept area of the wind turbine can be calculated using the formula to derive the area of a circle.

$$\mathbf{A} = \boldsymbol{\pi}\, \mathbf{r}^2 \qquad \mathbf{(1)}$$

Where, **r** = the length of one blade (m) **A** = swept area (m^2).

This outcome can then be combined with the wind speed and the air pressure of the site location to determine the power output of a wind turbine using the formula:

$$P = 1/2\rho AV^3 \qquad (2)$$

Where **ρ =** air density, **A =** swept area (m)**, V =** annual velocity (m/s) of wind, **P =** power. (KW)

This information is used to produce a power curve. This is a graph that indicated variable electricity outputs with wind speed (Ahmed, 2010). The power curve model shows how much electricity can be produced at any point in time relative to the wind speed. Although wind energy potential can be mathematically modeled there are many factors that affect the overall power production of a wind turbine. According to Betz's number, no turbine can capture more than 59.3% of the kinetic energy in wind because of the amount of wind remaining needed to move airflow away from the back of the rotor (Wagnerand Mathur, 2009). The relationship of power of the rotor blade and the power of the wind can be used to calculate the power coefficient. The power coefficient derives the maximum availability of power production taking into account the power capacity of the wind turbine and the wind energy potential of a specific location (Wagner and Mathur, 2009).The power coefficient formula is expressed as:

$$C_p = P_R/P \qquad (3)$$

Where, C_p = power coefficient (%), $\mathbf{P_R}$ = Power capacity of a wind turbine (KW), **P** = wind power potential (KW).

The power coefficient calculates the theoretical maximum power a wind turbine can produce giving a specific wind speed at any point in time. To determine the energy potential of a wind turbine the power that a wind turbine can produce over a period of time would need to be calculated (Ahmed, 2010). This is achieved by using the formula:

$$E=Pt \qquad (4)$$

Where **P** = Power (KW), **t** = time (hours), **E** = Energy (KWh).

Once the amount of energy that can be produced in a particular site has been calculated an assessment of the site specific environmental impacts that this technology will be required to be undertaken. This will provide research into the issues that need to be mitigated and whether the proposed diesel wind technology will reduce environmental impacts in comparison to the current installed diesel system installed in the remote communities.

2.3.4 Life Cycle Analysis

Life Cycle Analysis (LCA) is a method that has been increasingly applied to evaluating the environmental impacts of proposed projects, including that involving wind energy (Lenzen and Muksgaard, 2002). LCA evaluates the environmental impacts and resources used throughout a product's entire life cycle (Graedel, 1998). According to the International Standards Organization (ISO), (ISO 14040: 2006), LCA is defined as 'the compilation and evaluation of the inputs and outputs and the potential environmental impacts of a product system throughout its life cycle' (ISO 14040:2006). This method determines the environmental impacts from raw material acquisition through production use and disposal also known as a 'cradle to grave' analysis that incorporates a holistic approach (Guinee, 2002). An LCA is an 'objective' data-based process that covers all types of impacts upon the environment including energy use, raw material requirements, air emissions, water borne effluents, solid waste, land use, and other environmental releases incurred throughout the life cycle of a product, process or activity (Jaquetta and Callaghan, 1995). Jaquetta and Callaghan (1995) state that as 'knowledge of the environment increases, the assessment studies including LCA will become more representative of the real situation, and it follows that such techniques should be easily modified and updated at regular intervals'.

LCA has the capability of determining the environmental impacts of the technology as well as its use (Horne et al., 2009). LCA determines the environmental impacts that the technology creates from extraction of raw materials, manufacturing processes, implementation, use and disposal (Graedel, 1998). LCA's of multiple technologies can be compared to determine which technology is able to minimize environmental impacts.

According to Guinee (2002) the main applications of the LCA method are:

- Analyzing the origins of environmental impacts within a product/ process
- Comparing improvement variants
- For product design

- Comparing products / processes that complete a similar task

The LCA method requires all the main inputs to the processes that a product or service to be taken into account. When conducting an LCA the bottom-up process is most commonly used (Horne et al., 2009). This is where process based modeling begins at the bottom of the supply chain such as material extraction, energy production and transportation, each of these single processes are built upon, linking material, and energy flows of the technology or service under investigation (Horne et al., 2009). It is important to note that the bottom up process does allow for small or minor processes to be excluded providing that it can be justified that they will not have a large impact on the outcomes of the LCA (Horne et al., 2009)

The results of an LCA represent real time and does not rely on past similar projects for determining the environmental impacts associated with the project. An LCA provides a method for comparison due to the results output being made in a quantitative manner. This means that technologies with similar purposes can be evaluated for their impact so that a decision can be made before implementation.

ISO has developed standards specifically for the use of the LCA method. ISO: 14040-ISO14040-44 (ISO, 1997; ISO, 2000)) provides a skeleton framework as to how an LCA should be conducted and what steps are involved in producing a comprehensive LCA (International Standards Organization, 2000). According to the ISO: 14040-44 standards, an LCA are divided into four phases:

- ISO 14041: Goal and scope definition

This step states the objectives of the LCA, and outlines the boundaries and limitations of the study (Graedel, 1998). The system boundaries take into account all the factors impacting the environment (Schaltegger, 1996).This ensures the investigator to establish what types of data need to be collected in order to meet the goal of the LCA. A model of the processes that are to be evaluated will to be produced, whether this is a simple flow diagram or a complex mathematical model (Horne et al., 2009).

- ISO 14042: Inventory analysis

This is where inputs and outputs to and from the systems are identified and quantified. It is the stage for data collection. It follows the system boundaries set in the goal and scope stage. By obtaining the data and the associated environmental impacts the limitations of the project are brought forward in regards to data availability (Graedel, 1998).

- IS0 14043: Life cycle impact assessment (LCIA)

This step is aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system. This phase is further divided into three mandatory elements (Schaltegger, 1996):

  - Selection of impact categories, indicators for the categories and models to quantify the contributions of different inputs and emissions to the impact categories.
  - Assignment of the inventory data to the impact categories (classification).
  - Quantification of the contributions from the product system to the chosen impact categories (characterization).

Through classification and characterization the environmental effects of the processes selected in the inventory analysis can be quantified. This allows the overall impacts of the system under analysis to be evaluated (Schaltegger, 1996).

- 1SO 14044: Interpretation

This final stage of the LCA method is interpretation. This stage is where the findings of either the inventory analysis or both the inventory analysis and the LCIA phases are combined in line with the defined goal and scope of the study (Finnvedan et al., 2003).

The LCA method provides a broad view of the environmental impacts of a product or project. It takes into account the environmental impacts that are created throughout the life cycle of the subject under analysis. Applications of the LCA method can be used to evaluate whether implementing renewable energy systems in remote communities would reduce the environmental degradation caused by diesel generators from a holistic perspective (Schaltegger, 1996). The outcomes of an LCA can identify the process in which the greatest environmental impacts of a particular technology throughout its entire lifespan appear. This allows an understanding of the mitigation that needs to be applied to ensure sustainable decisions are made that minimize environmental impacts that are created by energy technology choices in regards to their potential location.

Schaltegger (1996) outlines the limitations of the LCA method which can be summarized as

- LCA is a steady state method based upon linear modeling
- LCA only focuses on environmental impacts and does not incorporate economic or social issues
- LCA relies on technical assumptions
- Availability of data determined the accuracy of the outputs of the LCA
- LCA is not able to replace the decision making

Ayres (1995) conducted a LCA critique; his study concludes that many methods used to conduct life cycle analyses are inadequate for the purpose of comparing technology. This is mainly due to errors formed when gathering data in order to determine the environmental impacts during the production stage of the technology under analyses. To ensure an LCA comparison can be conducted accurately, detailed environmental impacts need to be gained from published sources for the technology under analyses.

Many software packages are available to allow a user to produce an LCA. A major benefit of LCA software is that it allows you to interpret the results in different ways to ensure that the outcomes are accurate and comparable (PE International, 2009). Two major LCA software packages available are GaBi produced by PE international and Sima Pro produced by PRé Consultants (Hicks, 2010). Weaknesses of the software fall in the issues with the high cost of the software and complex user interface, as both software packages are designed for producing a highly detailed LCA (Hicks, 2010) but both Gabi and SimaPro allow a users input to ensure the data used is valid (Hicks, 2010). A major benefit of LCA software is that it allows you to interpret the results in different ways to ensure that the outcomes are accurate (Hicks, 2010).

2.3.5 LCA and Wind Energy Systems

The potential outcomes of an LCA on diesel and wind-diesel energy systems need to be understood. This section of the literature review aims to give an overview of the most relevant life cycle analysis research on wind turbines. The weaknesses and strengths used in previous studies will be taken into account during the methodology chapter of the proposed research.

Lenzen and Muksgaard (2002) conducted a review of wind turbines outlining the issues involved. The results for Lenzen and Muksgaard's (2002) study were achieved through the comparison of 72 LCAs previously produced followed by an analysis of uncertainties to determine if the same weaknesses appeared.

LCAs on wind turbines may include different components as other components may need to be included depending on whether the project includes energy storage (Lenzen and Muksgaard, 2002). Assessing the materials used to manufacture wind turbines is important. For example, the use of fiberglass and epoxy raise concern due to the fact these materials are not readily recycled. According to Lenzen and Muksgaard (2002) material choices can have a large impact on the overall results of an LCA.

Lenzen and Muksgaard (2002) outline that there needs to be more concerning when analyzing the method of disposal after the lifespan of a wind turbine. A reason for this could be a shortfall in information. This may be due to the fact that an LCA often occurs before the implementation of a particular technology, so the disposal routes are often unknown. At present, recycling the wind turbines is often the most economically viable method, and recycling also reduces the overall impact (Tremeac and Meunier, 2009). However, for example, steel is a recyclable material but if transporting the steel to the recycling plant is expected to cost more than selling the reprocessed product, the likelihood of the material being recycled is minimal.

Fleck and Huot (2009) conducted a study comparing the environmental and economic benefits of a small wind turbine with a diesel generator for use on an off grid residence. This comparison was done by conducting an LCA for each technology. The study concludes that wind turbines have a smaller impact on the environment. This is due to the low amount of greenhouse gases produced.

It was determined that residents that rely on energy that is off the grid are usually in remote areas with limited road access (Fleck and Huot, 2009). In most of these cases they have to purchase diesel which has been transported long distances. This will affect emissions in a LCA, and could result in the wind turbine being a more environmentally sound method for electricity production. Fleck and Huot (2009) state that many studies comparing diesel generator technology and wind technology do not take into account the impacts of the diesel fuel needed to supply a diesel generator. Transportation of the fuel would also lead to increased environmental impact which could prove to be a significant on the outcomes of an LCA.

Another study conducted by Tremeac and Meunier (2009) produced an LCA of two wind turbines located in France, one turbine was a 4.5MW the other 250W. Tremeac and Meunier (2009) determined the materials used in a wind turbine as well as the distance each part travelled before implementation. The impact assessment was determined using SimaPro LCA software. The results show that transportation for the smaller 250W turbine created the smaller impact after construction, yet the larger wind turbine created a smaller impact in transportation even though it travelled a greater distance. This can be attributed to the fact that its transportation method was by boat which creates lower amounts of greenhouse gases than by truck (Tremeac and Meunier, 2009).

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In order to conduct a valid LCA of a diesel-wind system it is important to take into account the transportation and the amount of diesel used. This ensures that the discrepancies highlighted in Fleck and Huot's (2009) and Tremeac and Meunier's (2009) studies are mitigated. In addition, both studies show that detailed plans for the wind turbines disposal need to take place to enable accurate calculations of environmental impacts through the life cycle analysis.

There are gaps in the research of life cycle analysis for wind turbines, especially in defining the impacts created during transportation and disposal. These gaps can be overcome. In order to overcome weaknesses, the life cycle analysis needs to include detailed impacts and from the studies critically reviewed. This includes the wind turbines manufacturing location, transportation methods, the use of the technology, and disposal routes when it finally enters the waste stream. This may incorporate significant research into extended product responsibility. If this is not the case, then the life cycle analysis needs to include the ability of reuse or recycling the majority of the waste. This must include whether its final disposal would involve landfill or incineration, both of which create significant environmental impact.

2.4 Conclusions from the Literature Review

Remote off grid communities in Ontario generate their electricity from diesel generators. These diesel generators have environmental impacts that need to be mitigated. Renewable energy technology has the potential to reduce the environmental impacts associated with the remote community's electricity generation.

An overview of different renewable energy technologies suggested that hydro, solar and wind energy have the potential to reduce the reliance of diesel. This is because these technologies do not rely on fossil fuel sources in order for electricity production nor do they directly lead to emissions being released into the environment. Unfortunately, these renewable technologies might not be able to fully replace this energy technology due to the intermittency of renewable technologies. In order to ensure that a secure electricity source can be provided that minimizes environmental degradation, a hybrid system of renewable energy technology coupled with a diesel generator can be installed to minimize diesel consumption.

Hydro generating electricity provides the steadiest electricity production but due to freezing of water in the winter hydro severe reductions in electricity production may occur during the remote communities peak energy demand Hydro electricity is also not available in all the remote communities. Solar energy is limited during the winter period and nights due to limited incoming radiation and therefore leads to severe electricity production during the winter period, therefore coupling solar with a diesel generator would not be a sufficient energy source during the winter months. Wind however, although intermittent, is not severely affected by the seasonal changes and is able to produce electricity during the winter period providing icing controls are added to the installed turbine.

It must be noted that although wind technology does not produce emissions during for the production of energy it still creates environmental impacts. Many of these impacts are created before and after the use stage of a wind turbines life cycle. Although implementing new technology comes with the cost of environmental impact. It needs to be determined whether implementing wind energy would in the long run reduce the environmental impacts being produced from traditional diesel generators in these northern communities of Ontario.

It is unlikely that a formal EA would be required as the scale of a project for a remote community would not be large enough to trigger an assessment.

Even if an EA is not triggered by law then a preliminary sitting assessment would be required to take place. There are many methods and tools that allow this assessment to be completed each method has the ability to meet different objectives.

Literature findings show that the LCA method is able to produce a ‘cradle to grave’ evaluation of the environmental impacts of a product or process creates. The LCA tool allows a comparison of the environmental impacts associated with multiple technologies that serve the same purpose. The LCA method ensures that that the correct decision is not based on a product’s life span, but production and disposal issues are also taken into account. This enables a better insight into the impacts associated with a technology. ISO 14040:2006 standards have been produced that enable all the critical steps of the model are completed, allowing for comparable results to be produced. Standards of this type are critical for ensuring a valid and reliable LCA is produced.

The variation in the weighting of environmental stressors affects the overall calculation for environmental impact, consequently preventing an exact comparison. This can be avoided by weighting the environmental stressors the same for each LCA conducted. Unfortunately standard weighting of environmental stressors would not be achievable for all LCAs developed for different technology applications but similar methods used to conduct the life cycle analysis are needed when comparing two technologies within the same study so that results can be accurately compared and a quantitative evaluation can take place.

To ensure that energy technologies are selected based upon their environmental impacts; the current diesel generators used in remote communities of Ontario can be compared to that of hybrid wind-diesel systems implemented in remote communities of Ontario. The LCA tool provides a suitable method for comparing these technologies as they provide an in depth cradle to grave evaluation of the potential environmental impacts of both technologies.

The outcome of a conducted LCA on current and proposed energy technology for remote communities of northern Ontario can improve the current method of environmental impact assessment and therefore encourage better choices when selecting the technology used to produce electricity. If the benefits of the implementation of hybrid wind systems are illustrated in a clear and unbiased manner it may encourage residents of northern communities and energy providers alike to work together to improve energy production from a sustainable perspective.

2.5 Objective

The purpose of this study is to evaluate whether wind energy is a technically feasible energy source in the nine First Nation communities in Ontario that are supplied electricity by Hydro One and currently rely on only diesel generators to supply them electricity. It will also be established whether there is the potential for a reduction in environmental impact created by electricity generation if remote communities implemented diesel-wind energy systems for the production of energy.

2.5.1 Significance

The phase in of renewable energy sources for remote communities in Ontario is not being done. Research needs to be undertaken that outlines the technical and environmental feasibility of wind energy for these off-grid locations, to assess if there can be an increased incentive to phase out diesel fuel for the purpose of producing electricity.

This study plays an important factor in identifying the environmental benefits associated with renewable energy options. This study will compare the environmental benefits associated with choices made regarding energy production for off-grid energy consumers. The results of this study are aimed to evolve the use of diesel-wind energy in remote areas, which in turn may reduce reliance on fossil fuel energy production.

Chapter 3: Method

This chapter illustrates the method used to determine the technical feasibility of hybrid diesel-wind electricity for the remote communities and the environmental impacts associated with the proposed hybrid diesel-wind and the current diesel system installed.

This is achieved by gaining the wind speed and calculating the wind energy potential for each community through the use of two wind turbines. The wind energy potential for each community is determined using the meteorological data available for each community. This enables a calculation of the potential wind energy available in each community. This then leads to determining whether hybrid diesel-wind is technically as viable energy source for each community. By determining the current energy demand and diesel usage by the communities currently relying only on diesel energy to support their energy demand the potential diesel savings through the use of hybrid diesel-wind is established. This is then used to determine whether either wind turbine has the potential to replace one diesel generator installed in the remote communities.

The communities that are able to replace a diesel generator with a wind turbine will be deemed to be technically viable for hybrid diesel wind. These communities will then undergo a LCA to establish the environmental impacts associated with the proposed hybrid diesel-wind system. The environmental impacts of the hybrid diesel wind system are then compared to the current diesel generating system installed in the community.

3.1 Method for Determining Technical Feasibility of Wind Energy

The first stage of the study determines how much diesel each community is currently using. Due to privacy reasons (Hydro One has a privacy agreement with the individual remote communities), this information could not be obtained directly from the community or the energy provider, therefore a calculation was required.

Hydro One provides the diesel and electricity consumption and population of three unidentified isolated communities in Ontario. The average energy consumption per capita in each of these communities was established. An estimate of the diesel consumption per capita is then calculated using population of the communities from Statistics Canada 2006 Census data. Multiplying the calculated diesel consumption per capita from the three unidentified communities by the population of the known remote communities provides estimation of the energy and diesel consumption of the remote communities under analysis.

The next stage calculates how much diesel is combusted in each diesel generator in place in the remote communities. This is achieved by determining the total energy capacity of the installed generator and calculating the percentage of the total capacity that each diesel generator represents. This is related to the annual diesel consumption. The wind turbine would have to offset the diesel consumed by at least one of the installed diesel generators in order to be deemed a viable energy source.

This study evaluates two different hybrid systems manufactured by WES. WES wind turbines are used in this study to determine the technical feasibility of wind energy as they are designed for off grid hybrid diesel systems and are fairly typical of typical wind turbine technology except, these wind turbines do not require an inverter or battery storage which reduces the amount of materials required to operate the system. The WES wind turbines also incorporate icing mitigation technology through the use of only two blades instead of the common three for vertical axis wind turbines. The wind turbine blades are composed of carbon and fiberglass which are also proven to reduce ice buildup. This manufacturer an Ontario based manufacturer, and has their products installed in remote communities in Nunavut, thus providing a sense of their reliability in cold climate remote communities.

To determine the wind energy potential of the WES wind turbines the remote communities' wind speeds need to be determined. The study involves an analysis of each of the communities technical wind power feasibility. Wind speed data was acquired through the use of the Canadian Wind Atlas--the method is used within Weiss and Illinca's (2009) study, which further supports this method. By inputting the geographical coordinates of each community the average annual wind speeds can be determined taking into account surface topography and altitude.

In order to increase the wind energy potential, wind speeds are evaluated with a tower height of 50 m. This is because Weiss and Illinca's (2009) study showed that only two communities in Ontario had wind energy potential at 25 m; therefore, to ensure there is increased potential for

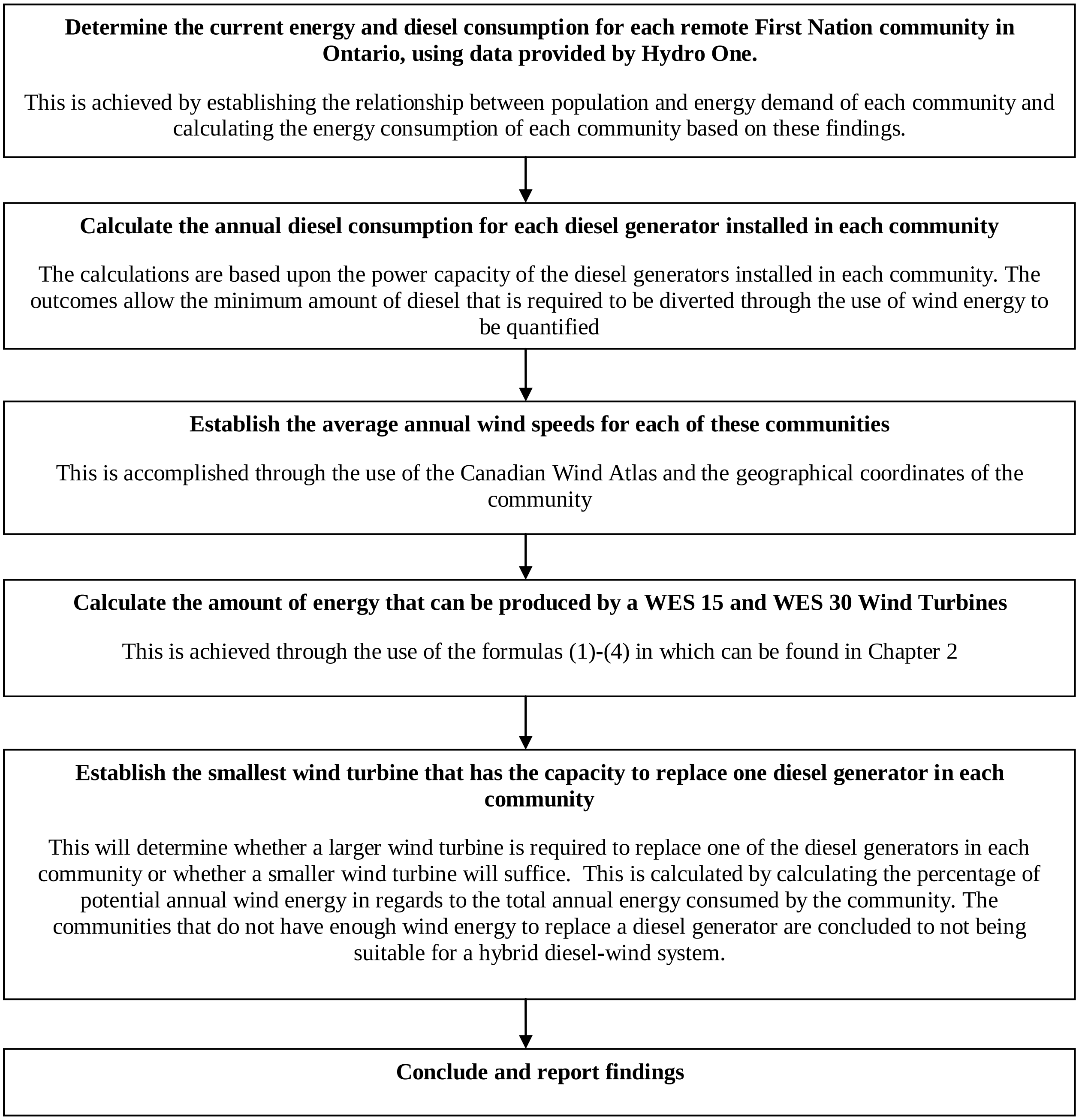

Figure 2 Step by step flow chart of wind feasibility assessment method

wind energy the tower height must be taller. Both the WES 15 and 30 are available with tower heights of 50 m (Wind Energy Solutions, 2010).

For this study the WES 15 and 30 wind turbines are compared for their potential energy output in each community under analysis. This is made possible through the calculation of the energy potential for a wind turbine located in each community. This will be achieved by using the swept area formula (1), followed the wind power formula (2) which can be used to calculate the potential energy (3).

Once the energy is determined it is compared to how much energy can be diverted away from diesel produced electricity. This is attained by determining the power output of each wind turbine and relating this power output to how much diesel would have had to be consumed if the electricity was produced by diesel generators (The step by step flow chart of the wind feasibility assessment method is shown in Figure 2).

If either the WES 15 or the WES 30 wind turbine is estimated to be able to reduce the number of diesel generators by one or more then hybrid diesel-wind generation is deemed feasible. An LCA to compare the environmental impacts for the entire life cycle of the feasible hybrid diesel- wind system and current diesel system is undertaken for those communities that have the potential for diesel wind electricity generation.

3.2 LCA Method

This section compares the environmental impacts of the current diesel generating systems and a proposed hybrid diesel-wind system for each remote community. This is achieved by:

1. Conducting a life cycle analysis of the current diesel generator for each remote community that has significant wind energy potential. The life cycle analysis represents the diesel generators' impacts throughout all life stages of the products' use. The impacts require extensive research into diesel generators' material usage in the manufacturing stage, transportation method to the current location as to which it is used, the amount of diesel fuel used to run the generator, maintenance requirements, and disposal methods at the end of the products' lifespan. This information is used to predict the environmental impacts that a diesel generator has, and focuses primarily on the types and quantities of emissions that are released into the environment

2. Producing a life cycle analysis of the hybrid-wind systems for each remote community that has significant wind to determine the overall impacts. This stage quantifies the impacts of a hybrid-wind system if installed in the wind viable remote communities. This method of representation of hybrid wind-diesel systems takes into account the environmental impacts

created throughout the entire life cycle of the product. This stage takes into account manufacturing of the wind turbine, transportation and installation, maintenance of both the diesel generator and the wind turbine, impacts produced in products use including amount of diesel required to supplement the wind energy and finally disposal methods.

3. Comparing of the outcomes of the LCAs of both the diesel generator and the hybrid-wind systems to determine which energy source produces lower environmental impacts, and determines the potential diesel emission savings if hybrid diesel- wind system were implemented in remote communities of Ontario. This stage summarizes the outcomes of the overall study and outline what significant findings were established. The impacts outlined are weighted for their significance and this predicts the quantity of emission savings which leading to a conclusion as to whether wind energy implementation in remote communities could drastically reduce the amount of emissions being released from unnecessary diesel combustion.

3.2.1 Conducting the LCA

To ensure that all aspects of an LCA are taken into account the method of application will follow the standards set in ISO 14040 (ISO 2006). An LCA is conducted for both the proposed hybrid diesel-wind system and the current diesel system installed in each community, which has proven to be technically feasible for hybrid diesel-wind energy.

According to ISO (2006) the 14040 standards, require four major steps to be completed in a life cycle analysis. First, the goal and scope of the analysis is defined. Second an inventory analysis is conducted,-this step involves data collection. The third step is the life cycle impact assessment (LCIA) where the environmental impacts associated with each life stage are weighted in terms of their severity (Graedel, 1998). A detailed schematic of the LCA method is shown in figure 3.

The goal and scope step outlines the boundaries and limitations of the study, the aims and methods that allow the goals to be achieved, and a detailed guide of how the results are going to be achieved. This will be achieved by looking at both diesel and hybrid diesel-wind systems as a whole and determining any similarities in the systems that may be excluded from the LCA. This stage of the study outlines the intended audience of the study, the scope of the study in terms of what system will be studies to what levels of detail and accuracy. The function of the LCA will be stated alongside the functional unit.

Definition of the Goal and Scope of the LCA

This step sets the objective of the LCA, defines the boundaries of the processes to be included and describes the impacts to be measured

↓

Conduct LCI

This stage requires the data for the materials and energy required each life cycle stage of the technologies to be obtained. This is achieved through literature research, contacting manufacturers, calculations and estimations. An LCI must be conducted for each community and each energy scenario under analysis. Once the data are obtained a data quality analysis is conducted to ensure the majority of data used is from reliable source.

↓

Produce a schematic plan of the processes within the GaBi software

This stage connects the inventory data for each process in the LCA to form the inputs/ outputs that are produced from the system under analysis for each of the communities and energy scenarios

↓

Conduct LCIA

This is achieved within the GaBi software. For each LCA three LCIAS are produced: classification, characterization and normalization

↓

Interpretation of Results

The results produced by GaBi can be interpreted within the software through the production of graphs or exported to excel. For this study the data will be exported to excel so that the LCAs for each community can be graphed together for the purpose of comparison.

↓

Conclusion

This step will state the findings of the LCIA and the significance of these findings discuss limitations to the study and complete with a conclusion

Figure 3 Step by step flow diagram of the LCA method

The time frame in which the analysis will take place considers determining the lifespan of both the diesel generators and winding turbines needs to be established.

Once the functional unit is established then the processes to be included in the study are described. The description of the technologies and services of both diesel wind system and the diesel system is analyzed so that system boundaries of the LCA will be put in place. This is where the cut off criteria of the inputs of the outputs of the processes that are included in the final LCA are outlined as well as the boundaries of the individual LCA processes.

A description of the life cycle impact assessment (LCIA) method is undertaken. This includes a description of the environmental impacts categories being assessed. This provides an understanding of the LCA process. The goal and scope stage of the LCA concludes with a discussion of the limitations and weaknesses of the proposed LCA of the diesel system and wind-diesel system for each community.

Step two, according to ISO 14040 (ISO, 2006) consists of the gathering of data that is required for the LCA; this stage is known as the life cycle inventory of LCI. This phase of the LCA involves the compilation and quantification of inputs and outputs for a given product system throughout its life cycle or for single processes (PE International, 2009). It is this stage of the LCA where all the inputs and outputs for each single process within the LCA boundaries are established.

Data are collected for all the major life stages of both the diesel generator and hybrid-wind systems. The major life stages include manufacturing, transportation, use of product and disposal at the end of the life span.

The inventory analysis is approached using the ‘bottom up method’ which begins with data collection in regards to the extraction and manufacturing of materials and ending with the disposal of the electricity system at the end of its lifespan. The inventory analysis is split into two sections. The first, involves the data collection of the current diesel system in place in each remote community, including the current diesel usage, the second section of the inventory analysis compiles data for each process of the proposed hybrid diesel-wind system.

The data collected in the inventory analysis are used to produce a schematic plan of the life cycle for the system under analysis. For each community analyzed, two plans are produced: one for the diesel system, and one for the hybrid diesel-wind system.

The method used to calculate the environmental impacts and emissions produced during the lifespan of both the diesel generator and the wind turbine is achieved in the third stage of the LCA. This is known as the life cycle impact assessment (LCIA). This is the stage in which all the LCI data is compiled and evaluated using classification, characterization and normalization methods. The classification method determines the total inputs and outputs of each process within a life cycle in terms of mass. The characterization method categorizes the inputs and outputs of each process in terms of emission type. The final method is normalization; this method categorizes the emissions into types of environmental impacts and evaluates the impact that these emissions have on the environment against a weighted equivalence. This determines the severity of the environmental impacts associated with the life cycle of the energy system.

The impact assessment is followed by the interpretation of the results. This is designed to highlight the main findings of the study and support these findings with an explanation as to why these findings may have arisen. This stage outlines and critically reviews the outcomes and weaknesses of the study, if any, which occurred when conducting the LCA. In this stage of the LCA a comparison of diesel generators and wind-diesel systems is made by graphing the potential impacts and comparing the data. A recommendation as to whether wind-diesel would be suitable for reducing environmental impact created by diesel generators for each community is made. The process that creates the largest environmental impacts can be established which can provide a basis for further investigation as to how environmental impacts can be reduced from electricity generation of remote communities. Weaknesses that arise in the analysis will be highlighted and supported by suggested methods that could improve future research within this field.

The outcomes of the research lead to a concluding report that will lead to suggestions for further research in this area of study.

3.2.2GaBi Software

The LCA of the diesel system and the proposed hybrid diesel-wind system is conducted using GaBi 4 software (PE International, 2009). GaBi 4 is a type of LCA modeling software that contains a comprehensive, up-to-date life cycle inventory database. The software was produced by PE International (2009) and is the most widely used LCA software for modeling products and systems in the world (PE International, 2009). GaBi 4 supports every stage of an LCA and conforms to the ISO14040:2006 standards (PE International, 2009).GaBi automatically tracks all material, energy, and emissions flows, giving instant performance accounting in environmental impact categories (Hicks, 2010). GaBi software is used in this study to produce a detailed impact assessment throughout the life stages of both a diesel system and a hybrid diesel-wind system for the northern communities of Ontario. In addition to its utility, access to GaBi 4 LCA software is provided free to students (PE International, 2009).

Within the GaBi software schematic plans of the systems processes can be created that link the relevant input and output flows of LCI data through the lifespan of the energy system. This allows the user to ensure that all relevant processes and the flows are recorded before an LCIA commences.

GaBi allows the user interpret the outcomes Life Cycle Impact Assessment (LCIA) using many methods. This study uses three methods: classification, characterization and normalization. The classification method categorizes individual inputs from the life cycle inventory into the main life stages (for example, production, transportation, use phase and disposal). The amount of emissions produced by each life stage is quantified in terms of mass. This enables the user to compare emissions from transportation in comparison to the emissions created during the disposal phases of the LCA to determine which life stage creates the largest environmental impact. The second method, known as characterization, determines the specific types of emissions that are released throughout each LCA conducted these emissions are measured by mass and are not weighted. The specific emissions measured are:

- Resource depletion
- Emission to air
- Emissions to freshwater
- Emissions to seawater
- Emissions to soil

GaBi software also allows the user to apply normalization methods to the LCIA using widely used impact assessment methods. This type of LCIA determines the environments impact that the emissions contribute. The aim of normalizations is to allow understanding of the relative importance and magnitude of the LCA results (Guinee et al., 2001).

There are many impact assessment normalization methods that can be applied within GaBi including Eco Indicator 99, Environmental Design of Industrial Products (EDIP) and Chemical Markup language 2001 (CML 2001). These environmental impact assessment methods differ as they categorize and evaluate different environmental impact categories, Eco indicator focuses on damage to human health, damage to the environment and damage to resources, and determines the impact on a global scale EDIP measures the environmental impacts for acidification potential, global warming potential, nutrient enrichment potential, photochemical oxidation potential and photochemical oxidant potential. The EDIP normalization method is based upon the impacts associated within Europe.

For this study the CML 2001 with the equivalence based on Canada method is applied. This is the methodology was produced of the Centre for Environmental Studies of the University of Leiden (PE International, 2009) and consists of a spreadsheet containing characterization factors for more than 1700 different flows. The CML 2001 method focuses on a series of environmental impact categories (Table 1).

Table 1 CML 2001 Normalization method, emission types, equivalence, unit of measurement and weighting

Emission Type	Equivalence Factor	Equivalence	Unit	Weighting
Abiotic Depletion (ADP)	Material Extraction	2.2E+09	kg Sb-Equiv.	4.62E-10
Global Warming Potential (GWP 100 years)	Carbon Dioxide (CO_2)	6.4E+11	kg CO2-Equiv.	1.56E-12
Ozone Layer Depletion Potential (ODP, steady state)	Chlorofluorocarbon (CFC)	8741686	kg R11-Equiv.	1.14E-07
Photochemical. Ozone Creation Potential (POCP)	Ethylene (C_2H_4)	8.2E+08	kg Ethylene-Equiv.	1.23E-09
Acidification Potential (AP)	Sulphuric Acid (SO_2)	4.1E+09	kg SO2-Equiv.	2.45E-10
Eutrophication Potential (EP)	Phosphate (PO_3)	1.8E+09	kg Phosphate-Equiv.	5.57E-10

Chapter 4 Calculating Wind Energy and Diesel Savings Potential for Isolated Communities of Ontario

According to Indian and Northern Affairs Canada (INAC) (2010) there are currently 23 remote communities in Ontario that are not connected to the national grid. Hydro One Remote Communities Inc. operates and maintains the generation and distribution assets used to supply electricity to 19 of these remote communities across northern Ontario, 15 of which are First Nations (Hydro One, 2010). Of the fifteen First Nations, wind turbines have been installed in Kasabonika Lake and Big Trout Lake, and a 490 kW mini hydro site is located in Deer Lake (RET Screen, 2009). These three communities will not be included in the study. Additionally, three communities do not have population data available and therefore these communities are also excluded from the study. Listed below in Table 2 are the remote First Nations communities that will be evaluated for wind energy potential.

Table 2 The characteristics of the remote communities investigated in the study

Community	Latitude	Longitude	Average Annual Temperature (^{0}C) (NCDI 2010)	Altitude (m) (Canadian Wind Atlas 2003)	2006 Population (Statistics Canada 2007)
Armstrong	50°.29’	-88°.91’	-1.2	400	1155
Bearskin	53°.92’	-90°.97’	-5.07	200	459
Fort Severn	56° 01’	-87°.59’	-4.73	400	305
Gull Bay	49°.82’	-89°.10’	-5.2	400	206
Kingfisher	53°.03’	-89°.84’	-2.14	200	313
Lansdowne	52°.19’	-88°.04’	-1.00	200	270
Sachigo	53°.89’	-92°.16’	-8.2	400	450
Wapekeka	53°.72’	-89°.54’	-1.9	200	350
Webequie	52°.99’	-87°.28’	-2.4	200	614

Each of the communities relies on three diesel generators to support their electricity needs, with the exception of Wapekeka, which has only two diesel generators installed (Table 3).

Table 3 Diesel generators installed in each community (Hydro One, 2009)

Remote Community	Diesel Generator Sets (A,B,C represents multiple diesel generators)					
	A		B		C	
	Brand	Power Output (KW)	Brand	Power Output (KW)	Brand	Power Output (KW)
Armstrong	Caterpillar	600	Cummins	1000	Caterpillar	1000
Bearskin	Caterpillar	250	Cummins	400	Caterpillar	600
Fort Severn	Caterpillar	250	Caterpillar	400	Caterpillar	600
Gull Bay	Caterpillar	125	Caterpillar	175	Caterpillar	250
Kingfisher	Detroit	250	Caterpillar	400	Caterpillar	600
Lansdowne	Caterpillar	250	Caterpillar	455	Caterpillar	825
Sachigo	Caterpillar	250	Caterpillar	400	Caterpillar	600
Wapekeka	Caterpillar	450	Caterpillar	820	-	-
Webequie	Caterpillar	250	Caterpillar	400	Caterpillar	600

The power output of each diesel generator is used to estimate how much diesel each generator consumes to supply the individual remote communities with their electricity.

4.1 Determining the Relationship between Population and Energy Demand

Hydro One provides information that shows the 2008 peak energy demands for each of the remote communities (Table 4). This information can be used to estimate the average yearly energy and diesel consumption per capita.

The peak energy demand per capita is calculated by dividing the peak demand by the population. Figure 4 shows the relationship peak energy demand and population. The R^2 value of 0.8101, shows that there is a strong positive relationship between population and peak energy demand. This suggests that population can be used as a basis for calculating the annual energy consumption of each community.

4.2 Energy Use Per Capita

Due to privacy restrictions, access to data on the energy demands for each community was not granted permission for use in this study. However, an estimate of the average fuel consumption per capita per year can be made using data that Hydro One (2009) provided for three unidentified First Nation remote communities that are currently provided electricity by Hydro One (Table 5).

Table 4 Population and peak energy loads (Hydro One, 2009)

Community	Population (Statistics Canada 2007)	Peak Energy Demand 2008 (KW)	Peak Energy Demand Per Capita (KW)
Armstrong	1,155	864	0.75
Bearskin	459	621	1.35
Fort Severn	305	524	1.72
Gull Bay	206	261	1.27
Kingfisher	313	457	1.46
Lansdowne	270	424	1.57
Sachigo	450	624	1.39
Wapekeka	350	506	1.45
Webequie	614	614	1.00
Mean	458	544	1.33

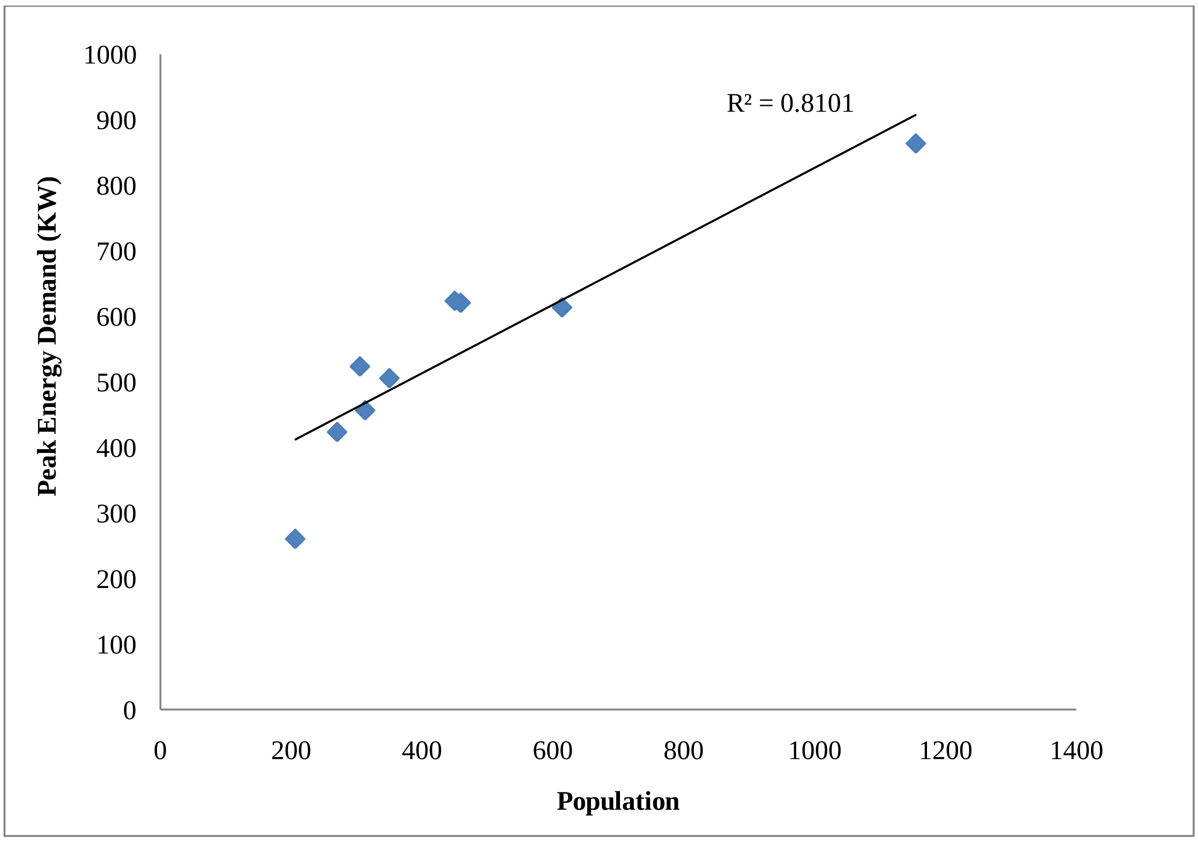

Figure 4 The relationship between population and peak energy demand for each community in 2008

Table 5 Energy usage and load of three unidentified remote communities of Northern Ontario (Hydro One 2009)

	Community A	Community B	Community C
Population	*	*	*
Generators (KW)	*	*	*
Winter Peak (KW)	1208	614	546
Winter Minimum (KW)	790	290	270
Summer Peak (KW)	777	516	334
Summer Minimum (KW)	350	215	150
Annual Energy Consumption (KWh)	5,830,000	2,900,000	2,280,000
Diesel Consumption (Liters)	1,640,000	880,000	735,000

*Excluded from table to ensure privacy agreement is held

Using the data from Table 5, the amount of energy needed to supply each person within a population is calculated. From this it is possible to estimate the average of how much diesel each person requires in a remote community. The data are then used to approximate the diesel usage of each individual remote community under analysis.

Table 6 Estimated per capita energy use in remote communities (data provided by Hydro One 2010)

	Per Capita Community A	Per Capita Community B	Per Capita Community C	Mean Energy* Use Per Capita
Winter Peak (KW)	1.01	0.93	1.61	1.18
Winter Minimum (KW)	0.66	0.44	0.79	0.63
Summer Peak (KW)	0.65	0.78	0.98	0.8
Summer Minimum (KW)	0.29	0.33	0.44	0.35
Annual Energy Consumption (KWh/yr)	4,858.33	4,393.94	6,705.88	5319.38
Diesel Consumption (l)	1,366.67	1,333.33	2,161.76	1,620.59

*Mean energy use per capita+ (A+B+C)/3

The estimation based upon the data provided by Hydro One (2009) (Table 6) is that each person living in a remote community of Ontario uses approximately 5,319.38 (KWh /yr) and this is equal to a per capita combustion of 1620.59 L of diesel fuel every year. The highest energy demand is estimated at 1.18 KW and the peak demand occurs in the winter. The difference between the peak and the minimum demand is 0.83 KW.

4.3 Remote Community Diesel Consumption

The energy demand per capita is used to estimate the annual energy demand and diesel usage of each community. Table 7 shows the estimated energy demand and diesel usage of each community. These calculations are based on the data from Table 6 highlighting the average energy use of per capita and then multiplying it by the population of each community.

Figure 5 illustrates the estimated peak energy consumption compared to the actual peak energy consumption of each community from 2008. The graph shows that there is a difference between the actual peak energy demands in 2008 in comparison to the estimated energy demand. It is unlikely this is a representation of the real situation. The difference in the 2008 peak energy demand and the estimated peak energy demand is a result of only one variable being used to calculate the estimated energy consumption. This calculation assumes that energy consumption per capita is the same for all the communities; this is unlikely as these communities have different energy demands as a result of the community's location, climate and facilities. This calculation considered only the consumption of energy per capita and did not consider increased energy consumption as a result of the operation of businesses in the community such as schools, airports and stores. As the data specifying the variables that affect the energy consumption of the community cannot be obtained due to privacy reasons, the estimated energy consumption using only population as a variable is used for the prediction of diesel consumption.

To determine the amount of wind energy that will be required to replace one diesel generator, the amount of diesel consumed by each diesel generator is established. For the purpose of this calculation it is presumed that each of the diesel generators in a community is equally used to supply electricity based on the diesel generator size. The estimated amount of diesel consumed is shown in Table 8.

Table 7 Estimated energy demand and diesel usage for specific remote communities of Ontario

	Armstrong	Bearskin	Gull Bay	Fort Severn	Kingfisher	Lansdowne	Sachigo	Wapekeka	Webequie
Winter Peak (kW)	1,366.8	543.15	243.77	360.92	370.38	319.50	532.50	414.17	726.57
Winter Minimum (kW)	727.65	289.17	129.78	192.15	197.19	170.10	283.50	220.50	386.82
Summer Peak (kW)	927.85	368.73	165.49	245.02	251.44	216.90	361.50	281.17	493.25
Summer Minimum (kW)	408.10	162.18	72.79	107.77	110.59	95.40	159.00	123.67	216.95
Annual Energy Consumption (kWh)*	6,143,890	2,441,600	1,095,790	1,622,410	1,664,970	1,436,230	2,393,720	1,861,780	3,266,100
Diesel Consumption (L)†	1,871,780	743,849	333,841	494,279	507,244	437,558	729,264	567,205	995,040

* Annual energy consumption= 5319.98 KWh * population of the community

† Annual diesel consumption+ 0.3 * estimated annual energy consumption

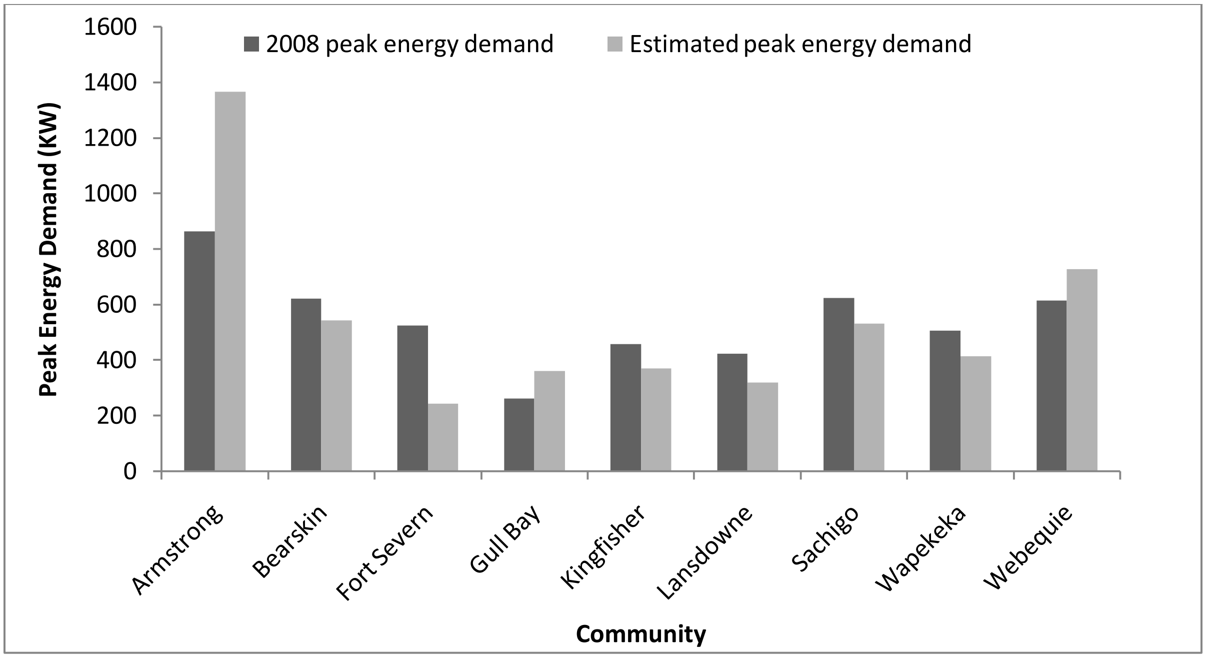

Figure 5 The estimated and 2008 peak energy demand

Table 8 Estimated diesel consumption of each diesel generator installed in the remote communities under analysis

	Diesel Generator					
Community	**A**		**B**		**C**	
	% of Total Power Output*	**Diesel Consumed †**	**% of Total Power Output**	**Diesel Consumed †**	**% of Total Power Output***	**Diesel Consumed †**
	%	(l)	%	(l)	%	(l)
Armstrong	23	430,509	39	720,634	39	720,634
Bearskin	20	148,770	32	238,032	48	357,048
Gull Bay	23	76,783	32	103,491	45	150,228
Fort Severn	20	98,856	32	158,169	48	237,254
Kingfisher	20	101,449	32	162,318	48	243,477
Lansdowne	16	70,009	30	131,268	54	236,282
Sachigo	20	145,853	32	233,365	48	350,047
Wapekeka	35	200,791	65	366,415	-	-
Webequie	20	199,008	32	3,181,413	48	477,619

***** Percentage of total power output = (100/ total energy capacity of all installed diesel generators) * capacity of diesel generator

† Diesel consumed= (100/ estimated annual diesel consumption) * percentage of total power output

4.4 Determining Which Wind Turbine is Suitable for Remote Community Use

This step begins the process of determining the technical feasibility of wind energy in the remote communities. The technical feasibility of wind determines whether the wind conditions allow electricity to be produced from wind. It does not incorporate specific site locations for wind turbine implementation. To determine how much electricity a wind turbine can capture depends on the size and type of wind turbine as well as the available wind speeds. In this study two Wind Energy Solutions (WES) wind turbines are compared. The WES 15, 80 KW wind turbine and the WES 30, 250 KW wind turbine are used to determine the potential energy for each community. Each of these wind turbines has a tower height of 49 m (WES 2010).

Table 9 Manufacturer's statistics for the WES 15 and WES 30 wind turbines

Supplier / manufacturer	Wind Energy Solutions	Wind Energy Solutions
Life expectancy	20 years	20 years
Nominal power	80KW	250 KW
Blade Length	7.8 m	13.5 m
Cut-out wind speed	25 m/sec	25 m/sec
Survival wind speed	60.0 m/sec	60.0 m/sec
Operating temperatures	-20^{o}C - +400^{o}C	-20^{o}C - +400^{o}C
Service / maintenance	Every 6 months	Every 6 months
Cut-in wind speed	2.7 m/s	2.7 m/s
Nominal wind speed	12.5 m/s	12.5 m/s
Noise emission at 8 m / sec	Less than 45 dBa at 100 m	Less than 45 dBa at 300 m

Determining the energy potential of each wind turbine in regards to its location requires multistep calculations as previously described in the literature review. The data required include the specifications of the wind turbine and the geographical information of the site location.

The first step is to calculate the swept area of each wind turbine, as this will be required to calculate the power output of each wind turbine.

The swept area can be calculated using the formula (1).

Therefore the swept areas are:

WES 15 wind turbine $A = \pi\ 7.8^2 = 191.13\ m^2$

WES 30 wind turbine $A = \pi\ 13.5^2 = 564.10\ m^2$

Before the power can be calculated the air density for the proposed site needs to be determined.

The air density of each community is calculated using the ideal gas law shown in formula (2). The outcomes of this calculation are shown in Table 10.

Table 10 Air density in relationship to temperature and pressure for each remote community

Community	Mean Temp (^oC) (Canadian Wind Atlas 2003)	Temperature (K)	Air Density (kg/m^2)	Average Annual Wind Speed (m/s)
Armstrong	-1.20	271.96	1.30	4.88
Bearskin	-5.07	268.09	1.32	5.38
Fort Severn	-4.73	268.43	1.31	6.97
Gull Bay	-5.20	267.96	1.32	5.20
Kingfisher	-2.14	271.02	1.30	5.32
Lansdowne	-1.00	272.16	1.30	4.96
Sachigo	-8.20	264.96	1.33	5.27
Wapekeka	-1.90	271.26	1.30	5.44
Webequie	-2.40	270.76	1.30	6.77

Table 10 shows the average annual wind speed of each community determined using the Canadian Wind Atlas (2003). The wind speed was taken at a height of 50 meters above ground level (magl). This wind data matches the height of the wind turbine tower height for both the WES 30 and the WES 15 wind turbines.

Due to the availability of wind data it is not possible to produce a load profile analysis of the wind energy potential. A load profile analysis determines the ability for wind turbines to produce energy during a daily, monthly and seasonal time period. Although this would allow a more in depth understanding as to whether the wind turbines would be able to meet the communities electricity demands on, The only data available for the remote communities is the estimated annual energy consumption, therefore only the annual energy potential of the wind turbine is calculated.

The air density and average wind speed shown in Table 11 can combined with the swept area to calculate the potential power of each wind turbines using the formula shown in formula (3).

Table 11 Potential power outputs of the WES 15 and WES 30 wind turbines

Community	WES 15 P (KW)*	WES 30 P (KW)*
Armstrong	14.44	42.54
Bearskin	19.64	57.83
Fort Severn	42.39	125.59
Gull Bay	17.74	52.24
Kingfisher	18.71	55.31
Lansdowne	15.16	44.64
Sachigo	18.60	55.00
Wapekeka	20.00	59.09
Webequie	38.55	114.09

*Power= $P = 1/2\rho AV^3$

The next step in the calculation is to determine how much energy a wind turbine could potentially produce over a period of time. This can be calculated using formula (4).

Table 12 Potential energy produced from WES 15 89kW and 250kW WES 30 wind turbines

	WES 15 80kW Turbine	WES 30 250KW Turbine
	E (KWh/yr)*	E (KWh/yr)*
Armstrong	126,578	372,897
Bearskin	172,160	506,926
Fort Severn	371,582	1,100,897
Gull Bay	155,505	457,925
Kingfisher	164,008	484,836
Lansdowne	132,890	391,305
Sachigo	163,044	482,119
Wapekeka	175,316	517,971
Webequie	337,922	1,000,090

*Energy production= P * T

4.5 Efficiency of the Wind Turbine

The power coefficient for each community is calculated using the formula (3) for the WES 30, 250 KW and the WES 15, 80 KW. The power coefficient for each wind turbine and each of their potential wind power outputs are shown in Table 13.

Table 13 The power coefficiency of each wind turbine

Community	WES 15 Power Coefficient* (%)	WES 30 Power Coefficient* (%)
Armstrong	18.0	17.0
Bearskin	24.5	23.1
Fort Severn	53.2	50.2
Gull Bay	22.1	20.9
Kingfisher	23.4	22.1
Lansdowne	18.9	17.9
Sachigo	23.3	22.0
Wapekeka	25.0	23.6
Webequie	48.3	45.6

* Power coefficient = potential power / predicted power

Although the WES 30 has shown greater energy potential, efficiency favors the WES 15 turbine. This is mainly due to its lower power rating where a smaller wind speed produces a larger percentage of its overall capacity when comparing it to the larger WES 30 turbine. This means that the WES 15 wind turbine is working at a better efficiency rate but producing a lower energy output.

4.6 Calculating Diesel Savings from Electricity Produced from Wind Turbine

Dividing the amount of energy consumed annually (KWh) by the annual diesel consumption (l) provides estimation for the amount of diesel needed to produce one KWh of energy.

Based upon these calculations it is determined that 0.3 l of diesel is required to produce an average of 1 KWh of electricity. This is in accordance with the estimated diesel consumption rates calculated earlier (Table 4).

The diesel savings are calculated by multiplying the potential energy output from the wind turbine by the amount of diesel required to produce 1 KWh of energy (0.3 l) (Table 14).

Table 14 Annual diesel savings from WES 15 and WES 30 wind turbines

	WES 15 Turbine	WES 30 Turbine
Community	**Diesel Savings (l)***	**Diesel Savings (l)***
Armstrong	37,973	112,307
Bearskin	51,648	1562 08
Fort Severn	111,474	336,110
Gull Bay	46,652	140,213
Kingfisher	49,202	147,101
Lansdowne	39,867	118,141
Sachigo	48,913	145,853
Wapekeka	52,595	158,817
Webequie	101,377	308,462
Total	539,702	1,467,004
Mean Average	59,967	163,000

* Diesel savings = annual energy production (KWh) * 0.3

4.7 Diesel Required for Hybrid Diesel-Wind Systems

Using diesel savings from each wind turbine under analysis and the diesel consumption from the diesel generators in each community, the amount of diesel still required can be calculated (Table 15).

Table 15 Diesel required for WES 15 and WES 30 hybrid diesel-wind systems

	WES 15 Wind Turbine	WES 30 Wind Turbine
Community	**Diesel Required for Hybrid diesel-wind (l)***	**Diesel Required for Hybrid diesel-wind (l)***
Armstrong	1,833,220	1,759,910
Bearskin	691,400	589,426
Fort Severn	381,073	158,861
Gull Bay	286,465	126,428
Kingfisher	457,277	359,534
Lansdowne	397,073	318,323
Sachigo	679,592	582,390
Wapekeka	513,794	409,408
Webequie	892,090	690,358

*Diesel required for hybrid diesel-wind = annual diesel consumption-diesel savings

The percentage of diesel savings is calculated based the total energy consumption of each community and the estimated potential diesel diversion by the wind turbine. The comparison of the technologies potential diesel consumption is shown in figure 6.

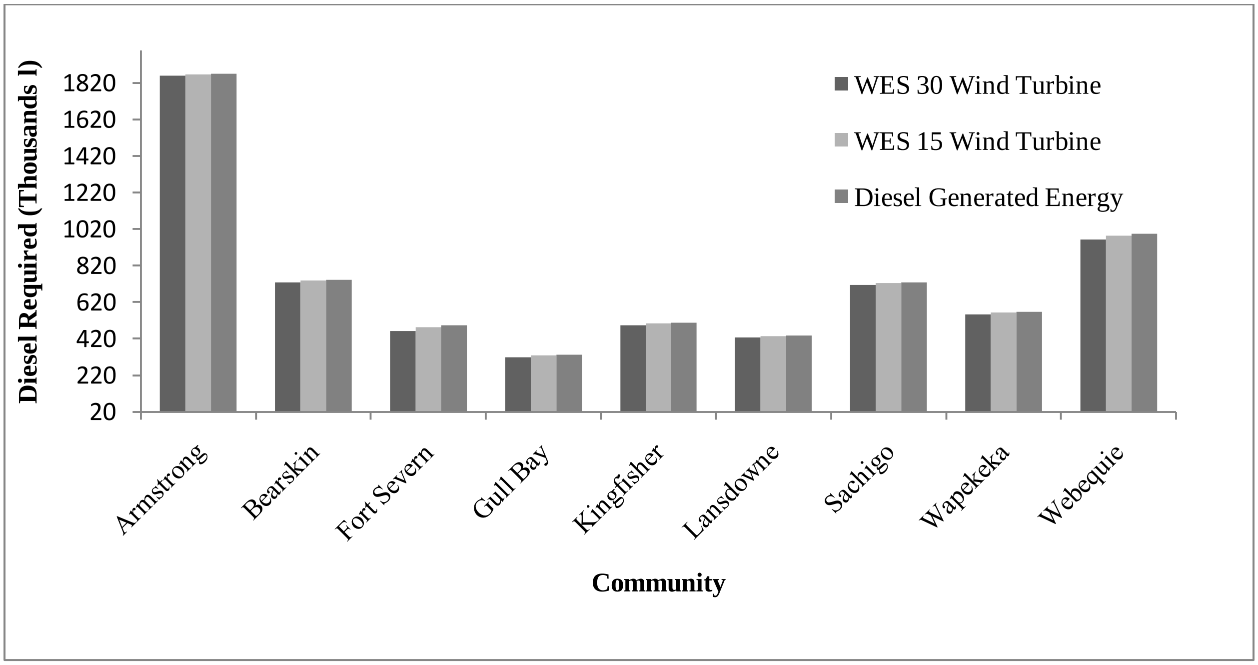

Figure 6 The estimated usage of diesel for hybrid diesel-wind and the diesel generator systems

4.8 Determining whether either wind turbine could replace a diesel generator

If the percentage of potential energy produced by a wind turbine is larger or the same as the percentage of overall energy input of the installed diesel generators currently in place, then the hybrid diesel-wind system will be deemed viable for the remote community.

By comparing the potential outputs of each energy system (Table 16) it can be determined whether the WES 15 or the WES 30 has the technical potential to replace at least one diesel generator with a hybrid diesel-wind system. The WES 15 hybrid diesel system would be able to replace diesel generator A in Fort Severn. The WES 15 wind turbine would be unable to replace any other diesel generators in the remote communities.

The WES 30 does have the potential to replace diesel generators in each of the communities with the exception of Armstrong and Wapekeka. Each of the other communities has the potential to allow at least one of their diesel generators to be replaced by a WES 30 wind turbine. Each community with the exception of Fort Severn and Gull Bay are able to replace their smallest diesel generator A with a WES 30 hybrid diesel-wind system.

Table 16 Comparing the potential energy outputs of each energy system

	Diesel Generators in Place (%)			Potential Hybrid Diesel Wind System (%)*	
Community	**A**	**B**	**C**	**WES 15**	**WES 30**
Armstrong	22	39	39	2	6
Bearskin	20	32	48	7	21
Fort Severn	23	32	45	23	68
Gull Bay	20	32	48	14	42
Kingfisher	20	32	48	10	29
Lansdowne	16	30	54	9	27
Sachigo	20	32	48	7	20
Wapekeka	35	65	-	9	28
Webequie	20	32	48	10	31

*Potential energy output of hybrid diesel-wind system= (100/ annual energy consumption) * potential energy production of wind turbine

Fort Severn is the only community that has the wind potential to replace two diesel generators with one WES 30 hybrid diesel-wind system; the wind potential allows 68% of Fort Severn energy demand to be produced by wind which replaces diesel generators A and C.

4.9 Summary of Findings

The outcomes of these results support the technical feasibility of the WES 30 hybrid diesel-wind system for use in the remote communities under analysis as an energy source that has the potential to decrease some of the diesel consumed in each community for electricity generation. The WES 30 wind turbine has the potential to produce a larger amount of energy in comparison to the WES 15 hybrid diesel- wind system. This means that the WES 30 has a greater potential diesel reduction. The WES 30 wind turbine has the potential to replace at least one diesel generator in each of the remote communities with the exception of Armstrong and Wapekeka. To ensure that this hybrid diesel-wind system would mitigate the environmental impacts caused by diesel combustion a further analysis needs to be conducted. This analysis must take into account the environmental impacts associated with all the life stages of the system.

Chapter 5 Life Cycle Analysis Comparing Environmental Impacts of Diesel Generated Power and Wind-Diesel Generated Power applied in Remote First Nations Communities

5.1 Goal and Scope

The goal of the LCA is to identify whether hybrid diesel-wind has the potential to reduce the environmental impacts associated with the current diesel generated electricity in remote communities of Ontario. This is achieved by comparing the LCA impacts of a proposed hybrid diesel-wind turbine system with the current diesel generated electricity system, where hybrid diesel-wind has been determined a feasible option.

The results of the proposed LCA are intended for a comparative analysis. The LCIA of the diesel system from each remote community is compared against the LCIA of the proposed hybrid diesel-wind system of each remote community.

The scope describes the system to be studied and directs how much information is to be collected, in what categories, and to what levels of detail and quality (Todd et al., 1999). The scope sets the boundaries, assumptions, limitations, and allocation procedures on which the rest of the study will be based.

This study measures the environmental impacts associated with the life stages of diesel generated fuel in remote communities of Ontario compared to those environmental impacts associated with the life stages of a proposed hybrid diesel-wind systems for the remote communities of Ontario, who have the potential wind energy to replace a diesel generator with a wind turbine.

5.1.1 Functional Unit

The functional unit provides a single reference point for the LCA, and determines the amount emissions and impacts created by both products in relationship to the functional unit.

The functional unit for this study is the delivery of the electrical energy demand of each remote community under analysis for a period of 20 years.

For each technology under analysis a cradle to grave perspective of each life cycle stage will be taken into account. This will allow the impacts associated throughout the lifespan of each technology to be established. The stages of the LCA are shown in Figure 7.

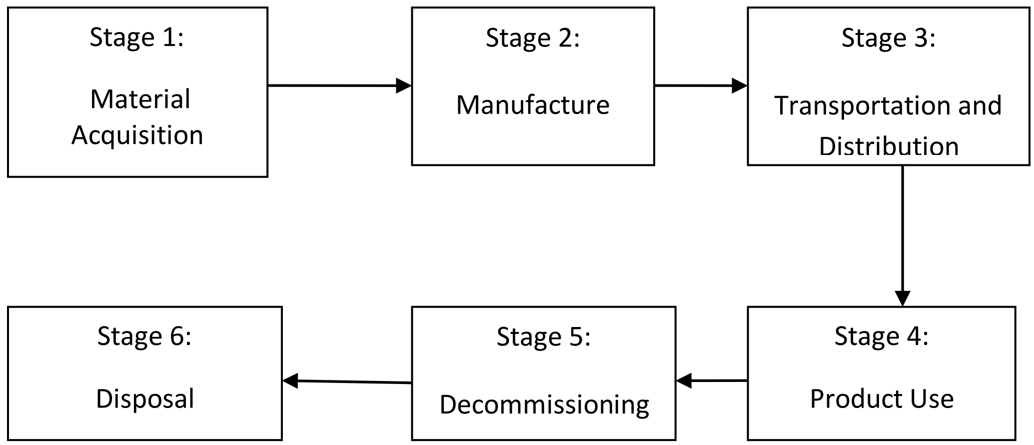

Figure 7 The life stages under analysis

5.1.2 Technology under Analysis

The technologies under analysis comprise of the diesel system currently installed in each community, and a proposed hybrid diesel-wind system that consists of one WES 30 wind turbine as well as diesel generators that allow community's the energy demand to be met.

5.1.3 System Boundaries

A system's boundaries are defined by cut-off criteria. Cut-off criteria are used to define the parts and materials included in and excluded from the product system (PE International, 2009). For both systems a process flow diagram can be seen in Figures 8 and 9. Those processes that fall within the dashed boundary are not included in the LCA.

The main reason behind the exclusion of some processes from the LCA for both the hybrid diesel-wind system and the diesel generator system are due to the lack of reliable data available.

The data for the transportation from material extraction to manufacturing of the energy system cannot be obtained from the manufacturers of both the diesel generators and the wind turbine. This data that cannot be obtained includes: The location in which the raw materials are extracted, the location in which the raw materials are processed, and distance the raw materials are delivered to the assembly plant for the energy systems. Although these are significant factors for producing the LCA, to ensure that the LCA of both the diesel system and the hybrid diesel-wind system is comparable the transportation of raw materials to the manufacturing location is excluded for both energy systems.

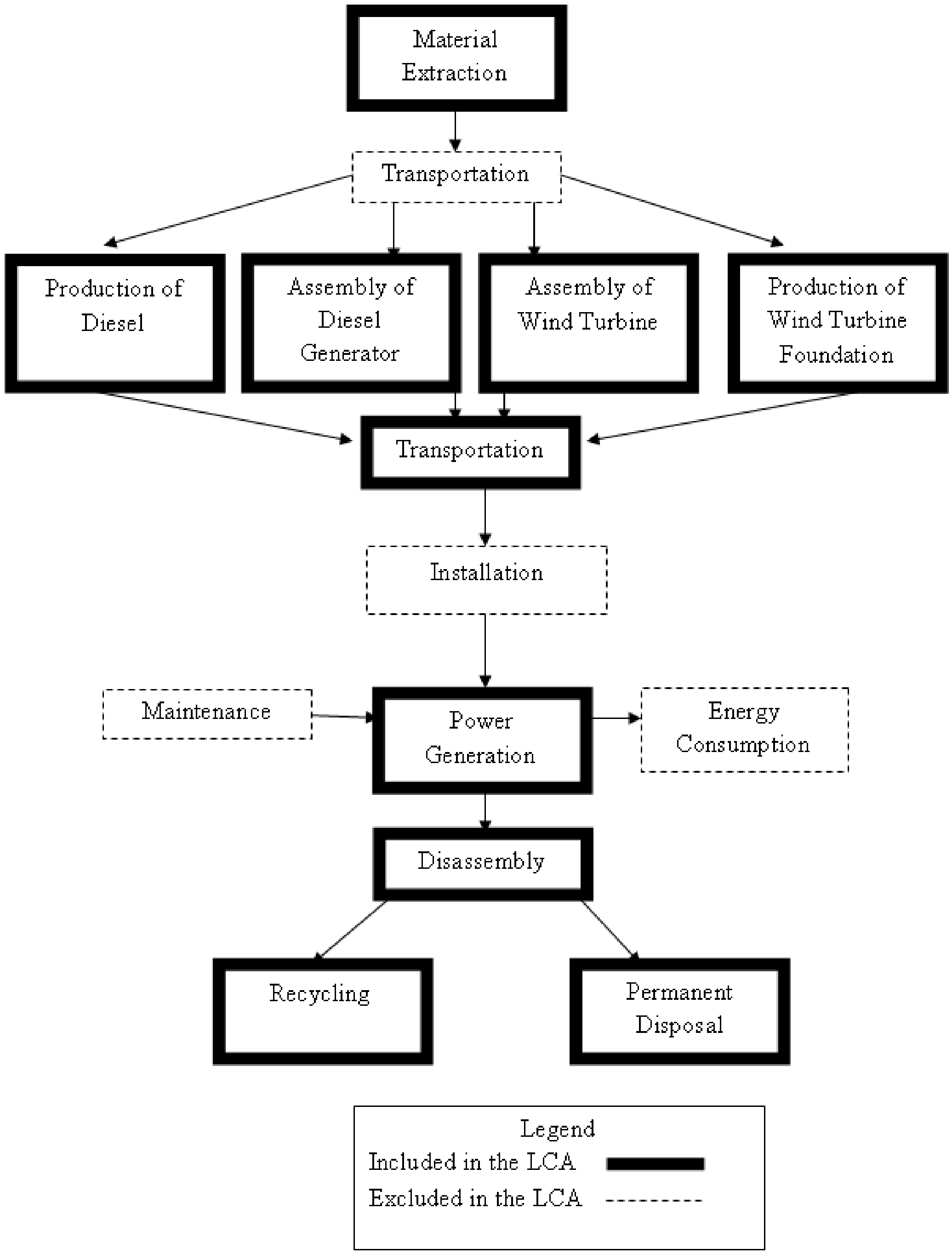

Figure 8 Flow diagram showing boundaries of the hybrid diesel-wind LCA

Another boundary in place in both LCAs is the exclusion of the energy system installation. This is again due to the lack of data availability as well as the LCA not being based on a specific site location within the community, which prevents an assumption to be made on the likely

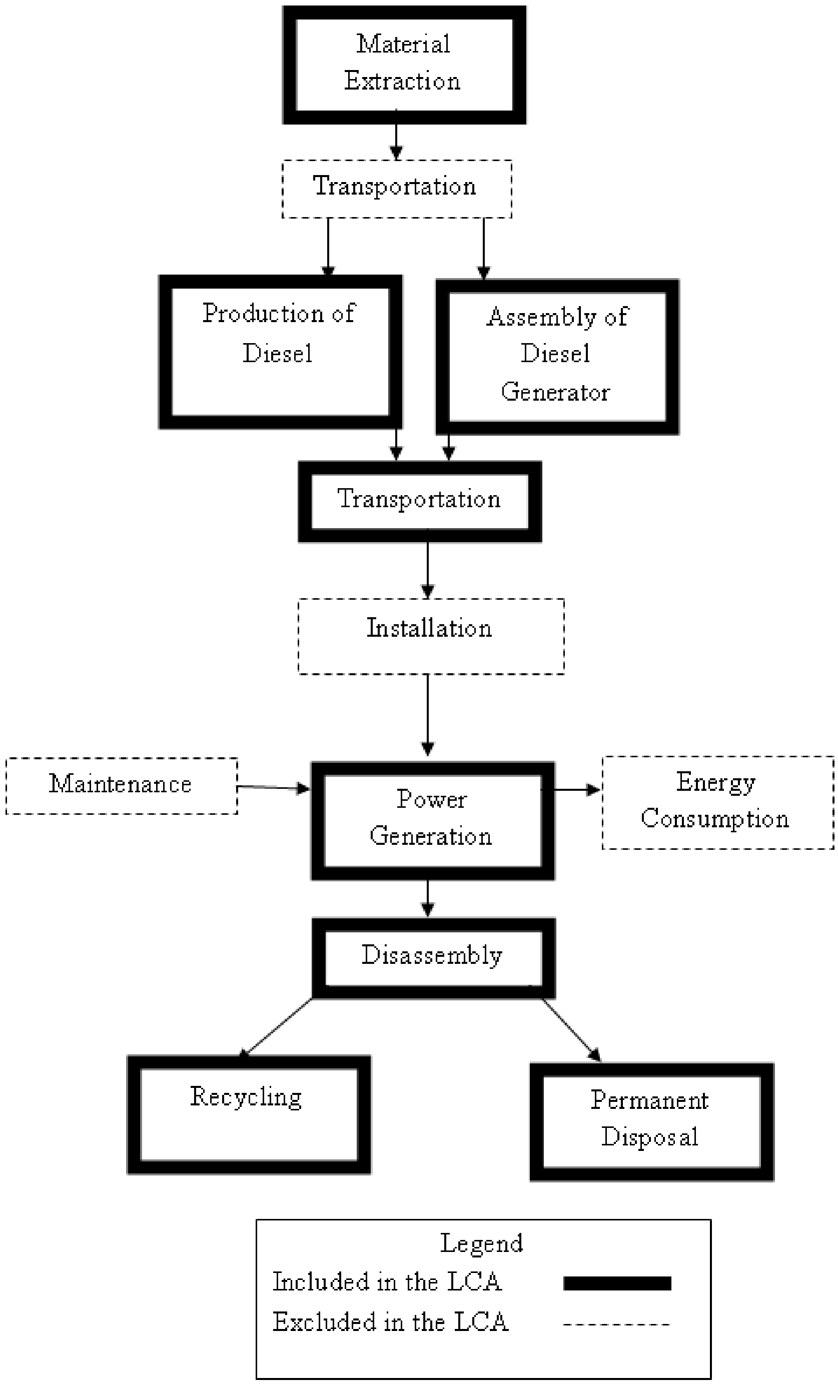

Figure 9 Showing the LCA boundaries of the current diesel system

requirements for implementing both energy systems. The data not available for this process includes: The materials required for construction, the number of construction workers needed for erection, the specific types of machinery required to achieve energy system installation, transportation of the construction workers and equipment to the site location and the time taken to implement the energy systems. The exclusion of this process is likely to reduce the overall environmental impacts of both the hybrid diesel-wind systems and the diesel generating system, however the implementation process is excluded from both energy systems LCA's which slightly mitigates the inaccuracy of the comparison of LCA of the two energy systems.

For both energy systems the maintenance process is excluded from the LCA. This is the final process that is excluded from the LCA due to data restrictions. The maintenance process requires data that describes: routine maintenance of the energy system, the type of components that need replacing over the lifespan of the system, equipment required to conduct repairs and maintenance checks and transportation of maintenance personnel to the community. Due to privacy restrictions with the current energy supplier and the remote communities much of the maintenance data cannot be obtained for the diesel generating energy system. To ensure both LCA's for the hybrid diesel-wind system and the diesel system remain comparable the maintenance process is excluded from both LCAs.

The final process excluded from the LCAs of both systems is the transmission and consumption of power. It is assumed that the community's consumption of the electricity for both energy systems will be the same, and the type of energy technology producing the electricity will not change the applications that consume electricity within the community.

5.1.4 Impact Assessment Method

The LCA is conducted using GaBi 4 software. The GaBi 4 is a type of LCA modeling software that contains a comprehensive, up-to-date life cycle inventory database, which allows the user to enter the LIC inputs and the outputs are automatically calculated. The software was produced by PE International in 2009. GaBi 4 supports every stage of an LCA and conforms to the ISO 14040: 2006 standards (PE International, 2009).

5.1.5 Data Quality Requirements

The data obtained for the LCA are recorded throughout the inventory analysis (LCI). The data qualities are calculated to ensure measurement of the data quality for the entire LCA. This is achieved by recoding the following information within the GaBi 4 modelling software:

- Completeness: The breadth of data collected. Whether the data allowed all the flows to be captured, or whether relevant flows recorded or individual relevant flows recorded, some relevant flows not recorded (PE international 2009).

- Data source: Recording whether the data obtained for the LCI is produced from measured, calculated or estimated sources.

- This information is used to conduct a data quality analysis of the LCI data: This is a tool available within the GaBi software that allows the user to determine whether the majority of the LCA results are based upon actual, calculated, estimated or published sources.

5.2 Inventory Analysis

The Inventory Analysis (LCI) is the LCA phase that involves the compilation and quantification of inputs and outputs for a given product system throughout its life cycle or for single processes (PE International 2009). It is in the LCI where all the inputs and outputs for each single process within the LCA boundaries are established.

The LCA compares the environmental impacts created by the energy production in each community if their energy was produced by diesel energy and those impacts created if at least one of their diesel generators was replaced with a WES 30 wind turbine for the same energy production

The collection of data will be split into two sections:

- The inventory of the current diesel system in each community
- The inventory of the proposed WES 30 hybrid diesel-wind system

This will allow better management of the inventory selection and a greater understanding of the inputs and outputs of the comparable LCA. The results of the LCI are presented in table format and are shown in appendices A.

5.2.1 LCI of Diesel System

There are currently multiple diesel systems operating in each of the remote communities under analysis. Each of the communities currently relies on three diesel generators that is with the exception with the community of Fort Severn which relies on only two diesel generators. Each unit has a lifespan of 8 years. The power output of each generator alongside the mass according to the manufacturer's specification documents is listed in Table 17.

The mass of each unit (Table 18) takes into account the diesel engine and the alternator used to produce electricity. The mass of each system is reported without any fluids, this is known as the dry mass.

Due to lack of available data, the material composition of a diesel generator is presumed to be the same as a typical combustion engine. Table 18 shows the components and the metal materials present in an engine. The data used for material composition from a diesel generator are obtained by Tukker et al. (2009). The authors used the Leontief matrix to calculate the composition of materials. The Leontief matrix is an input output analysis that enables the material composition of products that contain many different components (Tukker et al., 2009). The collected data are based upon a Japanese engine it is presumed that the metal components present in the diesel engine are the same as those used to produce electricity in each of the remote communities of Ontario.

The quantity of each material present in each component in a diesel generator is shown in Table 19 which was taken from Tukker et al. (2009) study. Table 19 shows that the majority of materials used in a combustion engine are cast and forged iron. This is due to the large size of the engine block which is primarily made of cast iron.

It is assumed that the remaining materials consist of plastic and rubber materials. Using the information shown in Table 19 and the mass of the diesel generator (Table 17), the inventory for the amounts of each material in each diesel generator present in the remote communities is calculated the results are shown in appendices A.

Table 17 Diesel generators installed in each remote communities their manufacturer and dry mass

Remote Community	Diesel Generator Sets (CAT, 2010)								
	A			B			C		
	Brand	Power Output (kW)	Mass of unit (kg)	Brand	Power Output (kW)	Mass of unit (kg)	Brand	Power Output (kW)	Mass of unit (kg)
Bearskin	Caterpillar	250	2,277	Cummins*	400	3,856	Caterpillar	600	3,968
Fort Severn	Caterpillar	250	2,277	Caterpillar	400	3,458	Caterpillar	600	3,968
Gull Bay	Caterpillar	125	1,407	Caterpillar	175	1,604	Caterpillar	250	2,277
Kingfisher	Detroit †	250	3,114	Caterpillar	400	3,458	Caterpillar	600	3,968
Lansdowne	Caterpillar	250	2,277	Caterpillar	455	4,563	Caterpillar	825	6,244
Sachigo	Caterpillar	250	2,277	Caterpillar	400	3,458	Caterpillar	600	3,968
Webequie	Caterpillar	250	2,277	Caterpillar	400	3,458	Caterpillar	600	3,968

†Source: Detroit (2010), * Cummins (2008)

Table 18 Component and material breakdown of the materials present in a typical combustion engine (Tukker et al., 2009)

Component	Materials
Cast and forges Materials	Iron, Ferroalloys
Hot rolled special steel	Iron, Ferroalloys, lead
NON Ferrous (NF) Metal castings and forgings	Aluminum, Zinc, Copper
Electrical equipment for engines	Lead, Aluminum, Copper, Ferroalloys
Cold-finished steel	Iron
Bearings	Lead
Bolts nuts and springs	Iron
Rolled and drawn aluminum	Aluminum
Electric wires and cables	Copper + Lead+ Aluminum
Other iron or steel products	Iron
Other general industrial	Iron
Coated Steel	Iron

Table 19 Composition of metals present in a typical combustion engine with alternator (Tukker et al., 2009)

Material	Quantity of metal materials a typical combustion engine with alternator (%)
Pig Iron	78.8
Ferro Alloys	1.2
Copper	0.7
Zinc	0.3
Aluminum	1.7
Plastic *	17.3
Total	100

*assumed

As with most combustion engines, coolant, engine oil and water are fluids are used in a diesel generator. According to caterpillar (CAT) maintenance schedule all diesel generators use a 50/50 of coolant and distilled water in their cooling system (Caterpillar Inc, 2010). Using the specification sheets provided by each manufacturer of the diesel generators the maximum capacity for each of the fluids required is established.

Another major component of the diesel system is the quantity of diesel required to operate the diesel system. By recalling Table 8 the annual consumption of diesel for each remote community required is obtained, this is multiplied by 20 to estimate the average diesel consumption for twenty years.

The next stage of the LCI determines the energy required to manufacture these materials (energy input). Using the data from Grimes et al. (2008) report on the 'Environmental Benefits of Recycling' the energy required to produce each material present in the diesel generator is established and documented in Table 21. This information is derived from a detailed survey of primary literature gathered by Grimes et al. (2008).

Table 20 Wet materials excluding diesel required for each diesel generator used for electricity generation in the remote communities of Ontario

Community	Diesel Generator	Oil (l)	Water (l)	Coolant (l)
Bearskin	A	38	28.9	28.9
	B	83.3	28.9	28.9
	C	38	40.9	40.9
Fort Severn	A	38	28.9	28.9
	B	38	28.9	28.9
	C	38	40.9	40.9
Gull Bay	A	16.5	10.5	10.5
	B	16.5	10.5	10.5
	C	38	28.9	28.9
Kingfisher	A	36	22.7	22.7
	B	38	28.9	28.9
	C	38	40.9	40.9
Lansdowne	A	38	28.9	28.9
	B	38	28.9	28.9
	C	68	80	80
Sachigo	A	38	28.9	28.9
	B	38	28.9	28.9
	C	38	40.9	40.9
Webequie	A	38	28.9	28.9
	B	38	28.9	28.9
	C	38	40.9	40.9

Table 21 The energy required to manufacture the materials required in a diesel generator derived from Grimes et al., (2008)

Material	Energy Required (MJ/kg)†
Pig Iron	14
Ferroalloys	19.2
Copper	16.9
Zinc	24
Lead	10
Aluminum	47
Plastic*	29.3

*Source (Bureau of International Recycling 2010)

†The energy required to produce each material is multiplied by the amount material in each diesel generator.

The next stage of the LCI is determining the inputs for the transport stage. According to Caterpillar Inc. (2010) Caterpillar’s large engine manufacturing center is located in Lafayette, Indiana, United States. This means that each generating system required transportation from its location of manufacturing to each remote community in Ontario (Table 22). Diesel generator systems are likely to be transported by train from Indiana to Northern Ontario. These diesel sets would have then been transported by transport truck from the closest railway station to the remote communities. This would be done in the winter periods when ice roads allow all the remote communities to be accessible.

Table 22 Distance travelled to deliver CAT manufactured diesel systems to remote community

Community	Closest Railway Station to Remote Community	Distance travelled by train (km)	Distance travelled by truck (km)
Bearskin	Sioux Lookout, ON	1,479	450
Fort Severn	Sioux Lookout, ON	1,479	724
Gull Bay	Armstrong, ON	1,510	55
Kingfisher	Sioux Lookout, ON	1,479	350
Lansdowne	Armstrong, ON	1,510	205
Sachigo	Sioux Lookout, ON	1,479	258
Webequie	Armstrong, ON	1,510	177

Although CAT diesel generators are the most popular manufacturer used in the remote communities Bearskin Lake uses a Cummins diesel generator manufactured in Charleston, South Carolina, US (Cummins Power 2010), and Kingfisher uses a Detroit diesel generator manufactured in Redford Michigan, US (Detroit Diesel 2010) to supply their energy (Table 23).

Table 23 Distance travelled to deliver Cummins and Detroit Diesel manufactured diesel systems to remote community

Community	Generator Brand	Location of Manufacturer	Distance by train (km)	Distance by truck (km)
Bearskin	Cummins	Charleston, SC (Cummins Power 2008)	2,767	450
Kingfisher	Detroit Diesel	Redford Township, MI (Detroit Diesel 2010)	1,615	350

It is assumed that all the diesel generators are delivered from the manufacturing location to the closest train station of the remote community and the road transport starting at the train station closest to the remote community will require individual transport trucks for each diesel generator in the system. It is important to note that this transportation journey will need to be repeated when diesel generators expire after 8 years and will need to be replaced. Using the distance required for transportation within the GaBi software determines how much fuel is required for the transportation process.

Although some communities are only accessible by air during the warmer seasons, due to limitations of data availability it is assumed that the diesel consumed for electricity production is transported by diesel operated transport truck from the refinery. The diesel fuel that supplies most of Ontario including the remote communities is refined in Sarnia, Ontario, at the Suncor refinery (Suncor, 2009). This is the closest distribution centre for diesel fuels; the distance from Sarnia to the remote communities is shown in Table 24. Most diesel trucks have a capacity of around 120 barrels of oil (Salazar, 2010); a barrel of oil holds 160 liters which means one transport truck can deliver 19,200 liters of diesel in a single journey.

Table 24 The distance and number of journeys required to supply the diesel demand

Community	Number of Journeys Required to Deliver Diesel* (per 20 years)	Distance from Suncor Refinery (km)
Bearskin	775	2,340
Gull Bay	348	1,522
Fort Severn	515	1,966
Kingfisher	528	1,672
Lansdowne	456	1,874
Sachigo	760	2,067
Webequie	1,037	1,846

*Number of journeys to deliver diesel= total diesel consumption for 20 years / 19,200

After the diesel generators have completed their life span they will need to be disposed. Table 25 shows the current diversion rates of all the materials present in a diesel generator. For the purpose of the LCA the materials not sent for recycling will be sent to permanent disposal. The most common method of permanent disposal in Ontario is landfill (Ministry of Environment, 2009). This is therefore presumed that the materials not sent for recycling were disposed of via landfill.

Table 25 Current diversion rates of materials present in a diesel system

Material	Diversion Rate in Ontario (%)	Reference
Plastic	32.5	(Enviros:RIS 2001)
Ferroalloys	78	(Statistics Canada 2006).
Aluminum	33	(Bureau of International Recycling 2010)
Lead	35	(Bureau of International Recycling 2010)
Copper	32	(Bureau of International Recycling 2010)
Zinc	30	(Bureau of International Recycling 2010)
Pig Iron	90	(Statistics Canada 2006).

The waste outputs and method of disposal for the solid materials used in the diesel systems of each community is shown in appendices A. This data are calculated based upon the diversion rate (%) shown in Table 25 and the total mass of each type materials present in each diesel generator (Table 17). The inputs and outputs of materials of the diesel system have been determines the GaBi software will establish the environmental impacts of the diesel generators life cycle. The outcomes of these impacts will be displayed in the life cycle impact assessment (LCIA) section of the study.

5.2.2 Inventory Analysis Hybrid Diesel-Wind System

The hybrid diesel-wind system consists of two major components: The WES 30 wind turbine, and the diesel generators. For each of the communities under analysis it is presumed that one WES 30 wind turbine is installed and the diesel generators required are dependent on the community's energy demand. In Chapter 4 the diesel generators still required for energy production alongside the wind turbine are calculated. The generator size and manufacturer of each of these communities are listed in Table 27. Each of these diesel generators have a lifespan of 8 years and therefore in a 20 year life span they will need to be replaced two and a half times, this means that those communities that require two diesel generators for energy production will need 5 diesel generators in a 20 year life span, whereas those communities with one diesel generator will require two and a half diesel generators in a life span.

The diesel generators used in the hybrid-diesel wind system are presumed to be the same as those used in the current diesel system with the removal of the diesel generators. This means that the inventory analysis will reflect that of the data collected in the inventory analysis of the diesel system.

Table 26 Diesel generators required for the WES 30 hybrid diesel-wind systems

Diesel Generator Sets (1, 2 represents multiple diesel generators)						
Remote Community	**1**			**2**		
	Brand	**Power Output (kW)**	**Mass of Unit* (kg)**	**Brand**	**Power Output (kW)**	**Mass of Unit* (kg)**
Bearskin	Cummins	400	3,856	CAT	600	3,968
Fort Severn	CAT	250	2,277	-	-	-
Gull Bay	CAT	125	1,407	CAT	250	2,277
Kingfisher	CAT	400	3,458	CAT	600	3,968
Lansdowne	CAT	455	4,563	CAT	825	6,244
Sachigo	CAT	400	3,458	CAT	600	3,968
Webequie	CAT	400	3,458	CAT	600	3,968

*Mass of diesel generators acquired from manufactures specification sheets Caterpillar, (2010) and Cummins (2010)

Using the data from Tukker et al. (2009), the amount of materials present in each of the diesel systems is determined to be the same as each diesel generator in the system (Appendix A). To meet the functional unit of the LCA the material input of the diesel generators used in the hybrid diesel-wind system is calculated for operation for a period of twenty years.

The next stage of the LCI is to determine the energy required to assemble the diesel generators in the hybrid diesel-wind system. This is achieved using the same method that determined the amount of energy required to assemble the diesel system (Table 21) and the results for the energy required to assemble diesel generators for the hybrid diesel-wind is shown in Appendices H-N.

The diesel generators in the hybrid diesel-wind system will require wet materials during the use phase of their life cycle.

The diesel required to operate the hybrid diesel-wind system was previously calculated in Chapter 4. This calculation was based upon the individual's annual consumption. For LCA the quantity of diesel is calculated based upon an estimated diesel consumption of twenty years (Table 27).

Table 27 Diesel required for the hybrid diesel-wind system for energy production annually and over a period of twenty years

Community	Diesel Required for Hybrid Diesel-Wind(l/yr)	Diesel Required for Hybrid Diesel-Wind (l/20yr)*
Bearskin	589,426	11,788,523
Fort Severn	158,861	3,177,225
Gull Bay	126,429	2,528,575
Kingfisher	359,534	7,190,686
Lansdowne	318,324	6,366,475
Sachigo	582,390	11,647,805
Webequie	690,359	13,807,178

*Diesel required for 20 years = diesel required for hybrid diesel-wind *20

The next stage of the inventory is to determine the distance that the diesel generators of the hybrid diesel-wind system must be transported for implementation in the remote community. Table 28 shows the diesel generators used in the hybrid diesel-wind system and the distance and method of transport required to implement this component of the hybrid diesel-wind system.

Table 28 Distance Generators Travelled from Manufacturer to Remote Community

<table>
<tr><th>Community</th><th>Manufacturer</th><th>Location of Manufacturer</th><th>Closest Railway Station to Remote Community</th><th>Distance travelled by train (km)</th><th>Distance travelled by truck (km)</th></tr>
<tr><td rowspan="2">Bearskin</td><td>CAT</td><td>Lafayette in Indiana</td><td rowspan="2">Sioux Lookout, ON</td><td>1,479</td><td>450</td></tr>
<tr><td>Cummins*</td><td>Charleston in South Carolina</td><td>2,767</td><td>450</td></tr>
<tr><td>Fort Severn</td><td>CAT</td><td>Lafayette in Indiana</td><td>Sioux Lookout, ON</td><td>1,479</td><td>724</td></tr>
<tr><td>Gull Bay</td><td>CAT</td><td>Lafayette in Indiana,</td><td>Armstrong, ON</td><td>1,510</td><td>55</td></tr>
<tr><td>Kingfisher</td><td>CAT</td><td>Lafayette in Indiana</td><td>Sioux Lookout, ON</td><td>1,479</td><td>350</td></tr>
<tr><td>Lansdowne</td><td>CAT</td><td>Lafayette in Indiana</td><td>Armstrong, ON</td><td>1,510</td><td>205</td></tr>
<tr><td>Sachigo</td><td>CAT</td><td>Lafayette in Indiana</td><td>Sioux Lookout, ON</td><td>1,479</td><td>258</td></tr>
<tr><td>Webequie</td><td>CAT</td><td>Lafayette in Indiana</td><td>Armstrong, ON</td><td>1,510</td><td>177</td></tr>
</table>

*Source: Cummins Power (2008)

The transportation of diesel is also a major component of the LCI. As with the diesel system the diesel is assumed to be sourced from the Suncor refinery in Sarnia. The transportation distances are calculated on the distance by road the Suncor refinery is to the remote community (Table 29).

Table 29 Transportation of diesel to remote communities for use in the hybrid diesel-wind system

Community	Number of Journeys Required to Supply 20 years of Diesel	Distance from Suncor Refinery (km)	Distance required to deliver diesel* (km)
Bearskin	616	2,066	1,268,494
Fort Severn	171	2,340	387,224
Gull Bay	205	1,522	200,442
Kingfisher	377	1,966	736,296
Lansdowne	334	1,672	554,414
Sachigo	609	1,874	1,136,874
Webequie	724	1,918	1,379,280

*Distance requires to deliver diesel= 20 year diesel consumption/ 19,200

The final stage of the LCI for the diesel generators for use in the hybrid diesel-wind system required the calculation of the quantity of materials sent to be recycled or landfill at the end of its lifespan. This data are calculated based upon the diversion rates shown in Table 30. This percentage is used to calculate the amount of materials sent for recycling. This is achieved by multiplying the input mass of each individual material by the diversion percentage. The remainder of the materials not sent for recycling is assumed to be permanently disposed via landfill (Appendices H-N).

The inventory analysis for the diesel generators present in the hybrid diesel-wind system is complete. The final stage of the LCA requires a detailed inventory analysis of the wind turbine to be conducted. This inventory analysis follows the same method as that used for the LCI of diesel generators. The inventory produced is integrated with the data produced in the inventory of the diesel generators for the hybrid diesel-wind system to illustrate the LCI for the whole hybrid diesel-wind system.

5.2.3 Inventory Analysis of the Wind Turbine

Unlike the diesel generator the wind turbines do not vary in size type or manufacturer, therefore the inputs and outputs for this section the inventory analysis are the same for all communities with the exception of the transportation stage. The particular wind turbine is WES 30 wind turbine, each community is presumed to have one wind turbine installed for a twenty year period

Table 30 shows the materials and masses of each material used to produce as WES 30 250kW wind turbine. This information was obtained by the manufacturer of WES 30 wind turbines and is recorded as measured data for data quality purposes.

Table 30 Materials present in WES 30wind turbines (WES 2010)

Component	Material	Mass of Component (kg)
Blades (x 2)	Carbon and glass fiber reinforced epoxy	3.6
Nacelle/ rotor	Steel	7.1
Tower (49 meter height)	Steel	2041
Foundation	Concrete with steel anchor	480,000*
Control panel	Aluminum	600

*Estimated based upon Kabir et al. (2012)

Both the blades and the foundation of the wind turbine are made of multiple materials. The ratio that these materials have in respect to the overall mass of the component is not provided by the manufacturer; instead an estimation of the material is used.

The size of a wind turbine foundation varies depending on the site conditions. For the purpose of this study the estimated material inputs will be derived from Kabir et al. (2011) it is estimated that for a wind turbine with a tower height of 36.6 m the foundation is estimates at 480,000 kg with 0.5 % of it made from steel and 99.5 % made from concrete (Kabir et al. 2011).

Whereas the WES 30 wind turbine has a foundation with a mass of 480,000 kg

Therefore 0.5 % of 480,000 kg = 2,410

= 2.410 kg of steel

99.5 % of 480,000 kg = 352,000 kg

= 352,000 kg of concrete

The wind turbine blades consist of epoxy and composite fiber. According to Wiley (1988) the mass of the epoxy is usually three times greater than the mass of the composite fibers used. In terms the blades of the wind turbine this would mean that 2.4 kg of the wind turbine blade is epoxy and 1.2 kg is carbon glass fiber mix (presuming carbon and glass fiber is a 50:50 mix). The total material input for the WES 30 wind turbine can now be totaled and is shown in Table 31 these materials are used for the input of the LCIA.

Table 31 Material input for the WES 30 wind turbine

Material Input: WES 30 Wind Turbine (kg)					Material Input: Foundation (kg)	
Carbon Glass Fiber	**Carbon Fiber**	**Epoxy**	**Steel**	**Aluminum**	**Steel**	**Concrete**
0.6	0.6	2.4	2,048	600	2,410	479,590

The next step of the inventory analysis is to determine the energy required to manufacture each material. To maintain consistency with the inventory analysis of the diesel system the energy required per material as published by Grimes et al. (2008) is used to determine the energy inputs of the wind turbine as shown in table 32. For those material not published in Grimes et al., (2008), Mathew et al, (2006) is used.

Table 32 Energy required for manufacturing the materials present in the WES 30 wind turbine

Material	Energy Required per 1 kg of material (MJ)	Energy required for total material in WES 30 wind turbine (MJ)*
Materials Used in the Wind Turbine	-	-
Glass Fiber	9.3(Mathew et al., 2006)	5.58
Carbon Fiber	9.3 (Mathew et al., 2006)	5.58
Epoxy	45.7 (Mathew et al., 2006)	109.68
Steel	19.2 (Grimes et al,. 2008)	39,324
Aluminum	47.0 (Grimes et al,. 2008)	28,200
Materials Used in the Foundation	-	-
Concrete	36.8 (Mathew et al., 2006)	17,648,900
Steel	19.2 (Grimes et al,. 2008)	46,272

*Energy required for total material in WES 30 wind turbine= mass of material (kg) * energy required (MJ)

In terms of transportation the WES 30 wind turbine is manufactured in the Netherlands and would be distributed via ocean freighter to Toronto, Ontario. Then the wind turbine and battery would be transported to each community. It is presumed that the majority of the wind turbine components would be delivered by train to the nearest station to the remote communities. From there the wind turbine would be transported via transport truck to its final destination (Table 33).

Table 33 Transportation method and distance to deliver WES 30 wind turbine

Community	Distance from Netherland to Toronto by ocean freighter (km)	Closest railway station to remote community	Distance from Toronto to railway station travelled by train (km)	Distance travelled by truck (km)
Bearskin	6,023	Sioux Lookout, ON	1,986	450
Fort Severn	6,023	Sioux Lookout, ON	1,986	724
Gull Bay	6,023	Armstrong, ON	1,321	55
Kingfisher	6,023	Sioux Lookout, ON	1,986	350
Lansdowne	6,023	Armstrong, ON	1,321	205
Sachigo	6,023	Sioux Lookout, ON	1,986	258
Webequie	6,023	Armstrong, ON	1,321	177

The foundation components are presumed to be manufactured in Canada. There are currently four large cement manufacturer's in Ontario the closest being St. Mary's cement plant in Bowmanville, Ontario (St. Mary's Cement Group 2011). It is presumed that the cement would be transported by train from Bowmanville to each remote community and then transported by truck to its final destination (Table 34).

The steel anchor also assumed to be manufactured in Ontario. It is presumed that this product comes from the closest large scale steel smelter. In this case it is Essar Steel Algoma located in Sault Ste. Marie, Ontario (Essar Steel Algoma, 2011). The steel anchor is presumed to be transported by train from Sault Ste Marie to the nearest train station of the remote community and then transported by truck to its final destination.

The next stage of the LCI is to gather information in regards to the use of the wind turbine for each community. Chapter 2 shows the potential energy output for a WES 30 wind turbine in each community. These energy outputs are presumed to be the only output the wind turbine generates during the use stage of the LCA. These energy outputs are highlighted in Table 35.

Table 34 Transportation method and distance for delivery of wind turbine foundation

		Cement Transportation		Steel Anchor Transportation	
Community	Closest Railway Station to Remote Community	Distance from Bowmanville to Closest Railway station (km)	Distance travelled by truck from Railway station to Community (km)	Distance from Sault Ste Marie to Closest Railway station (km)	Distance travelled by truck from Railway station to Community (km)
Bearskin	Sioux Lookout, ON	1,796	450	1,060	450
Fort Severn	Sioux Lookout, ON	1,796	724	1,060	724
Gull Bay	Armstrong, ON	1,655	55	919	55
Kingfisher	Sioux Lookout, ON	1,796	350	1,060	350
Lansdowne	Armstrong, ON	1,655	205	919	205
Sachigo	Sioux Lookout, ON	1,796	258	1,060	258
Webequie	Armstrong, ON	1,655	177	919	177

Table 35 Potential energy output of the WES 30

Remote Community	Potential WES 30 power output (KWh)*
Bearskin	506,926.
Fort Severn	1,100,900
Gull Bay	457,925
Kingfisher	484,836
Lansdowne	391,305
Sachigo	482,119
Webequie	1,000,090

The final stage of the inventory analysis is to determine the disposal routes of the WES 30 wind turbine in each community. Where comparable the hybrid diesel-wind system will be allocated the same diversion rates as for the diesel system (Table 26).

In Ontario fiberglass materials are not currently recyclable (Ministry of Environment, 2004) and it will be presumed that 100% of these materials will go to a permanent disposal facility (i.e. a landfill at the end of their lifespan). The cement in Ontario is being diverted at a rate of 83% (Statistics Canada, 2004); this is assumed 17% of the cement used for the wind turbine foundation will be permanently disposed of at the end of its lifespan via landfill (Table 36).

Table 36 Disposal path of materials present in the WES 30 wind turbine

	Material (kg)				
	Carbon Glass Fiber	**Epoxy**	**Steel**	**Concrete**	**Aluminum**
Input	1.2	2.4	4,459	479,590	600
Recycled	0	0	1,880	402,856	198
Landfill	1.2	2.4	2,579	76,734	402

5.3 Results of the LCI

Through the use of the GaBi software the results of the LCI are put into a LCA plan. This plan records all the relevant processes and the inventory data that are required for the processes to be modeled. The plan shows where the largest input/output flows are within the LCA of both energy scenarios in terms of mass.

The results show that for the diesel generator system the diesel production, transportation and combustion create the largest input/output flows in terms of mass. This is represented by the weight of the arrow connecting the processes (Figure 9). The heavier the weight of the connection arrow the larger the quantity of resources is running through a process.

The outcomes for the LCA plan of the hybrid diesel-wind systems show that diesel is also the largest flow of input/output masses, but is not the only large quantity of input/outputs. The materials required for the foundation of the wind turbine also require a large quantity of inputs and produce a large quantity of waste outputs. The LCA plan for hybrid diesel-wind in Bearskin is shown in Figure 11 for the LCA plans of the remaining communities refer to Appendices B.

When comparing the two LCA plans visually it is determined that diesel is the largest flow of input/outputs and therefore it can be assumed that the outcomes of the LCI are likely to show that the diesel process is likely to be the largest contributor to environmental impacts.

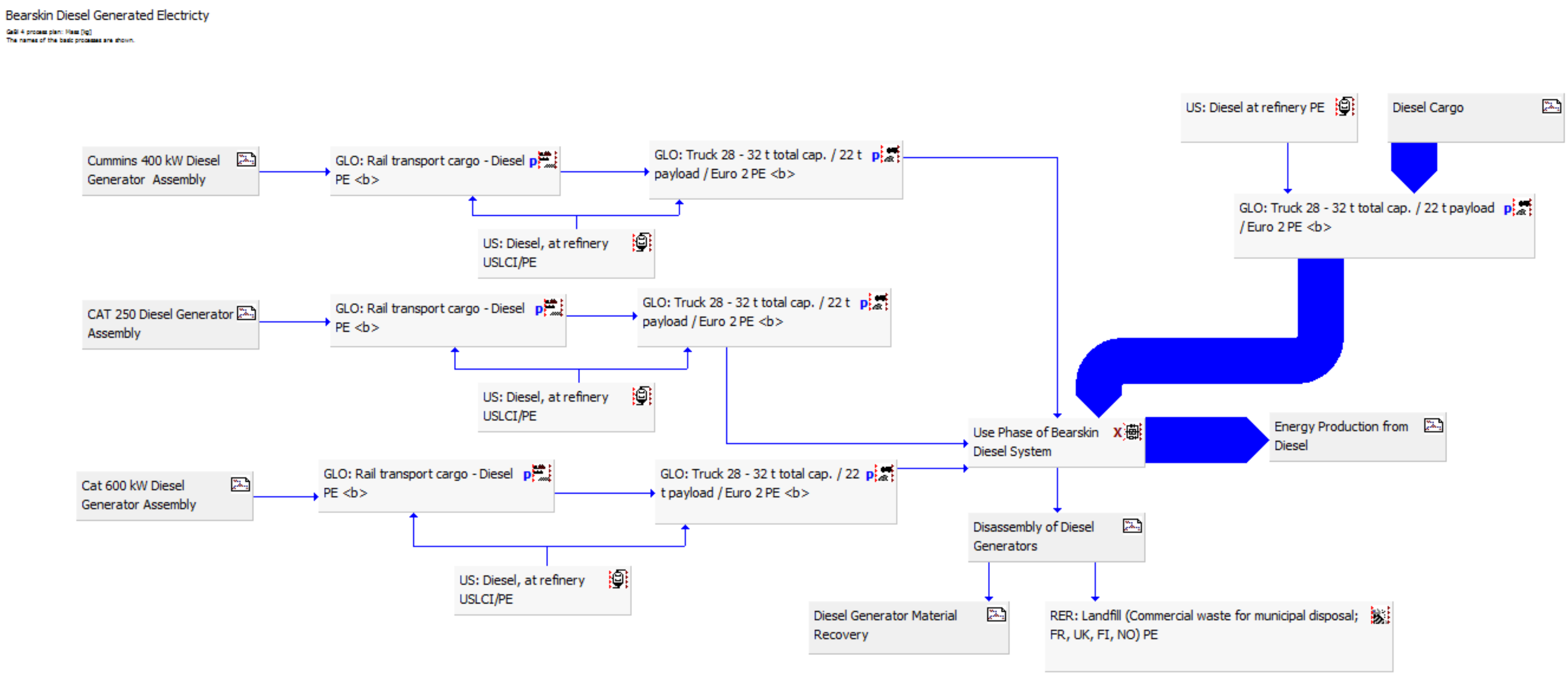

Figure 10 LCA plan for the diesel-system of Bearskin produces using GaBi 4

5.3.1 Consistency of LCI

For the purpose of this study all output flows are be connected or specified as an input directly from the environment or an output directly to the environment. Using the GaBi software it is possible to check the completeness of the LCA inventory analysis. This is achieved by using the 'completeness check' function within the GaBi program. This ensures that all flows moving through the plan are connected through the processes unless the flow is gained from the environment as a resource or released into the environment as a waste deposit no physical results are produced using this function.

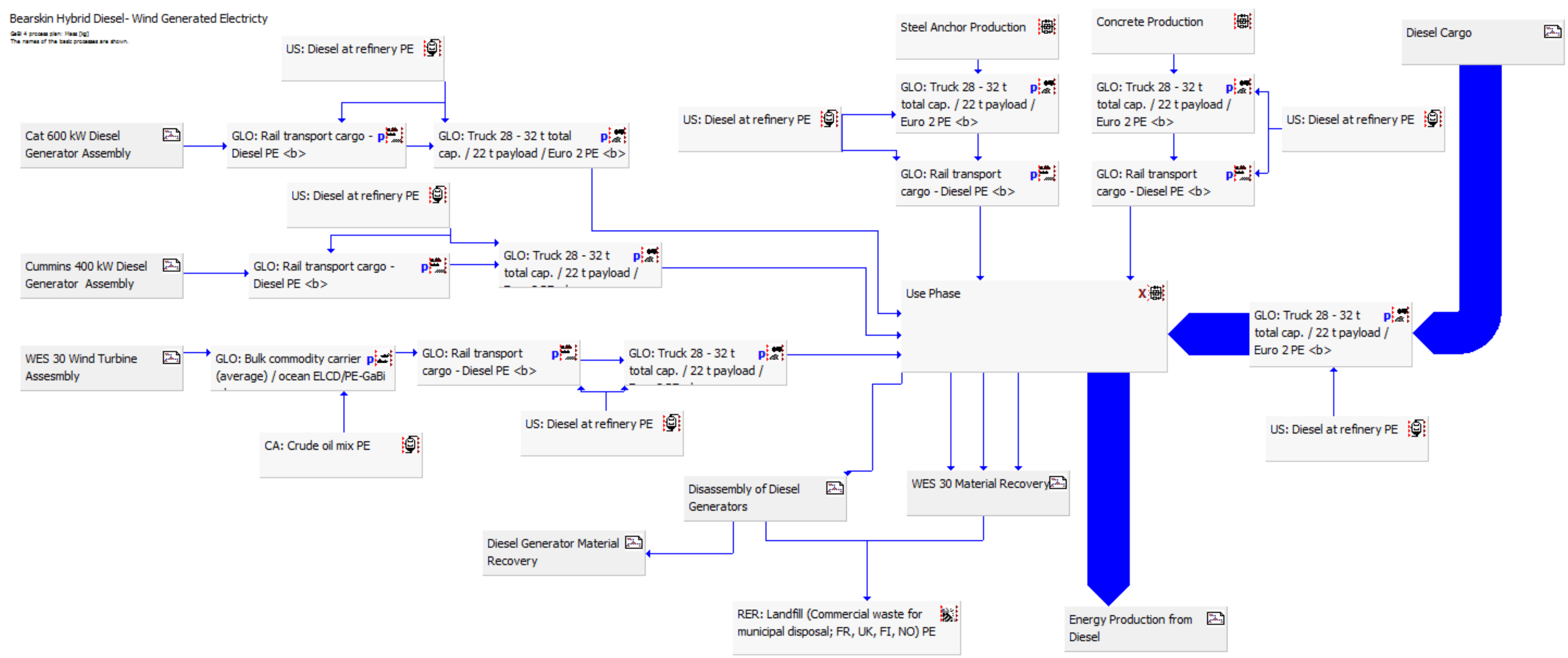

Figure 11 LCA plan for the hybrid diesel-system of Bearskin produces using GaBi 4

5.3.2 Evaluation of Data Quality

The LCA is a modeling method and not actual measurement of the outcomes and therefore many types of data are used and the sources in which they are gathered from. To ensure the data inputs are not based heavily on estimates alone an evaluation of the data sources can take place (Table 37). Using the GaBi software and referring back to the goal and scope of the LCA it is possible to determine whether the quality of data is high enough to allow the outcome of the LCA to be valid.

The data sources fall into one of four categories: Measured, calculated, literature, and estimated. As the data for the LCI are obtained the sources in which the data came from were recorded within GaBi. Once the LCI is complete the data quality can be measured.

Table 37 Data quality total for the LCI

Data Source	Total Data (%)
Measured	5
Calculated	29
Literature	46
Estimated	19
Total	100

Most data for the LCI are sourced from literature sources and calculated data. Therefore the quality of data used for this study is of medium quality. This is to be expected for a study that is based heavily on proposed scenarios rather than based upon real life situations. It must be noted that if a site visit took place for each of these communities more measurements could be taken, therefore increasing the overall quality of the data.

5.3.3 Classification of Inventory Analysis

Classification of the inventory analysis determines the impact that the individual inputs from the life cycle inventory has on each emission category. For the purpose of this study the inputs are sorted into categories. Table 38 shows the classification categories and the allocation of each classification category for the purpose of each LCA scenario.

The classified results are shown in Table 39 and Figure 12. Classification of the LCI data is achieved through the use of the GaBi 4 software. GaBi allows the user to group the processes on the LCA plan into life stages of the energy system. The results show that for both the diesel system and the hybrid diesel-wind system the largest quantity of input/ output flows occur in the assembly stage of the LCA.

Table 38 Classification categories for each LCA Scenario

Classification Category	Diesel LCA Allocation of Classification Category	Hybrid Diesel- Wind Allocation of Classification Category
Assembly	Diesel Generator Assembly • Material Extraction • Energy Required To Process Material Diesel Production At Refinery	Diesel Generator Assembly • Material Extraction • Energy Required To Process Material WES 30 Wind Turbine Assembly • Material Extraction • Energy Required To Process Material WES 30 Foundation Materials • Material Extraction • Energy Required To Process Material Diesel Production At Refinery
Transportation	Transportation Of Diesel Generator • By Train • By Truck Diesel Transportation By Truck	Transportation Of Diesel Generator • By Train • By Truck Transportation Of WES 30 Wind Turbine • By Ocean Freight • By Train • By Truck Transportation Of Foundation Materials • By Train • By Truck Diesel Transportation By Truck
Use	Diesel Combustion	Diesel Combustion Electricity Production From Wind
Material Recovery	Disassembly Of Diesel Generators Energy Required To Recycle Materials From Diesel Generators	Disassembly Of Diesel Generators Energy Required To Recycle Materials From Diesel Generators Disassembly Of Wes 30 Wind Turbine Energy Required To Recycle Wes 30 Wind Turbine
Permanent Disposal	Landfill Of Materials Not Recovered From Diesel Generators	Landfill Of Materials Not Recovered From Diesel Generators Landfill Of Materials Not Recovered From WES 30 Wind Turbine Landfill Of Materials Not Recovered From Wind Turbine Foundation

The outcomes from the characterization of each life cycle stage shows that hybrid diesel - wind can reduce the amount of input and output flows in comparison to a diesel energy system for all of the communities analyzed. Input and output flows are lower in the hybrid diesel-wind system for assembly, transportation and use life stages in comparison to the diesel system. However, the hybrid diesel-wind system requires a large amount of waste to be sent for recovery and permanent disposal which results in higher input/outputs in comparison to the diesel system. This is due to the excessive amount of materials that are needed for the wind turbine foundation.

Table 39 Classification of input/output flows for each life cycle stage

	Classification of Input/ Output flows in Each Life Cycle Stage (kg)					
Community	**Assembly**	**Transportation**	**Use**	**Material Recovery**	**Permanent Disposal**	**Total Input/ Output Flows**
Bearskin Diesel	59,497,948	3,362,526	43,856,908	175,828	8,260	106,901,469
Bearskin Hybrid	39,767,335	2,404,950	34,752,214	211,596	131,549	77,267,643
Fort Severn Diesel	44,224,237	3,756,961	29,142,391	168,900	7,934	77,300,422
Fort Severn Hybrid	26,594,298	830,548	9,366,364	115,040	127,013	37,033,263
Gull Bay Diesel	34,259,360	1,963,035	19,683,056	92,048	4,324	56,001,823
Gull Bay Hybrid	11,064,128	412,679	7,454,164	139,531	128,164	19,198,666
Kingfisher Diesel	31,730,502	3,294,997	29,906,779	183,470	8,210	65,123,957
Kingfisher Hybrid	25,656,193	1,427,157	21,197,926	204,668	131,223	48,617,167
Lansdowne Diesel	42,009,713	3,170,092	25,798,181	227,756	10,699	71,216,441
Lansdowne Hybrid	24,357,974	1,079,313	18,768,176	263,525	133,988	44,602,977
Sachigo Diesel	58,106,768	5,329,352	42,996,968	168,900	7,934	106,609,922
Sachigo Hybrid	25,225,232	2,056,894	44,092,659	185,389	125,002	71,685,177
Webequie Diesel	73,808,389	7,094,462	58,666,974	168,900	7,934	139,746,660
Webequie Hybrid	45,200,768	2,605,487	40,703,147	204,668	131,223	88,845,294

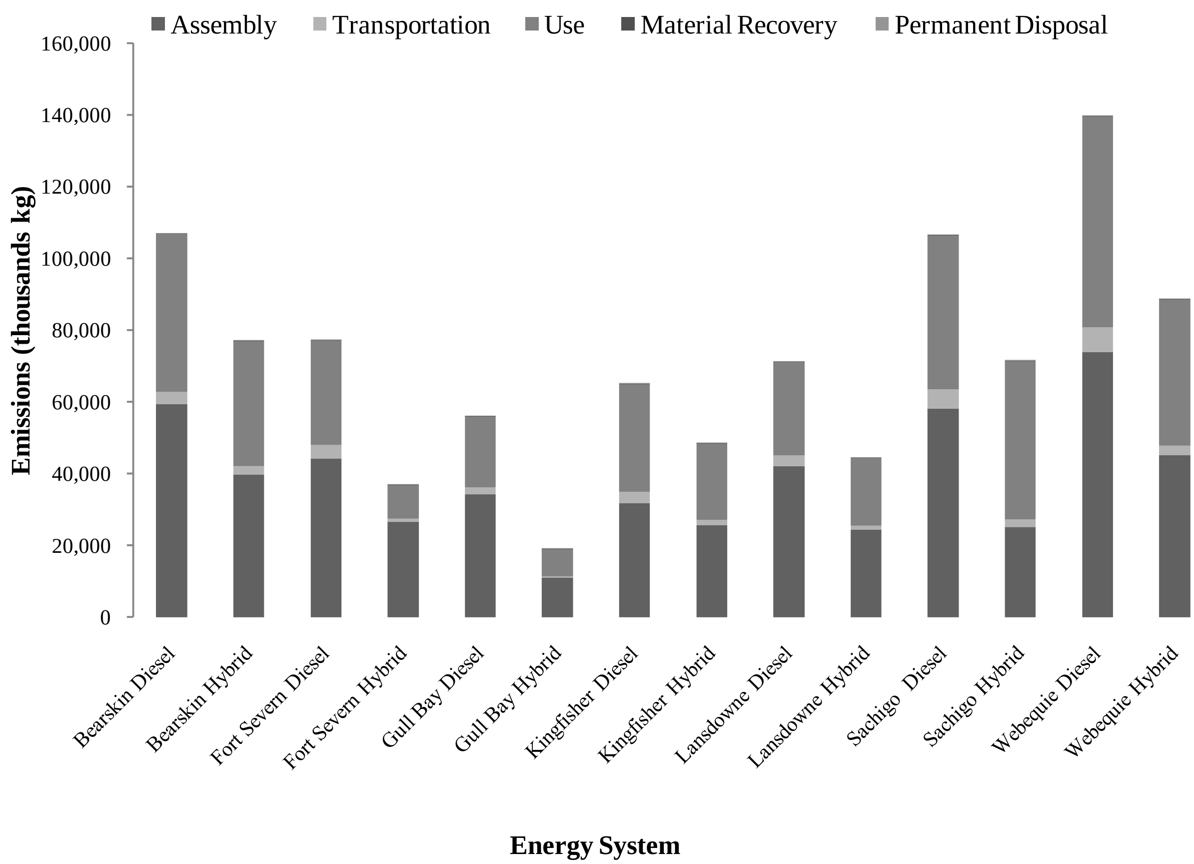

Figure 12 Classification of input/ output flows for the life cycle stages for each community and energy system

5.3.4 Characterization of Environmental Impacts

This stage of the LCIA determined the quantities and the type of environmental impacts created by the inputs and outputs of the LCA. The environmental impact and the units that characterize the environmental impacts are measured in kilograms and the categories for the measured impacts are as follows.

- Resource depletion
- Emission to air
- Emissions to freshwater
- Emissions to seawater
- Emissions to soil

These inputs and outputs within each process are automatically assigned within the GaBi 4 software. The characterization is compared to the different energy scenario for each community. The results for the characterization of environmental impacts are shown in Tables 40-46.

Table 40 Characterization for the quantity of environmental the characterized impact categories for each energy scenario for the community of Bearskin

	Resource depletion (kg)	Emissions to air (kg)	Emissions to fresh water (kg)	Emissions to sea water (kg)	Emissions to soil (kg)
Bearskin Diesel	42,146,730	64,354,639	208,617	190,836	648
Bearskin Hybrid diesel-wind	28,522,015	48,051,348	166,834	150,583	959

Table 41 Characterization for the quantity of environmental the characterized impact categories for each energy scenario for the community of Fort Severn

	Resource depletion (kg)	Emissions to air (kg)	Emissions to fresh water (kg)	Emissions to sea water (kg)	Emissions to soil (kg)
Fort Severn Diesel	30,665,923	44,488,724	141,085	126,085	437
Fort Severn Hybrid diesel-wind	16,795,601	19,729,760	60,440	41,106	588

Table 42 Characterization for the quantity of environmental the characterized impact categories for each energy scenario for the community of Gull Bay

	Resource depletion (kg)	Emissions to air (kg)	Emissions to fresh water (kg)	Emissions to sea water (kg)	Emissions to soil (kg)
Gull Bay Diesel	23,179,873	31,658,439	97,249	84,584	290
Gull Bay Hybrid diesel-win	7,258,143	11,489,206	42,737	32,113	563

Table 43 Characterization for the quantity of environmental the characterized impact categories for each energy scenario for the community of Kingfisher

	Resource depletion (kg)	Emissions to air (kg)	Emissions to fresh water (kg)	Emissions to sea water (kg)	Emissions to soil (kg)
Kingfisher Diesel	23,318,179	39,886,160	135,487	128,608	447
Kingfisher Hybrid diesel-wind	18,067,320	29,975,945	105,444	91,786	767

Table 44 Characterization for the quantity of environmental the characterized impact categories for each energy scenario for the community of Lansdowne

	Resource depletion (kg)	Emissions to air (kg)	Emissions to fresh water (kg)	Emissions to sea water (kg)	Emissions to Soil (kg)
Lansdowne Diesel	28,857,387	40,535,538	126,879	111,484	400
Lansdowne Hybrid diesel-wind	16,897,069	27,153,254	95,119	80,888	742

Table 45 Characterization for the quantity of environmental the characterized impact categories for each energy scenario for the community of Sachigo

	Resource depletion (kg)	Emissions to air (kg)	Emissions to fresh water (kg)	Emissions to sea water (kg)	Emissions to soil (kg)
Sachigo Diesel	40,788,990	62,766,494	203,432	186,251	632
Sachigo Hybrid diesel-wind	27,370,139	47,504,214	193,372	148,341	2,440

Table 46 Characterization for the quantity of environmental the characterized impact categories for each energy scenario for the community of Webequie

	Resource depletion (kg)	Emissions to air (kg)	Emissions to fresh water (kg)	Emissions to sea water (kg)	Emissions to soil (kg)
Webequie Diesel	52,563,511	83,109,428	272,821	253,138	848
Webequie Hybrid Diesel-Wind	32,562,239	55,537,516	192,707	175,887	1,040

5.3.5 Interpretation of Characterized LCIA Results

Emissions to air are the largest source of emissions for both the hybrid diesel-wind system and the diesel system. This is due to the large amount of emissions created by the combustion of diesel required for electricity production. The second largest emission category is due to the amount for resources required to manufacture the energy systems in each community. The smallest emissions released from both energy systems are a result of emissions to soil.

High wind speed mean that less diesel is consumed and therefore fewer emissions are released into the environment. The exception is the emissions released into soil.

To determine the reasons as to why soil emissions are higher for the hybrid diesel-wind system a comparison was made of the life stages that contribute to soil emissions (Figures 13 and 14). The quantity of soil emission sources show that permanent disposal of waste materials into landfill are the largest source of soil emissions for hybrid diesel-wind, whereas, transportation is the largest contributor to soil emissions within the diesel system. The higher soil emissions for the hybrid diesel-wind system are due to the disposal path that the wind turbine foundation would follow as it contains large quantities of materials. Therefore even with a high diversion rate large quantities of these materials will eventually require permanent disposal via landfill and landfill has a substantial environmental impact on soil.

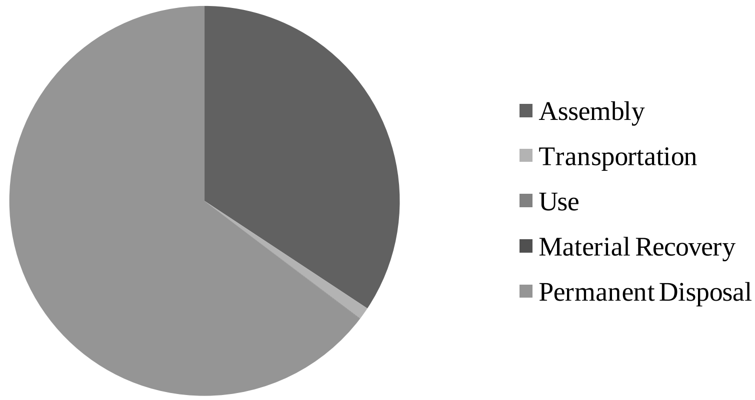

Figure 13 Sources of emissions to soil for Lansdowne using the hybrid diesel-wind energy system

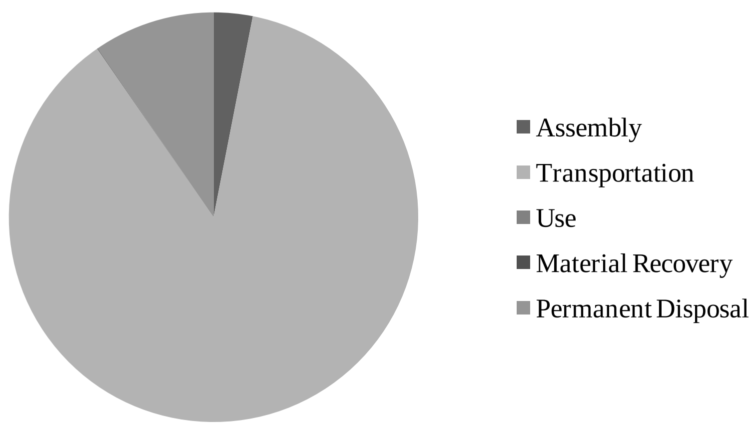

Figure 14 Sources of emissions to soil for Lansdowne using the hybrid diesel energy system

5.3.6 Normalization

Normalization of results calculates the severity of the emissions in relation to a particular environment also known as equivalence; it is the final data analysis stage of the LCIA. Using normalization as part of an LCIA also requires weighting factors to be taken into account. Results are shown in Tables 47 to 53. The normalized results are produced within the GaBi 4 software, GaBi 4.

Table 47 Bearskin LCIA normalization results for both energy scenarios

	Abiotic Depletion	**Acidification Potential**	**Eutrophication Potential**	**Global Warming Potential**	**Ozone Layer Depletion Potential**	**Photochemical Ozone Creation Potential**	**Total**
	(Kg Sb-Equiv.)	(kg SO2-Equiv)	(kg Phosphate-Equiv)	(kg CO2-Equiv)	(kg R11-Equiv)	(kg Ethylene-Equiv)	(CML 2001-Canada)
Diesel	1.98E-04	5.77E-05	3.60E-05	8.85E-04	1.40E-07	3.12E-05	1.21E-03
Hybrid Diesel- Wind	1.54E-04	4.31E-05	2.75E-05	7.11E-04	7.85E-08	2.37E-05	9.59E-04

Table 48 Fort Severn LCIA normalization results for both energy scenarios

	Abiotic Depletion	**Acidification Potential**	**Eutrophication Potential**	**Global Warming Potential**	**Ozone Layer Depletion Potential**	**Photochemical Ozone Creation Potential**	**Total**
	(Kg Sb-Equiv.)	(kg SO2-Equiv)	(kg Phosphate-Equiv)	(kg CO2-Equiv)	(kg R11-Equiv)	(kg Ethylene-Equiv)	(CML 2001-Canada)
Diesel	1.32E-04	3.84E-05	2.34E-05	5.89E-04	1.09E-07	2.07E-05	8.04E-04
Hybrid Diesel- Wind	4.54E-05	1.48E-05	9.07E-06	2.23E-04	6.74E-08	7.74E-06	3.00E-04

Table 49 Gull Bay LCIA normalization results for both energy scenarios

	Abiotic Depletion	**Acidification Potential**	**Eutrophication Potential**	**Global Warming Potential**	**Ozone Layer Depletion Potential**	**Photochemical Ozone Creation Potential**	**Total**
	(Kg Sb-Equiv.)	(kg SO2-Equiv)	(kg Phosphate-Equiv)	(kg CO2-Equiv)	(kg R11-Equiv)	(kg Ethylene-Equiv)	(CML 2001-Canada)
Diesel	8.98E-05	2.61E-05	1.55E-05	4.00E-04	8.74E-08	1.39E-05	5.45E-04
Hybrid Diesel- Wind	3.29E-05	9.10E-06	6.01E-06	1.69E-04	1.88E-08	5.10E-06	2.23E-04

Table 50 Kingfisher LCIA normalization results for both energy scenarios

	Abiotic Depletion	**Acidification Potential**	**Eutrophication Potential**	**Global Warming Potential**	**Ozone Layer Depletion Potential**	**Photochemical Ozone Creation Potential**	**Total**
	(Kg Sb-Equiv.)	(kg SO2-Equiv)	(kg Phosphate-Equiv)	(kg CO2-Equiv)	(kg R11-Equiv)	(kg Ethylene-Equiv)	(CML 2001-Canada)
Diesel	1.31E-04	3.60E-05	2.24E-05	5.89E-04	6.65E-08	1.98E-05	7.98E-04
Hybrid Diesel- Wind	9.39E-05	2.63E-05	1.69E-05	4.42E-04	4.95E-08	1.45E-05	5.94E-04

Table 51 Lansdowne LCIA normalization results for both energy scenarios

	Abiotic Depletion	**Acidification Potential**	**Eutrophication Potential**	**Global Warming Potential**	**Ozone Layer Depletion Potential**	**Photochemical Ozone Creation Potential**	**Total**
	(Kg Sb-Equiv.)	(kg SO2-Equiv)	(kg Phosphate-Equiv)	(kg CO2-Equiv)	(kg R11-Equiv)	(kg Ethylene-Equiv)	(CML 2001-Canada)
Diesel	1.18E-04	3.44E-05	2.08E-05	5.24E-04	1.06E-07	1.84E-05	7.15E-04
Hybrid Diesel- Wind	8.30E-05	2.32E-05	1.59E-05	3.97E-04	4.92E-08	1.29E-05	5.32E-04

Table 52 Sachigo LCIA normalization results for both energy scenarios

	Abiotic Depletion	**Acidification Potential**	**Eutrophication Potential**	**Global Warming Potential**	**Ozone Layer Depletion Potential**	**Photochemical Ozone Creation Potential**	**Total**
	(Kg Sb-Equiv.)	(kg SO2-Equiv)	(kg Phosphate-Equiv)	(kg CO2-Equiv)	(kg R11-Equiv)	(kg Ethylene-Equiv)	(CML 2001-Canada)
Diesel	1.94E-04	5.56E-05	3.43E-05	8.64E-04	1.36E-07	3.01E-05	1.18E-03
Hybrid Diesel- Wind	8.30E-05	2.31E-05	1.47E-05	3.94E-04	4.86E-08	1.28E-05	5.27E-04

Table 53 Webequie LCIA normalization results for both energy scenarios

	Abiotic Depletion	Acidification Potential	Eutrophication Potential	Global Warming Potential	Ozone Layer Depletion Potential	Photochemical. Ozone Creation Potential	Total
	(Kg Sb-Equiv.)	(kg SO2-Equiv)	(kg Phosphate-Equiv)	(kg CO2-Equiv)	(kg R11-Equiv)	(kg Ethylene-Equiv)	(CML 2001-Canada)
Diesel	2.62E-04	7.36E-05	4.55E-05	1.17E-03	1.67E-07	4.01E-05	1.59E-03
Hybrid Diesel- Wind	1.80E-04	4.98E-05	3.16E-05	8.26E-04	8.84E-08	2.75E-05	1.11E-03

Table 54 Reduction of environmental impacts from hybrid diesel-wind in each community

Bearskin	Fort Severn	Gull Bay	Kingfisher	Lansdowne	Sachigo	Webequie
-12%	-46%	-42%	-14%	-14%	-38%	-18%

5.3.7 Interpretation of Normalized LCIA Results

The outcomes of the LCIA using the CML 2001 Canada method show that in all environmental impact categories hybrid diesel-wind has a lower impact on the environment in comparison to a diesel system. This is the case for all communities. To further illustrate the comparison of the two energy systems Table 46-53 compare the energy scenarios for each remote community that has been analyzed in this study.

The community of Bearskin shows the smallest reduction in environmental impacts from hybrid diesel-wind. This is due to the low wind speeds at the location of this community and the community is not able to divert as much diesel electricity in to wind produced electricity. Bearskin has the potential to reduce environmental impacts produced through its electricity generation with the implementation of a hybrid diesel-wind system by 12 %. The environmental impact category that will see the largest decrease is global warming potential.

The community of Fort Severn has the potential to reduce the largest amount of environmental impacts through implementation of a hybrid diesel-wind system. Fort Severn is able to reduce the environmental impacts created by diesel generated energy by 46 % with the implementation of hybrid diesel-wind. This is because Fort Severn has a high wind speed and therefore is able to divert much of the diesel produced electricity into wind produced electricity as well as reducing the number of diesel generators by two in order to meet the electricity demand.

In each community analyzed the largest environmental impact is caused by global warming potential for both the diesel energy system and the hybrid diesel-wind system. Global warming potential is the environmental impact that has the greatest mitigation potential through the implementation of hybrid diesel-wind. This is because diesel combustion is the main source for this environmental impact and hybrid diesel-wind can reduce the quantity of diesel required for electricity generation in each of these communities. The second largest impact is cause by abiotic depletion which is a reflection of the large amount of resources required to produce both energy systems that have been analyzed.

Chapter 6 Discussion of Results

Of the nine remote First Nation communities that were analyzed for wind energy potential seven are determined to have enough wind energy to replace one of the current diesel generators in place with a hybrid diesel-wind system. Through further analysis the environmental impacts associated with both the hybrid diesel-wind system and the current diesel system in place are determined for the seven communities. The main reason behind this analysis is to establish whether hybrid diesel-wind would reduce the environmental impacts for electricity production in these remote communities located in Northern Ontario. An in depth study is conducted, which focuses on the environmental impacts created throughout all the life stages of both energy systems. This was achieved using the LCA method.

The outcomes of the LCA are summarized in Table 55

The outcomes of the LCA suggest that the main reasons behind the reduction in environmental impacts through the use of a hybrid diesel-wind are due to the decrease in diesel consumption.

The major relationship that can be found from the results of this study is that the larger the wind energy potential, the greater reduction in environmental impacts. This is due to the greater reduction is diesel consumption when comparing the two energy scenarios for each community. The communities of Fort Severn, Gull Bay and Sachigo saw the largest decrease in environmental impacts if hybrid diesel-wind replaced their current diesel systems for electricity generation. The communities of Bearskin, Lansdowne and Kingfisher have a smaller potential for reductions in environmental impacts.

The outcomes of the classified LCIA show that for each community the resources required for assembly and diesel production were the primary input/output in terms of mass. The second largest input/output was created during the use phase for each energy system. This is because of the large quantity of diesel that is required for combustion in order to produce electricity and the quantity of emissions created as a result of diesel combustion.

Table 55 Significant findings

Findings	Significance
Nine communities have the potential of producing electricity through implementation of a wind turbine	Wind energy is a feasible energy alternative for off grid electricity production in Ontario
Implementation of hybrid diesel-wind through the use of a WES 30 wind turbine can reduce diesel consumption	This could reduce the remote communities reliance on diesel fuel, which could help mitigate: • Impacts associated of rising fuel costs • Environmental impacts associated with the combustion of fuel
The WES 30 wind turbine has the potential to reduce the amount of diesel generators installed in seven of the nine communities by one.	This has the potential to: • Reduce the cost of replacing diesel generators, • Eliminate the environmental impacts caused by the diesel generator throughout its lifespan.
On a life cycle basis hybrid diesel-wind reduces the amount of resources required for off grid electricity production	This could reduce the amount of non renewable materials required, particularly diesel fuel. This can reduce the depletion of resources.
Emissions to air are the largest type of emissions for both the diesel system and the hybrid diesel-wind system.	Air emissions are significant in off grid electricity production. Methods need to be established to determine ways of reducing the amount of air emissions released into the environment.
Emissions to soil are estimated to be higher for the hybrid diesel-wind system in comparison to the diesel system.	This is a result of the disposal of the wind turbine foundation. In order to reduce the emissions to soil research into the methods of disposal of the hybrid diesel-wind system need to be improved.
Emissions created by diesel system are higher than the hybrid diesel-wind system	Hybrid diesel-wind could reduce the amount of emissions produced by diesels system in off grid remote communities.
The diesel system creates a larger environmental impact in all impact categories.	Hybrid diesel-wind reduces the impact that off grid diesel electricity is having on the environment.
Global warming is the largest impact that both energy systems have on the environment.	Global warming is a result of diesel combustion and is the largest contributor to environmental impacts in off grid electricity production.
Hybrid diesel wind has the potential to reduce the environmental impact caused by the diesel system between 14 and 46 %.	Even though a wind turbine is not able to replace the entire amount of diesel required for electricity production, even small amounts of wind energy can reduce the environmental impacts created by diesel generated electricity.
Emissions to soil are estimated to be higher for the hybrid diesel-wind system in comparison to the diesel system.	This is a result of the disposal of the wind turbine foundation. In order to reduce the emissions to soil research into the methods of disposal of the hybrid diesel-wind system need to be improved.
Emissions created by diesel system are higher than the hybrid diesel-wind system	Hybrid diesel-wind could reduce the amount of emissions produced by diesels system in off grid remote communities.

When only the measurements of emissions are considered, emissions to air are the largest emission category for all the communities and energy scenarios. This finding is a result of the fact that the majority of emissions that are released into the environment are due to the combustion of diesel. This is the case for both energy scenarios.

Using the characterization method, the environmental impacts of the hybrid diesel wind system are also lessened by the lifespan of the system. A hybrid diesel-wind system uses fewer materials due to the longevity of a wind turbine compared to diesel generator. A single WES 30 turbine can produce electricity for 20 years while a diesel generator can only produce electricity for 8 years.

The results from LCIA using the CML 2001 Canada normalization method showed that global warming is the largest environmental impact created by both energy systems. This reflects the outcomes of the characterization LCIA, as the global warming potential is mainly caused by the combustion of diesel fuel. The second largest impact was created by ADP which is caused by the amount of resources each energy system requires.

The results using the normalization method also showed that all categories of environmental impacts are lower with the hybrid diesel-wind system in comparison to the diesel system. This was the case for all the communities analyzed.

In contrast, the results from the classified LCIA found the hybrid diesel-wind system to be higher in the permanent disposal life cycle stage. This is mainly a reflection of the wind turbine foundation being of large mass. As such, the quantity of materials would be sent to landfill.

The characterization LCIA results also show that the emissions to soil would be slightly higher in the hybrid diesel-wind system than that of the diesel system. A further analysis looked into the reasons behind this result to determine the main cause of the emissions to soil in the hybrid diesel-wind LCA. The results show that like the classification results, permanent disposal of the wind turbine foundation through landfill are the main source for emissions to soil. Although the outcomes of both the classification and characterization results show the environmental impacts of a hybrid diesel-wind system are higher than diesel in one category, it does not prevent the usage of the former system from reducing the impacts of the latter.

Previous studies have shown that diesel-generated energy produces a large amount of emissions which lead to an increase in global warming potential (GWP). This study shows that greenhouse gasses are not the only emissions created from the use of a diesel generator system. Abiotc depletion (ADP) and acidification potential (AP) are also major environmental impacts created.

Little work has been done comparing hybrid diesel-wind systems to diesel system for off grid use. The most notable work that this study builds upon is that of Weiss and Illinca's (2010) study which determined whether wind energy was suitable for remote communities of Canada. The outcomes of Weiss and Illinca's (2010) study showed that only two communities in northern Ontario have enough wind energy potential to replace the diesel system for electricity generation. Whereas the outcomes of the LCA study shows that when diverting some of the diesel produced electricity with a hybrid diesel-wind system, seven communities have the potential to reduce negative environmental impact caused by off grid diesel generated electricity. When the entire lifecycle of each system is taken into consideration, the negative impacts of diesel systems or the ability of hybrid-diesel systems to offset negative impacts is greater than when using a non life cycle approach. Not only can hybrid diesel-wind reduce the diesel consumption it can also reduce the environmental impacts associated with the entire diesel generator energy system.

The results of this study show that there are feasible alternatives for the electricity production in these Northern communities of Ontario. Stakeholders in off grid electricity generation can also be shown the implications that the current energy system is having on the environment, not only from the use stage but from assembly to disposal. In addition this study provides an alternative energy system and predicts the potential environmental impact reductions that can be made by implementing hybrid diesel-wind. By showing that hybrid diesel-wind is environmentally feasible developers specialized in hybrid diesel-wind systems may be encouraged to look more in depth at these communities to turn recommendations into implementation.

6.1 Limitations

Although the study does strongly support hybrid diesel-wind as an energy system it must be noted that there are several limitations to the results. This section highlights the limitations of the study in order to lead to suggestions for future research in this field (Chapter 7).

A majority of the limitations occur due to the assumptions that are made during the calculations of the remote community's energy and diesel consumption (Table 56). This is a result of the restrictions on the release of data's regarding the energy consumption of remote communities. Each individual remote community's average diesel consumption is estimated based upon the given data of three unknown communities. Although steps are taken to ensure that these estimations were accurate and relationships between population and energy use conducted, the exact diesel consumption is not used in the LCA.

The energy consumption was estimated based upon population. This is only one variable that affects the energy consumption within a remote community. In order to increase the validity of the estimated energy consumption variables that affect the communities consumption of electricity should be considered. This would allow a more accurate estimation of the energy consumption for each community and also allow a load profile of the current energy requirements of the remote community to be formed. This could be used to further establish whether hybrid diesel-wind has the potential to meet the energy requirements of the off grid remote communities of Ontario.

The determination of the wind speed in each community is based upon average annual wind speed. Therefore it must be noted that the actual amount of diesel savings created by the implantation of a hybrid diesel-wind will fluctuate and therefore the environmental impacts associated with this system will also vary. This could be achieved by producing a load profile analysis of the wind energy potential. A load profile analysis establishes the fluctuations in the wind energy potential on a daily, monthly and seasonal basis, which provides a more accurate estimation of wind turbines energy potential.

The calculations of diesel and energy consumption are based upon a static quantity. This means that for the entire life cycle, the energy demand and diesel consumption is presumed to be the same. This is not representative of a real life situation as energy demands in each of these communities are likely to fluctuate as population changes, weather patterns fluctuate and demand for electricity increases. This would have impacted the outcomes of the LCIA diesel system results. It is assumed that as the demand for electricity changes so does the quantity of diesel required for combustion. This impacts the validity of results of the LCIA as diesel consumption is the major source for environmental impacts. In order to mitigate this limitation a more in depth study into the energy patterns of the remote communities would need to take place so that a more accurate calculation of the future energy trends could have been used within the study.

The inventory data collected and used to conduct the LCIA are mainly based upon literature research and calculations. Therefore the results are based upon a model and may not exactly be representative of the true situation. Very little could be done to mitigate the issue. In order to avoid this situation a real life example would need to be implemented in order to take measurements.

In terms of the LCI of the diesel generator systems, much of the inventory data required are not available. The exact material contents of the diesel generator could not be acquired through the manufacturers and therefore calculations were made based upon their specification sheets and literature that showed the average material types of a combustion engine. In addition the diesel generator was assumed to not have a storage facility where as this is not the case for the real life situation. Diesel generators are often stored indoors or on a cement foundation, due to the restriction in gaining the data for this it was excluded from the LCA.

Not all of the inventory data that affects the life cycle of the energy systems could be included in the study. In particular the impacts of implementation and maintenance of each energy system are not included as the data are difficult to obtain due to privacy disclosures between the energy companies and the remote communities. In addition there are few real life scenarios of the implementation of hybrid diesel-wind in northern off grid communities. Therefore an estimate could not be validated and these stages of the life cycle were removed from the LCA.

The LCIA CML 2001 normalization method was used for conducting the LCIA. Although this provided an in depth analysis, alternative methods such as Eco Indicator 99, and Sustainable Indices method may have produced different outcomes. This is because these impact assessment

Table 56 List of Assumptions and the impact they have on the results

Assumption	Impact on Results
Estimated annual energy consumption	• Diesel required for the hybrid diesel-wind system are based upon the estimated annual energy consumption • The estimated annual diesel consumption is estimated reduces the accuracy of the LCA for both the hybrid diesel-wind system and the diesel generating system
Energy consumption presumed to be the same for 20 years	This is an unlikely scenario and therefore reduces the accuracy in: • The amount of diesel required in both energy systems • The total percentage of energy that a wind turbine could produce This reduces the ability for the LCA to model the true environmental impacts of both energy systems
Efficiency of diesel generators not taken into consideration	It is likely that the diesel generators decrease in efficiency during their use and therefore it is likely that they would consume more diesel to meet the electricity demands of the community
Wind energy based upon average annual wind speed not a load profile	Wind energy varies and an average annual wind speed is not a true representation of the wind energy available. Only an estimated wind feasibility evaluation has been incorporated and the actual wind energy potential in each community may differ
Presumed diesel generators consist of only components present in a combustion engine	Due to data restrictions this assumption reduces the accuracy of the materials required for the assembly of the diesel generator, this reduces the validity of the outcomes of the LCIA
There is no storage/ foundation for diesel generators	Although diesel generators require indoor storage and a concrete pad this excluded from the LCA. This reduces the total amount of materials, emissions and environmental impacts associated with the diesel generating systems LCA
Assumed diesel is transported only by transport truck	As discussed diesel is transported to the communities by a number of transportation methods including plane and boat. This study assumes that diesel is only transported by truck, which reduces the accuracy of the LCIA when comparing it to a real life scenario
Assumed that process data obtained from GaBi is relevant to the location in which the actual LCA process takes place	Not all data obtained from the GaBi 4 database was obtained in the location in which the data is applied to in the LCAs of both energy systems. This has an impact on the accuracy if the emissions associated with a particular data source and therefore reduces the validity of the LCA
All the important environmental impact categories are considered	Not every environmental impact category was used for evaluating the two energy systems. If alternative environmental impact categories were used as a reference point then the outcomes of the study may be different
That the hybrid diesel-wind system is a financially feasible energy system	The study assumes that hybrid diesel-wind is a financially viable energy source and that the only requirement that establishes its suitability for use in remote communities is its ability to reduce environmental impacts associated with off grid electricity production

methods evaluate different environmental impact categories and use different equivalence factors to weight the overall impact on the environment. For example Eco Indicator 99 measures only three impact categories, damage to human health, damage to the ecosystem and damage to resources. This could result in the energy systems having a higher environmental impact in one of these categories. To ensure that the best normalization method was selected for the purpose of evaluation, many LCIA normalization methods could be applied.

It must be noted that there are also limitations within the GaBi software used to conduct the LCA of both energy systems, these limitations can be listed as:

- Not all processes required for the LCI of both energy systems are available within the GaBi software

This requires the user to research the inputs and outputs for the processes which results in different sources of data being used in the LCA. This can reduce the consistency in the LCI stage which could reduce the accuracy of the LCIA.

- Not all data processes are available for the exact location in which the data needs to be applied, for example, there is no landfill process for Canada only for Europe

This limitation could impact the quantity and types of inputs and outputs for each process. This is because processes in different countries may require different materials and energy sources for the inputs of process and this could result in different outputs in terms of emissions and waste materials produced.

- User interface difficult to navigate

The GaBi software has a complex user interface which results in a substantial amount of time required to produce an LCA. This does not reduce the accuracy of the results but it does require an experienced user of GaBi to fully exploit the functions in the software.

It must be noted that the recommendation for the use of hybrid diesel-wind is based upon the outcomes for determining only the technical feasibility of the hybrid diesel-wind system and the environmental impacts associated with this technology. It does not take into account the economic impact and therefore the hybrid diesel wind system cannot be deemed financially feasible at this time. In order to do establish the financial feasibility of hybrid diesel-wind further research would need to be conducted.

The majority of the limitations to the LCA are an outcome of the data available to form the LCI. This supports previous work done by Jacquetta and O'Callaghan (1995) who critique the LCA method and state that weaknesses of LCA lie particularly the in data collection stage, and many of these discrepancies could not be avoided. Although these limitations remain within the works completed, the overall outcomes of the results remain strong. Even with data discrepancies the difference between the LCIA for the diesel system and the hybrid diesel-wind system remain large, thereby suggesting that if these limitations could be resolved the major outcomes of the study would remain largely the same.

6.2 Significance of Outcomes

The outcomes of this study provide an in depth understanding of the different environmental implications of using a diesel system for off-grid use in Northern Ontario not only during the use stage but throughout the life cycle of the diesel system. The LCIA shows that the greatest implication is GWP which is a result of the combustion of diesel and therefore emissions being released into the atmosphere.

Although wind energy is not able to replace diesel generators as an energy source for these remote communities, the findings show that by implementing a hybrid diesel wind system in communities with enough wind energy environmental implications can be reduced. This supports its feasibility as an energy source. Although GWP will still be the largest environmental impact, the total impacts can be reduced between 12-46 % depending on amount of wind energy able to be harnessed for use in the communities.

The results of this study are significant. Energy sources are a global problem and much is being done to reduce environmental impacts created by electricity production, yet very little change in energy resources has been implemented for off-grid First Nations communities in Canada, particularly in Ontario. This study highlights the importance for the need to change the current energy source for remote communities of northern Ontario. The far north First Nations communities have limited options for their electricity generation due to their location and extreme climates.

This study shows that the diesel generated energy systems are creating large environmental impacts throughout the lifespan of the system, showing that a way of reducing them needs to be implemented. The major causes of these environmental impacts have been defined within this work which provides an understanding as to what the requirements are for improvement through alternative energy options.

Through evaluation it is determined that a potential alternative for many communities is electricity production through the use of hybrid diesel-wind. Seven of the nine of the communities evaluated are able to replace at least one diesel generator with a 250 kW wind turbine. This study shows that although diesel generated energy may not be completely avoided hybrid diesel-wind does have the potential to provide reductions in environmental impacts between 12-46 % when comparing it to the diesel generator system. This suggests that even small changes have the potential to have significantly large impacts. The magnitudes of outcomes refer to the seven communities analyzed. The results can also be used to assume the environmental impacts associated with off grid diesel electricity generation for all communities of northern Canada are likely to be similar.

The results of this study provide a reference that can be used to create awareness of this issue to the energy providers, the government, and the communities affected. Now that the issue has been presented and a method for curing this issue has been suggested action can be taken to protect the environment and allowing these communities to becoming more environmentally sustainable and have a secure energy resource.

Chapter 7 Conclusions

Remote communities of Ontario continue to rely on diesel energy to produce their electricity. This is creating unnecessary impacts on the environment. It is determined that there are alternative energy sources that can to divert some of the diesel reliance and reduce the overall environmental impact that off grid diesel generated electricity has on the environment. This can be achieved through the use of hybrid diesel-wind.

Nine remote First Nation communities are able to produce some electricity through the use of an 80 KW wind turbine or a 250 KW wind turbine. If a 250 KW wind turbine was installed, seven of the nine communities could be able to replace a large quantity of diesel fuel and reduce the number of diesel generators installed in each community by one. This also has the potential to reduce the amount of materials required to produce an additional diesel generator.

Through further analysis the environmental impacts created by the diesel system and the proposed hybrid diesel-wind system are quantified and compared using the LCA method. This allows a comparison to be made that determines whether the proposed hybrid diesel-wind system would reduce the environmental impact caused by off grid diesel generated electricity. The LCA is achieved through the use of GaBi 4 LCA software. The LCA method consists of four stages: Goal and scope definition, LCI, LCIA, and interpretation of results.

The LCA compares a hybrid diesel-wind system consisting of a WES 30, 250 KW wind turbine with a tower height of 50 m and diesel generators with the current diesel system implemented in the communities of Bearskin, Fort Severn, Gull Bay, Kingfisher, Lansdowne, Sachigo and Webequie. Inventory data are collected to describe the quantities of materials, energy use, and emissions produced for each life stage of the energy system. The five life stages are listed as:

- Assembly
- Transportation
- Use
- Material recovery
- Permanent disposal

Through classification of the inventory data, the results show that the assembly is the largest input/output flow in the LCA by mass. This means that the largest quantify of materials are required during the assembly phase of the LCA for both the diesel system and the hybrid diesel-wind system for each community. All the input/outputs flows are lower in each life stage of the wind-diesel system when comparing the diesel generated system to the hybrid diesel-wind system. That is with exception to the disposal life stage. As a result of the quantity of wind turbine foundation materials disposed of hybrid diesel-wind system has a greater amount of input/output flow in terms of mass during the disposal life stage.

The characterized LCIA shows that the quantity of emissions released into the environment and resources extracted are lower for the proposed hybrid diesel-wind system than that of the diesel system. The greatest quantities of emissions are released into the air. This is a primary result of the emissions released by diesel combustion. This is the case for both the diesel system and the hybrid diesel-wind system. The only emission that hybrid diesel-wind system could produce a greater quantity than the diesel generator system is amount of emissions to soil. This is again a due to the disposal of the wind turbine foundation.

The CML 2001 Canada normalization method determines the environmental impact potential that each emission could create. The outcomes of the normalization LCIA shows that the diesel system has a higher impact on the environment in all categories, when comparing to the proposed hybrid diesel-wind system. The results show that the size of reduction of environmental impacts through the implementation of hybrid diesel-wind is dependent on the available wind speed.

In summary the outcomes of the LCA show that the seven First Nations off-grid communities analyzed have the potential to reduce their environmental impacts caused by diesel generated electricity production through the implementation of hybrid–diesel wind. The total impact reductions are estimated to be between 12 and 46 %. The reduction quantity is dependent on the average wind speeds for each community. The higher the wind speed the lower the overall environmental impact.

This can reduce:

- The amount of diesel required for electricity production,
- The amount of transportation for the delivery of diesel fuel,
- The amount of materials required for diesel generated electricity

The importance of this study is to highlight that even though these remote First Nation communities are small; this method of electricity production is having impacts on the environment, a majority of which can be prevented. Hybrid diesel-wind is an energy alternative. Research supporting the feasibility of this type of energy system provides support towards a more sustainable, yet reliable method for off-grid remote electricity generation for the First Nation communities of Ontario.

7.1 Recommendations

This study focuses on the feasibility of hybrid diesel-wind, and the environmental impacts created by the current diesel systems in place in comparison to hybrid diesel-wind systems. Unfortunately with energy production and consumption many political, sociological, and economic issues will need to be considered before definitive conclusions can be made as to what changes can to be made in the energy production systems for remote off-grid communities of Ontario. There are many areas that go beyond the scope of this study that require further exploration.

The areas for further exploration can be listed as:

- Determining specific site locations for the implementation of a wind turbine in each remote community

To further ensure wind energy is a potential energy source, a site evaluation needs to be conducted. This would require potential wind turbine sites to be established within the community that meet the requirements for wind turbine implementation. This could include measuring the actual wind speeds in specific locations to calculate wind energy potential as well establishing whether topographic and soil conditions allow support the implementation of the wind turbine. If many sites are suitable for the installation of a wind turbine then feasibility of this alternative energy sources could be increased.

- Determine whether different wind turbine manufacturers offer the feasibility for wind energy harnessing for off grid communities.

To further support the feasibility of hybrid diesel-wind in remote communities of Ontario, further investigation of the energy potential for different size wind turbines need to be established. This study only analyses the wind energy potential of two WES wind turbines, but other wind turbine models may be more efficient at producing energy. This would be significant in determining the best solutions for implementing hybrid diesel-wind technology.

- Conduct an LCA of the hybrid diesel-wind system that includes the assembly and maintenance life stages of the energy system.

In order to produce a more in depth LCA of either the diesel systems or the hybrid diesel-wind system, collecting LCI data for the assembly and maintenance stages of the system is required. This data would need to undergo the LCIA to determine whether they have a significant impact on the overall outcomes. This would create a more in depth assessment of the environmental impacts associated with these energy systems.

- Conduct an in depth economic assessment comparing the costs of hybrid diesel-wind with the current diesel energy systems for each of the communities analyzed within this study.

Economic feasibility is a major factor in selecting alternative energy sources. Conducting an economic assessment would ascertain whether hybrid diesel-wind is an economically feasible energy source for implementation in remote off grid communities. There are many approaches to determine the economic cost of implementing energy systems, but life cycle costing is a potential method that could be used. Like the LCA method, it determines all the economic impacts throughout the life stages of the energy system.

- Determine whether other remote off grid communities across Canada have the energy potential to implement hybrid diesel-wind and determine if the environmental impacts associated with the proposed system would be lower than that of their current methods

This study focused only on First Nation communities of northern Ontario. To further support the need to implement cleaner renewable energy systems, a study could be conducted that uses the methods highlighted in Chapter 3 for remote communities across Canada. If the outcomes of this study show that hybrid diesel-wind is physically feasible and more environmentally responsible than diesel systems it would further support the validity of the outcomes of this study.

- Evaluation of alternative hybrid diesel- renewable energy sources such as solar and hydro energy.

Although a brief discussion took place on the feasibility of other energy resources for implementation in the remote communities of Ontario this study only focused on the environmental impacts associated with the current diesel systems and a proposed hybrid diesel-wind system. In order to ensure that the best options for reducing environmental impacts associated with energy production is selected, many different energy sources need to be evaluated and comparisons need to be made.

- Determining social response to a change in energy source for the remote communities

It must be determined if social support would be available in the face of new energy options being proposed for the remote communities of Ontario. Many projects that make economical and environmental sense do not gain public support. Therefore a study that determines the public attitudes towards these alternative energy systems may determine whether there is public support which would increase the opportunity for implementation to occur.

Appendices

Appendix A Life cycle inventory data

Table 57 Bearskin life cycle inventory for diesel system

System Components	Manufacturer	Mass of Unit (kg)	Power Output (%)	Diesel Consumption (l)	Power Output (KWh/ yr)
Diesel Generator A	Caterpillar 250	2,277	20	148,770	488,319
Diesel Generator B	Cummins 400	3,856	32	238,032	781,311
Diesel Generator C	Caterpillar 600	3,968	48	357,048	1,171,967

Diesel Generator Dry Material Input (kg)						
System Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator A	1,794	27	16	7	39	394
Diesel Generator B	3,039	46	27	12	66	667
Diesel Generator C	3,127	48	28	12	68	697

Wet Material Input (l)			
System Component	**Oil**	**Water**	**Coolant**
Diesel Generator A	38	29	29
Diesel Generator B	83	29	29
Diesel Generator C	38	41	41

Energy Required to Manufacture Materials (MJ)						
System Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator A	25,120	524	269	163	1,818	11,541
Diesel Generator B	42,540	889	456	278	3,083	19,546
Diesel Generator C	43,775	914	470	286	3,172	20,115

Distance to Deliver System (km)		
Component	**Train**	**Truck**
Diesel Generator A	1,479	450
Diesel Generator B	2,767	450
Diesel Generator C	1,479	450

Diesel Delivery		
Distance	Number of Journeys required for 20 years	Total Distance Travelled in 20 years (km)
2,340	775	1,813,500

Materials to be Recycled (kg)						
Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator A	1,615	21	5	2	13	128
Diesel Generator B	2,735	36	9	3	22	216
Diesel Generator C	2,814	37	9	4	22	223
Materials sent to Landfill (kg)						
Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator A	179	6	11	5	26	265
Diesel Generator B	303	10	18	8	44	451
Diesel Generator C	313	10	19	8	43	464

Table 58 Fort Severn life cycle inventory for diesel system

System Components	Manufacturer	Mass of Unit (kg)	Power Output (%)	Diesel Consumption (l)	Power Output (KWh/ yr)	
Diesel Generator A	Caterpillar 250	2,277	20	98,856	324,482	
Diesel Generator B	Caterpillar 400	3,458	32	158,169	519,172	
Diesel Generator C	Caterpillar 600	3,968	48	237,254	778,758	
Diesel Generator Dry Material Input (kg)						
System Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator A	1,794	27	16	7	39	394
Diesel Generator B	2,725	42	24	10	59	598
Diesel Generator C	3,127	48	28	12	68	687
Wet Material Input (l)						
System Component	**Oil**	**Water**	**Coolant**			
Diesel Generator A	38	29	29			
Diesel Generator B	38	29	29			
Diesel Generator C	38	41	41			
Energy Required to Manufacture Materials (MJ)						
System Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator A	25,120	524	269	163	1,819	11,341
Diesel Generator B	38,149	797	409	250	2,764	17,527
Diesel Generator C	43,775	914	470	286	3,173	20,115
Distance to Deliver System (km)						
Component	**Train**	**Truck**				
Diesel Generator A	1,479	724				
Diesel Generator B	1,479	724				
Diesel Generator C	1,479	724				
Diesel Delivery						
Distance	Number of Journeys required for 20 years	Total Distance Travelled in 20 years (km)				
1,966	515	1,012,490				

Materials to be Recycled (kg)						
Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator A	998	15	3	1	9	128
Diesel Generator B	1138	21	4	1	9	194
Diesel Generator C	1615	50	5	2	9	223

Materials Set to Landfill (kg)						
Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator A	111	4	7	2	16	265
Diesel Generator B	126	4	8	3	18	404
Diesel Generator C	179	6	11	5	26	463

Table 59 Gull Bay life cycle inventory for diesel system

System Components	Manufacturer	Mass of Unit (kg)	Power Output (%)	Diesel Consumption (l)	Power Output (KWh/ yr)
Diesel Generator A	Caterpillar 125	1,407	23	76,783	252,032
Diesel Generator B	Caterpillar 175	1,604	32	103,491	350,654
Diesel Generator C	Caterpillar 250	2,277	45	150,228	493,107

Diesel Generator Dry Material Input (kg)						
System Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator A	1,109	17	10	4	24	243
Diesel Generator B	1,264	19	11	5	27	278
Diesel Generator C	1,794	27	14	7	39	394

Wet Material Input (l)			
System Component	**Oil**	**Water**	**Coolant**
Diesel Generator A	16.5	11	11
Diesel Generator B	16.5	11	11
Diesel Generator C	38	29	29

Energy Required to Manufacture Materials (MJ)						
System Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator A	15,522	325	166	101	1,123	7,132
Diesel Generator B	17,696	369	189	115	1,283	8,131
Diesel Generator C	25,120	524	269	163	1,819	11,541

Distance to Deliver System (km)		
Component	**Train**	**Truck**
Diesel Generator A	1,510	55
Diesel Generator B	1,510	55
Diesel Generator C	1,510	55

Diesel Delivery		
Distance	Number of Journeys required for 20 years	Total Distance Travelled in 20 years (km)
1,522	348	52,965

Materials to be Recycled (kg)						
Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator A	165	21	5	2	13	79
Diesel Generator B	2,452	32	8	3	19	90
Diesel Generator C	2,814	37	9	4	22	127

Materials sent to Landfill (kg)						
Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator A	179	6	11	5	26	164
Diesel Generator B	272	9	16	7	39	187
Diesel Generator C	313	10	19	8	45	266

Table 60 Kingfisher life cycle inventory for the diesel system

System Components	Manufacturer	Mass of Unit (kg)	Power Output (%)	Diesel Consumption (l)	Power Output (KWh/ yr)
Diesel Generator A	Detroit 250	3,114	20	101,449	332,993
Diesel Generator B	Caterpillar 400	3,458	32	162,318	532,789
Diesel Generator C	Caterpillar 600	3,968	48	243,477	799,184

Diesel Generator Dry Material Input (kg)						
System Component	Iron	Ferrous Metals	Copper	Zinc	Aluminum	Plastic
Diesel Generator A	2,454	37	22	9	53	538
Diesel Generator B	2,724	41	24	10	59	598
Diesel Generator C	3,127	48	28	12	68	687

Wet Material Input (l)			
System Component	Oil	Water	Coolant
Diesel Generator A	36	23	23
Diesel Generator B	38	29	29
Diesel Generator C	38	41	41

Energy Required to Manufacture Materials (MJ)						
System Component	Iron	Ferrous Metals	Copper	Zinc	Aluminum	Plastic
Diesel Generator A	34,353	718	368	223	2,486	15,784
Diesel Generator B	38,149	797	409	250	2,764	17,527
Diesel Generator C	43,775	914	470	286	3,173	20,114

Distance to Deliver System (km)		
Component	Train	Truck
Diesel Generator A	1,615	350
Diesel Generator B	1,479	350
Diesel Generator C	1,479	350

Diesel Delivery		
Distance	Number of Journeys required for 20 years	Total Distance Travelled in 20 years (km)
1,672	528	882,816

Materials to be Recycled (kg)						
Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator A	2,208	29	7	3	17	175
Diesel Generator B	2,452	32	8	3	19	194
Diesel Generator C	2,814	37	9	4	22	223
Materials sent to Landfill (kg)						
Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator A	245	8	7	7	35	364
Diesel Generator B	272	9	16	7	39	404
Diesel Generator C	313	10	19	8	45	463

Table 61 Lansdowne life cycle inventory for the diesel system

System Components	Manufacturer	Mass of Unit (kg)	Power Output (%)	Diesel Consumption (l)	Power Output (KWh/ yr)
Diesel Generator A	Caterpillar 250	2,277	16	70,009	229,797
Diesel Generator B	Caterpillar 455	4,563	30	131,268	430,870
Diesel Generator C	Caterpillar 825	6,244	54	236,282	775,566
Diesel Generator Dry Material Input (kg)						
System Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator A	1,794	27	16	7	39	394
Diesel Generator B	3,596	55	32	14	78	789
Diesel Generator C	4,920	75	44	19	106	1,080

Wet Material Input (l)

System Component	Oil	Water	Coolant
Diesel Generator A	38	29	29
Diesel Generator B	38	29	29
Diesel Generator C	68	80	80

Energy Required to Manufacture Materials (MJ)

System Component	Iron	Ferrous Metals	Copper	Zinc	Aluminum	Plastic
Diesel Generator A	1,794	27	16	7	39	394
Diesel Generator B	3,596	55	32	14	78	789
Diesel Generator C	4,920	75	44	19	106	1,080

Distance to Deliver System (km)

Component	Train	Truck
Diesel Generator A	1,510	205
Diesel Generator B	1,510	5
Diesel Generator C	1,510	205

Diesel Delivery

Distance	Number of Journeys required for 20 years	Total Distance Travelled in 20 years (km)
1,874	456	775,836

Materials to be Recycled (kg)						
Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator A	1,615	21	5	2	13	128
Diesel Generator B	3,236	43	10	4	26	256
Diesel Generator C	4,428	58	14	6	35	351
Materials sent to Landfill (kg)						
Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator A	179	6	11	5	24	266
Diesel Generator B	360	12	22	10	52	53
Diesel Generator C	492	17	30	13	71	729

Table 62 Sachigo life cycle inventory for the diesel system

System Components	Manufacturer	Mass of Unit (kg)	Power Output (%)	Diesel Consumption (l)	Power Output (KWh/ yr)
Diesel Generator A	Caterpillar 250	2,277	20	145,853	478,745
Diesel Generator B	Caterpillar 400	3,458	32	233,365	765,991
Diesel Generator C	Caterpillar 600	3,968	48	350,047	1,148,987

Diesel Generator Dry Material Input (kg)

System Component	Iron	Ferrous Metals	Copper	Zinc	Aluminum	Plastic
Diesel Generator A	1,794	27	16	7	39	394
Diesel Generator B	2,725	42	24	10	59	598
Diesel Generator C	3,127	48	28	12	68	687

Wet Material Input (l)

System Component	Oil	Water	Coolant
Diesel Generator A	38	29	29
Diesel Generator B	38	29	29
Diesel Generator C	38	41	41

Energy Required to Manufacture Materials (MJ)

System Component	Iron	Ferrous Metals	Copper	Zinc	Aluminum	Plastic
Diesel Generator A	25,120	524	269	163	1819	11,341
Diesel Generator B	38,149	797	409	250	2764	17,527
Diesel Generator C	43,775	914	470	286	3173	20,115

Distance to Deliver System (km)

Component	Train	Truck
Diesel Generator A	1,479	258
Diesel Generator B	1,479	258
Diesel Generator C	1,479	258

Diesel Delivery

Distance	Number of Journeys required for 20 years	Total Distance Travelled in 20 years (km)
2,067	760	1,570,920

Materials to be Recycled (kg)						
Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator A	998	15	3	1	9	128
Diesel Generator B	1,138	21	4	1	9	194
Diesel Generator C	1,615	50	5	2	9	223
Materials sent to Landfill (kg)						
Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator A	111	4	7	2	16	265
Diesel Generator B	126	4	8	3	18	404
Diesel Generator C	179	6	11	5	26	463

Table 63 Webequie life cycle inventory for the diesel system

System Components	Manufacturer	Mass of Unit (kg)	Power Output (%)	Diesel Consumption (l)	Power Output (KWh/ yr)
Diesel Generator A	Caterpillar 250	2,277	20	199,008	653,220
Diesel Generator B	Caterpillar 400	3,458	32	3,181,413	1,045,152
Diesel Generator C	Caterpillar 600	3,968	48	477,619	1,567,729
Diesel Generator Dry Material Input (kg)						
System Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator A	1,794	27	16	7	39	394
Diesel Generator B	2,725	42	24	10	59	598
Diesel Generator C	3,127	48	28	12	68	687
Wet Material Input (l)						
System Component	**Oil**	**Water**	**Coolant**			
Diesel Generator A	38	29	29			
Diesel Generator B	38	29	29			
Diesel Generator C	38	41	41			
Energy Required to Manufacture Materials (MJ)						
System Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator A	25,120	524	269	163	1,819	11,341
Diesel Generator B	38,149	797	409	250	2,764	17,527
Diesel Generator C	43,775	914	470	286	3,173	20,115
Distance to Deliver System (km)						
Component	**Train**	**Truck**				
Diesel Generator A	1,509	177				
Diesel Generator B	1,509	177				
Diesel Generator C	1,509	177				
Diesel Delivery						
Distance	Number of Journeys required for 20 years	Total Distance Travelled in 20 years (km)				
1,846	1,037	1,914,302				

Materials to be Recycled (kg)						
Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator A	998	15	3	1	9	128
Diesel Generator B	1,138	21	4	1	9	194
Diesel Generator C	1,615	50	5	2	9	223
Materials sent to Landfill (kg)						
Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator A	111	4	7	2	16	265
Diesel Generator B	126	4	8	3	18	404
Diesel Generator C	179	6	11	5	26	463

Table 64 Bearskin life cycle inventory for hybrid diesel-wind system

System Components	Manufacturer	Mass of Unit (kg)	Power Output (%)	Diesel Consumption (l)	Power Output (KWh/ yr)
Wind Turbine	WES 30	2,655	20.76	n/a	506,926
Diesel Generator 1	Cummins 400	3,856	31.62	235,205	772,031
Diesel Generator 2	Caterpillar 600	3,968	47.62	354,221	1,162,688

Diesel Generator Dry Material Input (kg)

System Component	Iron	Ferrous Metals	Copper	Zinc	Aluminum	Plastic
Diesel Generator 1	3,039	46	27	12	66	667
Diesel Generator 2	3,127	48	28	12	68	687

Wind Turbine Material Input (kg)

Carbon Fiber	Glass Fiber	Epoxy	Steel	Aluminum
0.6	0.6	2.4	2048	600

Energy Required to Manufacture Materials (MJ)

System Component	Iron	Ferrous Metals	Copper	Zinc	Aluminum	Plastic
Diesel Generator 1	42,540	889	456	278	3,083	19,546
Diesel Generator 2	43,775	914	470	286	3,173	20,114
Wind Turbine	**Carbon Fiber**	**Glass Fiber**	**Epoxy**	**Steel**	**Aluminum**	
	5.6	5.6	110	39,324	28,200	

Distance to Deliver System (km)

Component	Train	Truck	Ocean Freighter
Wind Turbine	1,479	450	6023
Diesel Generator 1	2,767	450	
Diesel Generator 2	1,479	450	

Wind Turbine Foundation

Materials	Quantity (kg)	Energy Required to manufacture (MJ)	Distance by Truck to deliver (km)	Distance by Train to deliver (km)
Concrete	479,590	1.8E+07	450	1,796
Steel	2,410	4622	450	1,060

Diesel Delivery

Distance	Number of Journeys required for 20 years	Total Distance Travelled in 20 years (km)
2066	616	1268494

Materials to be Recycled (kg)						
System Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator 1	2,735	36	9	3	22	217
Diesel Generator 2	2,814	37	9	4	22	223
	Carbon Fiber	**Glass Fiber**	**Epoxy**	**Steel**	**Aluminum**	**Concrete**
Wind Turbine	0	0	0	663,418	198	868,534
Materials sent to Landfill (kg)						
System Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator 1	304	10	18	8	44	450
Diesel Generator 2	313	10	19	8	45	464
Wind Turbine	**Carbon Fiber**	**Glass Fiber**	**Epoxy**	**Steel**	**Aluminum**	**Concrete**
	0.6	0.6	2.4	187,118	177,892	402

Table 65 Fort Severn life cycle inventory for hybrid diesel-wind

System Components	Manufacturer	Mass of Unit (kg)	Power Output (%)	Diesel Consumption (l)	Power output (KWh/ yr)
Wind Turbine	WES 30	2,651	67.86	n/a	1,100,897
Diesel Generator 1	Caterpillar 250	2,277	32.14	15,8861	521,443

Diesel Generator Dry Material Input (kg)

System Component	Iron	Ferrous Metals	Copper	Zinc	Aluminum	Plastic
Diesel Generator 1	1,794	27	16	7	39	394
	Carbon Fiber	Glass Fiber	Epoxy	Steel	Aluminum	
Wind Turbine	0.6	0.6	2.4	2,048	600	

Energy Required to Manufacture Materials (MJ)

System Component	Iron	Ferrous Metals	Copper	Zinc	Aluminum	Plastic
Diesel Generator 1	25,120	524	269	163	1,819	11,541
Wind Turbine	Carbon Fiber	Glass Fiber	Epoxy	Steel	Aluminum	
	5.6	5.6	110	39,324	28,200	

Distance to Deliver System (km)

	Train	Truck	Ocean Freighter
Wind Turbine	1,479	724	6,023
Diesel Generator 1	1,479	724	

Wind Turbine Foundation

Materials	Quantity (kg)	Energy Required to manufacture (MJ)	Distance by truck to deliver (km)	Distance by Train to deliver (km?)
Concrete	479,590	1.8E+07	724	1,796
Steel	2,410	46,272	724	1,060

Diesel Delivery

Distance	Number of Journeys required for 20 years	Total Distance Travelled in 20 years (km)
2,340	171	387,224

Recycling (kg)

System Component	Iron	Ferrous Metals	Copper	Zinc	Aluminum	Plastic
Diesel Generator 1	1,615	21	5	2	13	128
Wind Turbine	Carbon Fiber	Glass Fiber	Epoxy	Steel	Aluminum	Concrete
	0	0	0	663,418	198	868,533

Landfill (kg)

System Component	Iron	Ferrous Metals	Copper	Zinc	Aluminum	Plastic
Diesel Generator 1	179	6	11	5	26	266
Wind Turbine	Carbon Fiber	Glass Fiber	Epoxy	Steel	Aluminum	Concrete
	0.6	0.6	2.4	187,118	177,892	402

Table 66 Gull Bay life cycle inventory for hybrid diesel-wind

System Components	Manufacturer	Mass of Unit (kg)	Power Output (%)	Diesel Consumption (l)	Power output (KWh/ yr)
Wind Turbine	WES 30	2,651	41.79	n/a	457,925
Diesel Generator 1	Caterpillar 125	1,407	22.61	75,481	247,758
Diesel Generator 2	Caterpillar 250	2,277	35.6	118,847	390,102

Diesel Generator Dry Material Input (kg)

System Component	Iron	Ferrous Metals	Copper	Zinc	Aluminum	Plastic
	1,109	17	10	4	24	243
	1,794	27	16	7	39	394
Wind Turbine	**Carbon Fiber**	**Glass Fiber**	**Epoxy**	**Steel**	**Aluminum**	
	0.6	0.6	2.4	2048	600	

Energy Required to Manufacture Materials (MJ)

System Component	Iron	Ferrous Metals	Copper	Zinc	Aluminum	Plastic
Diesel Generator 1	15,522	324	166	101	1,123	7,132
Diesel Generator 2	25,120	524	269	163	1,819	1,1541
Wind Turbine	**Carbon Fiber**	**Glass Fiber**	**Epoxy**	**Steel**	**Aluminum**	
	5.6	5.6	110	39,324	28,200	

Distance to Deliver System (km)

Component	Train	Truck	Ocean Freighter
Wind Turbine	1,510	55	6,023
Diesel Generator 1	1,510	55	
Diesel Generator 2	1,510	55	

Wind Turbine Foundation

Materials	Quantity (kg)	Energy Required to manufacture (MJ)	Distance by truck to deliver (km)	Distance by Train to deliver (km?)
Concrete	479,590	1.8E+07	55	1,655
Steel	2,410	46,272	55	919

Diesel Delivery

Distance	Number of Journeys required for 20 years	Total Distance Travelled in 20 years (km)
1522	205	200412

Recycling (kg)						
Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator 1	998	14	3	1	8	79
Diesel Generator 2	1,615	21	5	2	13	128
Wind Turbine	**Carbon Fiber**	**Glass Fiber**	**Epoxy**	**Steel**	**Aluminum**	**Concrete**
	0	0	0	663,418	198	868,533
Landfill (kg)						
Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator 1	111	4	7	3	16	164
Diesel Generator 2	179	6	11	5	26	266
Wind Turbine	**Carbon Fiber**	**Glass Fiber**	**Epoxy**	**Steel**	**Aluminum**	**Concrete**
	0.6	0.6	2.4	187,118	177,892	402

Table 67 Kingfisher life cycle inventory analysis for hybrid diesel-wind

System Components	Manufacturer	Mass of Unit (kg)	Power Output (%)	Diesel Consumption (l)	Power output (KWh/ yr)
Wind Turbine	WES 30	2,651	29.12	n/a	484,836
Diesel Generator 1	Caterpillar 400	3,458	27.44	139,188	456,867
Diesel Generator 2	Caterpillar 600	3,968	43.44	220,347	723,262

Diesel Generator Dry Material Input (kg)

System Component	Iron	Ferrous Metals	Copper	Zinc	Aluminum	Plastic
Diesel Generator 1	2,725	42	24	10	59	598
Diesel Generator 2	3,127	48	28	12	68	687
Wind Turbine	Carbon Fiber	Glass Fiber	Epoxy	Steel	Aluminum	
	0.6	0.6	2.4	2048	600	

Energy Required to Manufacture Materials (MJ)

System Component	Iron	Ferrous Metals	Copper	Zinc	Aluminum	Plastic
Diesel Generator 1	38,149	797	409	250	2,764	17,527
Diesel Generator 2	43,775	914	470	286	3,173	20,114
Wind Turbine	Carbon Fiber	Glass Fiber	Epoxy	Steel	Aluminum	
	5.6	5.6	110	39324	28200	

Distance to Deliver System (km)

System Component	Train	Truck	Ocean Freighter
Wind Turbine	1,479	350	6,023
Diesel Generator 1	1,479	350	
Diesel Generator 2	1,479	350	

Wind Turbine Foundation

Materials	Quantity (kg)	Energy Required to manufacture (MJ)	Distance by truck to deliver (km)	Distance by Train to deliver (km?)
Concrete	479,590	1.8E+07	350	1,060
Steel	2,410	46,272	350	1,796

Diesel Delivery

Distance	Number of Journeys required for 20 years	Total Distance Travelled in 20 years (km)
1,966	377	736,296

Recycling						
Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator 1	2,452	32	8	3	19	194
Diesel Generator 2	2,814	37	9	4	22	223
Wind Turbine	**Carbon Fiber**	**Glass Fiber**	**Epoxy**	**Steel**	**Aluminum**	**Concrete**
	0	0	0	663,418	198	868,533
Landfill (kg)						
	Iron	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator 1	272	9	16	7	39	404
Diesel Generator 2	313	10	19	8	45	463
Wind Turbine	**Carbon Fiber**	**Glass Fiber**	**Epoxy**	**Steel**	**Aluminum**	**Concrete**
	0.6	0.6	2.4	187,118	177,892	402

Table 68 Lansdowne life cycle inventory for hybrid diesel-wind

System Components	Manufacturer	Mass of Unit (kg)	Power Output (%)	Diesel Consumption (l)	Power output (KWh/ yr)
Wind Turbine	WES 30	2,651	27.25	n/a	391,305
Diesel Generator 1	Caterpillar 455	4,563	24.37	106633	350,010
Diesel Generator 2	Caterpillar 825	6,244	48.38	211691	694,850

Diesel Generator Dry Material Input (kg)

System Component	Iron	Ferrous Metals	Copper	Zinc	Aluminum	Plastic
Diesel Generator 1	3,596	55	32	14	78	789
Diesel Generator 2	4,920	75	25	19	87	1,080
	Carbon Fiber	**Glass Fiber**	**Epoxy**	**Steel**	**Aluminum**	
Wind Turbine	0.6	0.6	2.4	2048	600	

Energy Required to Manufacture Materials (MJ)

System Component	Iron	Ferrous Metals	Copper	Zinc	Aluminum	Plastic
Diesel Generator 1	50,338	1,052	541	329	3,647	23,129
Diesel Generator 2	68,828	1,438	423	449	4,108	31,650
Wind Turbine	**Carbon Fiber**	**Glass Fiber**	**Epoxy**	**Steel**	**Aluminum**	
	5.6	5.6	110	39,324	28,200	

Distance to Deliver System (km)

	Train	Truck	Ocean Freighter
Wind Turbine	1510	205	6,023
Diesel Generator 1	1,510	205	
Diesel Generator 2	1,510	205	

Wind Turbine Foundation

Materials	Quantity (kg)	Energy Required to manufacture (MJ)	Distance by truck to deliver (km)	Distance by Train to deliver (km?)
Concrete	479.590	1.8E+07	205	1,655
Steel	2,410	46,272	205	919

Diesel Delivery

Distance	Number of Journeys required for 20 years	Total Distance Travelled in 20 years (km)
1,672	334	534,414

Recycling (kg)						
System Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator 1	3,236	43	10	4	26	256
Diesel Generator 2	4,428	58	8	6	29	351
Wind Turbine	**Carbon Fiber**	**Glass Fiber**	**Epoxy**	**Steel**	**Aluminum**	**Concrete**
	0	0	0	663,418	198	868,533
Landfill (kg)						
System Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator 1	360	12	22	10	52	533
Diesel Generator 2	492	16	18	13	59	729
Wind Turbine	**Carbon Fiber**	**Glass Fiber**	**Epoxy**	**Steel**	**Aluminum**	**Concrete**
	0.6	0.6	2.4	187,118	177,892	402

Table 69 Sachigo life cycle inventory for hybrid diesel-wind

System Components	Manufacturer	Mass of Unit (kg)	Power Output (%)	Diesel Consumption (l)	Power output (KWh/ yr)
Wind Turbine	WES 30	2,651	20.14	n/a	482,119
Diesel Generator 1	Caterpillar 400	4,563	31.93	232,854	764,315
Diesel Generator 2	Caterpillar 600	6,244	47.93	349,536	1147,311

Diesel Generator Dry Material Input (kg)

System Component	Iron	Ferrous Metals	Copper	Zinc	Aluminum	Plastic
Diesel Generator 1	1,701	42	14	10	48	598
Diesel Generator 2	1,952	48	16	12	56	687

Wind Turbine	Carbon Fiber	Glass Fiber	Epoxy	Steel	Aluminum
	0.6	0.6	2.4	2,048	600

Energy Required to Manufacture Materials (MJ)

System Component	Iron	Ferrous Metals	Copper	Zinc	Aluminum	Plastic
Diesel Generator 1	23,818	797	233	250	2,275	17,527
Diesel Generator 2	27,332	914	269	286	2,613	20,114

Wind Turbine	Carbon Fiber	Glass Fiber	Epoxy	Steel	Aluminum
	5.6	5.6	110	39,324	28,200

Distance to Deliver System (km)

	Train	Truck	Ocean Freighter
Wind Turbine	1,479	258	6023
Diesel Generator 1	1,479	258	
Diesel Generator 2	1,479	258	

Wind Turbine Foundation

Materials	Quantity (kg)	Energy Required to manufacture (MJ)	Distance by truck to deliver (km)	Distance by Train to deliver (km?)
Concrete	479,590	1.8E+07	258	1,796
Steel	2,410	46,272	258	1,060

Diesel Delivery

Distance	Number of Journeys required for 20 years	Total Distance Travelled in 20 years (km)
1,874	609	1,136,874

Recycling (kg)						
System Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum (kg)**	**Plastic**
Diesel Generator 1	1,531	32	4	3	16	192
Diesel Generator 2	1,757	37	5	4	18	221
Wind Turbine	**Carbon Fiber**	**Glass Fiber**	**Epoxy**	**Steel**	**Aluminum**	**Plastic**
	0	0	0	663,418	198	868,533
Landfill (kg)						
System Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator 1	170	9	10	7	32	406
Diesel Generator 2	195	10	11	8	37	466
Wind Turbine	**Carbon Fiber**	**Glass Fiber**	**Epoxy**	**Steel**	**Aluminum**	**Concrete**
	0.6	0.6	2.4	187,118	177,892	402

Table 70 Webequie life cycle inventory for hybrid diesel-wind

System Components	Manufacturer	Mass of Unit (kg)	Power Output (%)	Diesel Consumption (l)	Power output (KWh/ yr)
Wind Turbine	WES 30	2,651	30.62	n/a	1,000,090
Diesel Generator 1	Caterpillar 400	3,458	26.69	265,576	8,71,722
Diesel Generator 2	Caterpillar 600	3,968	42.69	424,783	1,394,299

Diesel Generator Dry Material Input (kg)

System Component	Iron	Ferrous Metals	Copper	Zinc	Aluminum	Plastic
Diesel Generator 1	1,701	41	14	10	48	598
Diesel Generator 2	1,952	48	16	12	56	687
	Carbon Fiber	Glass Fiber	Epoxy	Steel	Aluminum	
Wind Turbine	0.6	0.6	2.4	2048	600	

Energy Required to Manufacture Materials (MJ)

System Component	Model	Iron	Ferrous Metals	Copper	Zinc	Aluminum	Plastic
Diesel Generator 1	Caterpillar 400	23,818	797	233	250	2275	17,527
Diesel Generator 2	Caterpillar 600	27,332	914	269	286	2613	20,114
		Carbon Fiber	Glass Fiber	Epoxy	Steel	Aluminum	
Wind Turbine	WES 30	5.6	5.6	110	39,324	28,200	

Distance to Deliver System (km)

	Train	Truck	Ocean Freighter
Wind Turbine	1,510	177	6,023
Diesel Generator 1	1,510	177	
Diesel Generator 2	1,510	177	

Wind Turbine Foundation

Materials	Quantity (kg)	Energy Required to manufacture (MJ)	Distance by truck to deliver (km)	Distance by Train to deliver (km?)
Concrete	479.590	1.8E+07	177	1,655
Steel	2.410	46,272	177	919

Diesel Delivery

Refinery Distance (km)	Number of Journeys required for 20 years	Total Distance Travelled in 20 years (km)
1,918	724	137,928

Recycling (kg)						
System Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator 1	1,531	32	4	3	16	194
Diesel Generator 2	1,757	37	5	4	18	223
Wind Turbine	**Carbon Fiber**	**Glass Fiber**	**Epoxy**	**Steel**	**Aluminum**	**Concrete**
	0	0	0	663,418	198	868,533.6
Landfill (kg)						
System Component	**Iron**	**Ferrous Metals**	**Copper**	**Zinc**	**Aluminum**	**Plastic**
Diesel Generator 1	170	9	9	7	32	404
Diesel Generator 2	195	10	11	8	37	464
Wind Turbine	**Carbon Fiber**	**Glass Fiber**	**Epoxy**	**Steel**	**Aluminum**	**Concrete**
	0.6	0.6	2.4	187,118	177,892	402

Appendix B Schematics of System Life Cycle plans

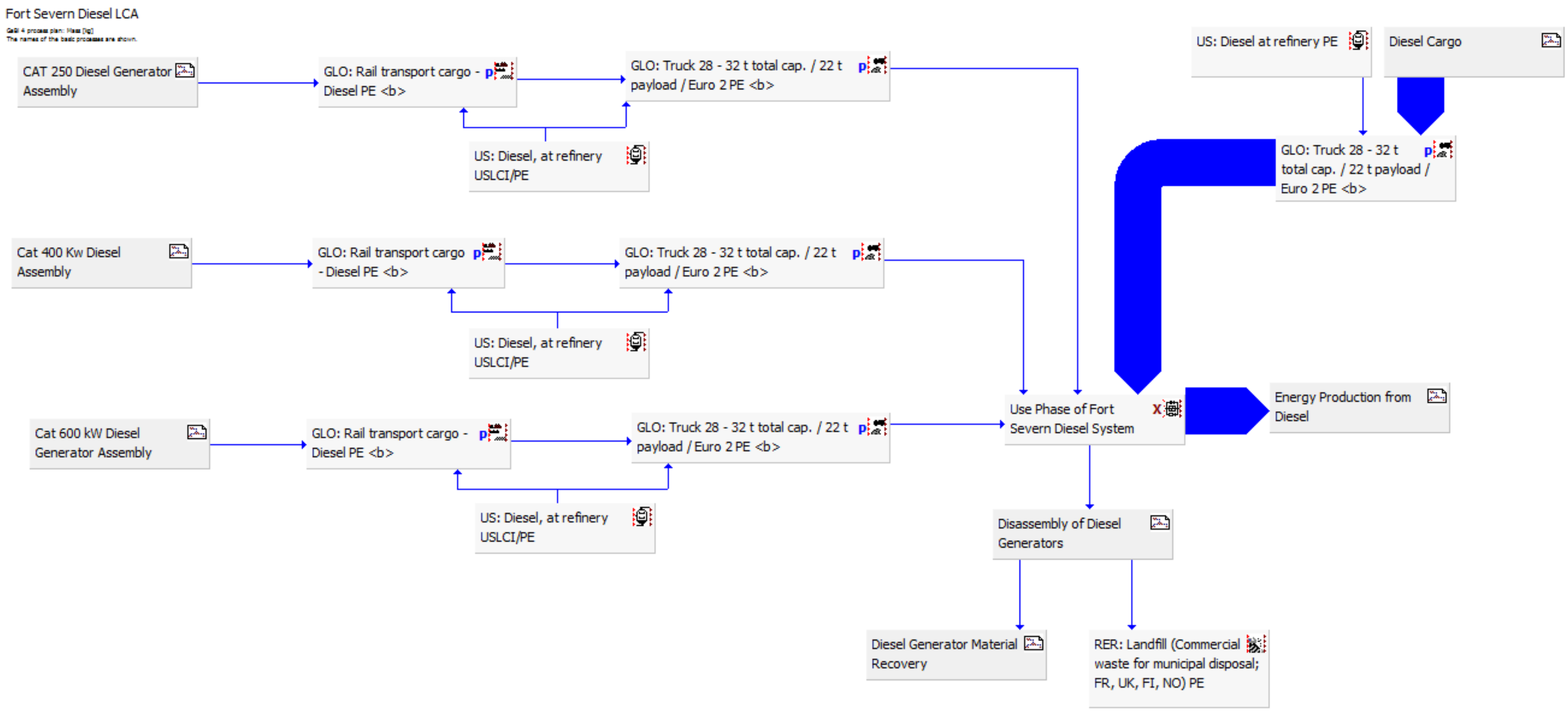

Figure 15 Fort Severn LCA plan for diesel system

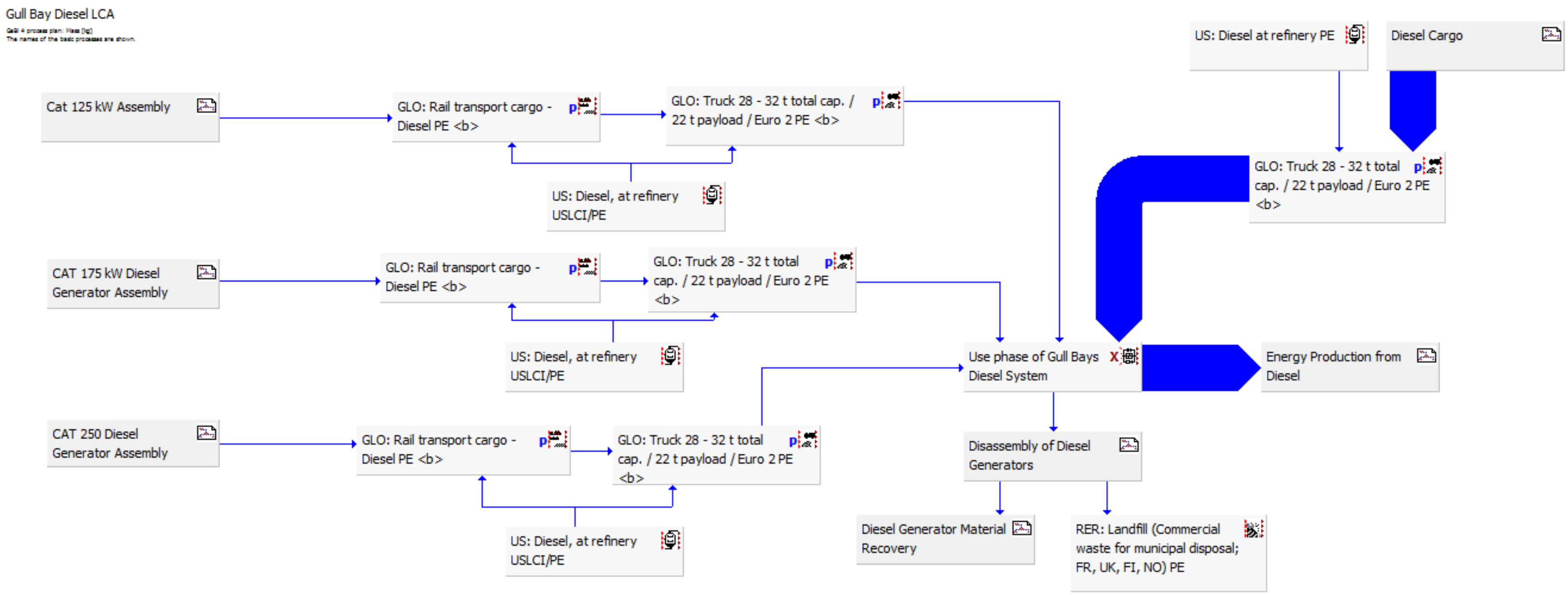

Figure 16 Gull Bay LCA plan for diesel system

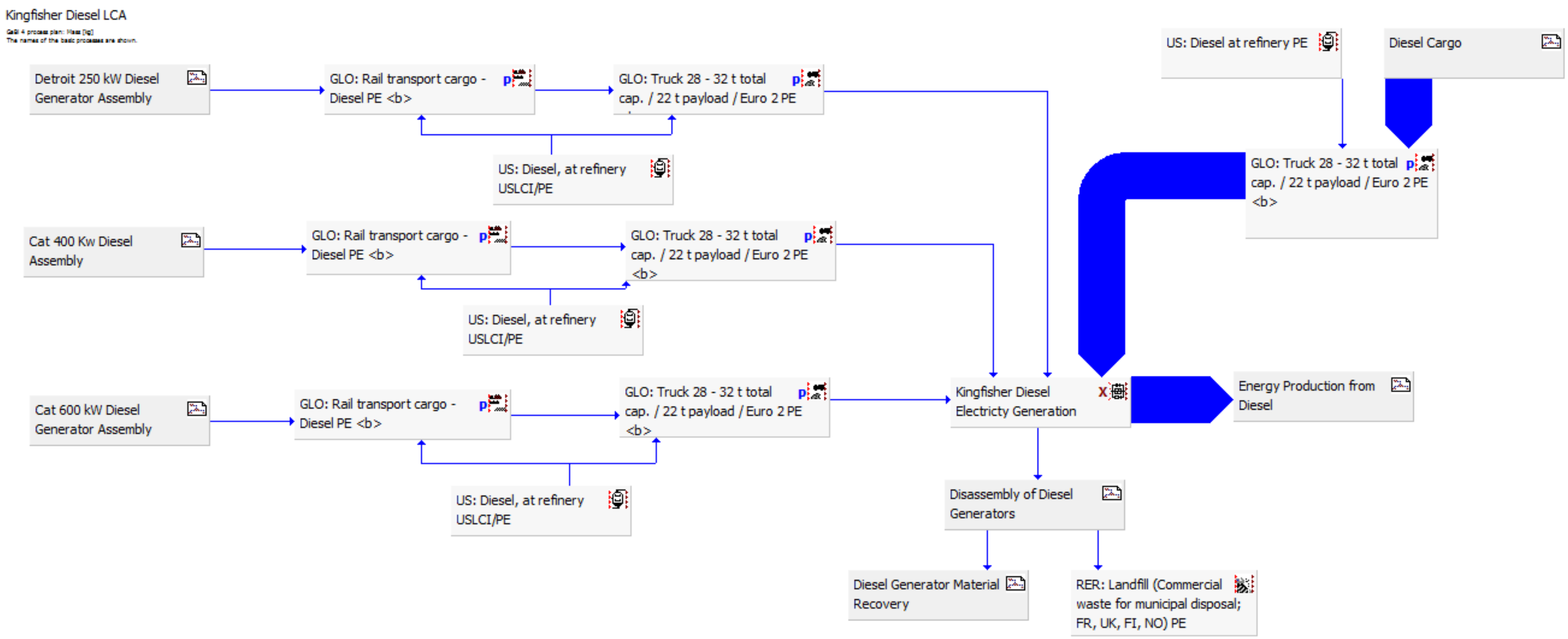

Figure 17 Kingfisher LCA plan for diesel system

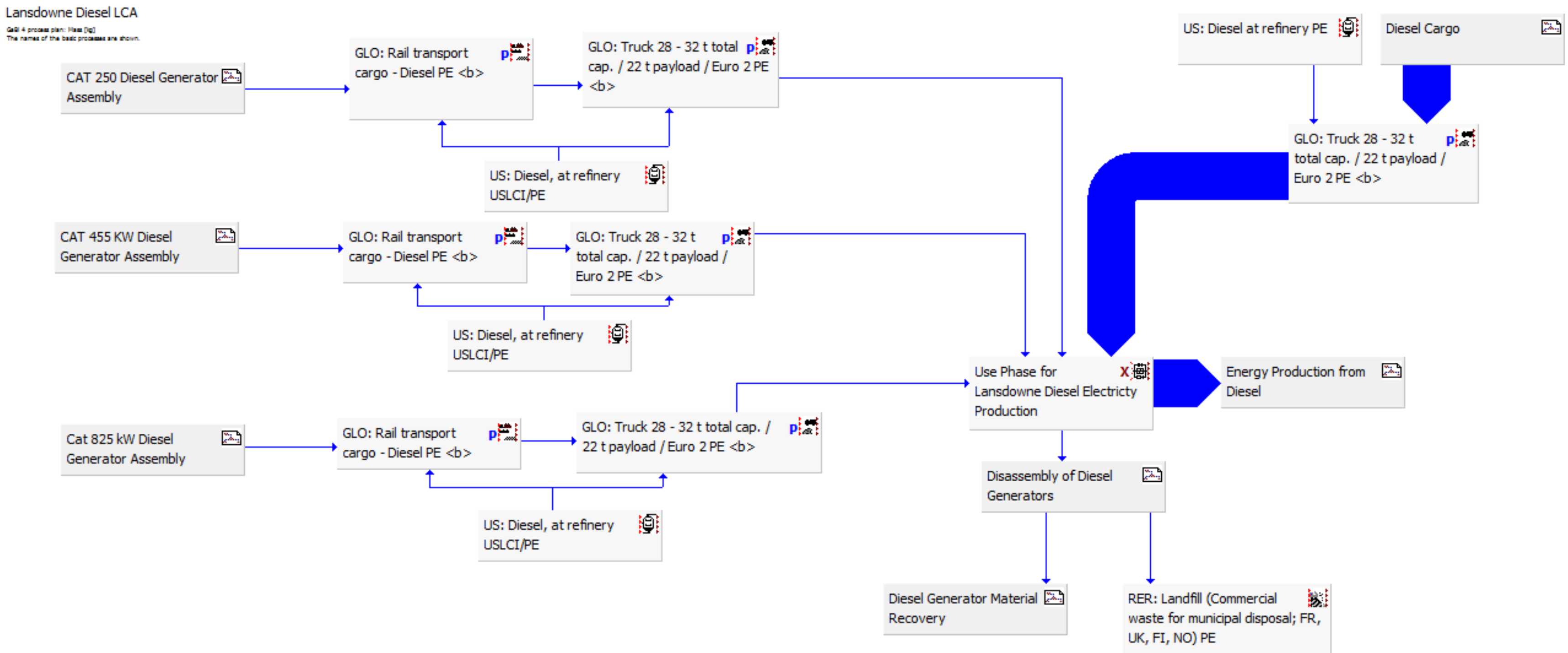

Figure 18 Lansdowne LCA plan for diesel system

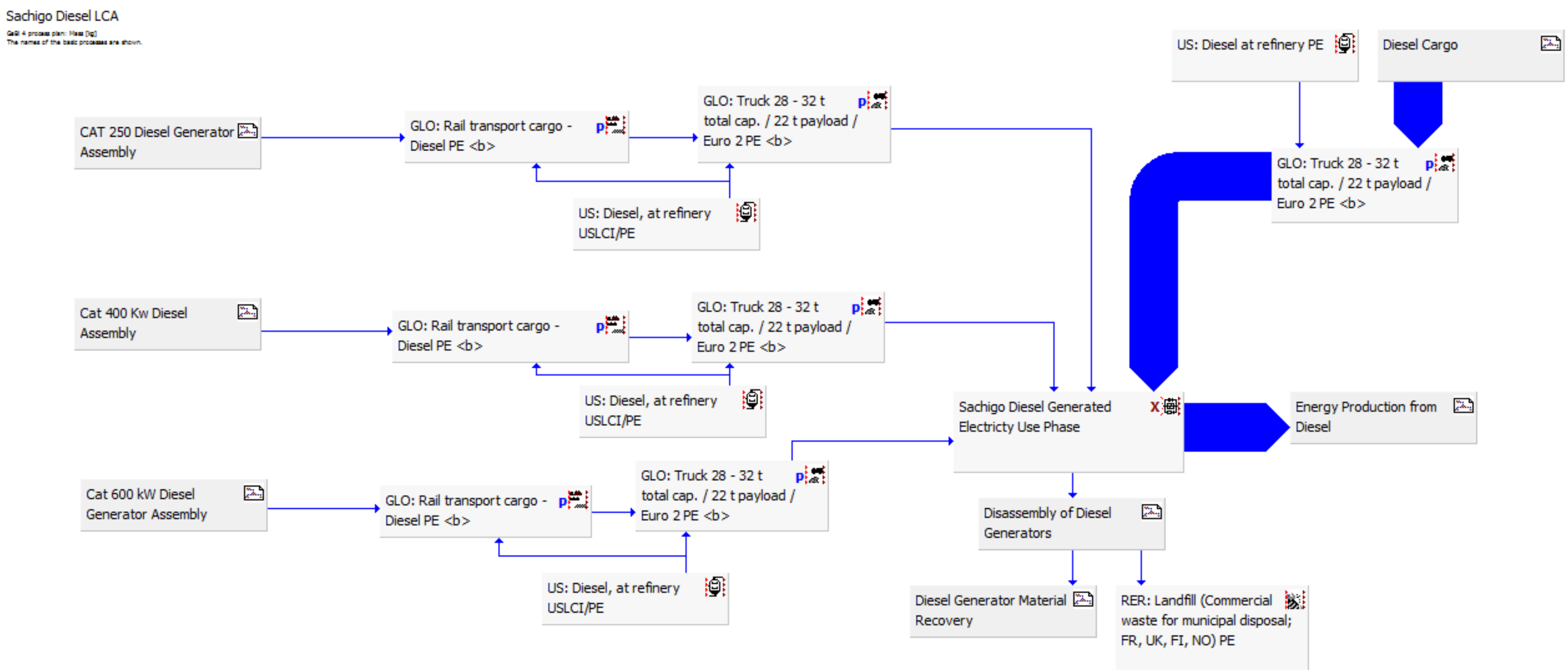

Figure 19 Sachigo LCA plan for diesel system

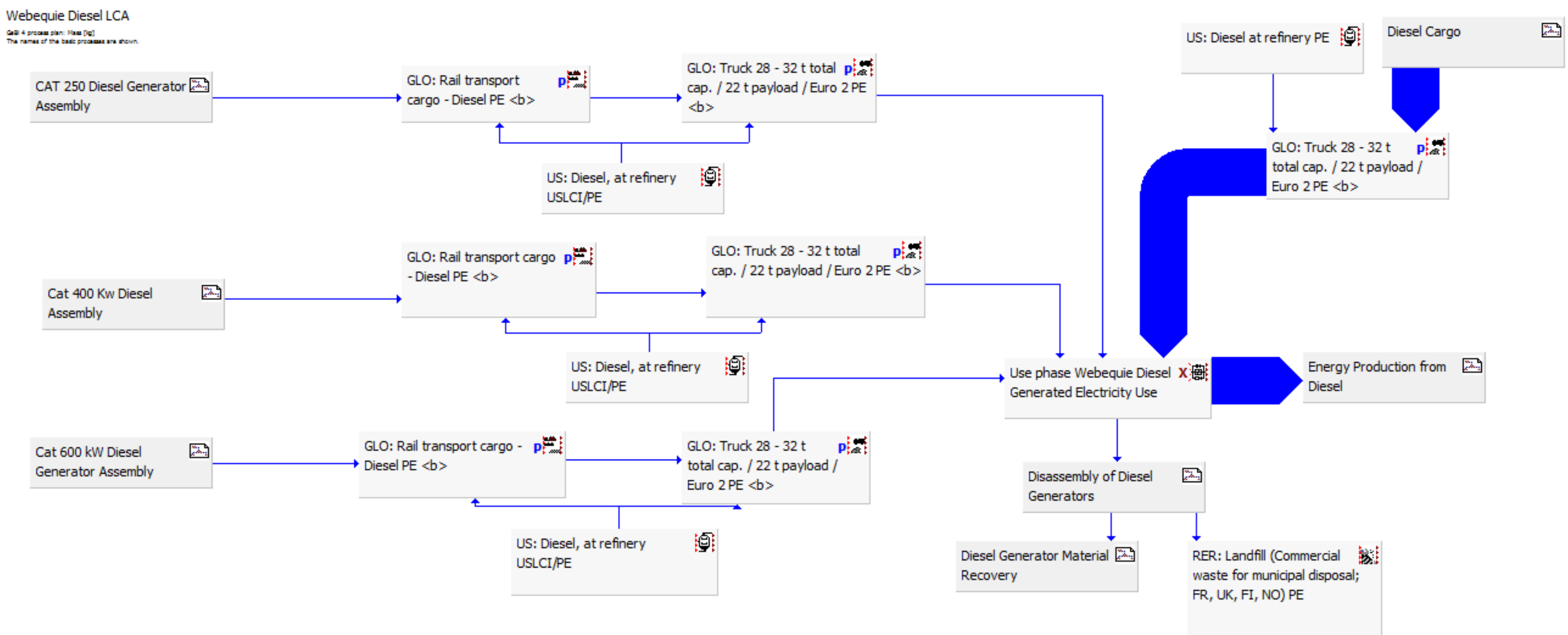

Figure 20 Webequie LCA plan for diesel system

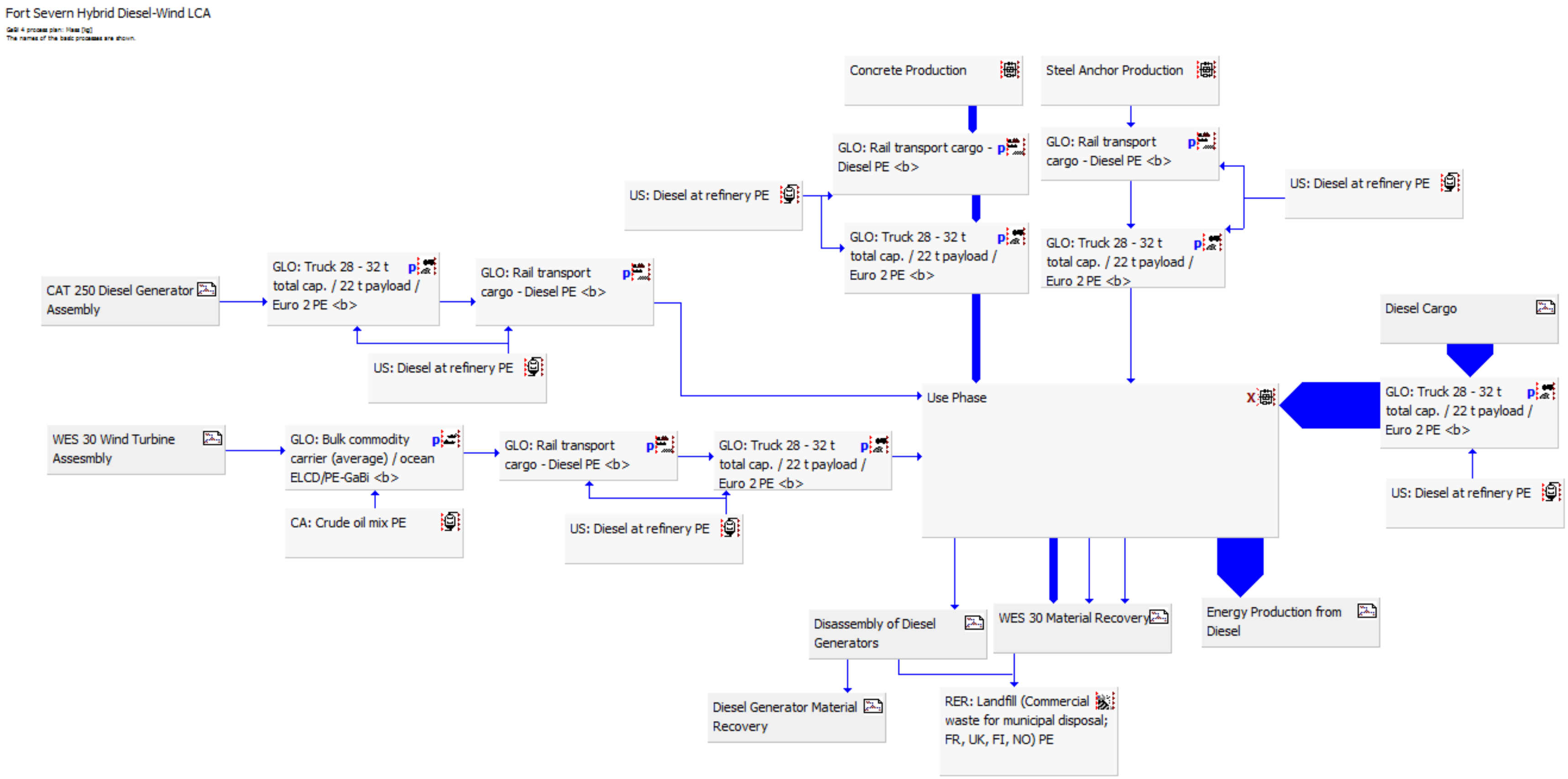

Figure 21 Fort Severn LCA Plan for hybrid diesel-wind

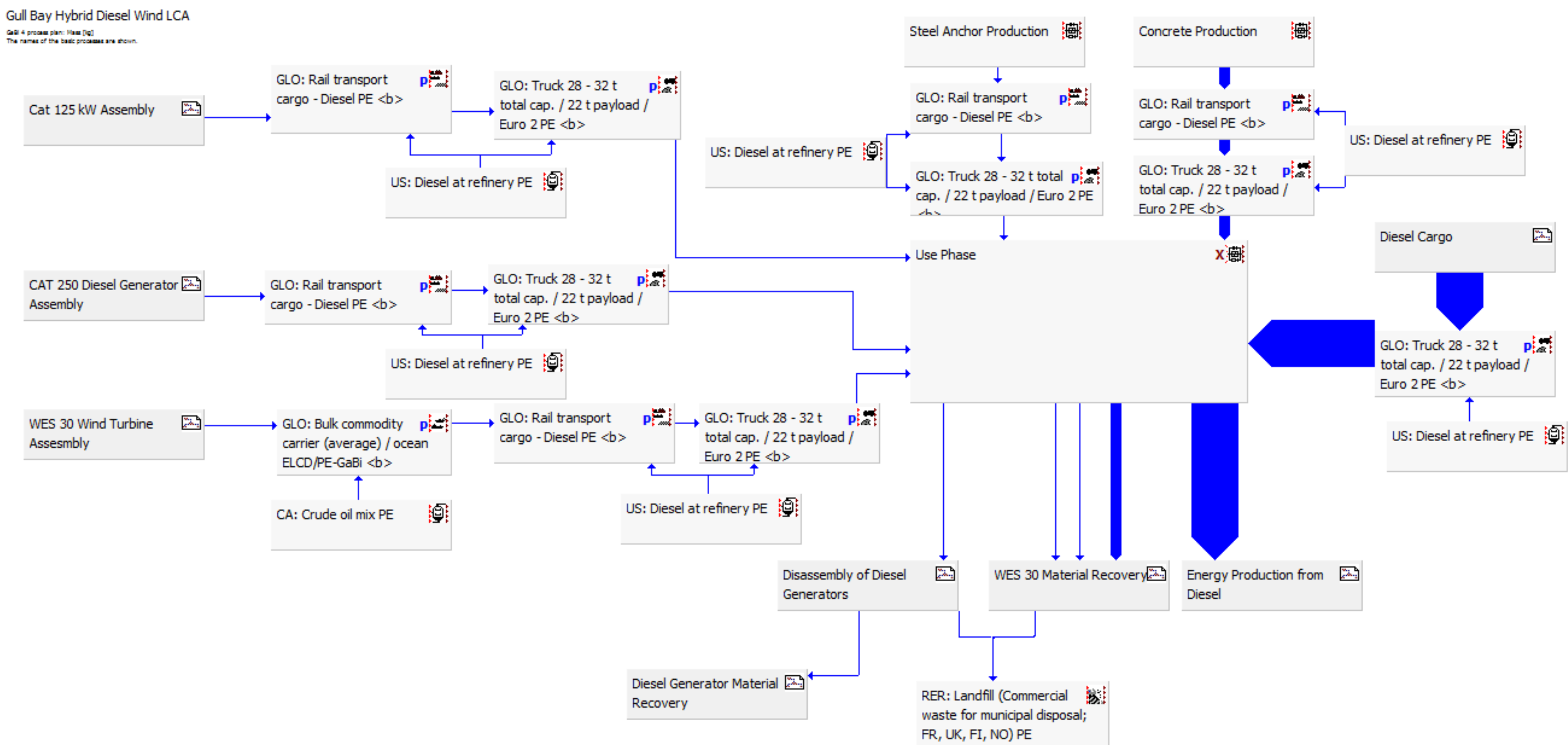

Figure 22 Gull Bay LCA plan for hybrid diesel-wind

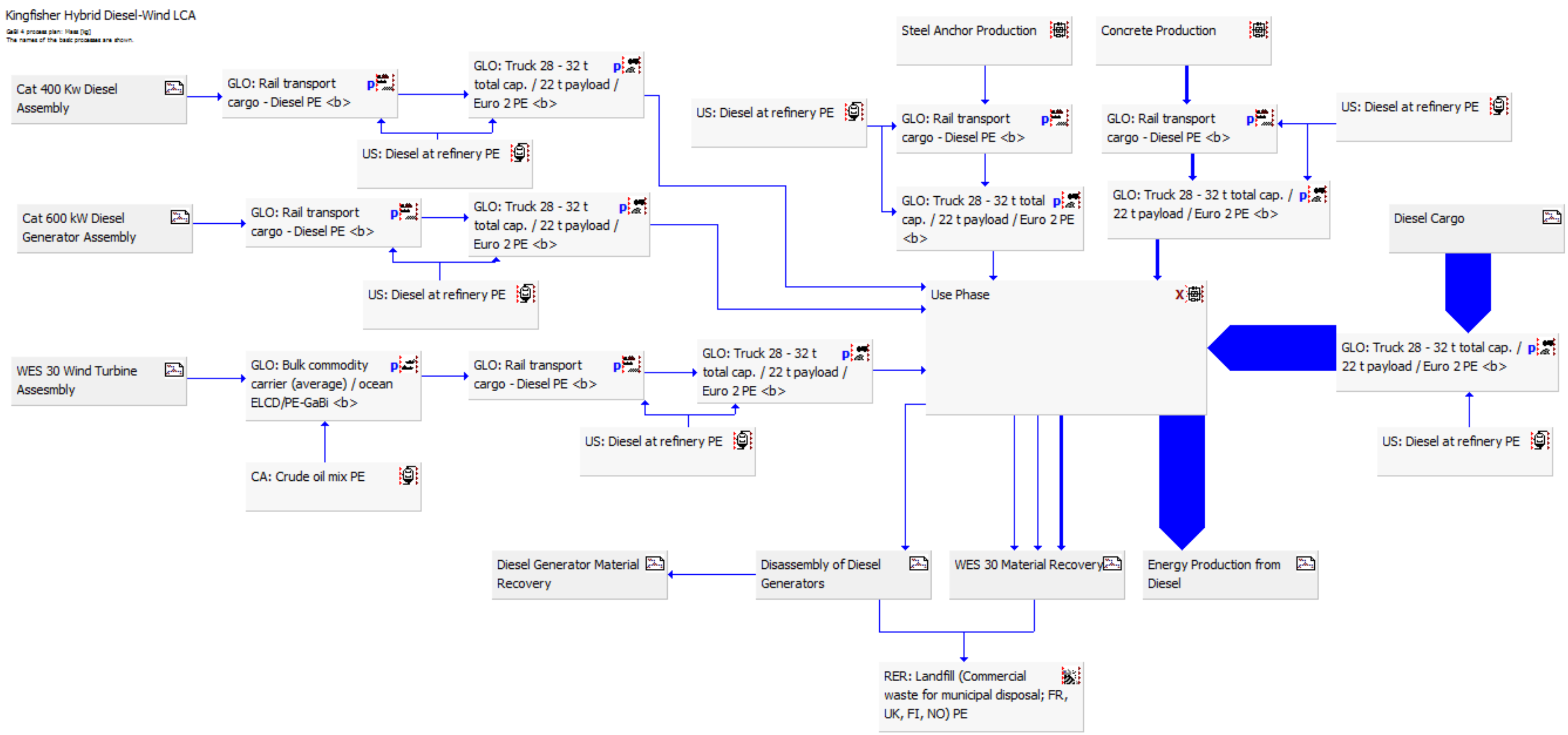

Figure 23 Kingfisher LCA plan for hybrid diesel-wind system

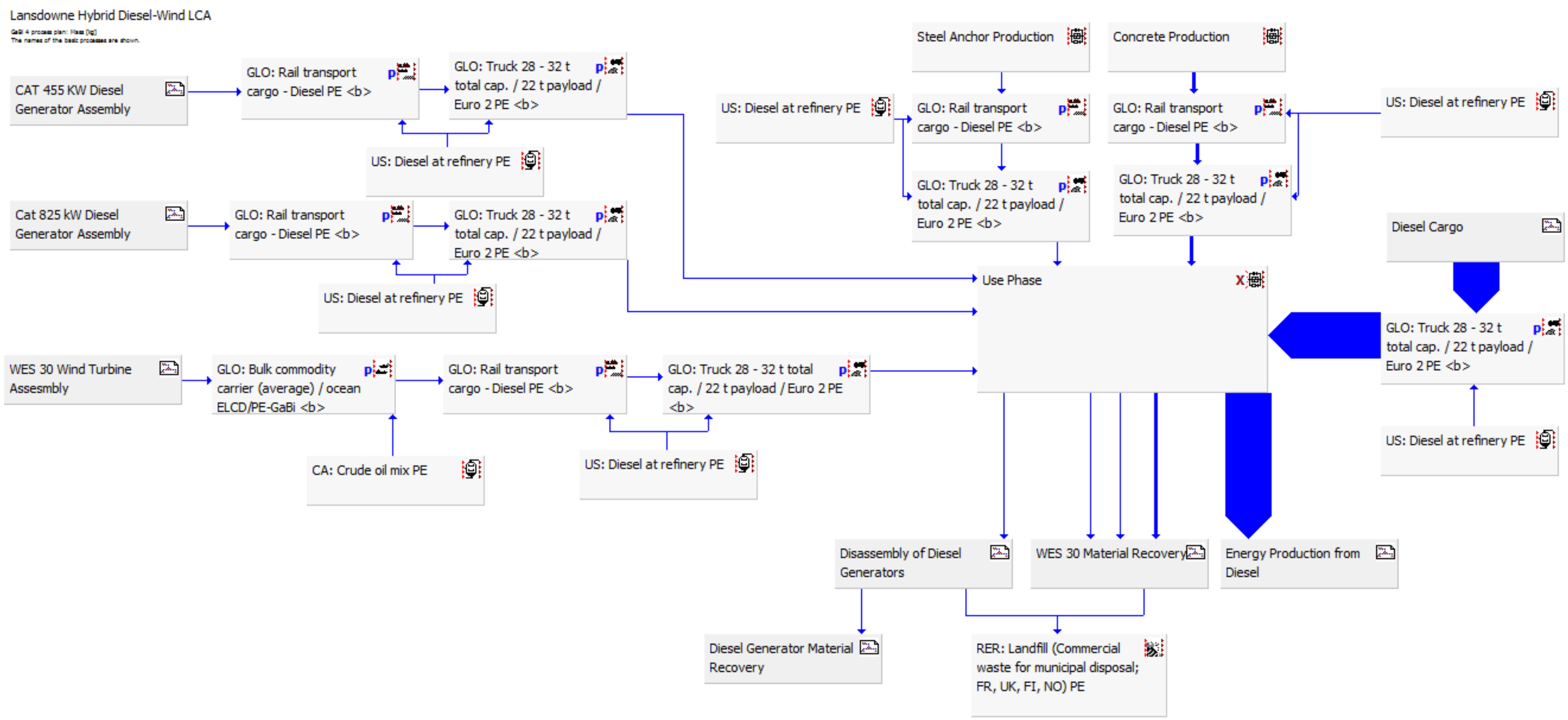

Figure 24 Lansdowne LCA plan for hybrid diesel-wind

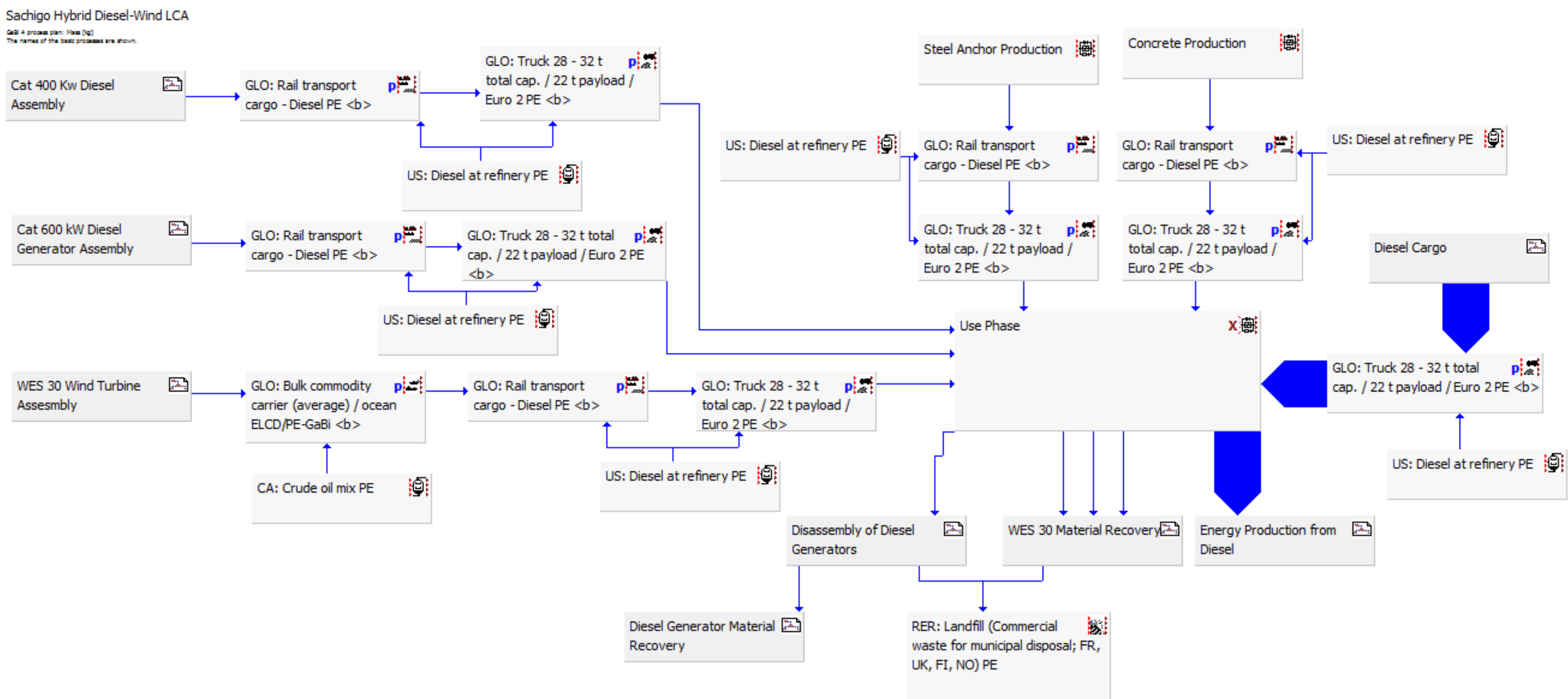

Figure 25 Sachigo LCA plan for hybrid diesel-wind

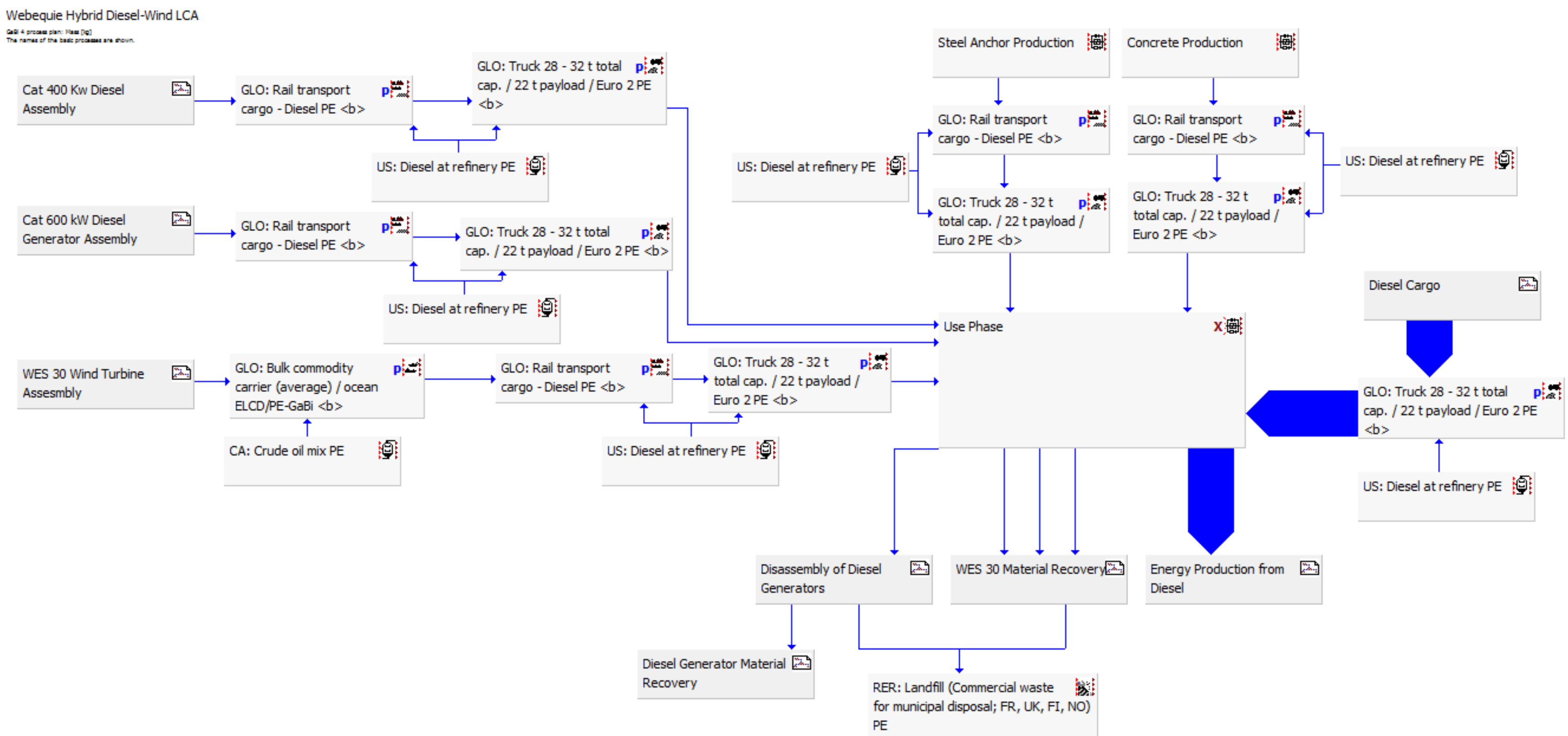

Figure 26 Webequie LCA plan for hybrid diesel-wind

List of Abbreviations

Table 71 List of Abbreviations

Acronym	Explanation
ADP	Abiotic depletion
AP	Acidification potential
CANWEA	Canadian Wind Energy Association
CEAA	Canadian Environmental Assessment Agency
EA	Environmental assessment
EIA	Environmental impact assessment
EP	Eutrophication potential
FIT	Feed in tariff
GWP	Global warming potential
IESO	Independent Electricity System Operator
INAC	Indian and Northern Affairs Canada
ISO	International Standards Organization
LCA	Life cycle analysis
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
OLD	Ozone layer depletion
POCP	Photochemical ozone creation potential
WES	Wind energy solutions

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