NEAR-OPTIMUM COST MINIMISATION OF TRANSPORTING BIOENERGY CARRIERS FROM SOURCE TO INTERMEDIATE DISTRIBUTORS

by
Theari Roberts

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Supervisor: Mr. Theunis Gysbert Dirkse van Schalkwyk
Department of Industrial Engineering

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“You see that pale, blue dot? That's us. Everything that has ever happened in all of human history has happened on that pixel. All the triumphs and all the tragedies, all the wars, all the famines, all the major advances ... it's our only home. And that is what is at stake, our ability to live on planet Earth, to have a future as a civilization. I believe this is a moral issue, it is your time to cease this issue, it is our time to rise again to secure our future.”

- Al Gore, 2006 –

DECLARATION

By submitting this dissertation, I declare that the entirety of the work contained therein is my own, original work, that I am the owner of the copyright thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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ABSTRACT

The world is facing an energy crisis with worldwide energy consumption rising at an alarming rate. The effects that fossil fuels have on the environment are also causing concern. For these two reasons the world is determined to find ‘cleaner’, renewable and sustainable energy sources.

The Cape Winelands District Munisipality (CWDM) area has been identified as the study area for a bioenergy project. The CWDM project aims to determine the possibility of producing bioenergy from lignocellulosic biomass, and transporting it as economically as possible to a number of electricity plants within the study area. From the CWDM project a number of research topics were identified.

The aim of this thesis is to determine the best location for one or more processing plants that will maximise the potential profit through the entire system. This is achieved by minimising the overall life cycle cost of the project. It takes into account costs from establishing and maintaining the crops, harvesting, transportation, conversion and generation; with a strong focus on the transport costs.

In conjunction with a Geographical Information Systems (GIS) specialist and taking into account various factors such as electricity demand, heat sales and substation locations, 14 possible plant locations were identified. The possible supply points for each of the 14 plant locations were then analysed by GIS again to yield data in terms of elevation, road distances and slope.

The transport costs were calculated using the Vehicle Cost Schedule (VCS) from the Road Freight Association (RFA) and fuel consumption calculations. It takes into account slope, laden and unladen transport and considers different transport commodities.

These calculations together with the other associated costs of the life cycle are then combined with the results of the GIS into an EXCEL file. From this a transportation optimisation model is developed and the equivalent yearly life cycle cost of each of the 14 demand points are minimised by means of LINGO software. Initially runs were done for 2.5 MW capacity plants. From the high profit areas identified here, a single area was chosen and further runs were done on it.

These runs were performed to determine the effect of different plant capacities on the life cycle costs, as well as how it affects the farm gate price that can be paid to the farmer. It also determined the effect of farmer participation at different plant capacities.

The results indicate that it is currently possible to pay a farmer between R 300.00 and R 358.00 for a ton of biomass. It also revealed that with higher participation from farmers in the CWDM project, lower costs and higher farm gate prices will result, since the transport costs will be lower. Although all the costs within the life cycle are variable over time, the transport cost is the only cost that varies spatially and this will have a major effect on the overall system cost.

The thesis found that generating electricity from woody biomass is feasible for all areas that were considered as well as for all variations considered during the sensitivity analysis. For the recommended plant size of 5 MW the transport of logs will be optimum.

OPSOMMING

Die tempo waarteen energieverbruik wêreldwyd styg is ’n rede tot kommer. Die nadelige effek wat fossiel brandstowwe op die omgewing het, is ook ’n probleem. Hierdie twee redes is hoofsaaklik wat die wêreld dryf om ‘skoner’ hernieubare en volhoubare energie bronne te vind.

Die Kaapse Wynland Distrik Munisipaliteit (KWDM) area is identifiseer as ’n studie area vir ’n bio-energie projek. Die doel van die KWDM projek is om die vervaardiging van bio-energie vanaf plantasies, die vervoer van hierdie bome sowel as die prosessering koste by die fabriek te bepaal en te evalueer. Vanuit die KWDM projek het `n aantal tesisse ontwikkel waarvan hierdie een is.

Die doel van hierdie tesis is om die beste posisie vir een of meer prosesserings fabrieke te bepaal wat die potensiële wins van die KWDM projek sal maksimeer. Dit is ook gemik daarop om die ekwivalente jaarlikse oorhoofse lewenssiklus koste van die projek te minimeer. Dit neem die vestiging en onderhoud van gewasse, oeskostes, vervoerkostes en proseskostes in ag, met ’n spesifiek fokus op die vervoerkoste.

In samewerking met `’n “Geographical Information Systems” (GIS) spesialis en deur verskeie faktore, soos elektrisiteitsverbruik, inkomste vanaf hitte verkope en substasie posisies, in ag te neem is 14 moontlike fabriek posisies identifiseer. Verder is die moontlike voorsienings areas van elk van die 14 fabriek posisies weer deur GIS analiseer om resultate in terme van hoogte bo seespieël, padafstand en helling te verkry.

Die vervoerkostes is verkry vanaf die “Vehicle Cost Schedule” (VCS) van die “Road Freight Association” (RFA), asook berekeninge wat die brandstof verbruik in ag neem. Hierdie kostes sluit in die effek van gradiënt, gelaaide en ongelaaide vervoer sowel as verskillende vervoer produkte.

Hierdie berekeninge sowel as die ander kostes in die siklus en die resultate van GIS is kombineer in ŉ EXCEL leer. Hierdie data word dan gebruik om ŉ LINGO model te ontwikkel en die oorhoofse lewenssiklus koste van elk van die 14 fabriek posisies te minimeer. Optimering is gedoen vir 2.5 MW kapasiteit fabrieke. Uit die beste areas is een area identifiseer en verdere lopies is daarop gedoen.

Die doel van hierdie lopies is om die effek van verskillende fabriekskapasiteit op die lewensiklus koste te bepaal, asook die effek daarvan op die prys wat aan die boer betaal word vir hout. Hierdie lopies is ook gebruik om die effek van boer deelname te bepaal.

Die resultaat dui aan dat dit tans moontlik is om ŉ boer tussen R 300.00 en R 358.00 te betaal vir ŉ ton biomassa. Dit het ook gewys dat hoe meer boere deelneem aan hierdie projek hoe laer is die oorhoofse lewensiklus koste en hoe hoër is die prys wat betaal kan word vir hout aangesien die vervoerkoste laer sal wees. Alhoewel al die lewensiklus kostes veranderlik is oor tyd, is dit net die vervoerkoste wat ŉ ruimtelike komponent ook het en dit sal ŉ groot effek op die oorhoofse lewenssiklus koste hê.

Die tesis bevind dat dit lewensvatbaar is vir alle areas in die studie om elektrisiteit op te wek vanaf hout biomassa, selfs al word die uiterse variasie in die sensitiwiteitsanalise gebruik. Vir die aanbeveling van ŉ 5 MW fabriek sal die goedkoopste vervoer opsie boomstompe wees.

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To my Creator:

Thank You for all Your blessings and all the grace that You have bestowed upon me.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

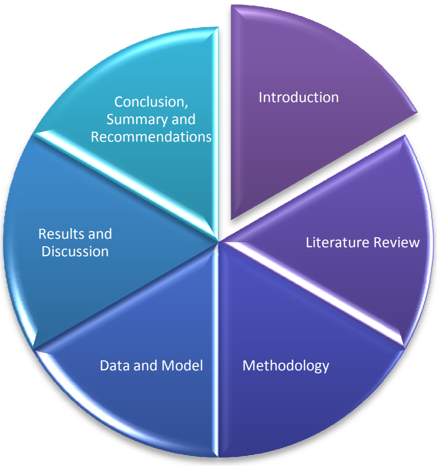
ABBREVIATIONS

CD	Compact Disc
CWDM	Cape Winelands District Municipality
FS	Total cost (LINGO model)
GVM	Gross Vehicle Mass
GHG	Greenhouse Gas
GIS	Geographic Information Systems
Ha	hectare
MW	Megawatt
N	Nodes
NERSA	National Energy Regulator of South Africa
REFIT	Renewable Energy Feed in tariff
RFA	Road Freight Association
RHFA	Relatively Homogeneous Farming Area
SANERI	South Africa’s National Energy Research Institute
SRWC	Short Rotation Woody Crop
VCS	Vehicle Cost Schedule

GLOSSARY

COMBUSTION	The total burning of feedstock in an 'oxygenated' environment at atmospheric pressure.
COMMINUTED MATERIALS	Mechanically reduced in size by chippers, tub grinders and/or shredders
FARM GATE PRICE	The price that can be paid to farmers per ton biomass.
FARMER PARTICIPATION	The percentage of farmers with available and suitable land that decides to supply biomass to the plants.
GASIFICATION	Thermo conversion of a solid feedstock into gas at atmospheric pressure without oxygen.
FIRST GENERATION BIOFUELS	Fuels from food sources such as; ethanol from sugar or corn, biodiesel from vegetable oils.
LIGNOCELLULOSIC FEEDSTOCK	See second generation biofuels.
PYROLYSIS	Thermo-chemical conversion of solid feedstock into liquid at atmospheric pressure without oxygen.
RENEWABLE ENERGY	Renewable energy harnesses naturally occurring non-depletable sources of energy, such as solar, wind, biomass, hydro, tidal, wave, ocean current and

	geothermal, to produce electricity, gaseous and liquid fuels, heat or a combination.
SECOND GENERATION BIOFUELS	Fuels from whole crops such as; Wood, energy crops, residues, wastes. Also known as lignocellulosic feedstocks.



1. INTRODUCTION

Current global energy consumption is forcing the human race to re-evaluate its conventional energy supply methods. In 2007 alone, the worldwide consumption of energy was the equivalent of 8 286 million tonnes of oil equivalent or 96 366 Terawatt-hours (TWh), and electricity consumption was 18 187 TWh (International Energy Agency 2009). The alarming rate at which energy sources are being used and the effects that conventional fuels have on the environment are both causes for concern. In 2007 worldwide carbon emissions were a staggering 28 963 million tonnes (International Energy Agency 2009). The search for sustainable, ‘cleaner’ fuel sources has begun.

1.1 Background

“Oil fuels the modern world (Youngquist 2000).” No other substance has had such a definitive impact on the world as has oil. The applications of oil and all its refined and derived forms are endless. Apart from its use as an energy source, it is the basis of petrochemical products such as plastics, medicines, paints and numerous other useful materials. At present, oil is abundantly available; energy is extracted from oil relatively easy; it is energy dense, easy to transport and store, relatively safe and very versatile (Youngquist 2000).

It is clear that at this point in time no alternative energy source quite matches up to the desirable characteristics displayed by oil. But the fact remains that oil, just like any other fossil fuel, is a finite resource. The increasing demand for energy sources worldwide makes it crucial that alternative energy sources are found. It is also important to focus on sustainable alternative energy sources to provide sufficient energy for generations to come. Unfortunately, the shift from fossil fuels to alternative fuels will not be easy and will require a lot of time and financial investment (Youngquist 2000).

In general, renewable energy sources are considered to be sustainable, but sensible management is still needed to enhance their sustainability and especially their contribution to the energy mix (Department of Minerals and Energy 2003). Sustainability is associated with the lesser impact that these energy sources have on the environment and the fact that they can be used without compromising future generations` energy needs (Open University 2001). In short, sustainability entails providing for the present without compromising the future of our planet and coming generations (Brundtland 1987).

Renewable energy sources have much lower energy densities than today`s fossil fuel sources and therefore require large areas of land to produce. Also, the costs associated with renewable projects are much higher than those associated with conventional fuels. Only by reducing the cost of renewable energy or increasing the cost of conventional fuels can renewable energy become competitive. In this regard, one option is to implement a carbon policy that restricts carbon emissions to a minimum, and if a company cannot comply with this policy, it is forced to pay a levy. Nonetheless, the fact remains that the world is facing an energy crisis and the time to act is now (Open University 2001).

The potential for renewable energy supply in South Africa is very high, and targets of up to 10 000 GWh from renewable energy sources have been set in place for 2013. To encourage developers to invest in such projects, the National Energy Regulator of South Africa (NERSA) has set appropriate tariffs, known as Renewable Energy Feed-in Tariffs (REFIT). These tariffs will cover the cost of establishing such a project and allow for a reasonable profit (National Energy Regulator of South Africa 2009).

Although these tariffs will apply to any renewable energy source, for the purpose of this project, biomass as a source is considered. Biomass is any organic matter such as plants, food products, wood products and waste products. It is important to note that the South African government has placed a restriction on the use of food sources such as maize and wheat as energy sources as the use of food sources may lead to a rise in food prices and compromise food security. Therefore, the two main biomass sources considered in South Africa are sugarcane in the wetter, eastern parts of the country and woody biomass in the drier, western parts. Thus, the feedstock studied in this project is woody biomass or lignocellulosic biomass.

The University of Stellenbosch was approached by the Cape Winelands District Municipality (CWDM) to determine the feasibility of a bioenergy project in this region. The study considers the entire bioenergy process from producing woody biomass to generating electricity, including analyses of harvesting, transport, and the life-cycle. It also incorporates various academic fields such as agricultural economics, forest science, industrial engineering, process engineering and geography. It will also contribute to the South African National Energy Research Institute`s (SANERI) research on developing alternative energy projects.

This thesis is concerned with optimising the transport and related costs of the CWDM project. It considers different truck configurations, fuel consumption and focus on choosing the best location for plants that will minimise the total cost based on certain criteria.

1.2 Problem statement and research questions

The aim of the thesis is to determine the best location for one or more processing plants that will maximise the potential profit through the entire system. A detailed analysis of the total transport cost of woody feedstock from the plantations to the plant(s) forms a vital part of the system. This is done by means of transport modelling, an optimisation technique that allows one to determine the total transport which takes the following into consideration: the most economical routes to the plant(s); whether there should be more than one plant, how much fibre should be transported from each growing area to each plant; the best mode of transportation; the best form of the product to be transported; and the saving on transport costs by using a mobile or decentralised processing plant located at a growing area to save on transporting the bulky feedstock.

1.3 Research approach and methodology

Trucks are chosen from the Road Freight Association`s (RFA) Vehicle Cost Schedule (VCS), and fuel consumption is calculated based on work done by Prof. C.J. Bester, Lecturer at the Department Civil Engineering, University of Stellenbosch, who specialises in transport engineering.

Furthermore, the optimal locations for plants are chosen using multiple criteria, supported by a geographic information system (GIS), after which the total system cost is minimised as determined by LINGO. This process is repeated for various plant sizes.

1.4 Research design

According to Mouton this thesis has characteristics from all of the following research designs:

- Statistical modelling and computer simulation studies.
- Secondary data analysis (SDA).

- Methodological studies.
- Theory-building or model-building studies.
- Literature reviews (Mouton 2001).

1.5 Study area

The CWDM serves as case study for the project. It covers an area of 22 300 square kilometres (2.23 million hectares) and comprises five local municipalities (see Table 1 and Figure 1).

Table 1: Local municipalities within the CWDM

Name of local municipality	Major towns	Size (ha)
Breede River	Ashton, Bonnievale, McGregor, Montagu, Robertson	332 982
Breede Valley	De Doorns, Rawsonville, Touwsrivier, Worcester	299 332
Drakenstein	Paarl, Wellington	153 772
Stellenbosch	Stellenbosch, Pniel, Franschhoek	83 113
Witzenberg	Ceres, Prince Alfred Hamlet, Tulbagh, Wolseley	1 360 762
Total Area:		2 229 961

(Department of Agriculture: Western Cape 1999)

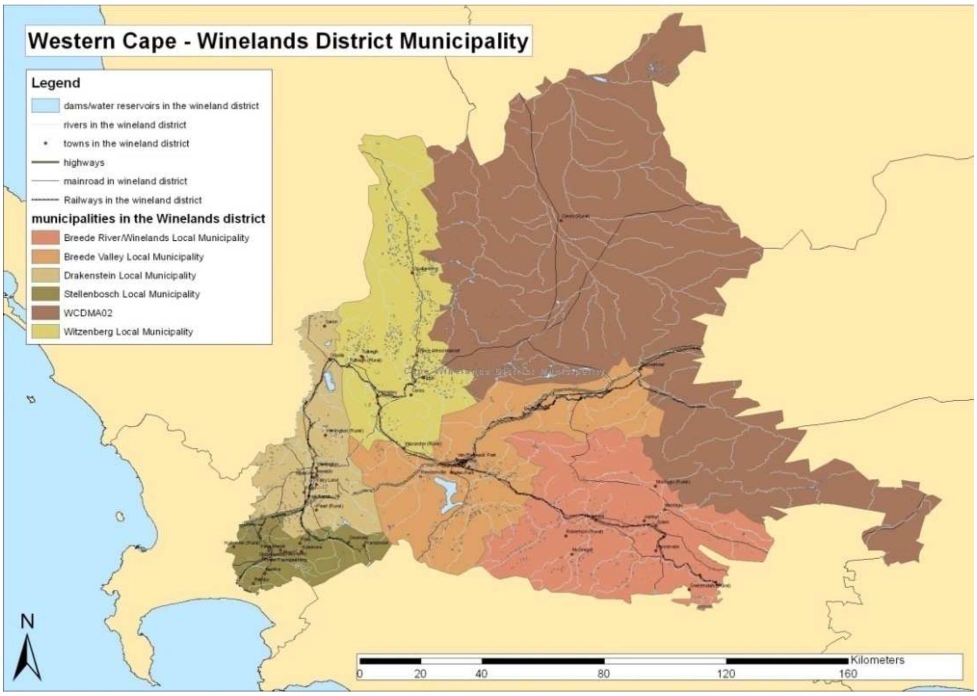


Figure 1: Map of the CWDM and its local municipalities (Department of Agriculture: Western Cape 1999)

1.6 Chapter layout

This thesis is presented in six chapters, followed by a list of references and annexures. The first chapter serves as a general introduction to the thesis and the CWDM project. In Chapter 2, the focus is on the relevant literature applicable to all phases present within a bioenergy project, with special reference to the CWDM project.

Chapter 3 centres around the methodology followed to achieve a near-optimum answer for the transport phase of the CWDM project, with Chapter 4 focusing on the LINGO model used to solve the optimisation problem. In Chapter 5, we discuss the results of the model.

The last chapter comprises a conclusion and future recommendations that can be made for such a project. Figure 2 gives a graphical representation of the chapter layout.

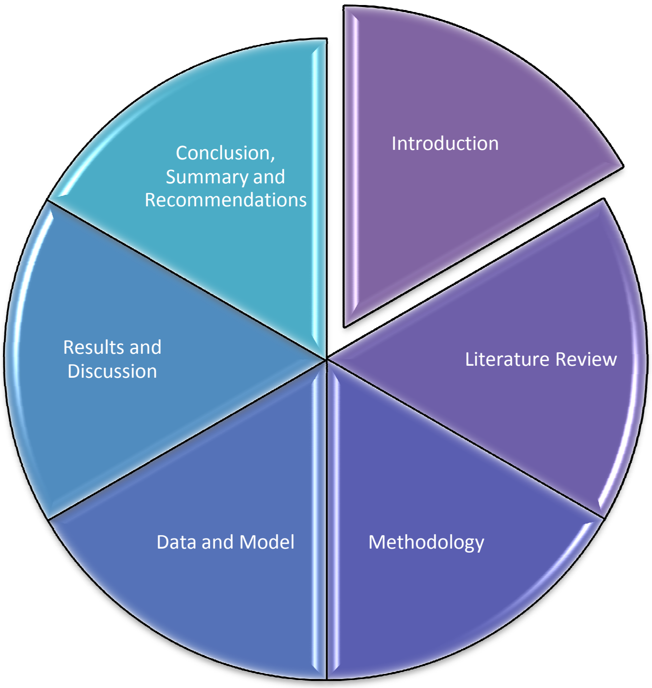
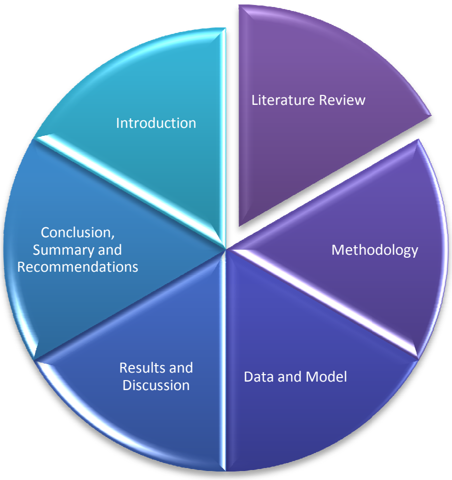


Figure 2: Chapter layout



2. LITERATURE REVIEW

The goal of this chapter is to give an overview of the most relevant literature on bioenergy, specifically the use of woody biomass to produce electricity. This chapter covers all aspects of the bioenergy process, with the focus being on the transportation of woody biomass.

2.1 Bioenergy considerations

“The continuous growth of global energy consumption raises urgent problems. On the other hand, the use of fossil fuels causes numerous environmental problems, such as local air pollution and greenhouse gas (GHGs) emissions.” (Hamelinck, Suurs and Faaij 2005).

The world is set on finding cleaner, renewable and sustainable sources of energy. One of the options that in recent years has been studied anew is energy from biomass sources. The advantages of biomass are that it is available worldwide, it can be used to produce electricity and biofuels, and it is possible to consume biomass on a carbon-neutral basis. Currently, some of the disadvantages of biomass are the high costs associated with producing enough utilisable energy from it as well as the large areas of land producing it requires. “In theory, energy farming, especially on surplus agricultural land worldwide can contribute between 33 and 1130 exa-joule (EJ) per year in 2050 without jeopardising the world`s food supply.” At the moment, global energy consumption is about 410 EJ (Hamelinck, Suurs and Faaij 2005).

Biomass can be collected from dedicated energy crops, forest residues or industrial products (i.e. pulp and paper production, sawmills or bagasse from sugar production).

Also, different forms of bioenergy exist:

- ‘Raw’ biomass (chips, logs, bales).
- Intermediate energy carriers (bio-oil, charcoal).
- High-quality energy carriers (ethanol, methanol, synthetic diesel, hydrogen, electricity) (Hamelinck, Suurs and Faaij 2005).

It is logical that biomass from forestry and industry will be used first to produce bioenergy because these operations are in close proximity to conversion facilities and because of the cheaper costs associated with existing processes (Hamelinck, Suurs and Faaij 2005). Refer to Table 2.

Table 2: Input data for bioenergy sources used in this study

	Forestry residues			**Energy crops**		
Region	Scandinavia			Scandinavia	Eastern Europe	Latin America
Form	Logs	Chips	CRLs	Bundles	Bundles	Logs
Costs (€/tonne$_{wet}$)	9.3	27.5	17.4	48.5	18.4	16.8 - 10.2
Costs (€/GJ$_{HHV}$)	0.9	2.6	1.5	3.9	1.5	1.1 - 0.7
Diesel use (MJ$_{HHV}$/tonne)	20	600	220	47 - 25	25	60 - 48
Moisture content (%)	50	50	45	37	37	20

	Forestry residues			Energy crops		
Ash (db) (%)	0.2	0.2	0.2	1.6	1.6	0.5
C (daf) (%)	47.4	47.4	47.4	49.5	49.5	49.8
H(daf) (%)	6.3	6.3	6.3	5.8	5.8	5.8
O (daf) (%)	46.2	46.2	46.2	43.4	43.4	44.2
N (daf) (%)	0.1	0.1	0.1	0.4	0.4	0.1
Avg. ps. (mm)	3000	30	3000	3000	3000	1000
Density (kg/m^3_{bulk})	462	219	251	160	160	280
HV (GJ_{HHV}/$tonne_{dry}$)	20.8	20.8	20.8	19.5	19.5	19.4
Average yield (tonne/km^2 yr)	0.6	0.43	0.43	370 - 675	675	467 - 583
Supply window	Oct.–Mar.	Oct.–Mar.	Oct.–Mar.	Oct.–Mar.	Oct.–Mar.	Whole year

(Hamelinck, Suurs and Faaij 2005)

The use of biomass as a bioenergy source has dual purposes. It seeks to reduce greenhouse gas (GHG) emissions, while addressing increased energy demand. The increased worldwide utilisation of renewable energy sources will therefore lead to trading options between countries in the form of liquid/gaseous fuels, electricity, renewable certificates as well as carbon credits (Schlamadinger, et al. 2005).

If produced sustainably, biomass can be used as a carbon-neutral energy source with the following benefits:

- It can be converted to valuable energy carriers such as electricity, heat and liquid/gaseous fuels.
- Reduction of greenhouse gas emissions.
- Reduction of local air pollution.
- Reduction of dependence on limited fossil fuel resources (Schlamadinger, et al. 2005).
- Meeting of domestic energy needs and reduction of the importation of fuel.

- Diversification of rural economies with local socioeconomic benefits.
- Reduction of poverty.
- Energy from biomass is less land intensive than energy from food sources as marginal land is utilised (Mangoyana 2008).
- Increase of export possibilities.
- Increase of job opportunities for rural areas as well as an increase in overall national employment (IPCC, 2007b; Commission of European communities, 2006; Francis et al., 2005; Ackom and Ertel, 2005).

Furthermore, the cost of biofuels can be reduced by using by-products as a trading commodity (Mangoyana 2008).

Currently, little attention has been given to the development of bioenergy markets worldwide, since the potential of such markets is yet unrecognised in most regions. Especially in developing countries where the cost of land, labour and production is lower compared to developed countries, a large potential for such markets exists, giving developing countries the opportunity to export biomass or the products thereof at a lower cost (Schlamadinger, et al. 2005).

One of the major benefits associated with bioenergy production is the reduction of carbon emissions. Biomass is seen as a carbon-neutral energy source, which means that the carbon uptake from plants will roughly equal the carbon released into the atmosphere during the conversion process. This means that when trading between countries occurs, the exporter will have a carbon flux from the atmosphere to the biomass and the importer will have a carbon flux from the energy system to the atmosphere, which will consequently cancel each other out. The reduction of carbon emissions will have a benefit to the entire atmosphere and not just the local environment (Schlamadinger, et al. 2005).

Due to the rise in food prices as well as the high poverty rate in the sub-Saharan Africa region, the use of food-based bioenergy sources is not suitable, but feedstocks such as woody biomass, agricultural waste and certain grass species can be used (Tilman, Reich, et al. 2001) (Tilman, Reich and Knops, Biodiversity and Ecosystem sustainability in a decade-long grassland production 2006). These feedstocks, which are especially advantageous as they require low inputs, can be planted on marginal land and, due to their perennial nature, can help rehabilitate wastelands (Mangoyana 2008).

Therefore, it is concluded that in the South African context energy crops produced on marginal or surplus agricultural land will make the largest potential contribution to bioenergy systems, especially in developing countries where food sources are scarce and will provide extra income for rural communities (Hoogwijk, et al. 2003).

2.2 Biomass to electricity process

The basic biomass process for generating electricity is shown in Figure 3.

Figure 3: Basic biomass production and conversion process

The four main phases of the process are biomass production, preprocessing, transportation and electricity generation. The production phase refers to preparing the land and planting the tree species. Woody biomass crops are perennial in nature, and thus this phase will be repeated every couple of years depending on the tree species being used.

Preprocessing includes harvesting and preparing the feedstock for transportation or for utilisation at the plant. Transportation entails moving feedstock from the plantation to the plant. The last phase entails converting the feedstock into different products and possibly generating electricity from it, which will be the outcome for the CWDM project. Table 3 gives a general idea of the different options available for a biomass process.

Table 3: Operation types, with possible options and key model variables

Operation type	Options	Key variables
Biomass production	Forestry residues Energy crops Felling Industrial waste Chipping Baling	Harvesting window Production costs (location-dependent)
Pretreatment	Storage Chipping Drying Pelletising	Equipment capacity Capital operations and management Energy consumption (power, fuel, heat) Load factor Dry matter loss Moisture loss
Transport	Truck Train Ship	Transport distance Speed Capacity Product weight Product volume Capital, operations and management Fuel consumption Load factor Transfer time and costs

Operation type	Options	Key variables
Energy conversion	Power Methanol Pyrolysis oil	Conversion efficiency Capital, operations and management Load factor

(Hamelinck, Suurs and Faaij 2005)

2.3 Biomass production

The net energy yield of perennial crops can be between 220-550 giga-joules per hectar (GJ/Ha) per year. This is much higher than the energy extracted from annual crops. Compared with food-based sources such as sugar, starch and oil crops, lignocellulosic biomass (e.g. wood and grass) yields higher energy values. In the long term, the key criteria for selecting biofuels are higher overall efficiencies and lower overall costs (Hamelinck and Faaij 2006).

Biomass will play a substantial role in the future as a source for energy carriers such as electricity and transport fuels. It is especially attractive as it leads to lower carbon dioxide emissions in transport systems. Due to the newness of the technology used to produce energy, the initial costs are high, but over time, these costs will become more competitive with well-known existing technology. Of all the possible biofuels available, fuel from lignocellulosic biomass is the most attractive. This can be attributed to the fact that lignocellulosic biomass has better projected economies, and it has a higher fuel yield per hectare. In terms of growth and harvesting, the feedstock needs less additional energy, and it is possible for it to grow under many different circumstances. This contrasts with annual crops that require high-quality land and input (Hamelinck and Faaij 2006) (Berglund and Börjessen 2006).

Comparisons between fuel from corn and fuel from lignocellulosic biomass have shown that the latter is preferable due to the following reasons:

- The availability of large quantities that can be utilised.

- In comparison to fuel from grain, it exhibits significantly lower GHG emissions.
- Eases pressure on food sources and eradicates conflict over food for human consumption versus food as a fuel source.
- The better use of marginal land can have uplifting effects for rural economies (Carolan, Joshi and Dale 2007).

For the CWDM project, the yield from perennial crops has already been calculated in a previous study done by C.C.C. von Doderer (Von Doderer 2009). In this study, firstly, the physical capacity of the CWDM area was assessed by means of a land suitability assessment using GIS. From this initial assessment, the following areas were excluded:

- Non-agricultural land (this included urban areas, bare rock and mines).
- Ecologically sensitive areas.
- Areas with very steep gradients (Von Doderer 2009).

Secondly, suitable tree species were chosen and their productivity rates were determined. This was also accomplished by means of a GIS, and by using data on temperature extremes, frost, precipitation and terrain limitations. Afterwards, the productivity of the CWDM area was determined by combining the available land and the productivity rates of the identified species. The result was an estimated production of about 1 412 000 tonnes of fresh biomass when using only exotic species such as *Eucalyptus cladocalyx* and about 1 306 000 tonnes when using indigenous species such as *Acacia karoo*. It was found that a combination of indigenous and exotic species gave a higher average yield because indigenous species perform better in drier areas and exotic species perform better in wetter areas (Von Doderer 2009). Refer to Figure 4 for the relatively homogenous farming areas which refer to the species chosen.

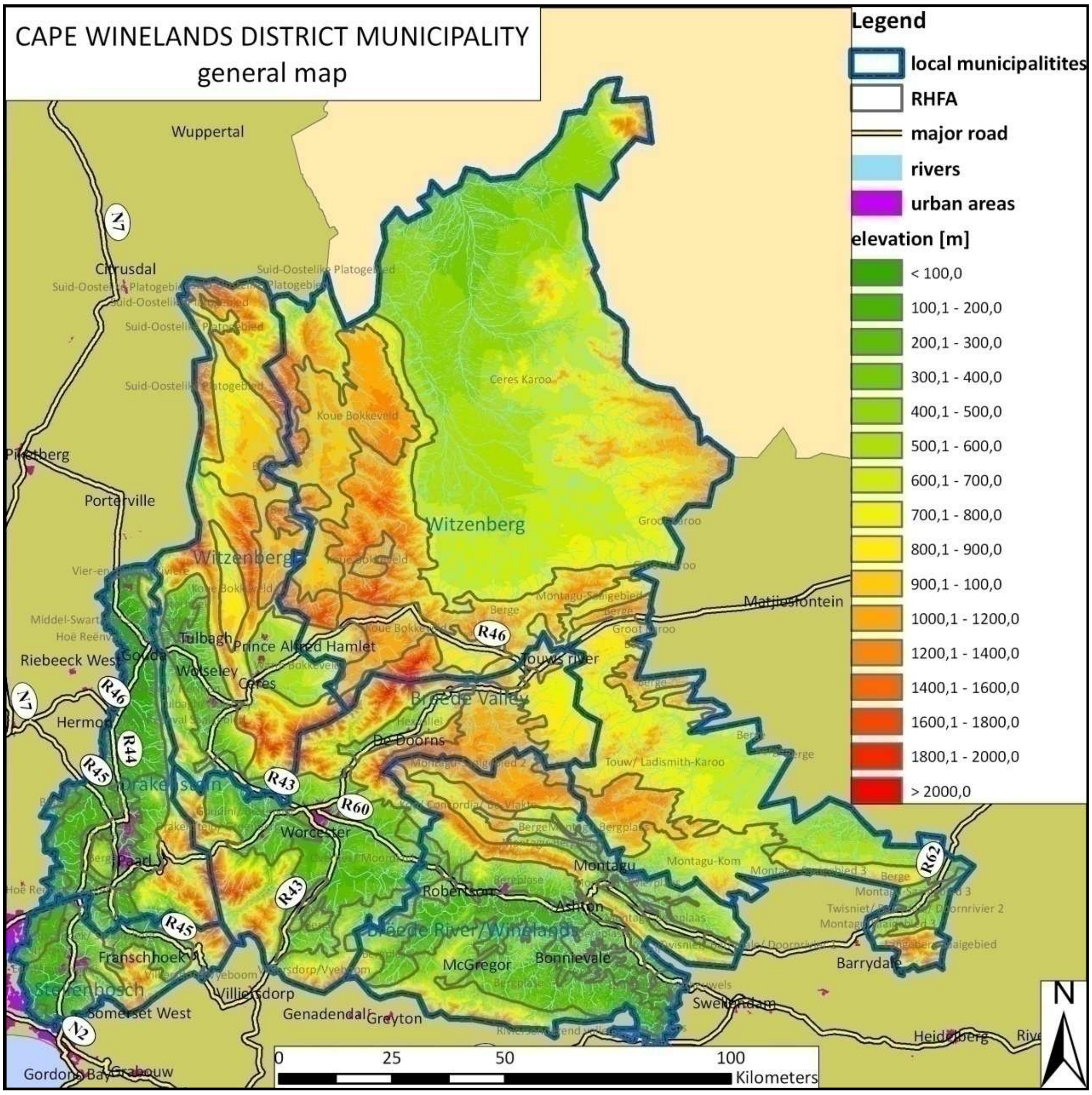


Figure 4: Relativavely homogeneous farming areas (RHFAs)

2.4 Biomass harvesting

The major steps in procuring biomass, which include the transportation phase, are the following:

- Harvesting or felling.
- Processing and drying.
- Transportation and delivery.
- Storage (Von Doderer 2007).

Woody biomass harvesting systems are used to fell and recover wood for bioenergy production. This includes transporting the biomass to a central location where it can be processed or loaded on to trucks to be transported to a bioenergy facility. Biomass is harvested either together with conventional timber or as a separate operation, but the most important consideration is the cost-effectiveness of such a system (Ashton, et al. 2007). In the case of the CWDM project, all of the wood harvested will be used for bioenergy processing.

In general, large-scale harvesting systems will be more cost efficient than specialised smaller systems, because large-scale systems can harvest more material per machine hour than smaller systems. A number of aspects need to be taken into account when considering the cost-effectiveness of a system. These are capital costs, operation and maintenance costs, and transportation costs. The amount of material – total volume of biomass that can be harvested from a site – as well as the market price of biomass are also important considerations. Two of the more conventional harvesting systems used today are one-pass and two-pass systems (Ashton, et al. 2007).

One-pass systems: Traditionally one-pass systems are used to harvest roundwood and biomass simultaneously. According to Stokes, et al., 1984, when using conventional harvesting equipment (fellers or bunchers, harvesters, skidders and forwarders), this is the most cost-effective method. It is also favoured because, other than adding a chipper, few, if any, modifications are needed to the system. Apart from the value that is added to forest products, it also leads to a reduction in the cost of land preparation or reforestation. Two examples of one-pass systems are whole-tree harvesting and a harvester-forwarder combination (Ashton, et al. 2007).

Whole-tree harvesting first uses fellers or bunchers to fell all material. An important consideration here is the terrain on which the felling takes place. For steep slopes, a more expensive tracked swing-to-tree machine is used and for level slopes, a less expensive rubber-tyred, drive-to-tree machine is used. Next, skidders transport the material to the log landing where the material is sorted into biomass and traditional products. The biomass, along with the limbs and tops of the traditional products are chipped, while the traditional products are transported to the market. A drawback of this system is grit contamination, as the material is dragged over ground (Ashton, et al. 2007) (Stokes, Watson and Savelle 1984).

The harvester-forwarder combination uses a harvester that incorporates all processes (felling, delimbing, bucking and piling) and separates the material into biomass and traditional product materials. Both types of material are transported by a forwarder to the log landing, where the biomass is chipped and the traditional product materials are transported to the market. It is important to note that using this system, leaves, needles, parts of branches and the tops remain on site. Forwarders eliminate most potential grit contamination (Ashton, et al. 2007).

Two-pass system: The two-pass method collects the biomass and traditional product materials in separate phases. This method has not proven to be as cost-effective though. In a two-pass system, the biomass is left either on site or at the landing for later utilisation. With this method, smaller more specialised equipment can be used if conventional equipment is not available, making it especially suitable for small-scale farmers. Harvesting of biomass can be done either before or after harvesting of traditional product material (Ashton, et al. 2007).

During pre-harvesting, all material that cannot be used for traditional products is harvested for use as biomass and then transported to a collection point. Later, harvesting of traditional product material takes place. This system is beneficial as it leads to a reduction of vegetation on the stand. Post-harvesting involves harvesting material for traditional products first, and subsequently harvesting biomass (Ashton, et al. 2007).

Once again, it is important to note that for the CWDM project all of the wood harvested will be used as biomass.

Due to new bioenergy regulations that were established in Austria, a remarkable effort in developing forest networks to supply biomass as a renewable energy source is being undertaken. Harvesting plays a crucial role when designing a forest network. In the Western Cape, the current network of roads will have to suffice. Important questions about where chipping should take place and where terminals should be located need to be answered efficiently in order to obtain optimal results. Chipping can take place either at a central terminal by using an industrial-sized chipper or at regional terminals by using mobile chippers. With the former, a large catchment area is needed to ensure the optimal supply of biomass to the plant(s) takes place. An optimal system will take into account harvesting, transportation and overall system costs (Gronalt and Rauch 2007). These are typical questions that can optimally be answered using operations research, specifically transportation and network models.

According to studies, it is better to chip the biomass as late as possible in the process to prevent fungal degradation after chipping. Fungi causes health risks, and a decrease in the energy content of the biomass. If chipping takes place at the harvesting site, biomass should preferably be used within 14 days to prevent fungal degradation (Forsberg 2000).

Generally, logs, chips and bales are stored in the open air to dry. With long-distance transport, it is important to note that chips have a low density, and this will lead to an increase in transport costs (Hamelinck, Suurs and Faaij 2005). Figure 5 clearly shows how different forestry materials have different volumes for the same total mass, which plays a major role in transporting these materials.

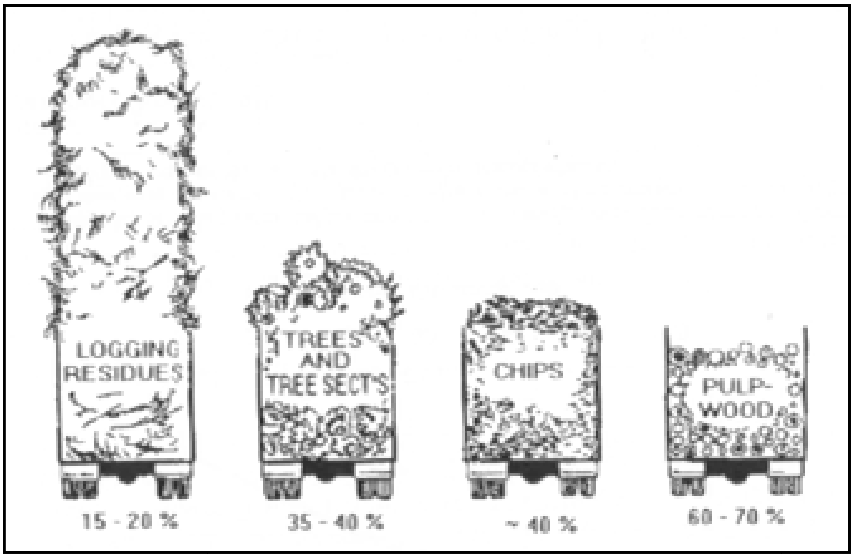


Figure 5: Proportion of solids in uncompacted logging residues, tree sections, wood chips and conventional pulpwood. All loads have the same solid content (Richardson, et al. 2002).

Junginger et al., explain: "… [the] maximum economic transport distance of forest fuel depends on local factors such as infrastructure and plant size and should not simply be adopted from literature." (Gronalt and Rauch 2007). This confirms that a transport model must be built and optimised using available local data.

Table 4 shows typical values that are applicable to biomass, which is converted to various energy carriers through densification.

Table 4: Generic performance data and characteristics for treatment used in the chain modelling

	Sizing		Drying	Densification		Pyrolysis
	Roll crusher	Hammer mill	rotary drum	Pellet press	Piston press (briquettes)	
Base scale (tonne/h)	10	50	100	6	5	1 MW_{LHV} input
Base capital	0.14	0.37	5	0.12	0.425	0.1

	Sizing		Drying	Densification		Pyrolysis
	Roll crusher	Hammer mill	rotary drum	Pellet press	Piston press (briquettes)	
(M€)						
Scale factor R	0.7	0.7	0.7	0.61	1	0.62
Load factor (%)	90	90	100	90	90	90
O&M (%	20	20	3	197	37	4
Lifetime	15	15	15	10	10	25
Energy-e (kWh/tonne)	8.22	3.5	20	28	34	37.2
Energy-h			2.5 GJ/twe			
Form	Chips	Chips	Chips	Pellets	Briquettes	Pyro oil
Average particle size (mm)	3000 - 30	30-Oct	30	10	40 - 125	N/A
Bulk density (kg/m^3 bulk)	240	240		650	600	1175
All matter loss/action (%)	2	2	1			
Moisture content			7%	8%	10%	*f* (feed)

(Hamelinck, Suurs and Faaij 2005)

The following information is from a study that was undertaken in Japan on the feasibility of using logging residues to be utilised as bioenergy (Yoshioka, et al. 2006). The study focused on the cost, energy and carbon emissions generated during the harvesting and transportation of the biomass to the conversion plant. Hauling distances ranged from 100 m to 1 000 m, whereas transport distances ranged between 20 km and 80 km. According to where chipping took place, three types of systems were identified:

- In-forest (chipping at a landing at the forest site).
- Landing (chipping at a landing alongside a forest road).
- Plant (chipping at the energy-conversion plant) (Yoshioka, et al. 2006).

For the in-forest and landing systems, mobile chippers were used, and for the plant system, a large-scale chipper was used (Yoshioka, et al. 2006).

The results showed that for this specific study, the in-forest system was the most cost- effective, and the plant system was the least cost-effective. Therefore, introducing the chipper into the process earlier could lead to lower costs. With regard to the fuel consumption for each system, the landing and in-forest systems were almost on a par, with the plant system's fuel consumption being the highest (Yoshioka, et al. 2006). Refer to Table 5.

Table 5: The cost and fuel consumption in each of the three systems

Operating site	Process	Cost (US$/Mg)			Fuel consumption (dm^3/Mg)		
		'In-forest' type	'Landing' type	'Plant' type	'In-forest' type	'Landing' type	'Plant' type
Landing in forest	Comminuting	95.1			14.6		
Strip road	Hauling	44.1 - 90.2	161 - 329	161 - 329	1.08 - 3.28	3.92 - 12.0	3.92 - 12.1
Landing alongside a forest road	Comminuting		66.5			10.2	
Forest road and public road	Transporting	112 - 222	112 - 222	409 - 809	5.78 - 23.1	5.78 - 23.2	21.1 - 84.3
Energy-conversion plant	Comminuting			22.7 - 45.5			3.29 - 6.57
Total		251 - 407	339 - 618	592 - 1185	21.5 - 41.0	19.9 - 45.3	28.3 - 103
Cost per MWh of bioenergy (US$/MWh)a		46.2 - 75.0	62.5 - 114	109 - 218			
[Preliminary							

Operating site	Process	Cost (US$/Mg)			Fuel consumption (dm^3/Mg)		
		'In-forest' type	'Landing' type	'Plant' type	'In-forest' type	'Landing' type	'Plant' type
sensitivity analysis]b							
Transporting cost by a pulp chip trailer (US$/Mg)		10.4 - 41.7	10.4 - 41.7	38.1 - 152			
Total cost							
Per Mg of dry biomass (US$/Mg)		150 - 227	238 - 437	222 - 527			
Per MWh of bioenergy (US$/MWh)		27.6 - 41.8	43.8 - 80.5	40.9 - 97.1			

(Yoshioka, et al. 2006)

When comparing this study`s results with studies done in the UK, Sweden and Finland, it emerged that the costs of harvesting systems in Japan were substantially higher – see Figure 6 and Figure 7 for details. Reasons for this could be low machine power, small load capacities, and machines not being fully adapted for this type of work, as well as inadequate experience in the biomass field. Therefore, improvement of machinery and field-related experience are crucial to overcoming high costs (Yoshioka, et al. 2006).

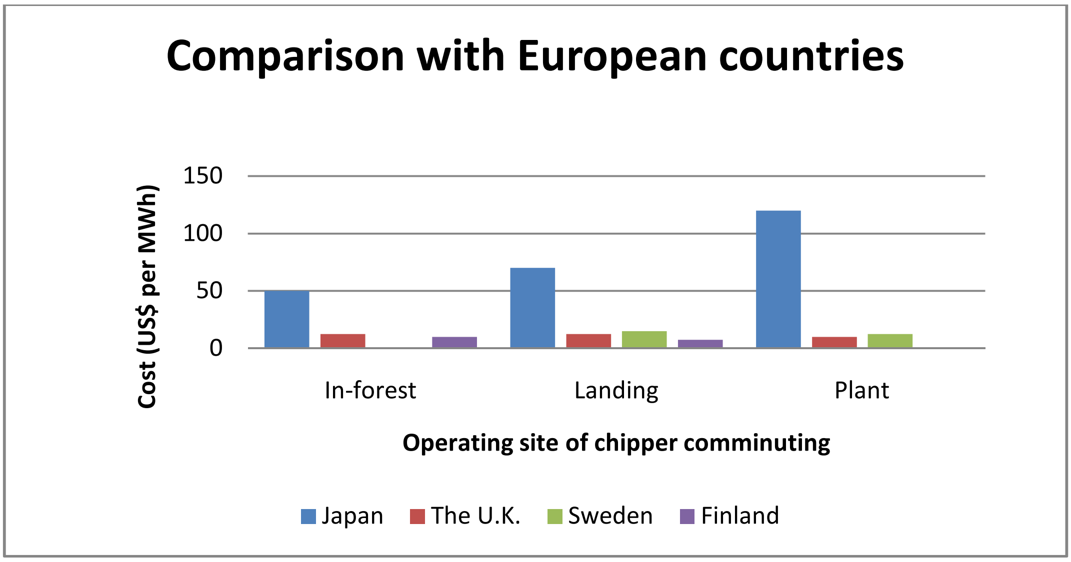


Figure 6: Cost Comparison with European countries (Yoshioka, et al. 2006)

With regard to carbon emissions, it was concluded that Japan was on the same level as Finland and that it is possible to reduce domestic carbon emissions when logging residues are used as an alternative energy source. Unfortunately, the benefit of utilising bioenergy will only be recognised if these initiatives are supported by the government of the country in question, e.g., taxing carbon emissions from fossil fuels (Yoshioka, et al. 2006).

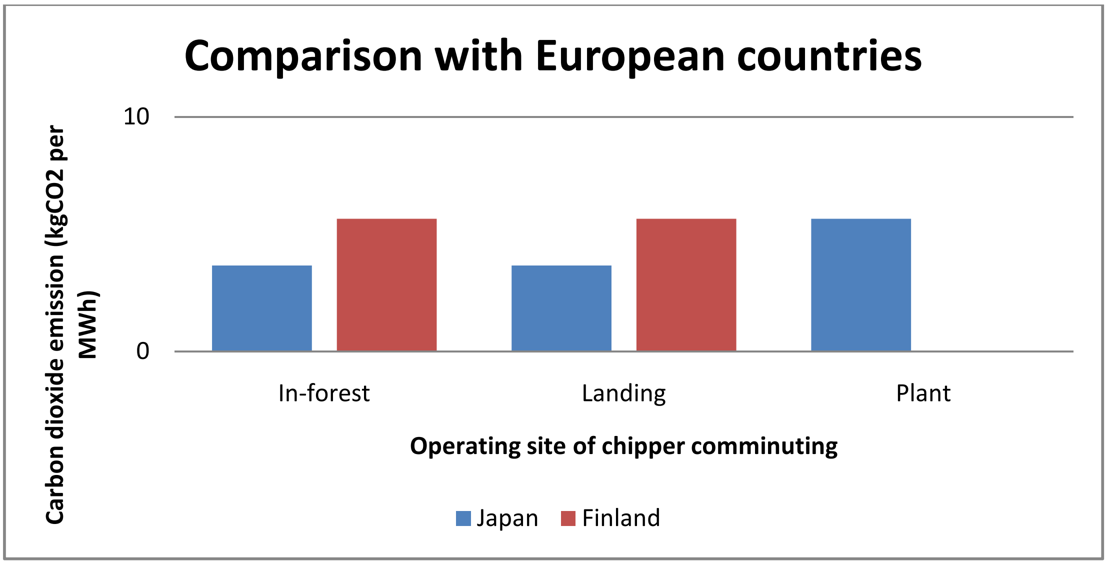


Figure 7: Carbon Comparison with European countries (Yoshioka, et al. 2006).

Drying of the feedstock can be done either by storing the wood at stands in the plantation, but the wood will dry only to a certain moisture content, and then it will still be necessary to dry it further for use at the plant. There are several reasons for drying biomass before it can be converted.

1. Improved efficiency of combustion or gasification.
2. Dry feedstock is required to increase the heating value of the biogas, making it suitable for the gas turbine (for biomass-integrated gasification/combined cycle application).
3. Reduced possibility of decomposition, matter loss, and fire and health hazards.
4. Reduced weight of the biomass, which can reduce the cost associated with the transportation phase.

Drying does not seriously affect the volume of the biomass (Hamelinck, Suurs and Faaij 2005). This is an important consideration when transporting biomass.

Harvesting data for the CWDM project was given by the forestry department at the University of Stellenbosch.

2.5 Biomass transport

Transportation increases emissions, which can decrease the benefits associated with bioenergy, and net energy input (Forsberg 2000). That is why the transportation relating to a project must be studied in detail to ensure that it does not negatively affect the overall project.

In contrast with freight haulers, fleets of trucks will be needed to transport biomass, due to regular loading and unloading as well as the time spent on rural roads, which will affect the cost structure as well as the time frame of these operations (Rogers and Brammer 2009).

The following table, Table 6, taken from the UK Department for Transport`s Freight Best Practise Guide, includes costs for different types of trucks (Rogers and Brammer 2009). For South Africa, the Vehicle Cost Schedule (VCS) (Road Freight Association 2009) is applicable and will be benchmarked to the data.

Table 6: Lifetime costs for different types of trucks

Truck size	26-ton rigid	32-ton rigid	26-ton rigid and trailer	32-ton rigid and trailer	33-ton articulated	44-ton articulated
Payload (ton)	15.5	20			18.5	26
Life (years)	6	7	6	7	7	6
Distance (km/year)	80 500	64 400	80 500	64 400	96 600	112 700
Capital cost (€)	59 000	77 000	78 300	96 400	84 800	104 200
Annuity (€/year)	13 500	15 800	18 000	19 800	17 400	23 900
R&M (€/year)	4 790	9 820	4 790	9 820	6 560	1 033
Insurance (€/year)	2 130	2 340	2 130	2 340	2 700	3 410
Driver (€/year)	24 300	23 100	24 300	23 100	22 800	24 700
Road tax (€/year)	690	1 270	690	1 270	1 270	1 270
Fixed cost (€/year)	45 400	52 300	49 900	56 300	50 700	63 600
Fixed cost (€/day)	197	228	217	245	220	276
Fuel (€/year)	17 300	17 300	17 300	17 300	23 100	33 300
Tyres (€/year)	1 550	2 520	1 550	2 520	2 410	3 140
Variable cost (€/year)	18 900	19 900	18 900	19 900	25 500	36 400

Truck size	26-ton rigid	32-ton rigid	26-ton rigid and trailer	32-ton rigid and trailer	33-ton articulated	44-ton articulated
(€/km)	0.24	0.31	0.24	0.31	0.27	0.32
(€/km/ton)	0.015	0.016	0.013	0.017	0.013	0.012

(Rogers and Brammer 2009)

Some studies have suggested that converting biomass to bio-oil close to the plantation and then transporting the bio-oil to the generation plant may lead to a reduction in transport costs. This is because pyrolysis dries the biomass to produce bio-oil, solid char and gasses, which lead to a lower mass of bio-oil being transported. For low-ash woody biomass, the conversion to bio-oil can lead to the mass being only 75 % of the original biomass (Rogers and Brammer 2009). Other sources suggest 66 % of dry wood mass and 40 % of wet wood mass (De Waal 2009).

Advantages of a centralised plant:

- The combined handling of the biomass and other plant operations at one location will lead to economies of scale.
- Labour optimisation.
- A single location will reduce the handling of biomass and bio-oil.
- Reduced bio-oil buffer storage needed.
- Savings on overall plant development costs.
- Compared to one centralised plant, multiple sites will increase administration fees (Rogers and Brammer 2009).

In general, truck transportation will be used for shorter distances, typically less than 100 km, where there are a number of sites, or in the absence of rail and ship infrastructure.

Costs associated with truck transportation include:

- Total driving costs.

- Loading/unloading costs.
- Number of trips.
- Trip distances (Hamelinck, Suurs and Faaij 2005).

When looking at road haulage operations, there are four main features to take into account:

- High annual distance travelled by each truck.
- Time spent on loading and unloading.
- Load management – lessening the handling time and optimal utilisation of trucks.
- Proportion of time spent on major and minor roads (Rogers and Brammer 2009).

These factors must be considered when modelling the transportation.

Driving costs include flat kilometre costs and fuel costs. These, especially fuel costs, will usually differ from region to region. It is important to remember that the trucks will be dedicated, and therefore they will return empty (Hamelinck, Suurs and Faaij 2005). Refer to Table 7.

Table 7: Selection data for means of transport, for both solid biomass and liquid energy carriers

	Truck (solids - liquids)	Train (solids - liquids)	Small ship	
			Small	Large
Cargo capacity (tonne)	40 - 25	1000	4000	63,000
Cargo capacity (m^3)	130 - 33	2500	6700	105,000
Investment (M€)			11.4	23.8
O&M			10%	8%
Lifetime			25	25
Charter costs (€/occasion)			4.9	10.1

Charter costs (€/km)	0.85 - 1.24	8450/d+4 - 10560/d+5		
Other charges (€/trip)			4.8	75.6
Speed average (km/h)	65	75	27.8	27.8
Energy-e (kWh/km)		163		
Energy-f (MJ_{HHV}/km)	18.1		647	2517
Load/unload speed (m^3/h)	260 - 500	240 - 500	60	300
Load/unload costs (€/m^3)	0.5	0.23		
Load/unload costs (€/tonne)			7.4	2

(Hamelinck, Suurs and Faaij 2005)

"The carbon dioxide emissions of transportation chains are assumed to be a direct function of the (secondary) energy usage and local efficiency parameters. In this case, the amount of carbon dioxide released in converting the biomass and associated losses are considered to be compensated for by the carbon dioxide caught in the harvested biomass at the beginning of the chain." (Hamelinck, Suurs and Faaij 2005).

Usually, biomass is considered to be used locally. This is due to the large areas of land where biomass is produced, resulting in the development of harvesting systems and transportation networks leading to an increase in the costs associated with producing biomass on large areas of land. Evidently, an optimum distance must be reached between the economy of scale of the conversion plant and the variable costs associated with transporting biomass. Even so, trading with neighbouring regions and countries does take place and trading over long distances is on the rise (Schlamadinger, et al. 2005).

Trucks are used for transporting biomass over short distances (taken to be less than 100 km), especially when multiple sites have to be visited and also where rail and waterway infrastructure does not exist (Van Dam, et al. 2009). From the previous paragraphs, and comparing the local circumstances, it would seem that truck transport would be the most viable option.

Transport equipment performance:

When determining the transport time of a truck, three components are of importance: travel time, load time and unload time.

$$t_{tr} = (t_{haul} + t_{return} + t_{load} + t_{unload})/E_t$$

t_{tr} = total transport time per load (h)

t_{haul} = forwarding time per load (h)

t_{return} = return time per load (h)

t_{load} = loading time per load (h)

t_{unload} = unloading time per load (h)

E_t = efficiency factor for the transport equipment due to obstacles that may increase transport time (<1)

Transporter capacity is expressed in terms of mass to be transported.

$$W_b = k\rho_b V$$

W_b = the wet mass of biomass (Mg)

ρ_b = the wet bulk density of biomass (Mg/m^3)

V = volume of the container (m^3)

k = coefficient k represents less than maximum payload scenarios

The wet bulk density can be estimated from:

$$(1/\rho_b) = ((1 - M_w)/\rho_d) + (1/\rho_w)$$

ρ_b = bulk density of biomass at moisture content of M_w

ρ_d = dry bulk density (kg/m^3) of biomass

ρ_w = bulk density of water (1000 kg/m^3)

M_w = decimal fraction mass basis

The effective transport rate is the ratio of transport capacity and the total transport time.

$$W_t = W_b/t_{tr}$$

W_t = rate of mass transport (wet Mg/h)

W_b has a maximum value based on the legal weight limit of the road. In other words, if W_b exceeds the legal limits then V or k has to be reduced (Sokhansanj, Kumar and Turhollow 2006).

Unprocessed biomass has a low-mass density, which will lead to the size of a load being restricted by its volume and not by its mass. Therefore, the economies of scale of transporting low mass-density products will require that the load be optimised in one way or another, either by making sure the load is compacted or the size of the load space is increased within legal dimensions. The economy of scale applicable to chipping at the plant or a central location versus smaller chippers at the plantation favours a central fixed location (Ranta and Rinne 2006).

Chipping at a central point is more cost-effective than chipping at the plantation. However, the increased handling and transportation associated with a central point will negatively affect the transport cost, especially over a short distance. At present, the value of forest biomass is relatively low, which makes the profitability of transporting biomass a critical issue (Johansson, et al. 2006). In a study done by Bjorheden and Eriksson it was concluded, “optimising forest fuel supply essentially means minimising transport costs” (Björheden and Eriksson 1989).

Terminals or central chipping points are used specifically to increase the quality of forest fuel and ensure sufficient amounts are delivered to the plant on time. Chipping is an essential part of preprocessing, as the actual conversion process requires biomass chips. Chipping the biomass also improves bulk volume, homogeneity and handling. Unfortunately, chipping negatively affects storage as the chips must be used as quickly as possible to avoid microbial activity, loss of energy and the possibility of self-ignition (Johansson, et al. 2006) (Marrison and Larson 1996).

Drying biomass before transporting it does not significantly decrease transport costs, as volume is still the limiting factor. But it does reduce fuel consumption and emissions, as well as damage caused to roads and bridges (Johansson, et al. 2006).

When choosing a suitable truck, the criteria to be considered are its application, the specific country`s legislation and economics. The most important factor when considering a truck’s role will be its power requirements. Especially in forestry applications where a lot of time is spent transporting heavy loads across gravel and dirt roads where the terrain is often mountainous, the truck will require much higher power and torque than, for instance, long-distance transporting. The rule of thumb when determining the minimum power requirements for trucks for forestry applications is the gross combined mass (GCM) of the vehicle, divided by 100 to arrive at the required horsepower (hp). This number is then divided by 1.346 hp/kW to attain the required kilowatts (kW) of the truck (Krieg and Brink 2000).

Not only is the power requirement of the truck important, but several other factors are also involved. They are the following:

- Volumes harvested annually.
- Terrain conditions.
- Empty running requirements.
- Road conditions.
- Type of timber products and their state of conversion.
- Number of supply and demand points (Krieg and Brink 2000).

The critical factor when it comes to transport is payload. Obviously, the truck with the lowest unladen mass and highest payload mass will be the most economic configuration. Rigid-drawbar configurations usually fall into this category (Krieg and Brink 2000).

Manoeuvrability of the chosen truck is another factor to consider. From local research, it was realised that semi-drawbar trailers followed closely by rigid-drawbar configurations were the most manoeuvrable. Conversely, interlink configurations were the least manoeuvrable. Interestingly, interlink and rigid-drawbar configurations can be reversed relatively easy, but the semi-drawbar trailer cannot (Krieg and Brink 2000).

2.6 Biomass conversion

There are two approaches possible when converting biomass into fuels: either thermo-chemical processes (mostly used for the production of Fischer-Tropsch diesels and hydrogen) or biochemical processes (mostly used for producing ethanol).

Concerning economies of scale and optimal plant sizes in biorefineries, tradeoffs between the plant size and the transportation costs will play a major role in deciding the optimum plant size. “Generally, in process industries, the capital cost of equipment increases as a function of throughput, according to the power law equation, with an exponent of around 0.6.” Also, the bigger the plant the greater the distance needed to collect feedstock, the higher the transport cost (Carolan, Joshi and Dale 2007).

The total efficiency of a technology can be raised by removing carbon dioxide during the process, but this will lead to higher investment costs, which in turn will lead to higher production costs. Therefore, the economic impact of such a step at this point in time is uncertain (Hamelinck and Faaij 2006).

Electricity generation is currently considered one of the best uses of energy from biomass. At present, over 9 GWe energy are produced from biomass worldwide. “Pyrolysis is the thermal degradation of biomass in the absence of an oxidizing agent, whereby the volatile components of a solid carbonaceous feedstock are vaporized in primary reactions by heating, leaving a residue consisting of char and ash" (Bridgwater, Toft and Brammer 2002). Pyrolysis produces three products: gas, vapour condensed as a liquid, and a solid char. Two types of pyrolysis processes exist: fast pyrolysis and vacuum pyrolysis (also known as slow pyrolysis). Fast pyrolysis is used to maximise the liquid fraction and is done at higher temperatures, whereas vacuum pyrolysis is done at lower temperatures with a lower liquid fraction. The char can be sold or used to generate heat. The gas component has a medium heating value and is usually used within the pyrolysis process itself. The liquid component is the actual bio-oil that can be used for a variety of applications, including generating electricity (Bridgwater, Toft and Brammer 2002). Slow and fast pyrolysis are two of the conversion processes that are evaluated in the modelling of the process.

Combustion is already a well-known and established method of converting biomass to energy. There are also a number of different ways of generating electricity from the heat produced during conversion, but the most commonly used method is through a steam turbine. "Thermo-chemical gasification is the conversion by partial oxidation at elevated temperatures of a carbonaceous feedstock into a gaseous energy carrier consisting of permanent, non-condensable gasses" (Bridgwater, Toft and Brammer 2002). Different configurations for gasifiers exist, but fluid-bed gasifiers are used mostly, especially when generating more than 1 MWe electricity. Gasification produces a non-condensable gas and an ash residue. The gas is then fed into a gas turbine to generate electricity. System decoupling entails the conversion and generation processes being performed separately in time and space. However, this is only possible in pyrolysis processes where the liquid can be transported and used at a later stage. The main reason for decoupling would be to improve the cost-effectiveness of a system (Bridgwater, Toft and Brammer 2002).

Uses for pyrolysis products:

- High-value chemicals: preservatives, fertilisers, bonding agents, bio-lime, etc.
- Commodities: flavouring agents, char.

- Fuels.
- Electricity.
- Heat.
- By-products and wastes (Honsbein 2007).

The integrated production of higher value chemicals and commodities, as well as fuels and energy will lead to the optimised utilisation of resources, maximised profitability, maximised benefits and minimised wastes (Honsbein 2007).

The data for converting biomass and generating electricity for the CWDM project was compiled by R. de Waal and the Department of Process Engineering at the University of Stellenbosch.

It is important to note that a cost analysis of different biofuel-producing technologies has been done in many different ways; therefore, a high variability will be present in the data and the quality thereof (Hamelinck and Faaij 2006). We therefore need to determine costs from first principles and primary data as far as possible.

2.7 Life-cycle analysis

The main goal of life-cycle assessments is to access all potential impacts on humans and the environment across all sectors – air, water, waste and even health impacts (Von Blottnitz and Curran 2007). This is usually done for all steps of a product or activity`s life-cycle (Forsberg 2000).

Life-cycle analysis comprises a system boundary and a life-cycle inventory that is specific to the project being investigated. The boundary of a life-cycle analysis is defined by the start and end points of the process in relation to space and time (Davis, Anderson-Teixeira and DeLucia 2009).

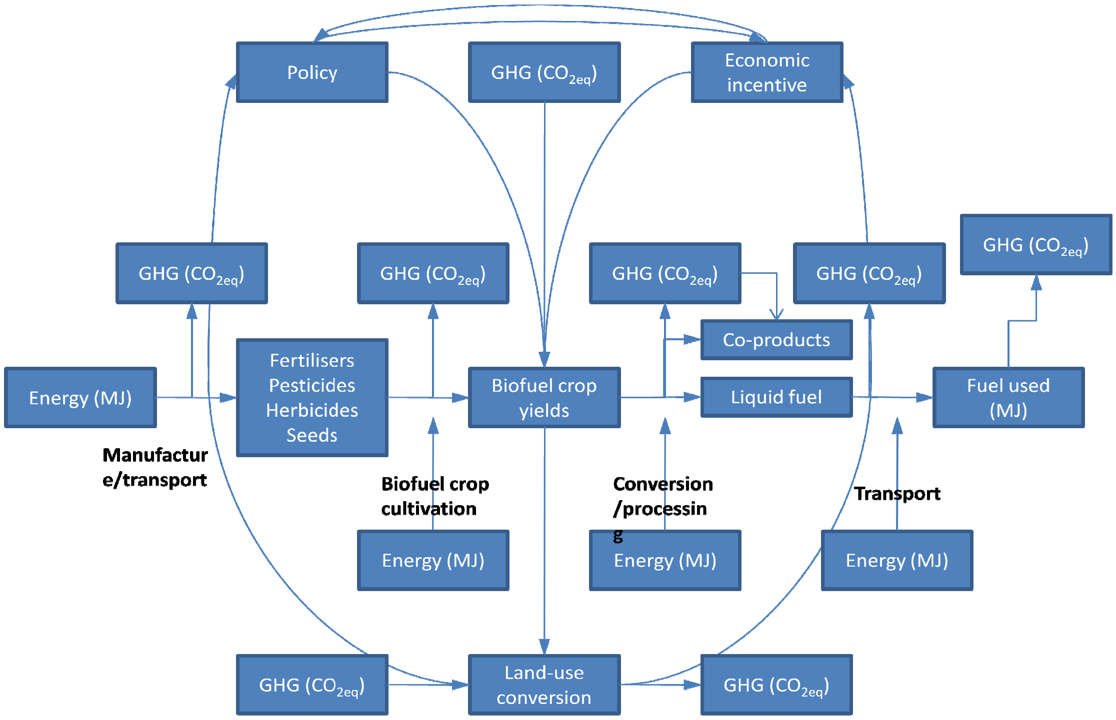


Figure 8: Example of a life-cycle analysis of an energy crop (Davis, Anderson-Teixeira and DeLucia 2009).

In Figure 8 the life-cycle analysis of an energy crop is shown. The size and location of the plantation is the space boundary. The number of rotations considered is the time boundary. Lastly, the use of fertiliser and the transportation of post-harvest materials are the start- and end-point boundaries. All steps of a life-cycle analysis include energy and GHG uptakes and/or energy and GHG emissions (Davis, Anderson-Teixeira and DeLucia 2009).

Life-cycle assessments are concerned with the overall process of a product – also known as the cradle-to-grave approach – where all steps from the initial production to the final usage, as well as all raw materials concerned with these steps are taken into account (Von Blottnitz and Curran 2007). Refer to Figure 9.

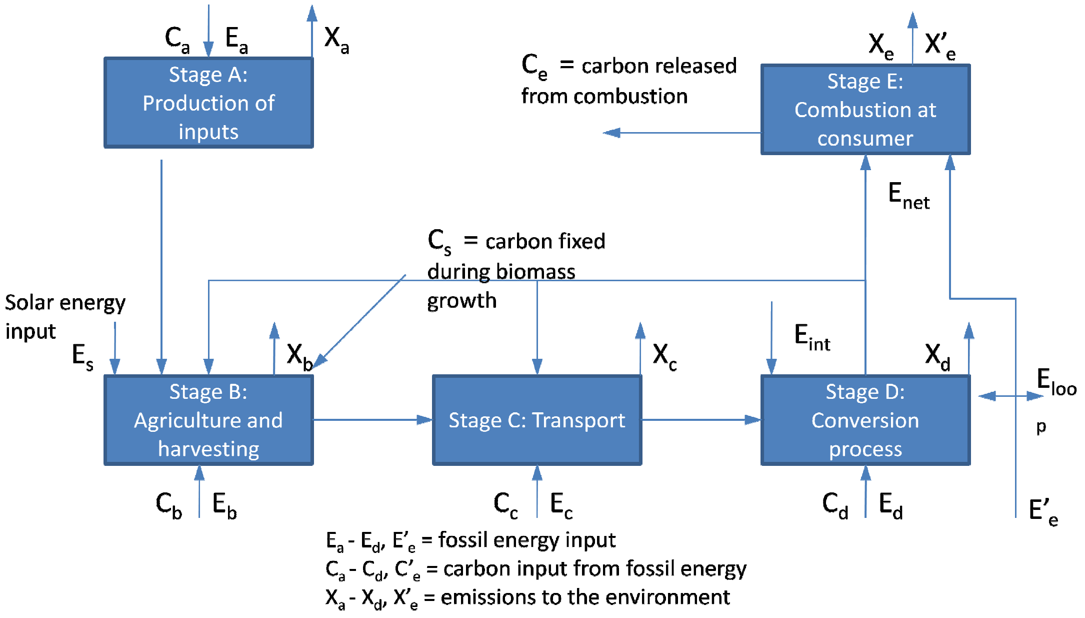


Figure 9: Material flow and environmental interventions across the life-cycle stages in a biofuel system (Von Blottnitz and Curran 2007).

A full life-cycle analysis of this project is the focus of a current PhD study by C.C.C. von Doderer.

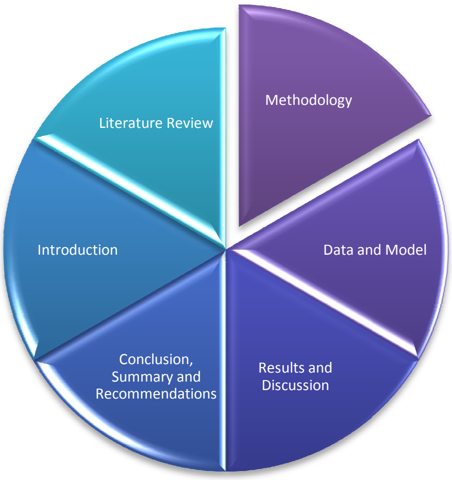
2.8 GIS analysis

Projects involving producing biomass for energy are sensitive to the geographic characteristics surrounding them, which can have a major affect on the plant's profitability. Therefore, selecting the correct locations for plants is of high importance, especially focussing on minimising the transportation costs to these locations (Panichelli and Gnansounou 2008).

Planning the transport network for biomass power plants is crucial to the success of energy projects as biomass is distributed over large areas. "GIS is a powerful tool for integrating data relating to various factors and for performing spatial analyses to evaluate feasibility and location optimisation" (Shi, et al. 2008).

Site selection for locating a power plant is usually done according to two approaches: suitability analysis and optimality analysis. In short, suitability analysis will weigh favouring factors against constraining factors, and through this decide on where best to locate a plant. Optimality analysis is based on the supply and demand of power plants, much as is done in businesses today, and through this, an optimal location is chosen. In practise, using both suitability analysis and optimality analysis to reach a decision is preverable (Shi, et al. 2008).

The above-mentioned article is particularly applicable to the CWDM project from a GIS perspective. It was decided to include the advantages associated with GIS modelling in the CWDM project, due to the complex nature of the project and the large study area. In the following chapter, the GIS application will be discussed in detail. The idea of using both a suitability analysis and optimality analysis will be explored in the subsequent chapter.



3. METHODOLOGY

The methodology consists of acquiring, verifying and preparing the data to be included in the various models. Thereafter, Geographical Information System (GIS) software is used to visualise and analyse the data. Finally, the data is used to determine the lowest total cost through the system, given the various processes, locations and transport modes that might be involved. These areas are explained in more detail below.

3.1 Data acquisition

See phase 1 below.

3.2 GIS analysis

The GIS analyses were done by Dr. A. Van Niekerk (Van Niekerk 2009) for the duration of the project.

3.2.1 Phase 1

The first phase of the GIS analysis was to determine the production potential of the entire Cape Winelands Area based on using 2.5 MW plants. The data required for the first was provided by Mr. C.C.C. von Doderer (Von Doderer 2009) in Shape file format, containing polygons that represent the potential production areas in the form of relatively homogeneous farming areas (RHFAs). Two tables were also included. The first table defines the expected minimum, mean and maximum growth performance of both exotic and indigenous tree species, and the second table defines the availability of land in each of the RHFAs. Refer to Appendix 3 and Appendix 4 for these tables (Van Niekerk 2009).

3.2.1.1 Data preparation

Firstly, the polygons that represent the potential production areas were combined with the expected minimum, mean and maximum growth performance for both exotic and indigenous tree species. These polygons were then converted to raster format at a resolution of 100x100 metres (i.e. 1 ha) (Van Niekerk 2009).

Secondly, the land availability factor table was combined with the polygons. Polygons with a land availability factor of more than 0 % were subsequently converted to raster format. The rasters from the first procedure were then multiplied by the rasters of the second procedure to determine the potential of each raster (Van Niekerk 2009).

On a per-cell basis, the rasters do not represent true performance because available biomass varies spatially. Thus, an assumption was made that availability will be the same for all cells with the same availability factor (Van Niekerk 2009).

Lastly, for the entire study area, the rasters were converted to hexagons using GIS. The radius of the hexagons was chosen to be 1 000 metres. The reason for this coarse resolution is the extraordinarily long computer processing time required for the analysis. Summarising the values of the cells in each hexagon gave the minimum, mean and maximum production values for both exotic and indigenous tree species (Van Niekerk 2009).

3.2.1.2 Analysis

At present, GIS has very limited capabilities when it comes to optimising regions based on production, and although location-allocation modules are available for GIS, they are only useful when a specific location (for instance, a plant) is known. Only then is it possible to allocate resources to such a location based on the location`s capacity (Van Niekerk 2009).

The only software that has more location-allocation functionality than GIS is FlowMap. FlowMap was originally developed to conduct accessibility studies, such as determining the accessibility of government services. With FlowMap`s *combined expansion and relocation modelling* function, it was possible to produce near-optimal site locations, but it was also necessary to specify the number of sites in an area. This was done by dividing the total production in the study area by 33 000 tons, as this is the amount of biomass necessary to supply a 2.5 MW plant. This was found to be the most optimal method to optimise regions (Van Niekerk 2009).

3.2.1.3 Results and discussion

The aforementioned method was first applied to the minimum growth performance of exotic species. The total potential production capacity under this scenario yields 538 540 tons, and a total of 17 possible production regions. Figure 10 illustrates these 17 regions with their possible plant locations, and Table 8 gives the expected volume per region (Van Niekerk 2009).

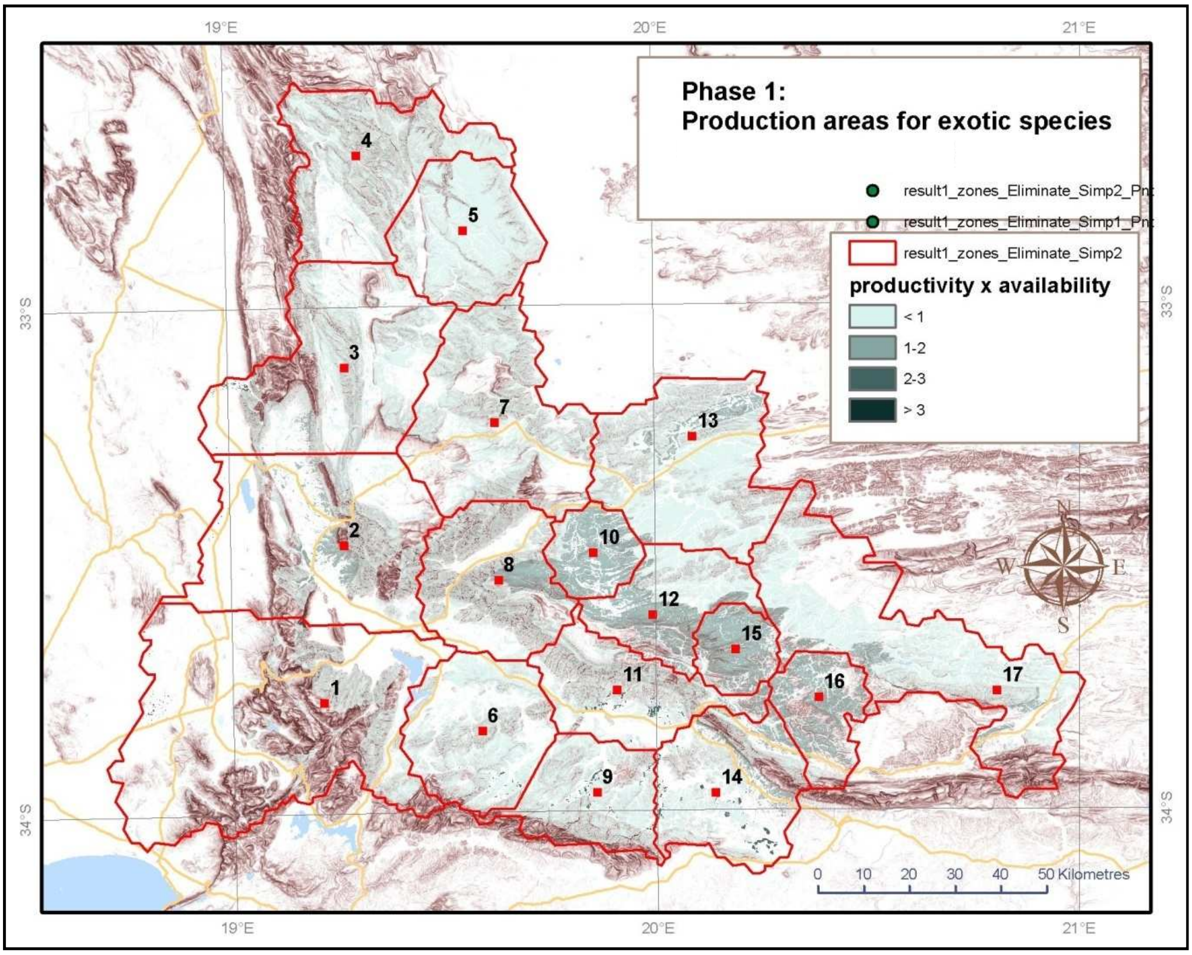


Figure 10: Proposed plant locations and production regions for exotic species in a minimum growth scenario (Van Niekerk 2009)

Table 8: Production volumes per region for exotic species in a minimum growth scenario

REGION	PRODUCTION (tons)	AREA (km^2)
1	19 825	2 689
2	26 623	1 767
3	31 788	1 546
4	30 698	1 099
5	33 082	821
6	33 039	909
7	32 676	1 369
8	33 043	912

9	25 463	660
10	33 164	335
11	31 500	751
12	36 606	522
13	33 529	1 224
14	37 549	828
15	33 282	296
16	38 027	335
17	28 830	1 725

(Van Niekerk 2009)

In the regions given in the above table, the volumes range between 19 824 and 38 027 tons, with most of the regions having a production of about 33 000 tons per year. The region with the lowest production volume is region one with a production of 19 824 tons. From Figure 10, it is clear that the FlowMap algorithm prefers sites located in high-growth performance or availability areas (such as the areas around Robertson) and that the remaining areas (such as those in region 1) are assigned to the closest facility that has not reached full capacity. Therefore, this approach seems to work, as production in the low-production areas will most probably be too expensive to be considered for producing biofuel (Van Niekerk 2009).

This result assumes that all plants will be 2.5 MW in size, but it is possible to combine regions that will serve larger plants. Obviously, the size of such a larger area will be dependent on the maximum transport distance that can be reached without jeopardising the financial feasibility of the plant. However, it is still possible to determine the optimal location of a plant with FlowMap should areas be combined. Table 9 shows the number of possible 2.5 MW and 5 MW plants for both exotic and indigenous species under the minimum-, mean- and maximum-growth scenarios (Van Niekerk 2009).

Table 9: Total production for each scenario and possible number of plants

Species	Scenario	Total Production (Tons)	Number of 2.5 MW Plants	Number of 5 MW Plants
Exotic	Minimum growth	538 540	17	9
	Mean growth	1 121 939	34	18
	Maximum growth	1 705 339	52	27
Indigenous	Minimum growth	663 694	21	11
	Mean growth	1 072 048	33	17
	Maximum growth	1 480 402	45	23

(Van Niekerk 2009)

The phase 1 methodology does not consider accessibility to roads, which will play a major role in the final decision for plant locations. It is logical from Figure 10 that placing a plant near Rawsonville and transporting biomass from Stellenbosch will not be feasible due to the two mountain ranges that need to be traversed. Also, a more realistic boundary between regions 11 and 12 will be the watershed between the Breede River valley and the Koo valley. Fortunately, FlowMap has the capability of specifying 'no-go' areas where movement might be difficult or the slope might be too steep (Van Niekerk 2009).

3.2.1.4 Processing time

The analysis for exotic species under minimum growth performance took two days to complete on a very powerful DELL server, with several manual interventions, which further delayed the analysis. For other more detailed scenarios, it is expected that the processing time will be considerably longer. Therefore, the factors that have to be taken into account must be carefully considered in order to reduce processing time (Van Niekerk 2009).

3.2.2 Phase 2

The next phase of the GIS analysis was to create optimal production areas by using the highest mean growth performance of both exotic and indigenous species per polygon (Van Niekerk 2009).

3.2.2.1 Data preparation

Hexagons were created in the same way as for phase 1, by rasterising the production values using a 100-metre grid spacing to improve computational efficiency. Next, the total production per hexagon was calculated. As proposed in phase one, areas with an average slope of 25 degrees were identified as being obstructive. The resulting hexagons are shown in Figure 11, with the purple cells showing no-go areas (Van Niekerk 2009).

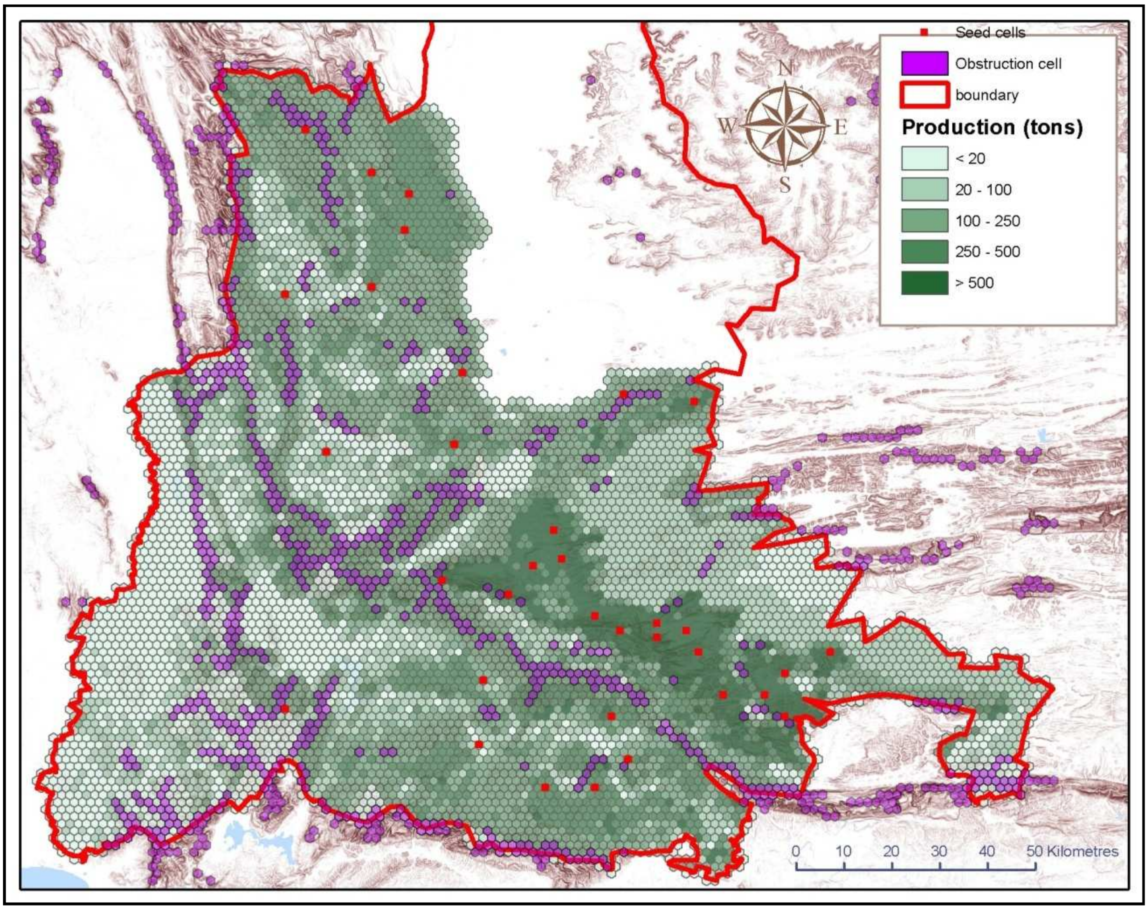


Figure 11: Optimal production per hexagon and no-go areas (Van Niekerk 2009)

3.2.2.2 Analysis

In the next step, the hexagons were grouped into regions with a total production of 33 000 tons. Unfortunately, FlowMap could not do such a grouping without specifying distance constraints. A new algorithm was subsequently developed in ArcView. This algorithm uses a cellular automation approach to group hexagons into regions. Basically, each hexagon is considered a 'seed' cell from which a number of region-growing iterations are done. If the production capacity of the 'seed' cell is less than 33 000 tons, it is grouped with its immediate neighbours. The production capacity of the group is then analysed. This process is repeated until a capacity of 33 000 tons is reached or exceeded. This process excludes all obstructive cells. A graphical representation of this procedure can be seen in Figure 12 (Van Niekerk 2009).

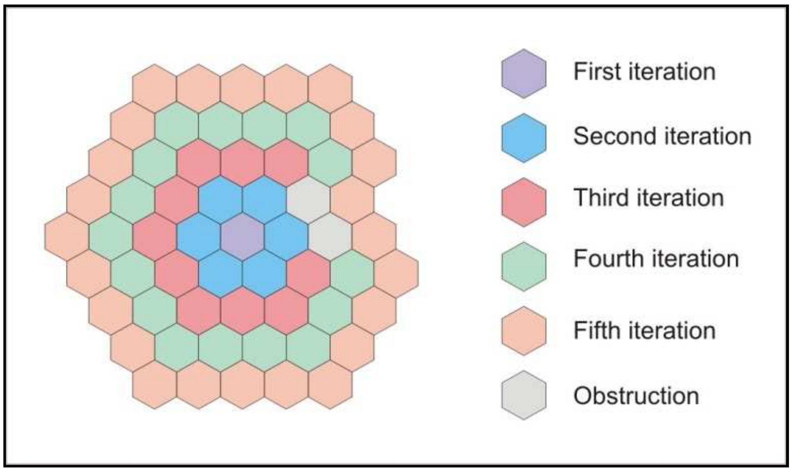


Figure 12: A graphical representation of the ArcView algorithm (Van Niekerk 2009)

The algorithm is repeated for each cell in the region. The grouping that reaches or exceeds 33 000 tons with the least number of iterations is allocated to its seed. This is then repeated for all cells that have not been allocated yet. The advantage of this method is that by identifying the most productive hexagons, optimal regions are also developed. A major disadvantage of this algorithm is the huge amounts of processing time required. To identify the production regions with this algorithm took two weeks of processing on a very powerful server (Van Niekerk 2009).

3.2.2.3 Results and discussion

In Figure 13, it can be seen that 34 regions were identified. Very productive regions are smaller and more circular and have a total production of more than 33 000 tons. The lower the production, the larger the regions, and even then, some of these regions` total production are below 33 000 tons. This could be because there is not enough biomass to yield 33 000 tons or because of the competition between regions for space. To save computation time, a threshold was specified, as can be seen in regions 4 and 34, but for larger areas, this threshold can be increased (Van Niekerk 2009).

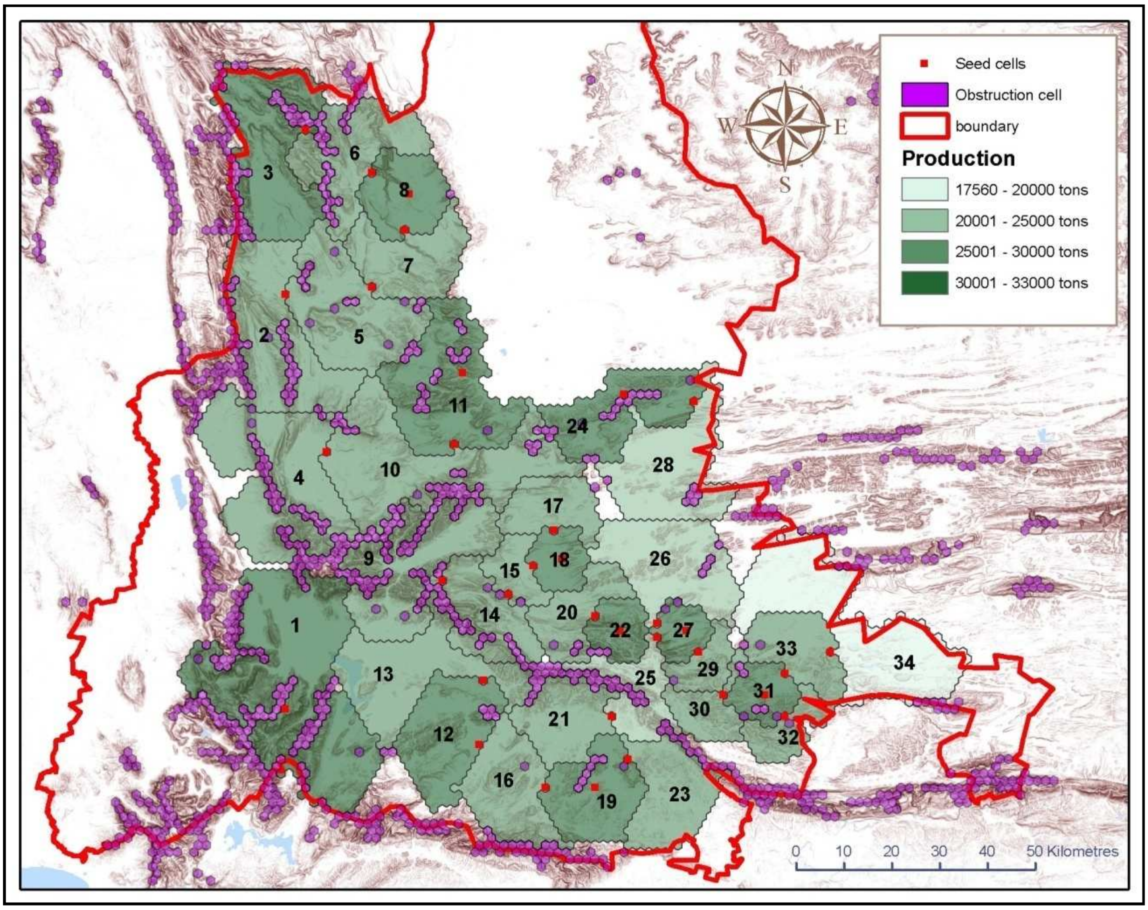


Figure 13: Phase 2 production regions and seed cells (Van Niekerk 2009)

In Figure 13, the red 'seed' cells within each region are theoretically the locations from where transportation costs will be the lowest. It is clear that many of these 'seed' cells do not fall in the centre of the region. This is because high-capacity regions were allocated first. 'Seed' cells of lower-capacity regions positioned themselves in areas with the highest production capability, which in many cases were on the edges of high-capacity regions. Further analyses are needed to determine the optimal location of 'seed' cells within each region by including road networks and other useful infrastructures (Van Niekerk 2009).

3.2.3 Phase 3

During phase 3, accessibility to roads was taken into account. The methodology used in phase 2 was repeated to determine the optimal location of plants based on cost factors given to each type of road. Prof. C.J. Bester, lecturer with the Department of Civil Engineering, University of Stellenbosch, who specialises in transport engineering, was approached regarding these cost factors. To assist the GIS in deciding where to locate plants, it was decided that a factor of 1 would be given to national and major roads, a factor of 1.2 would be given to minor and rural roads, a factor of 1.5 would be given to gravel and farm roads, and a factor of 2 would be given if no roads existed (Bester 2009). These cost factors are based on the road roughness for the different types of roads used – refer to Figure 14 (Southern Africa Bitumen and Tar Association 1989).

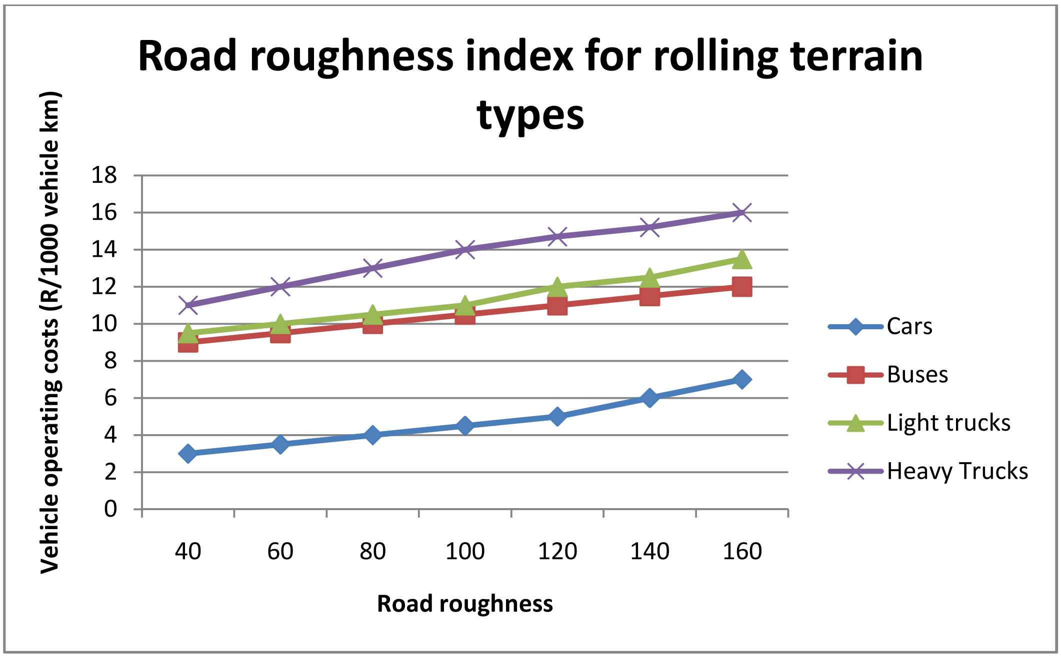


Figure 14: Road roughness index and associated vehicle operating costs (Southern Africa Bitumen and Tar Association 1989)

In Figure 15, the application of cost factors to roads and areas where no roads exist can clearly be seen, as most of the plant locations have moved to within one kilometre from the nearest road. For this analysis, more detail was given on each hexagon for every region. The raw data consisted of 14 203 hexagons, of which 7 690 hexagons cannot be used as they fell in restricted areas or areas with too steep slopes. For a summary of the raw data, refer to Appendix 5 (Van Niekerk 2009).

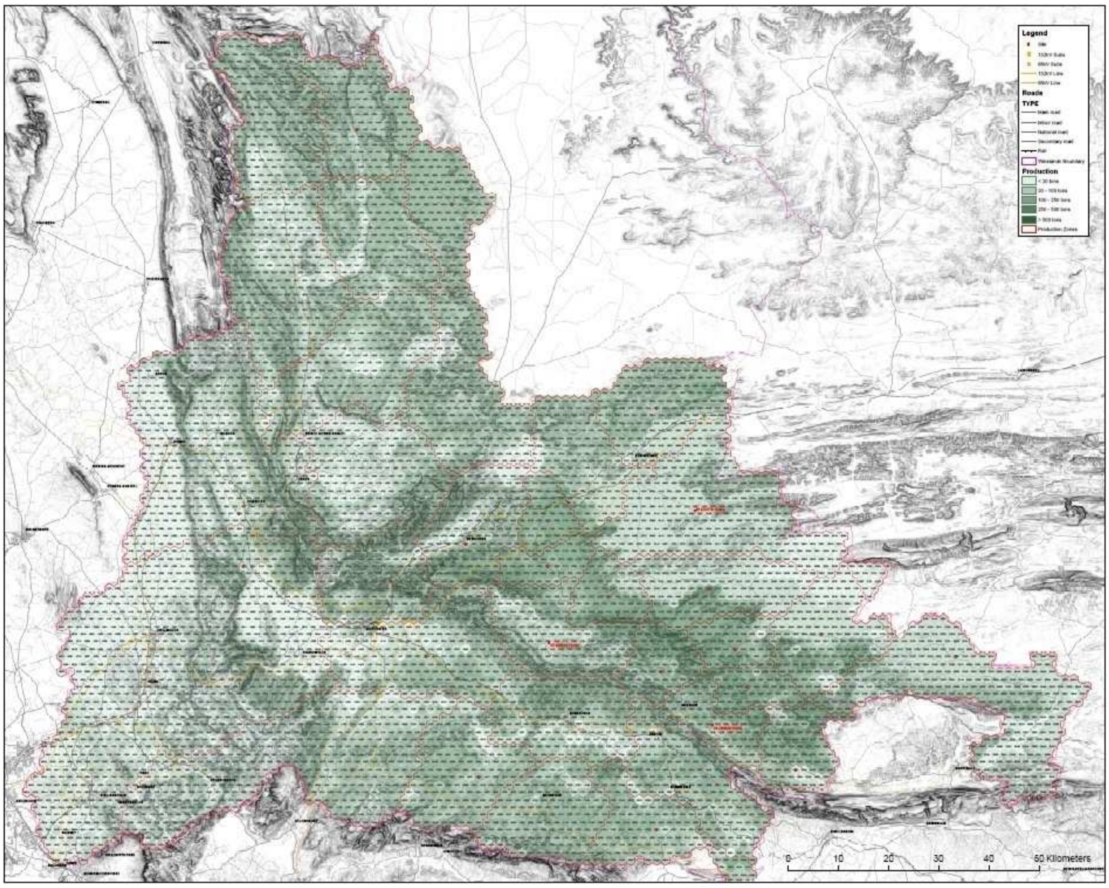


Figure 15: Phase 3 production regions and plant locations (Van Niekerk 2009).

From here on it was decided to focus on choosing the most suitable locations for plants based on the information at hand. It was clear that regions such as Stellenbosch, Rawsonville and the region northeast of Montagu were not optimal regions, and it was also clear that other factors needed to be taken into account. These factors were the demand for electricity of the towns within the Cape Winelands, the location of ESKOM substations in and around towns, and the income from sales of excess heat.

3.3 Demand-point considerations

For the CWDM project, the decision concerning demand points is a crucial task, as it will have a significant effect on the feasibility of the project. It was decided to consider three factors when choosing demand points, these are:

- Electricity demand for each town.
- Substations in and around towns.
- Income from sales of excess heat.

All of these factors are discussed below.

3.3.1 Electricity demand and forecasting

The amount of electricity consumed in the Cape Winelands was obtained from ESKOM. To determine how electricity consumption will increase over the next 25 years, forecasts were made using the data. First, the basic forecasting technique is explained, and then illustrated using one of the demand points, followed by a summarised table of the forecasts of demand for the whole area. For the data used for forecasting and the subsequent forecasts, refer to CD 1 and the included CD index file for further guidelines.

3.3.1.1 Basic forecasting technique

When a time series exhibits both trend and seasonality, the best forecasting technique to use is Winter`s method. Winter`s method is basically an expansion of Holt`s method, by taking into account the effect of seasonality. Both of these methods fall into the category of extrapolation forecasting methods, where future values are predicted based on past values. Extrapolation methods simply assume that there will be a recurrence of past trends in the future, and do not consider what caused past data.

The basics of Winter’s method will be explained graphically, while the detailed mathematical explanation is included in Appendix 3.

Winter uses three components of past data to forecast future values; these are the level of past data, the trend of past data and the seasonal cycle of past data. Referring to the time series below in Figure 16, the various components are identified in the historical data on the left. The solid blue line is a plot of the historical series, and the level at any time is the corresponding value on the dotted blue trend line. The trend is the change in level from one time period to the next, shown as the vertical line of the small triangle at time periods 9 and 10. The seasonal cycle index is simply calculated as the series value on the solid blue line divided by the dotted blue-level value. For example *s* at time 17 would be 20.415/17.578 = 1.1614. The three parts' values are averaged using exponential smoothing, detailed in Appendix 3. From times 18 to 34, the three parts are extended to the future time to generate forecasts (Winston 2004) (Van Wijck n.d.).

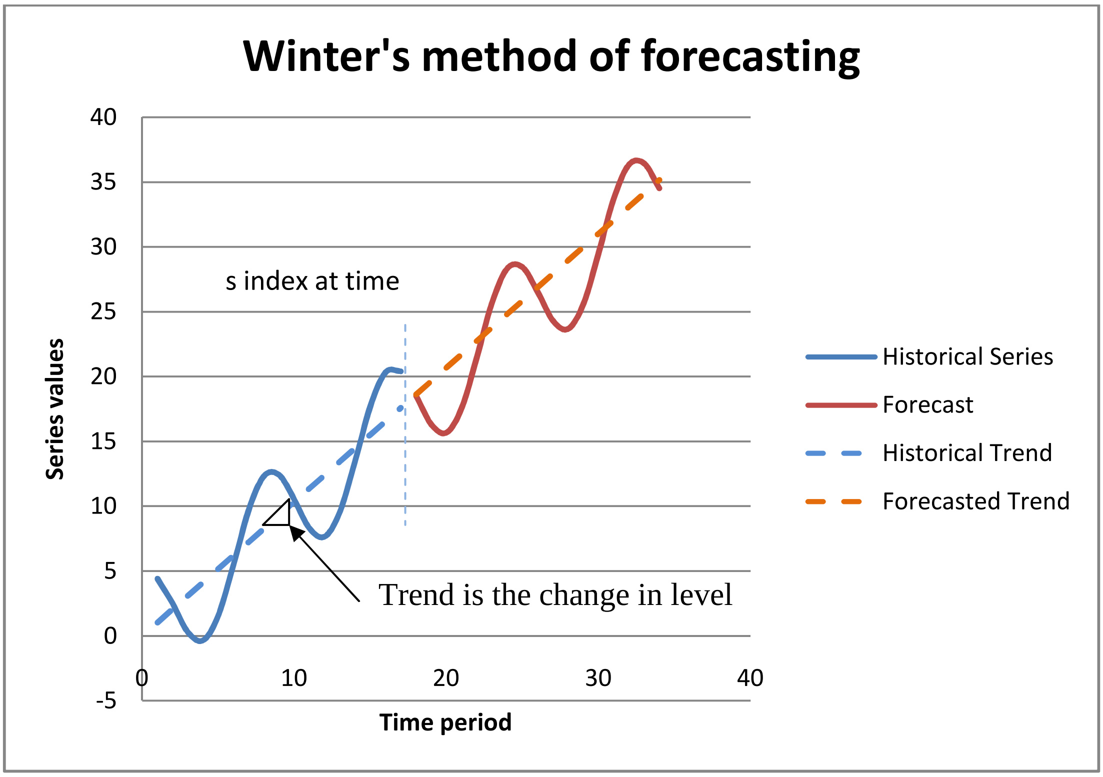


Figure 16: Graphical explanation of the time series components of Winter`s method

3.3.1.2 Electricity demand forecasting for CWDM area

Electricity data was received from ESKOM for several towns in the CWDM area. As an example, Robertson`s total consumption forecasts are shown. The data received was plotted and a trend line was determined. Refer to Figure 17.

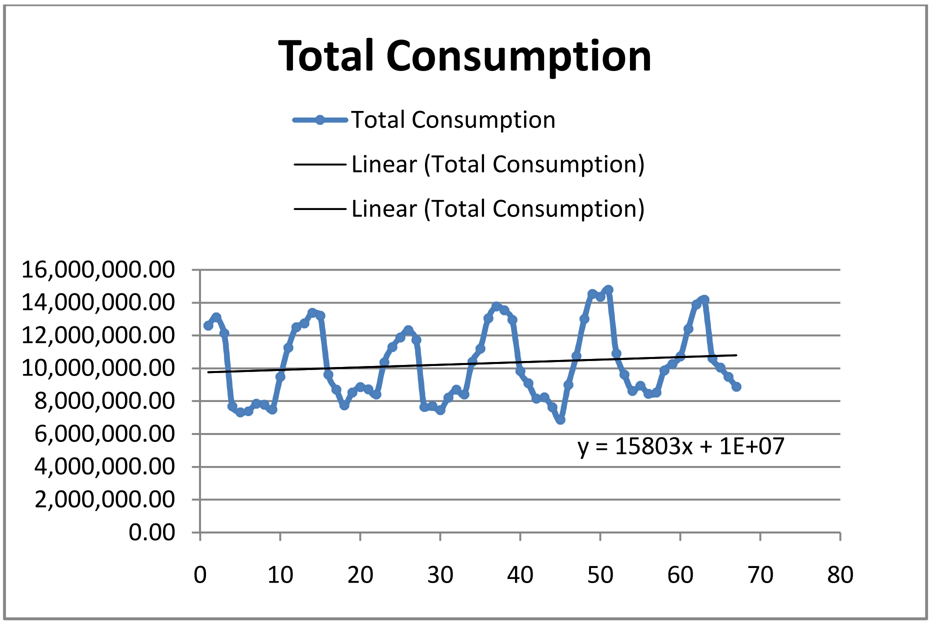


Figure 17: Data with trend line

Forecasts were done on a monthly basis until the end of 2033 (it would be beneficial to update the forecasts with the real values as time progresses, to make the forecasts more accurate). A base level of 10 08 686.50 kWh was determined. From here on the trend of total consumption could be found from the trend line equation to be 15 803 kWh. After this, a forecast was made, and the level, trend and seasonal cycles of the data were updated. Forecasts made from historical values were compared to real values, from which an error was determined. The sum of these errors were subsequently minimized by using the solver function in EXCEL, where the total error is minimized by changing the α, β and γ parameters. The result, which yields the forecasts is illustrated in Figure 18.

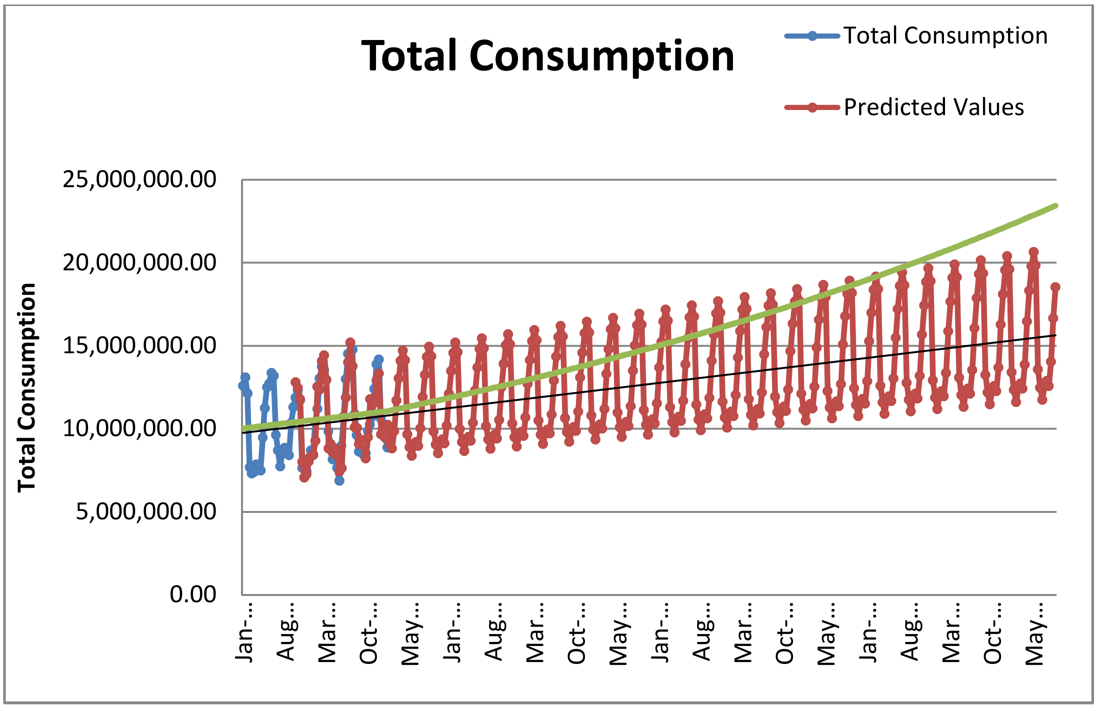


Figure 18: Total consumption forecast for Robertson

The total consumption, actual kVA maximum demand and actual kW maximum demand were forecast for 19 demand points in the CWDM area. These areas and their forecasts are listed in Table 10.

Table 10: Forecast summary for CWDM area

Forecast summary for CWDM area							
Municipality	**Demand point**	**Total consumption**		**Actual kVA maximum demand**		**Actual kW maximum demand**	
		Dec-09	**Dec-33**	**Dec-09**	**Dec-33**	**Dec-09**	**Dec-33**
Stellenbosch	**Cloetesville**	5362935.58	15047542.71	14139.81	40853.62	12588.48	37668.21
	Franschhoek	3528416.97	11826806.69	7783.46	27933.01	6363.70	26364.13
	Stellenbosch	18736037.02	18938940.69	41313.15	41738.65	40566.44	37239.39
Drakenstein	**Dwarsrivier**	24528328.12	49010341.71	50085.87	93095.57	48238.54	91795.00
	Paarl	45263629.17	56533714.01	96046.50	121314.58	87056.48	104031.72
	Wellington	9031377.99	14931995.55	20815.41	34821.34	19468.37	33945.17
Witzenberg	**Bon Chretien**	6270558.74	12709443.95	13391.61	19132.69	15356.17	19556.51
	Ceres	3282230.12	5579328.61	9346.59	12432.24	9250.76	13310.67
	Tulbagh	1127012.61	1986614.53	2669.63	4444.21	2516.37	4063.85

	Wolseley	958601.97	1646035.98	2412.85	3572.93	2159.24	3827.87
Breede Vallei	**De Doorns**	934571.15	1708275.62	2185.78	3896.47	2016.94	4312.96
	Touwsrivier	728651.62	1090009.45	1858.33	2780.69	1818.58	2691.16
	Worcester	24528328.12	49010341.71	50085.87	93095.57	48238.54	91795.00
Breederivier	**Ashton**	4939713.21	8288787.10	9145.53	14342.33	8711.65	13523.97
	Bonnievale	3581285.52	6009746.30	6758.40	11931.45	6091.93	9282.23
	McGregor	666114.04	416871.67	1744.02	1111.96	1673.46	1037.27
	Montagu	3256262.01	4263515.92	6349.58	10545.01	6259.69	10864.58
	Noree	1679422.73	2175276.82	3966.44	7098.34	3560.84	6183.89
	Robertson	13987448.35	19142490.10	25749.38	40309.47	24486.52	38522.45

For the full data and forecasts, refer to CD 1 and the included CD index file for further guidelines.

3.3.2 Substations

ESKOM was approached at an early stage in the project to discuss their potential involvement in the CWDM project. It was also necessary to determine where substations and major gridlines were located, as costs needed to be minimised for all investors in the project. These gridlines and substations were included on the GIS maps, and demand points were chosen based on the locations of the gridlines and substations.

3.3.3 Income from excess heat sales

To increase the profitability of combustion and gasification plants, it is possible to sell the excess heat produced by these processes to external customers. For this to be possible, plants needed to be located near these customers; therefore, plants will be located in industrial areas to optimise heat exchange. Typical heat consumers include canning industries, distilleries, cheese factories and food processing factories. Industry costs for heat production are shown in Figure 19.

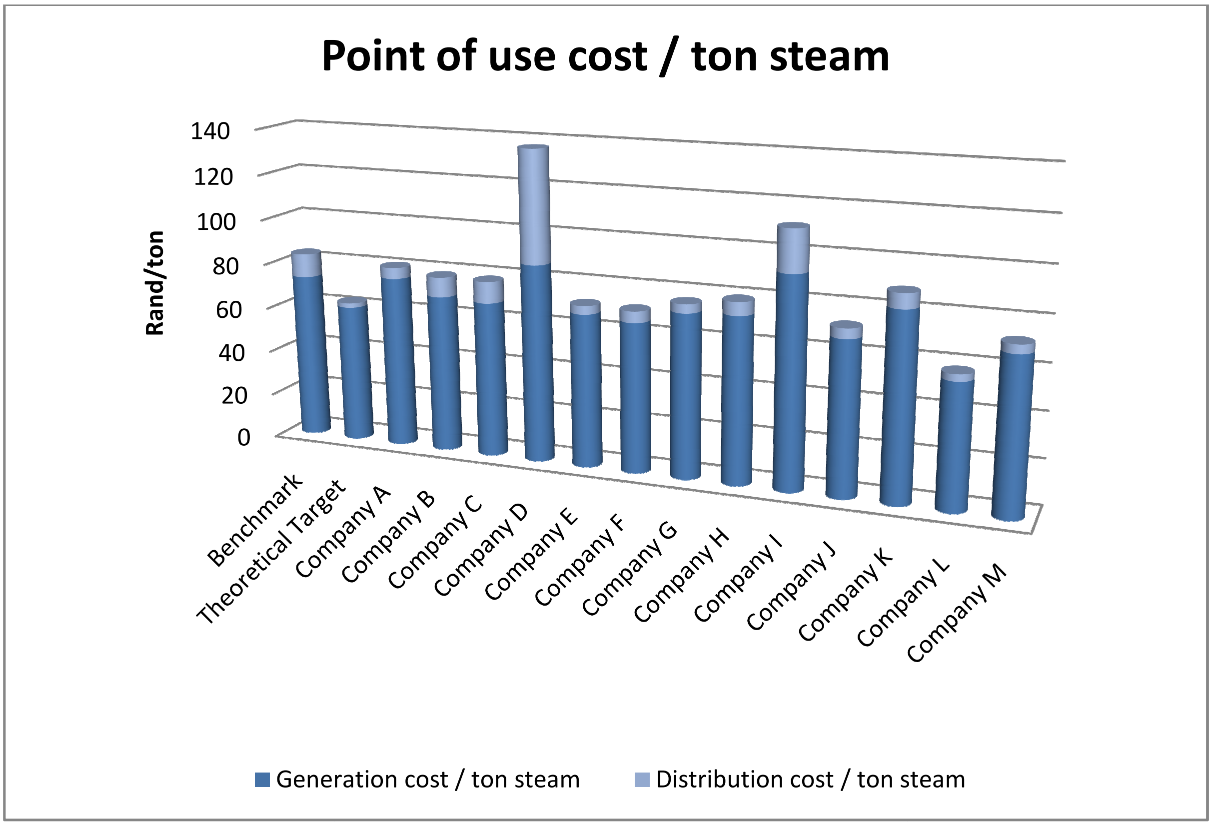


Figure 19: Industry costs for heat production (Anonymous 2004)

Cost values for heat production range from R55.00 to R140.00 per ton. For this project it was decided that heat would be sold for R50.00 per ton, as an incentive for heat consumers to buy heat from the CWDM`s plants. It is possible for a biofuel electricity generating process to produce 50 % kWh heat of the equivalent kWh electricity (Bilgen 2000) ; (Do Espirito Santo 2009). A 2.5 MW plant generates 19 800 000 kWh of electricity per year; therefore, it generates 9 900 000 kWh of excess heat. Assuming that the return water (in a closed system) is heated from 50°C to 100°C, then ΔT = 50 Kelvin, and thus the energy required per kilogram of water for this is 50 x 4.183 kilo-joules per kilogram Kelvin (kJ/kg.K). Additionally, the energy needed for evaporation is 2250 kJ/kg (Gieck and Gieck 1990).

Then per ton kJ = (4.183 x 1000 x 50) + (2250 x 1000)

= 209 150 + 2 250 000

= 2 459 150 kJ, and can be converted to kWh by dividing by 3600

= 683 kWh

Then the ton steam/year = 9 900 000 ÷ 683

= 14 494.876 ton

= R50 x 14 494.876

= R 724 743.80

Percentage of Income = R 724 743.80 ÷ (R 1.18 x 19 800 000)

= 3 %

This means that the income from the sale of steam will be approximately equal to 3 % of the income from the sale of electricity.

3.3.4 Identified demand points

From the above three considerations and from the results of the GIS analysis, it was decided to include the demand points listed in Table 11.

Table 11: Demand points

Plant	Town/Area
1	Paarl
2	Franschhoek
3	Wolseley
4	Ceres
5	Rural Koue-bokkeveld
6	Rural Cederberge
7	Worcester

Plant	Town/Area
8	De Doorns
9	Robertson
10	Touwsrivier
11	Ashton
12	Bonnievale
13	Montagu
14	Rural Montagu

All of the above points except for points 5, 6 and 14 are situated in industrial areas where it is possible to sell heat to external customers. Thus, these points will generate an extra 3 % of income compared to the rural points. Also, all of the above points except points 6 and 14 are situated close to substations; therefore, points 6 and 14 will incur a higher cost to transmit electricity, as it might be necessary to build new substations or lay new transmission cables.

3.4 Cost considerations

Costs for the entire life-cycle of the CWDM project will now be discussed with a focus on transport costs. The harvesting costs and the processing costs were received from other participants in the CWDM project and will be only briefly discussed.

3.4.1 Harvesting costs

Three different types of harvesting processes were considered; these are the following:

- Motor-manual harvesting.
- Semi-mechanised harvesting.
- Fully mechanised harvesting.

The most important factor that needs to be taken into account is the slope classes. It is possible to do motor manual harvesting on slopes of between 0 and 35 % whereas semi-mechanised harvesting can only be done on slopes of up to 20 %, and fully mechanised harvesting can be done on slopes of up to 10 %. Refer to Table 12 for the costs associated with each method (Ackerman and von Doderer 2009).

Table 12: Harvesting costs

Harvesting costs				
	Slope class			**Total cost**
Harvesting method	**0-10 %**	**11-20 %**	**21-35 %**	
Motor-manual harvesting	R 71.00		R 80.00	R72.8
Semi-mechanised harvesting	R 74.00		*N/A*	R75.2
Fully mechanised harvesting	R 165.00	*N/A*	*N/A*	R129.2
Slope ratio CWDM area	0.6	0.2	0.2	

(Ackerman and von Doderer 2009)

These costs include the capital needed to establish and maintain the plantations.

3.4.2 Transport costs

For transport costs, the Vehicle Cost Schedule (VCS) of the Road Freight Association (RFA) was used. For the full VCS, refer to CD 1 and the included CD index file for further guidelines. The fuel consumption of the VCS was updated and calculated specific to the trucks chosen for the CWDM project. The chosen trucks with their associated costs can be found on the VCS, concepts 5 through to 11. In the following section, the fuel consumption calculations are shown. After deliberation, concept 11 was chosen for the purpose of the model.

3.4.2.1 Procedure for estimating the fuel consumption of a given vehicle

The general form of calculation for estimating fuel consumption at a constant speed and gradient is (Bester 1981):

$$F = p_1 + \frac{p_2}{V} + p_3 V^2 + p_4 G$$

Where

F = fuel consumption (ml/km)

V = speed (m/s)

G = gradient (m/m)

p_1 = bAM/η

p_2/V = idling fuel consumption (ml/km)

p_3 = 0.5bρ$C_D$$A_F$/η

p_4 = bMg/η

b = fuel conversion factor (ml/kWs)

A = rolling resistance coefficient (N/kg)

M = mass (kg)

η = drive line efficiency

ρ = air density (kg/m^3)

C_D = aerodynamic drag coefficient

A_F = frontal projected area (m^2)

g = gravitational acceleration (m/s^2)

These parameters can be divided into three groups: those associated with air and rolling resistance, those associated with the engine of the specific vehicle and those which are constant and directly measurable (Bester 1981).

The parameters that are directly measurable or can be attained from manufacturers' specifications are the mass, M, and the frontal projected area, A_F. Other known parameters are the gravitational acceleration, g (9.81 m/s^2), drive-line efficiency, η (0.86 for trucks) and the air density, ρ (1.225 kg/m^3 at sea level) (Bester 1981).

It is possible though to calculate the air density at a specific altitude through the use of the following equation:

$$\rho_A = \rho_{SL}(1 - (2.26 \times 10^{-5})E)^{4.255}$$

where

ρ_A = air density at altitude (kg/m^3)

ρ_{SL} = air density at sea level (kg/m^3)

E = elevation (m).

For the purpose of this thesis, it will be assumed that air density value is the same as at sea level. The frontal projected area of trucks ranges between six and ten square metres depending on the load it carries (Bester 1981).

The parameters associated with air and rolling resistance are the aerodynamic drag coefficient, C_D, and the rolling resistance, A. From the literature, the aerodynamic drag coefficient for trucks can assume values from 0.75 to 1.32. For the rolling resistance, a value of 0.56 N/kg is assumed as most trucks these days run on tubeless radial tyres (Bester 1981) .

The parameters associated with the engine of the specific vehicle are the fuel conversion factor, b, and the idling fuel consumption, p_2. From the literature, the fuel conversion factor for trucks can assume values from 0.065 to 0.075 ml/kWs and idling fuel consumption values from 500 to 800 ml (Bester 1981).

3.4.2.2 Calculations for chosen truck concept

The mass and the frontal projected area were measured and found to be M = 17 520 kg for unladen mass (M = 37 987.2, 43 004 and 41 520 kg when laden with chips, logs and bio-oil, respectively) and the frontal projected area was determined from SCANIA specifications, refer to Appendix 7, A_F = 8.545 m^2 (SCANIA 2009). The values for g, η and ρ were 9.81 m/s^2, 0.86 and 1.225 kg/m^3 respectively. The rolling resistance and aerodynamic drag coefficients were taken as the average for trucks.

Thus, A = 0.01 N/kg (Melson 2007) and C_D = 1.0. The fuel conversion factor, b was taken as 0.07 ml/kWs because the truck has a diesel engine. The idling fuel consumption of a Mitsubishi truck of 783 ml/km was used because of its similarity in engine size and fuel type to published values in the VCS.

Therefore:

P_1 = 14.26046512

P_2 = 783

P_3 = 0.426007994

P_4 = 13989.51628

Thus:

$F = 14.26046512 + 783/V + 0.426007994V^2 + 13989.51628G$

The fuel consumptions at different speeds and gradients were calculated. In Table 13 and Figure 20, the fuel consumption for different speeds over a constant gradient is illustrated. It is clear that the fuel consumption is the lowest at 40 km/h.

Table 13: Fuel consumption at different speeds over a constant gradient

Fuel Consumption at different Speeds (Gradient = 0 m/m)							
Parameters	**Symbol**	**Unit**	**Specific value**	**Specific value**	**Specific value**	**Specific value**	**Specific value**
Fuel consumption	F	ml/km	168.35	137.32	179.58	259.87	371.16
Speed	V	m/s	5.56	11.11	16.67	22.22	27.78
Gradient	G	m/m	0	0	0	0	0

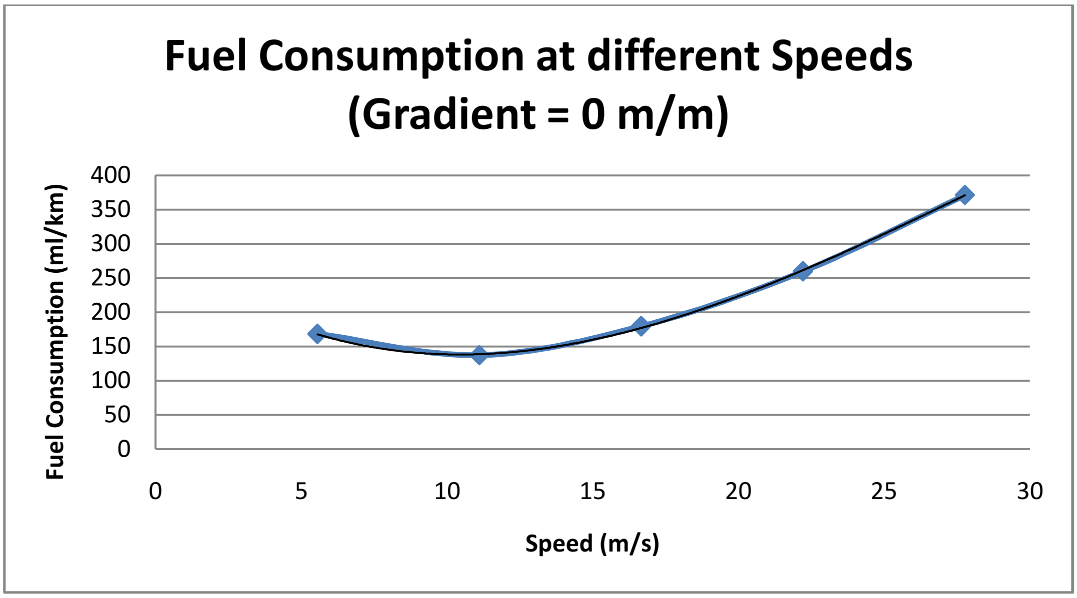


Figure 20: Fuel consumption at different speeds over a constant gradient

In Table 14 and Figure 21, the fuel consumption for different gradients at a constant speed are illustrated. It is clear that the fuel consumption is the lowest for level gradients.

Table 14: Fuel consumption at different gradients over a constant speed

Fuel Consumption at different Gradients (Speed = 16.667 m/s)							
Parameters	**Symbol**	**Unit**	**Specific value**	**Specific value**	**Specific value**	**Specific value**	**Specific value**
Fuel consumption	F	ml/km	179.58	249.52	319.47	389.42	459.37
Speed	V	m/s	16.67	16.67	16.67	16.67	16.67
Gradient	G	m/m	0	0.005	0.01	0.015	0.02

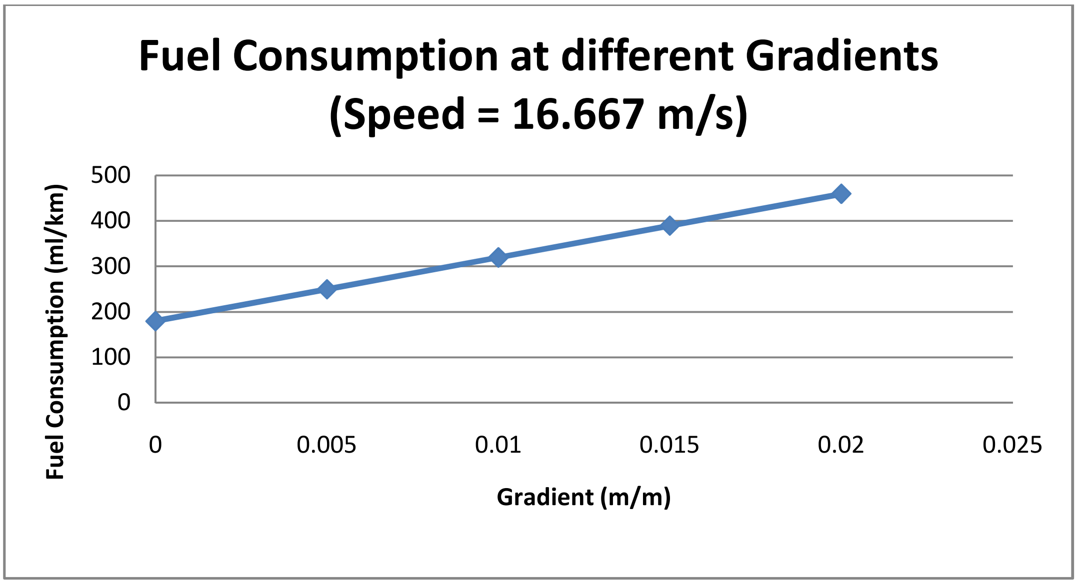


Figure 21: Fuel consumption at different gradients over a constant speed

In Table 15 and Figure 22 the fuel consumption for different gradients and different speeds is illustrated. It is clear that the fuel consumption is the lowest between 30 to 40 km/h over level gradients. These results will differ when travelling downhill.

Table 15: Fuel consumption at different gradients and different speeds

Fuel Consumption at different Gradients and different Speeds										
Fuel Consumption (ml/km)										
	Speed (m/s)									
Gradient (m/m)	**2.78**	**5.56**	**8.33**	**11.11**	**13.89**	**16.67**	**19.44**	**22.22**	**25.00**	**27.78**
0	299.43	168.35	137.80	137.32	152.81	179.58	215.60	259.87	311.84	371.16
0.005	369.38	238.30	207.75	207.27	222.76	249.52	285.54	329.82	381.78	441.11
0.01	439.32	308.24	277.70	277.22	292.71	319.47	355.49	399.76	451.73	511.05
0.015	509.27	378.19	347.65	347.17	362.66	389.42	425.44	469.71	521.68	581.00
0.02	579.22	448.14	417.59	417.11	432.60	459.37	495.39	539.66	591.63	650.95
0.025	649.17	518.09	487.54	487.06	502.55	529.31	565.33	609.61	661.57	720.90
0.03	719.11	588.03	557.49	557.01	572.50	599.26	635.28	679.56	731.52	790.84
0.035	789.06	657.98	627.44	626.96	642.45	669.21	705.23	749.50	801.47	860.79
0.04	859.01	727.93	697.39	696.90	712.39	739.16	775.18	819.45	871.42	930.74
0.045	928.96	797.88	767.33	766.85	782.34	809.10	845.13	889.40	941.36	1000.69
0.05	998.90	867.82	837.28	836.80	852.29	879.05	915.07	959.35	1011.31	1070.63

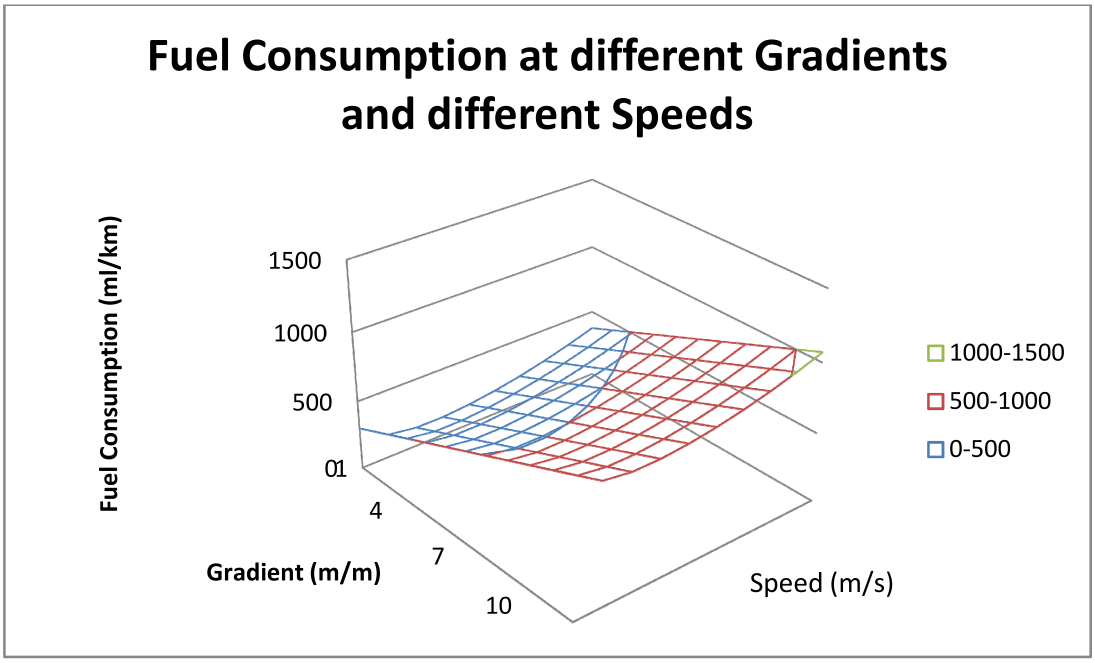


Figure 22: Fuel consumption at different gradients and different speeds

The rest of the transport costs were calculated by taking into account the slope, height and location of the different production areas and are illustrated in the next chapter. For information on other considerations for efficient transport, refer to

3.4.3 Conversion and generation costs

The conversion and generation costs were determined by Mr. Rasmus de Waal and are summarised in Table 16 (De Waal 2009).

Table 16: Conversion and generation costs

Conversion and generation costs					
	2.5 MW	**5 MW**	**7.5 MW**	**10 MW**	**15 MW**
Fast pyrolysis	R 0.5536	R 0.4466	R 0.3962	R 0.3651	R 0.3242
Slow pyrolysis	R 0.8304	R 0.6699	R 0.5943	R 0.5476	R 0.4863
Gasification	R 0.6695	R 0.5181	R 0.4500	R 0.4087	R 0.3564

Conversion and generation costs					
Combustion	R 0.4004	R 0.3600	R 0.3419	R 0.3305	R 0.3142
Mobile fast pyrolysis	R 0.4449	R 0.3413	R 0.2928	R 0.2631	R 0.2241
Mobile slow pyrolysis	R 0.6673	R 0.5119	R 0.4393	R 0.3946	R 0.3361
Decentralised fast pyrolysis	R 0.5813	R 0.4689	R 0.4160	R 0.3833	R 0.3404
Decentralised slow pyrolysis	R 0.8719	R 0.7034	R 0.6240	R 0.5750	R 0.5106
Decentralised gasification	R 0.7030	R 0.5440	R 0.4725	R 0.4291	R 0.3742
Decentralised combustion	R 0.4204	R 0.3780	R 0.3590	R 0.3471	R 0.3299
Gas turbine	R 0.1087	R 0.1053	R 0.1034	R 0.1020	R 0.1001
Decentralised gas turbine	R 0.1142	R 0.1106	R 0.1085	R 0.1071	R 0.1051

To determine the cost per kWh of transmitting electricity by cable, ESKOM was approached. It was assumed that the average length of new cable needed for the two rural plants that are not close to substations would be 19 km. As it costs R 500 000 per km of cable (Smit 2009), the total capital required is calculated to be R9 500 000. The present payment value per year is then calculated to be R1 394 830.28. Dividing by 19 800 000 kWh yields a cost of 7 cents per kWh.

3.5 Building a transportation model

A transportation problem generally requires the following information:

- A number of supply points, m. Goods are shipped *from* the supply points. Supply point i can supply a maximum amount, s_i.
- A number of demand points, n. Goods are shipped *to* the demand points. Demand point j can receive a minimum amount, d_j.
- There is a cost, c_{ij}, incurred for each unit shipped from supply point i to demand point j.

Thus:

x_{ij} = the number of units shipped from supply point i to demand point j.

It is also possible to illustrate this data using a transportation tableau, as follows:

c_{11}	c_{12}	…	c_{1n}	s_1
c_{21}	c_{22}	…	c_{2n}	s_2
⋮	⋮		…	⋮
c_{m1}	c_{m2}	…	c_{mn}	d_m
d_1	d_2	…	d_n	

The value of x_{ij} can be placed in the blank space of the *ij*th cell, if x_{ij} is a basic variable.

From this the general formulation of a transportation problem is:

$$\min \sum_{i=1}^{i=m} \sum_{j=1}^{j=n} c_{ij} x_{ij}$$

Subject to the following constraints:

For $i = 1, 2 . . . m$:

$$\sum_{j=1}^{j=n} x_{ij} \leq s_i$$

For $j = 1, 2 . . . n$:

$$\sum_{i=1}^{i=m} x_{ij} \geq d_j$$

For $i = 1, 2 . . . m$ and $j = 1, 2 . . . n$:

$$x_{ij} \geq 0$$

It is also possible to have maximisation transportation problems. Three types of transportation problems exist. These are:

- A balanced transportation problem
- A total supply exceeds total demand transportation problem

- A total demand exceeds total supply transportation problem

Therefore, a balanced transportation model is where:

$$\sum_{i=1}^{i=m} s_i = \sum_{j=1}^{j=n} d_j$$

And it can be written as follows and subject to the following constraints:

$$\min \sum_{i=1}^{i=m} \sum_{j=1}^{j=n} c_{ij} x_{ij}$$

For *i* = 1, 2. . . *m*:

$$\sum_{j=1}^{j=n} x_{ij} = s_i$$

For *j* = 1, 2. . . *n*:

$$\sum_{i=1}^{i=m} x_{ij} = d_j$$

For *i* = 1, 2. . . *m* and *j* = 1, 2. . . *n*:

$$x_{ij} \geq 0$$

Balanced transportation problems are relatively simple to solve. This is unfortunately not the case for unbalanced problems. Therefore, if the total supply exceeds the total demand, it would be best to create a 'dummy' demand point, with demand being equal to the excess supply. Because the 'dummy' point does not really exist, the cost associated with shipping to this point is equal to zero. The amount shipped to the demand point will then indicate the amount of supply not being used. If the total supply is less than the total demand, the problem has no feasible solution. In this case, some demand will be left unmet, and a penalty cost may be incurred (Winston 2004).

3.5.1 Transhipment Problem

In a transportation problem, goods are only shipped from a supply point to a demand point. But this is not always the case; there can also be a point *through* which goods are shipped. These points are known as transhipment points. Fortunately, finding the optimal solution for a transhipment problem is closely related to finding a solution for a transportation problem. Also, unbalanced transhipment problems can be solved in a similar way to transport problems, with the use of ‘dummy’ points (Winston 2004).

For transhipment problems, supply points can send goods, but not receive. Conversely, demand points can receive goods, but not send, and transhipment points can both receive and send goods (Winston 2004).

3.5.2 Network models

When using a network to illustrate the logic behind a problem, two sets of symbols are used: nodes and arcs. Arcs begin and end with nodes with a direction of motion occurring between these nodes. When a sequence of arcs exists, it is known as a chain. A path will then be the chain where a terminal node of an arc and the initial node of the next arc are identical. This leads to the concept of shortest-path problems, where each arc has a length associated with it and the goal will be to determine the shortest path (Winston 2004).

3.5.3 The shortest-path problem as a transhipment problem

It is possible to model transhipment problems as shortest-path problems. Instead of just associating a length with each arc, a cost is added in the form of a cost per unit per length. If movement between the two nodes is not possible, the cost will become M, i.e. a large positive number and movement from a node to itself will incur a cost of zero (Winston 2004).

3.5.4 Minimum-cost network flow problems

The transportation, transhipment and shortest-path problems are all specialised cases of minimum-cost network flow problems (MCNFP). To define a MCNFP, let:

x_{ij} = number of units of flow sent from node i to node j through arc (i,j)

b_i = net supply (outflow – inflow) at node i

c_{ij} = cost of transporting one unit of flow from node i to node j via arc (i,j)

L_{ij} = lower bound on flow through arc (i,j) (if no lower bound exists, $L_{ij} = 0$)

U_{ij} = upper bound on flow through arc (i,j) (if no upper bound exists, $U_{ij} = 0$)

Then the MCNFP may be written as:

$$\min \sum_{all\ arcs} c_{ij}x_{ij}$$

s.t.

$$\sum_{j} x_{ij} - \sum_{k} x_{ki} = b_i$$

(for each node i in the network) flow balance equation.

$$L_{ij} \leq x_{ij} \leq U_{ij}$$

(for each arc in the network) flow through each arc satisfies the arc capacity restrictions.

It is important to note that MCNFP have to be balanced (Winston 2004). Therefore, the CWDM model is not just one of these types of problems, but a combination of, and a development on all of them – refer to Figure 23, below.

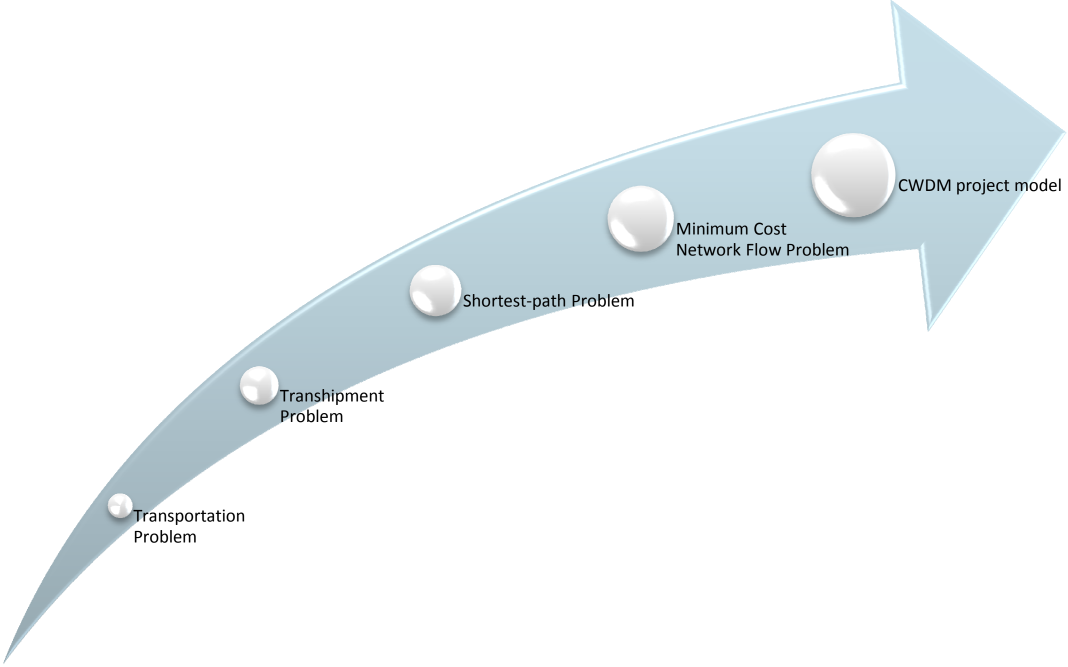
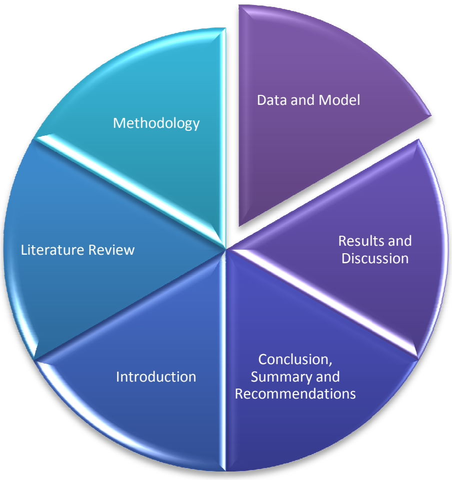


Figure 23: Development of the CWDM project model

3.6 Data verification

The model of the CWDM problem was verified using three techniques. First, a transportation problem was developed and verified through the execution of simple scenarios, which was then calculated by hand to see if similar answers were achieved. Secondly, after the completion of the final model an expert on LINGO programming was consulted. Finally, the model was verified by comparing the results of the sensitivity analysis with the power equation to determine if the same trends are present within the results. Refer to Figure 31.

In the next chapter, the data and model for the CWDM project are discussed.



4. DATA AND MODEL

This chapter serves to explain and demonstrate the CWDM project model. This model is associated with specific data files. When doing runs with the model, both the specific data file and the corresponding LINGO model must be open.

4.1 EXCEL data file

The data file is an EXCEL file and it starts with an introduction sheet showing the variables, nodes and decision matrix of the whole CWDM process. Refer to Table 17 for the variables and their corresponding nodes, and refer to Table 18 for the route decision matrix. Also refer to CD 1 for the files and the included CD index file for further guidelines.

Table 17: Data file introduction table

Process	Description	Variable	Nodes
Supply	Supply point	S	N1
Harvesting methods	Motor-manual system	H_1	N2
	Semi-mechanised system	H_2	N3
	Fully mechanised system	H_3	N4

Process	Description	Variable	Nodes
Chipping process	Roadside	C_R	N5
Conversion processes	Mobile slow pyrolysis	M_{SP}	N6
	Mobile fast pyrolysis	M_{FP}	N7
Transport methods	Logs	T_L	N8 - N2007
	Chips	T_C	N8 - N2007
	Bio-oil	T_B	N8 - N2007
Chipping process	Plant	C_P	N10017
Conversion processes	Combustion	P_C	N10018
	Gasification	P_G	N10019
	Slow pyrolysis	P_{SP}	N10020
	Fast Pyrolysis	P_{FP}	N10021
	Decentralised combustion	D_C	N10022
	Decentralised gasification	D_G	N10023
	Decentralised slow pyrolysis	D_{SP}	N10024
	Decentralised fast pyrolysis	D_{FP}	N10025
Generation processes	Gas turbine	G_T	N10026
	Decentralised gas turbine	D_{GT}	N10027
Electricity transmission	Transmission of electricity	T_E	N10028
Demand	Demand point	D	N10029

Table 18: Route decision matrix for CWDM problem

	To																					
From	**H_1**	**H_2**	**H_3**	**C_R**	**M_{SP}**	**M_{FP}**	**T_L**	**T_C**	**T_B**	**C_P**	**P_C**	**P_G**	**P_{SP}**	**P_{FP}**	**D_C**	**D_G**	**D_{SP}**	**D_{FP}**	**G_T**	**D_{GT}**	**T_E**	**D**
S	√	√	√																			
H_1				√			√															
H_2				√			√															
H_3					√	√		√														
C_R					√	√		√														
M_{SP}									√													
M_{FP}									√													
T_L										√												
T_C											√	√	√	√	√	√	√	√				
T_B																			√	√		
C_P											√	√	√	√	√	√	√	√				
P_C																					√	
P_G																					√	
P_{SP}																			√			
P_{FP}																			√			

	To																					
D_C																					√	
D_G																					√	
D_{SP}																				√		
D_{FP}																				√		
G_T																					√	
D_{GT}																					√	
T_E																						√

As previously described, the model should minimise costs while satisfying the flow constraints. The decision matrix illustrates all the possible paths for the CWDM problem. Over these paths or arcs, a certain volume will be sent by the model (if it chooses to do so) from node to node, and a cost will be incurred over each arc used. The goal for the model is to minimise these costs. The cost parameters of the arcs are all in rands per kWh. The nodes have capacity constraints on them, in kWh, which limit the volume entering and exiting a node.

The route matrix in Table 18 has been converted into a network diagram to graphically illustrate these nodes and arcs. In Figure 24, the circles represent the nodes, also known as the state, and the arrows the arcs, where the direction of material flow is shown. The three transport nodes T_L, T_C and T_L are all actually the same set of points, but they have different arcs entering and leaving them, and to simplify this concept they are shown separately.

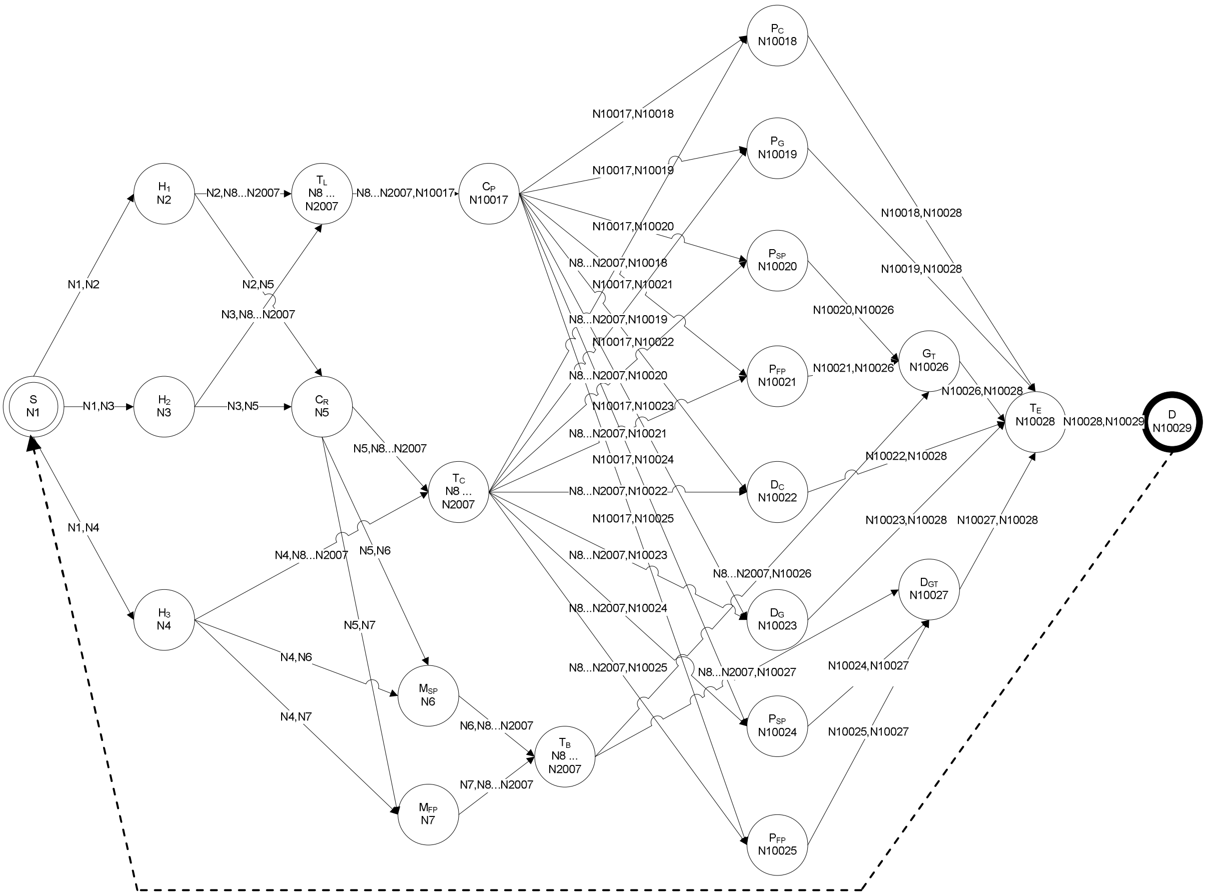


Figure 24: Network diagram of CWDM problem

Refer to Appendix 8 for a larger version of the network diagram in Figure 24. Node N1 is shown as the supply point, which requires an explanation. In a typical transport problem, there would be a factory that manufactures a product, or a mine that supplies some raw material. In the CWDM model the physical reality of trees that supply biomass, which is converted to chips or bio-oil, which in turn is transported and then converted to energy in the form of electricity, is modelled only as a flow of energy. This means the model sees only the energy value of the wood, chips, bio-oil or electricity and the associated costs of the energy transportation or transmission.

So, although the supply node N1 is not there in the physical world, the model requires it as a starting node to create the flow of energy for the demand node or end user. It might look similar to a dummy supply node that is used when the demand outstrips the supply, but it is a very different principle that is at work here.

The actual energy flow starts when the harvesting begins. Energy embodied in the scattered trees on the land, is harvested and densified to piles of logs at the pickup positions, or chipped into containers, ready to be transported or converted. To force the model to transport a minimum kWh-equivalent volume, a minimum dummy volume is specified from the last node N10029 to N1, equal to the capacity of the plant that is being analysed. The dotted line shown in figure 1 represents this. Therefore, the arc N10029 to N1 allows us to create a single constraint that will force the model to generate enough flow to satisfy the plant's capacity.

The next four sheets in EXCEL contain the fuel consumption formulas, as explained in chapter 3, for unladen trucks, trucks laden with chips, trucks laden with logs and trucks laden with bio-oil. The most important consideration here is the payload that each type of material can reach. For the chosen truck, a six-axle articulated vehicle, the total unladen mass is 17 520 kg and the maximum payload is 31 980 kg. The percentage of payload logs can reach is 80 % and for chips, this figure is 64 % (Ackerman and von Doderer 2009). For bio-oil this figure was calculated by taking the volume of the tanker as 20 000 litres and the density of bio-oil as 1.2 kg/l (Dynamotive 2009). This yields a mass of 24 000 kg, which corresponds to 75 % of the payload of this specific truck.

The next sheets are the 'import data' sheet and the 'transport cost per supply area' sheet. On the import data sheet, all the costs except for the transport costs are shown. Costs in rands per ton are converted to rands per kWh equivalents by multiplying by 600 kWh/ton, as that is the expected yield in kWh from one ton of wood. The sheet contains the harvesting costs as described in the previous chapter and the chipping costs. There are two chipping costs, one for chipping at the plant and the other for chipping at the roadside at the plantation. There are also the process costs from the previous chapter and the transmission costs. All costs are expressed in R/kWh.

The transport cost page contains the results from the final GIS analysis as well as all calculations needed to determine the transport cost per supply area. The final GIS analysis was done on the 14 chosen demand points by determining the distance of all supply points to a specific demand point, as well as the production per supply area and the height of the supply area above sea level. The biggest difference between this GIS analysis phase and previous phases is that instead of using hexagons, squares of 100 ha were used.

From the GIS data, the total equivalent distance was calculated, yielding a single 'main road distance' that incorporates the effect of less smooth roads. This was done by taking the distance of the midpoint of a square to the nearest road and multiplying it by a factor of 6. This is done to give a cost penalty to the fact that there are no roads there. This distance was then added to the weighted road distance, giving an overall weighted distance that takes into account the quality of the road surface.

Next, the height difference between each supply area and demand area is determined. From this, the gradient of the supply area to the demand point is determined. Although this is not an accurate representation of the reality, it does take into account the general tendency of the slope towards the demand point, as driving uphill or downhill will make a big difference, especially once the truck is fully loaded.

After this the rand-per-kilometre cost of laden and unladen trucks is determined by taking the fuel consumption equation from the previous sheets in the EXCEL file and substituting the calculated gradient into the equation. The fuel consumption is then added to the other associated costs as taken from the VCS, and a transport cost is calculated based on whether the truck is driving uphill laden, downhill laden, uphill unladen or downhill unladen. Then the cost per roundtrip from the demand point to the supply area and back is determined. This takes into account that the trucks will be driving empty to the plantations and full to the plants.

From the ‘production per supply’ area, the number of trips needed to retrieve all biomass from a point is determined. Some areas have a very low yield, and because of this, it was decided that only areas that can supply a quarter of a truckload or more would be considered, hence 6 tons. A penalty of R 100 has also been added to ‘less than a truckload’ areas, as the loading and unloading as well as the drive time will be influenced negatively compared with full trucks. Also, for the bio-oil option, the tons produced were multiplied by 39.6 % to convert it to the actual mass of the bio-oil itself.

After this, the number of roundtrips per area and the total cost per roundtrip per area is multiplied, and then divided by the potential kWh per supply area. This is the transport cost used in the model in R/kWh. The transport cost is the highest for chips, due to its low payload, and bio-oil is the cheapest, as it has a low relative mass and high kWh. These costs are sorted from the lowest to the highest, and the first 2000 values are used. The reason for this is that the amount of data in the EXCEL file is fairly substantial, causing the file to respond slowly; also this data is read into the LINGO file, and too much data causes the processing time of the model to escalate significantly. It is possible to create larger files, but then the linking between sheets in EXCEL must be kept to a minimum Unfortunately, this will not lessen the run time of LINGO but will actually cause it to run longer due to more variables being used.

The costs from the ‘import data’ page and the ‘transport costs per supply’ area (the first 2000 values) are then imported into the next sheet, namely the model data page. This page consists of a list of nodes with the corresponding capacities that they are allowed to have, as well as a list of links (arcs), with the corresponding cost of sending one unit of kWh through that link. This is the data imported into the LINGO file.

The next two sheets contain the export map and export data from the LINGO model. The map gives a visual representation of which areas were chosen by the model. The data page contains the total cost (FS) of harvesting, chipping, transporting, processing, and generating, through to transmitting electricity. It also contains the volume sent from node to node.

Each chosen demand point has its own data file which works out the optimum distances for that specific demand point, but the other costs such as the harvesting, chipping, converting, generating and transmitting costs will be similar, except where a plant is a rural plant. For rural plants, the centralised combustion and gasification processes will be more expensive, and there will be a higher transmission cost associated with these, as explained in the previous chapter. For these data files, refer to CD 1 and the included CD index file for further guidelines.

4.2 LINGO model

LINGO is a powerful optimisation modelling language. It is specifically used to solve large-scale transport problems, but can be used for a variety of applications. In general, for optimisation problems, one will have an objective function, variables and constraints. The objective function is used to express what exactly is needed to be optimised. The variables are the values that one knows or has control over (LINDO Systems Inc. 1998) (Schrage 1998). For the CWDM problem, the transport costs are a typical example of what variables are. Constraints typically limit the value that a variable can have, for example, the capacities of each node in the CWDM problem are constraints.

An effective way to express the objective function and constraints of a problem is through mathematical equations. Below are the mathematical equations corresponding to the objective function and the constraints of the CWDM problem. For the CWDM problem the cost should be minimised; thus the objective function is as follows:

$$\boldsymbol{Objective = Minimise\left[\sum_{(i,j)=1}^{34029} Cost(i,j) \times Volume(i,j)\right]}$$

This means that for every arc (1 to 34 029) the cost multiplied by the volume must be added and minimised. Next, the constraints of the CWDM problem must be dealt with. First, the model is not allowed to use more than the available capacity of each node. Thus, for every node (1 to 2020):

For i = 1, 2, 3, ... , 2020 do (j refers to nodes connected to i):

$$\sum_{(i,j)=(1,j)}^{Number\ of\ links\ on\ (i,j)} Volume(i,j) \leq Cap(i)$$

Each node can only send what it receives. In this case, the j node *sending* units to the i node is not the same as the j node *receiving* units from the i node.
For i = 1, 2, 3, ... , 2020 do:

$$\sum_{(j,i)=(j,1)}^{Number\ of\ links\ on\ (j,i)} Volume(j,i) = \sum_{(i,j)=(1,j)}^{Number\ of\ links\ on\ (i,j)} Volume(i,j)$$

From the network diagram (Figure 24), it is clear the three transport nodes are actually the same set of points but that these have different arcs going into and leaving them. This is also a constraint that must be added to the model; otherwise, the model will wrongly choose arcs and combine them with other arcs to form routes that do not exist. For example, nodes N2 and N3 enter nodes N8, N9, ... , N2007 and must then leave though node N10017, but without these constraints this will not be the case, as the model sees the three transport nodes as one and will therefore choose to leave via node N10026 which is not possible. Thus, focusing on the three transport nodes yields the following constraints, for the first transport node, T_L:

For j = 8, 9, 10, ... , 2007 do:

$$Volume(2,j) + Volume(3,j) = A(j)$$

For i = 8, 9, 10, ... , 2007 do:

$$Volume(i,2009) = B(i)$$

For i = 8, 9, 10, ... , 2007 do:

$$A(i) = B(i)$$

This makes the incoming arcs equivalent to A and the outgoing arcs equivalent to B, and then A is made equivalent to B, which forces the model to choose one of the transport nodes based on the volume going into the node as well as the volume leaving that same node. For the next transport node T_C:

For j = 8, 9, 10, ... , 2007 do:

$$Volume(4,j) + Volume(5,j) = C(j)$$

For i = 8, 9, 10, ... , 2007 do:

$$Volume(i,2009) + Volume(i,2010) + Volume(i,2011) + Volume(i,2012) + Volume(i,2013) + Volume(i,2014) + Volume(i,2015) + Volume(i,2016) = D(i)$$

For i = 8, 9, 10, ... , 2007 do:

$$C(i) = D(i)$$

For the last transport node, T_B:

For j = 8, 9, 10, ... , 2007 do:

$$Volume(6,j) + Volume(7,j) = G(j)$$

For i = 8, 9, 10, ... , 2007 do:

$$Volume(i, 2017) + Volume(i, 2018) = H(i)$$

For i = 8, 9, 10, ... , 2007 do:

$$G(i) = H(i)$$

As this is a minimisation problem, the model will obviously choose not to send any volume as that would be the cheapest option, so to force the model, the following constraint is added:

$$Volume(1) = Cap(1)$$

Basically, it states that the volume of node N1 is equal to the capacity of node N1, which forces the model to send volume and determine the least cost path.

The LINGO model works according to the above equations. Refer to Figure 25 at the end of the chapter for the model's syntax. The model is divided into five parts. The first part contains the sets; the sets are the variables with their corresponding values that the model can be expecting. If there are any values missing, the model will not run and will give an error message indicating that the number of variables and the number of values are not the same. In the CWDM model, these sets are the nodes from N1, N2, ..., N10029 with their corresponding capacities, and the arcs N10029,N1, N1,N2, ..., N2007,N10027 with their corresponding costs. The volume values are determined by LINGO itself, as that will be directly related to the solution given by the model.

The next part is the data input. In this part, LINGO imports data from EXCEL into the model, but both files need to be open to achieve this. Also, LINGO and EXCEL communicate through ranges. To select a range in EXCEL, simply select the data needed, right-click, choose the *name a range* option and enter the range name. It will be added to EXCEL`s memory, and whenever data is imported from EXCEL to LINGO, LINGO will simply search for the range specified in this section and retrieve the values from that range.

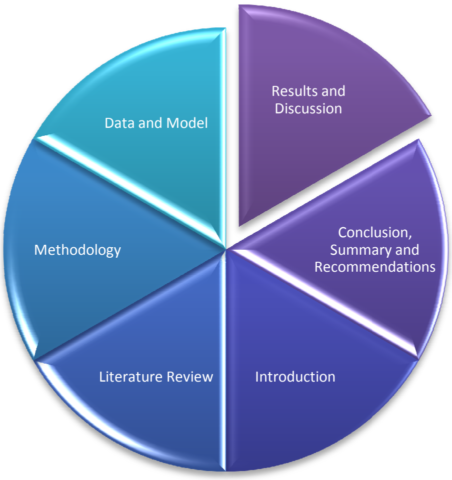
The next two parts are the objective function and the constraints. These are the equations that were explained previously. LINGO functions are printed in blue. For example, the objective function entered into LINGO simply states that it has to minimise FS (the label given to the overall cost for this model). To do this it has to determine the cost multiplied by the volume for all nodes F and then add all the F`s together to calculate FS. This is done for all the constraints as well.

The last part is the data output part where LINGO takes the solution and exports it into EXCEL for further use. After entering the syntax of the model and making sure it is correct, the model can be solved by selecting the *solve* button. For the CWDM model, it took between 4 and 5 minutes to solve, and approximately 2000 iterations.

With the data and model having been explained, the results for the CWDM model will be discussed and compared in the following chapter.

```
MODEL:
SETS:
NODES / N1 , N2 , N3 , ... , N10029 /:F, A, B, C, D, G, H, CAP;
ARCS(NODES,NODES)/ N10029,N1 , N1,N2 , ... , N2007,N10027 /:COST, VOLUME;
ENDSETS

!DATA INPUT;
DATA:
COST,  CAP = @OLE('\LINGO\PLANT.XLSX') ;
ENDDATA

!OBJECTIVE FUNCTION;
[OBJ] MIN = FS;
@FOR(NODES(I)| I #LT# @SIZE(NODES):F(I)=@SUM(ARCS(I,J):(COST(I,J)*VOLUME(I,J))));
FS=@SUM(NODES:(F));

!CONSTRAINTS;
@FOR(NODES(I): [CAPS] @SUM(ARCS(I,J):VOLUME(I,J)) <= CAP(I));
@FOR(NODES(I): [VOLS] @SUM(ARCS(J,I): VOLUME(J,I)) = @SUM(ARCS(I,J):VOLUME(I,J)));

@FOR(ARCS(I,J) | I #GT# 1 #AND# I #LT# 3 #AND# J #GT# 7 #AND# J #LT# 2008: [VOLSA] A(J) = VOLUME(2,J)+VOLUME(3,J));
@FOR(ARCS(I,J) | I #GT# 7 #AND# I #LT# 2008 #AND# J #EQ# 2008 : [VOLSB] B(I) = VOLUME(I,J));
@FOR(NODES(I) | I #GT# 7 #AND# I #LT# 2008 : B(I) = A(I));

@FOR(ARCS(I,J) | I #GT# 3 #AND# I #LT# 5 #AND# J #GT# 7 #AND# J #LT# 2008: [VOLSC] C(J) = VOLUME(4,J)+VOLUME(5,J));
@FOR(ARCS(I,J) | I #GT# 7 #AND# I #LT# 2008 #AND# J #GT# 2008 #AND# J #LT# 2010 : [VOLSD] D(I) = VOLUME(I,2009)+VOLUME(I,2010)+VOLUME(I,2011)+VOLUME(I,2012)+VOLUME(I,2013)+VOLUME(I,2014)+VOLUME(I,2015)+VOLUME(I,2016));
@FOR(NODES(I) | I #GT# 7 #AND# I #LT# 2008 : D(I) = C(I));

@FOR(ARCS(I,J) | I #GT# 5 #AND# I #LT# 7 #AND# J #GT# 7 #AND# J #LT# 2008: [VOLSG] G(J) = VOLUME(6,J)+VOLUME(7,J));
@FOR(ARCS(I,J) | I #GT# 7 #AND# I #LT# 2008 #AND# J #GT# 29 #AND# J #LT# 31 : [VOLSH] H(I) = VOLUME(I,2017)+VOLUME(I,2018));
@FOR(NODES(I) | I #GT# 7 #AND# I #LT# 2008 : H(I) = G(I));

@FOR(ARCS(I,J)| J #EQ# 1 : [FORCE] @SUM(ARCS(I,J):VOLUME(I,J)) = CAP(J));

!DATA OUTPUT;
DATA:
@OLE('\LINGO\PLANT.XLSX') = FS, VOLUME;
ENDDATA
```

Figure 25: LINGO syntax for CWDM problem model



5. RESULTS AND DISCUSSION

The model was run for each of the 14 demand points using a 2.5 MW capacity plant to determine the different costs for each demand point. From this, one of the more productive regions, Robertson, was chosen, and runs were done for 2.5, 5, 7.5, 10 and 15 MW plants at 100% participation. Participation of 100% assumes that all of the farmers with available and suitable land will take part in the project and deliver biomass. As this will not be the case in reality, the model was also run for all five possible plant capacities and at 50% and 20% participation.

5.1 Demand point results with 2.5 MW capacity plants

The model was run for all the chosen demand points with 2.5 MW capacity plants. Refer to Figure 26.

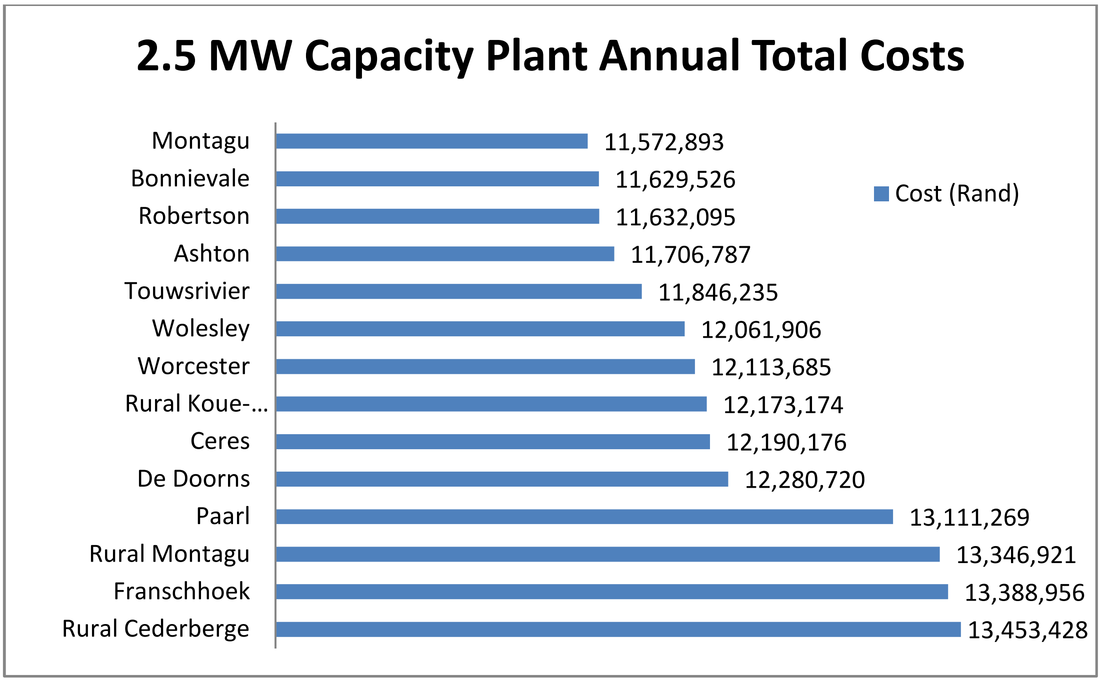


Figure 26: Annual life cycle costs for a 2.5 MW capacity plant

From Figure 26, it can be seen that demand points to the east (Robertson, Ashton, Bonnievale and Montagu) have the lowest life cycle cost, due to high productivity. The highest life cycle costs are present in areas with low production and rural areas where the costs are higher for certain processes, and the advantage of selling heat to generate extra income is absent. The additional income from heat sales were offset against costs in the model.

From the difference in income and the costs in Figure 1, the farm gate price per ton of biomass is determined. This is the price that can be paid to farmers for their wood. The yearly income is calculated by multiplying R 1.18 – the price set by ESKOM to be paid per kWh of electricity from biomass (National Energy Regulator of South Africa 2009) – by 19 800 000 kWh per year. Thus, for a 2.5 MW plant, the yearly income will be R 23 364 000. Then, subtracting the yearly life cycle cost and dividing this by the mass of the biomass, in tonnes (33 000 ton), used by a 2.5 MW plant yields the potential farm gate price that can be paid per ton to a farmer – see Figure 27, below.

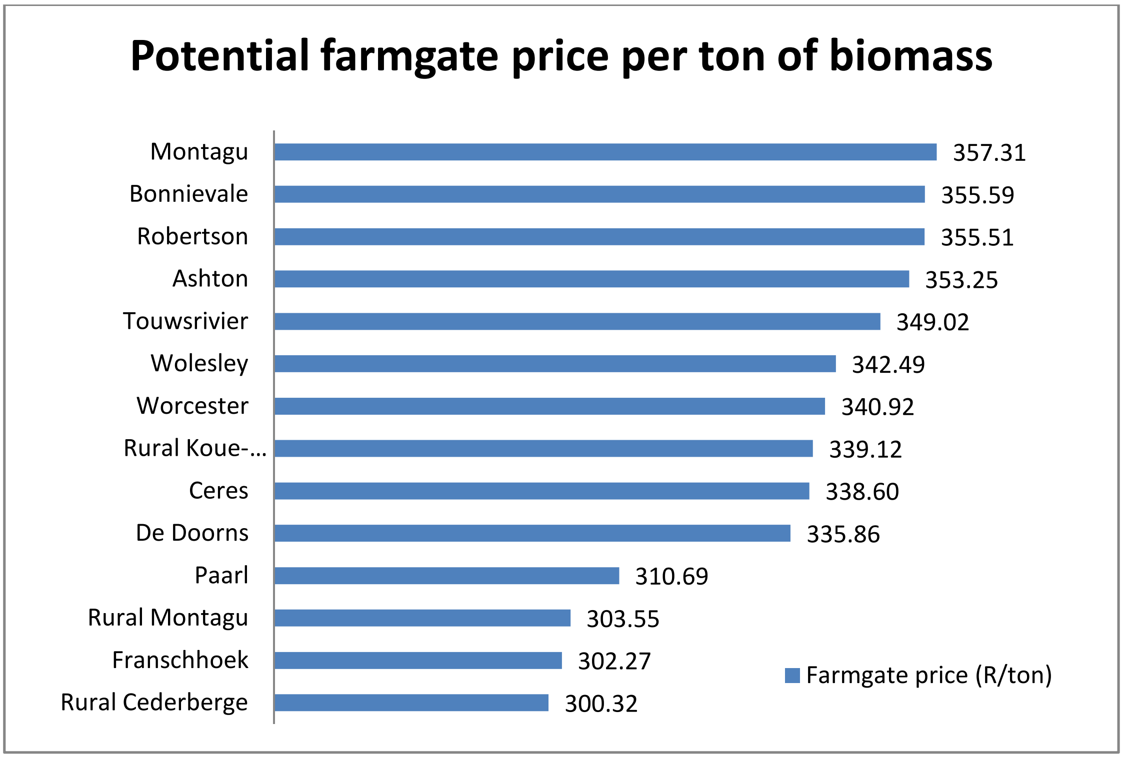


Figure 27: Potential farm gate price per ton of biomass

To illustrate the difference between very productive areas, rural areas and low production areas, refer to Figure 29 and Figure 30. In these figures y refers to the chosen demand points. From these it is immediately clear that in the case of 100% farmer participation, all the areas have the potential to participate in the farming of woody biomass.

It can also be seen that the results could be grouped into three relatively unique groups, where the best five areas have farm gate prices that differ by only about R8 per ton. The central five areas have farm gate prices that differ by less than R7 per ton, while the bottom four differ by about R10. One area for each of the three groupings identified above is shown below, with the typical area from where it will get its woody biomass. It can also be observed when analysing the output file and the graph that the cheapest option for the case of 100% farmer participation is to transport logs and use a combustion process to generate electricity.

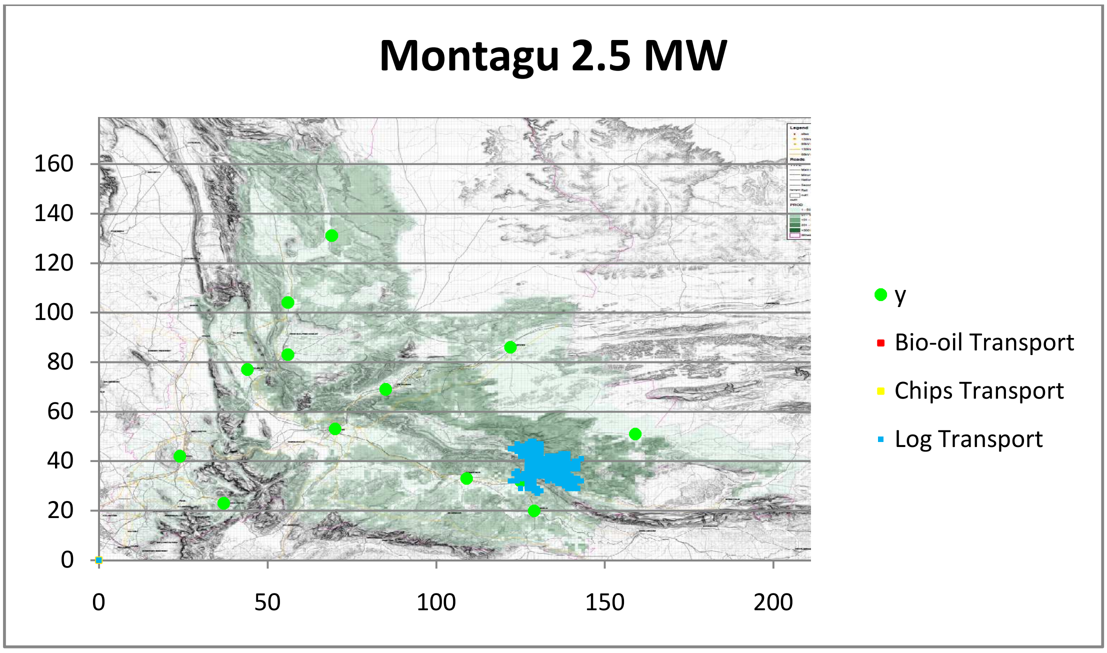


Figure 28: Montagu – high production area

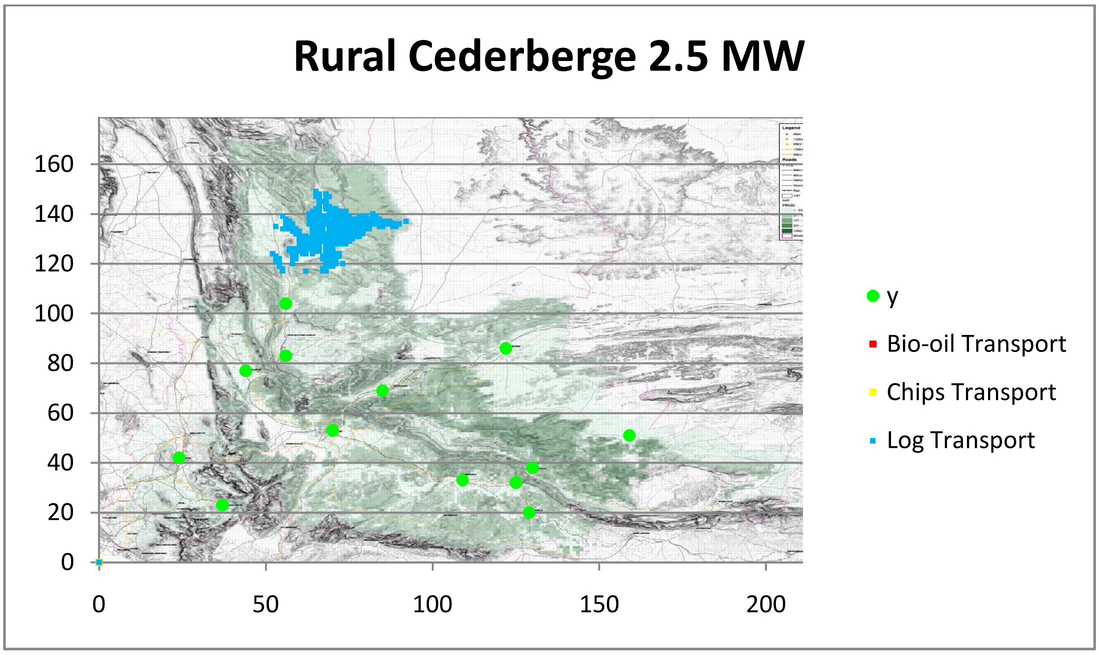


Figure 29: Rural Cederberge – high production but higher system costs

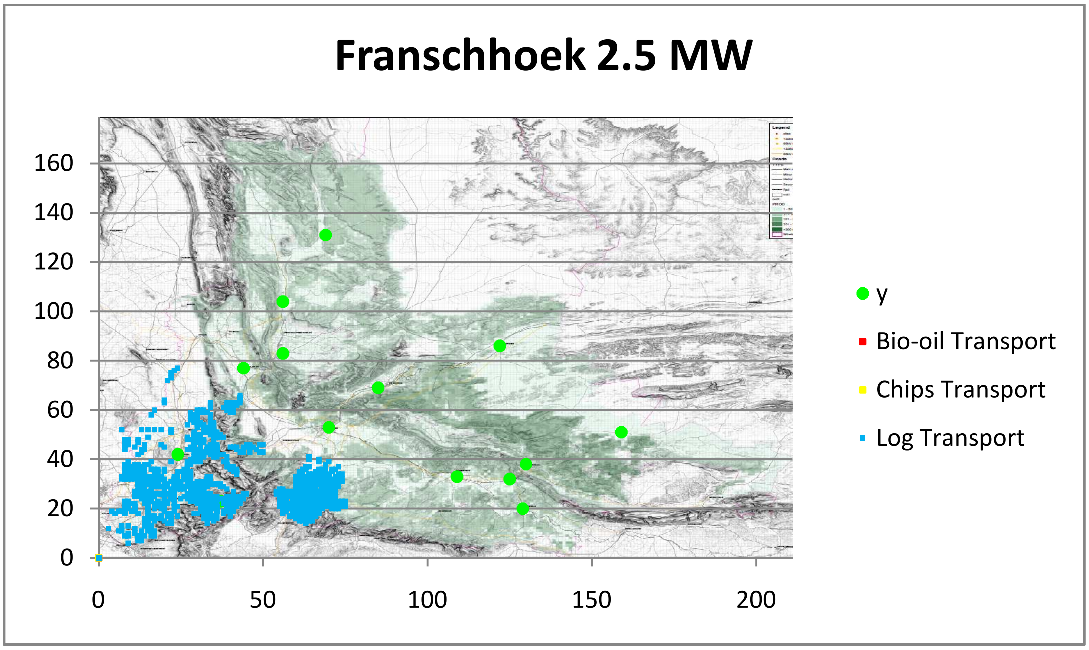


Figure 30: Franschhoek – low production area

For the other area maps with their production areas, refer to Appendix 10. After the initial runs to determine the production areas and associated costs of each of the demand points, it was decided to do a run on one area using different plant capacities, and also to do a sensitivity analysis for the potential production participation. This refers to the instances where farmers do not want to supply feedstock for bioenergy production, and this will have an effect on the transport cost, as it would have to be transported from further away than would otherwise be the case. It was decided to use Robertson for this expanded analysis. For the results, refer to Figure 31.

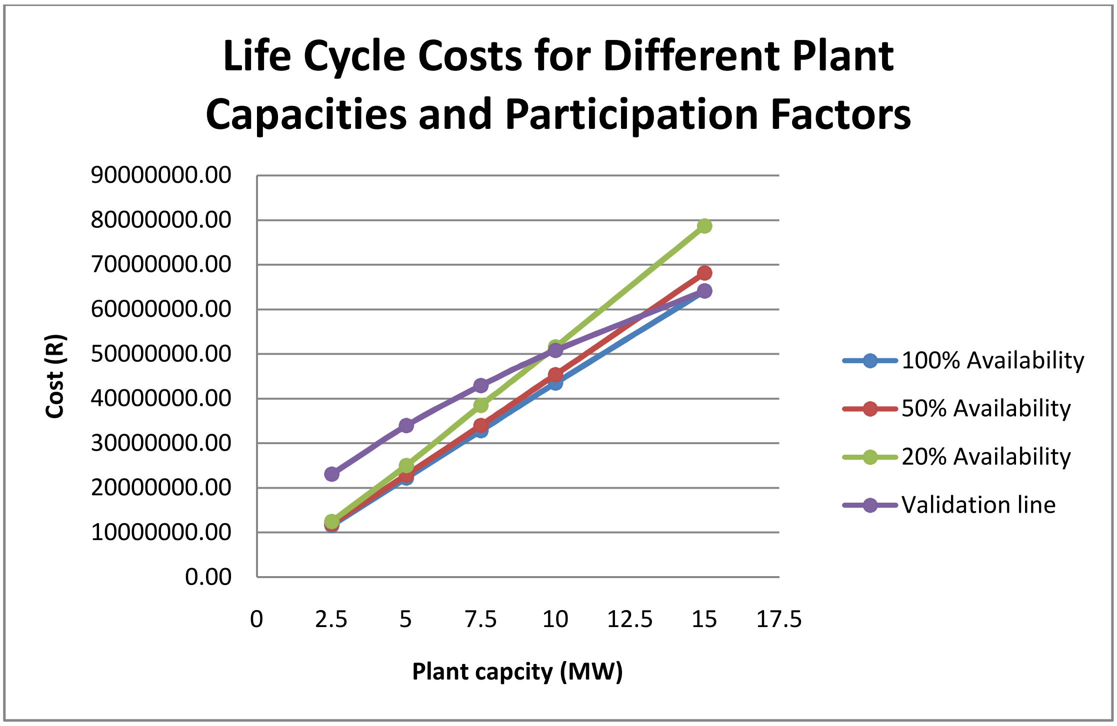


Figure 31: Life cycle costs for different plant capacities and participation factors – Robertson

In Figure 31 it is clear that life cycle costs will become more expensive as a lower percentage of farmers participate in the supply of feedstock. The higher costs are particularly clear for the 15 MW plant. The purple line in Figure 31 is a validation line that is worked out from a 'rule of thumb' formula used in process engineering. The formula is known as the power equation and is applicable to scaling costs with plant capacity:

$$\left(\frac{Plant\ size\ 1}{Plant\ size\ 2}\right)^{0.6} = \left(\frac{Capacity\ cost\ 1}{Capacity\ cost\ 2}\right)$$

With this line, the values received from the model are validated; it is obvious that all of these plant costs are still going up but they will probably reach a peak later on and then level out.

However, the difference between 100% participation and 50% participation is not as great as the difference between 100% participation and 20% participation, which is more than 15 million rand for a 15 MW plant. This will have a substantial effect on the price that can be paid to the farmers for their feedstock – refer to Figure 32, below.

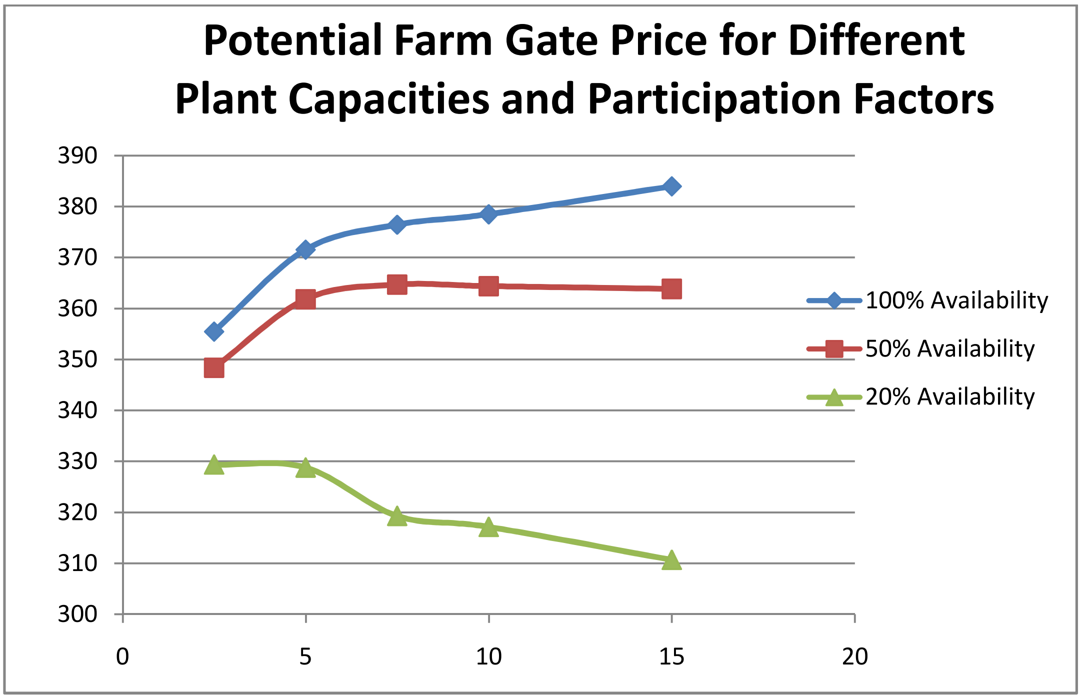


Figure 32: Potential farm gate price for different participation factors at different plant capacities

In Figure 32, the green line refers to 20% farmer participation in supplying feedstock, and the price that can be paid to the farmers is as low as R310 per ton. The tendency in the line also makes it clear that it would be better to choose smaller plants in this case. The red line refers to 50% farmer participation, and reaches its peak between the 5 MW and the 7.5 MW plants; thus, these plant sizes will be optimal for this scenario. In the 100% participation scenario (blue line), the price to the farmer keeps on rising at a constant rate. Although this is an unrealistic scenario, it does present quite a high price that can be paid to farmers supplying feedstock. To illustrate the difference in participation using a 5 MW capacity plant for Robertson, refer to Figure 33, Figure 34 and Figure 35.

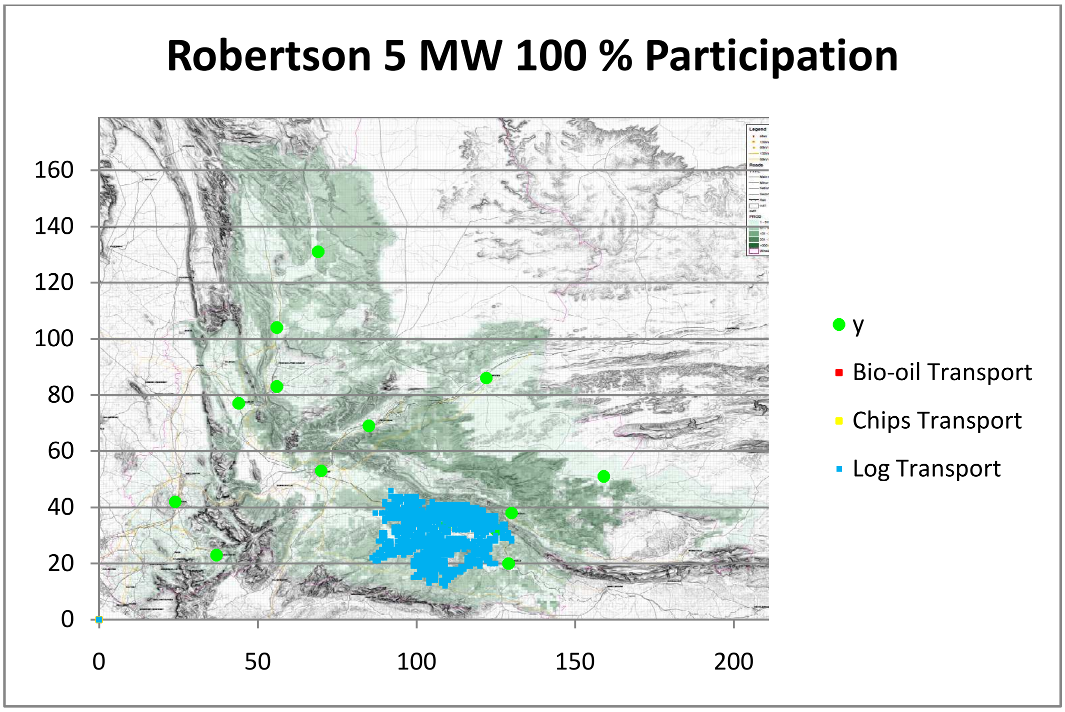


Figure 33: Production area with a 5 MW capacity plant and 100% participation for Robertson

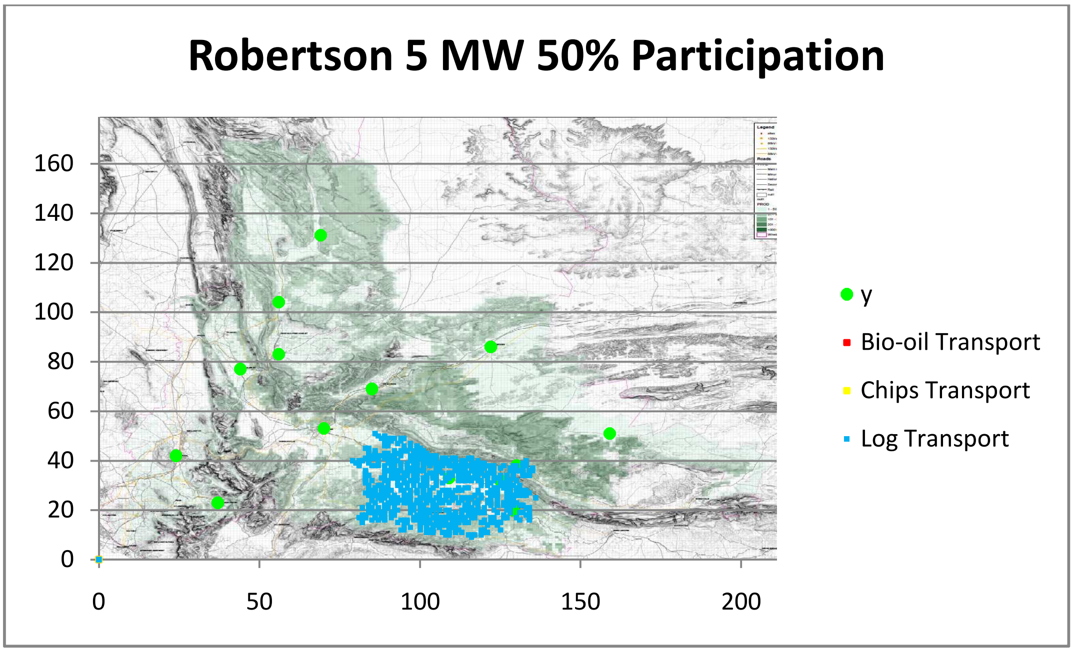


Figure 34: Production area with a 5 MW capacity plant and 50% participation for Robertson

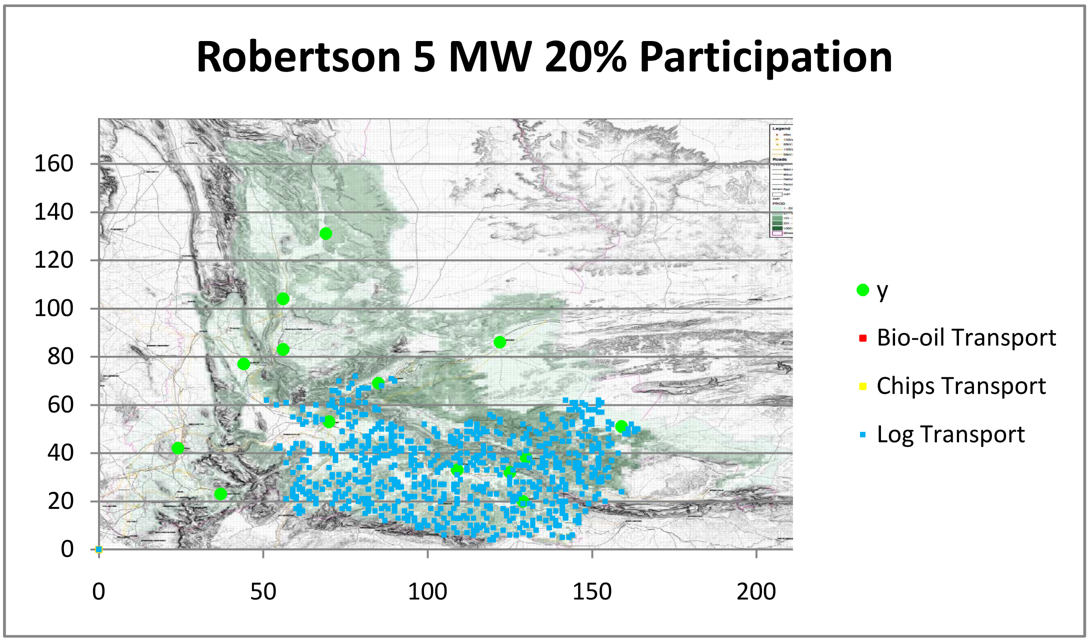


Figure 35: Production area with a 5 MW capacity plant and 20% participation for Robertson

Another interesting observation from the results is that for larger capacity plants and lesser participation, the model tends to choose a combination of both logs and bio-oil. This is because the transport cost of bio-oil is low compared to logs, but the actual pre-processing, conversion and generation processes are more expensive than for logs. At longer distances, the advantage that logs have over bio-oil in terms of a cheaper process is offset by higher transport costs, and hence bio-oil becomes more economic. Refer to Figure 36, Figure 37 and Figure 38 for an illustration of this occurrence.

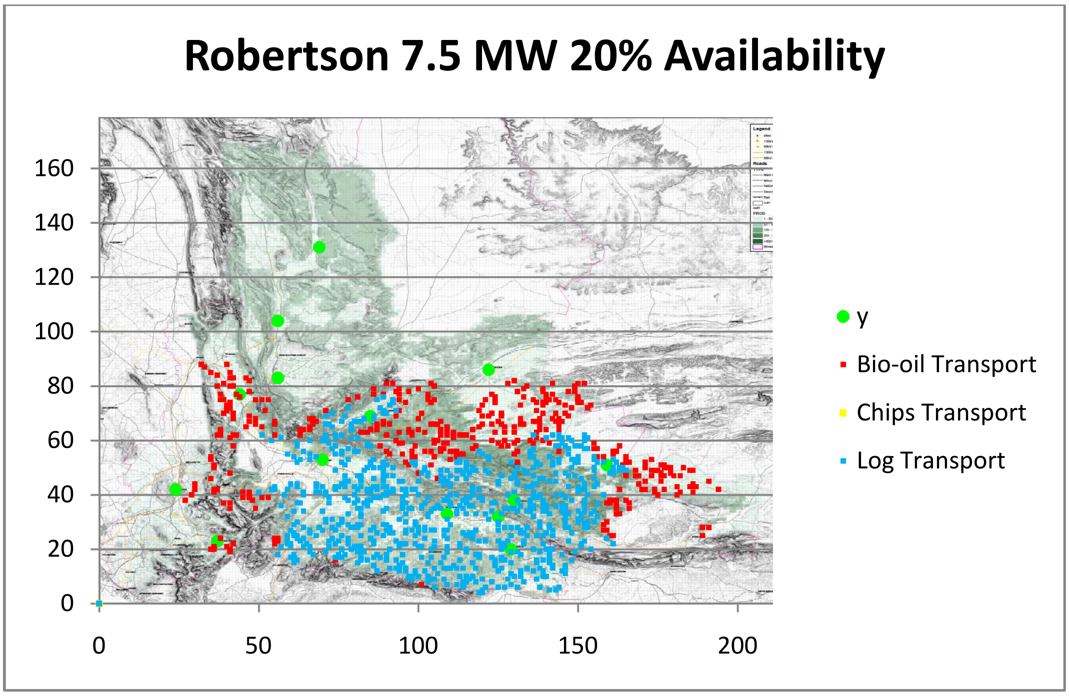


Figure 36: Bio-oil vs log transportation for a 7.5 MW plant for Robertson

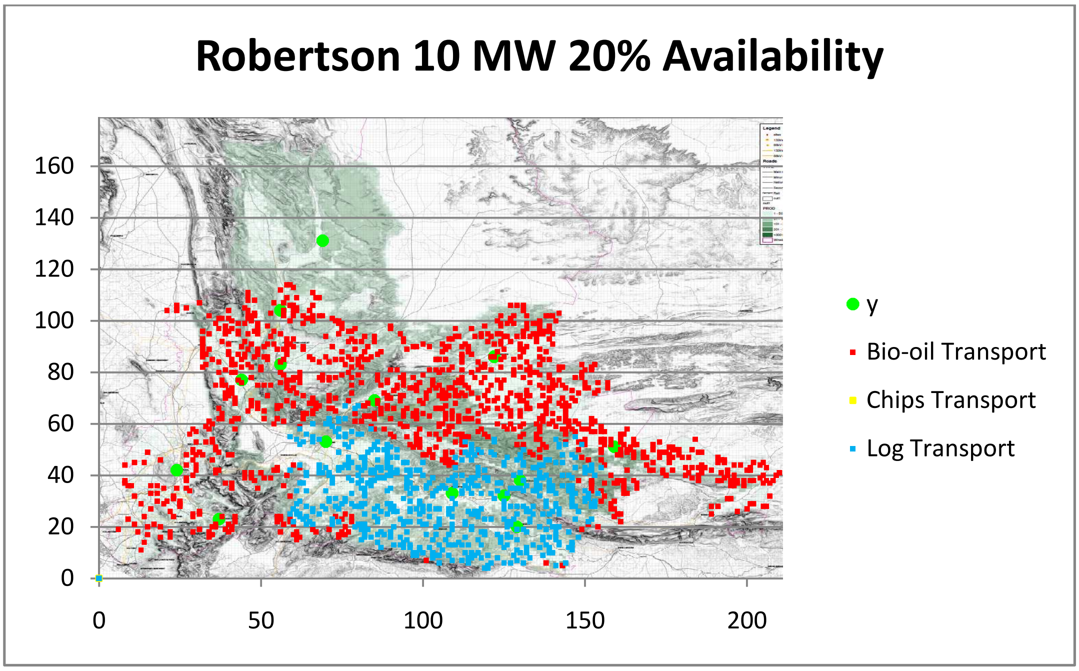


Figure 37: Bio-oil vs log transportation for a 10 MW plant for Robertson

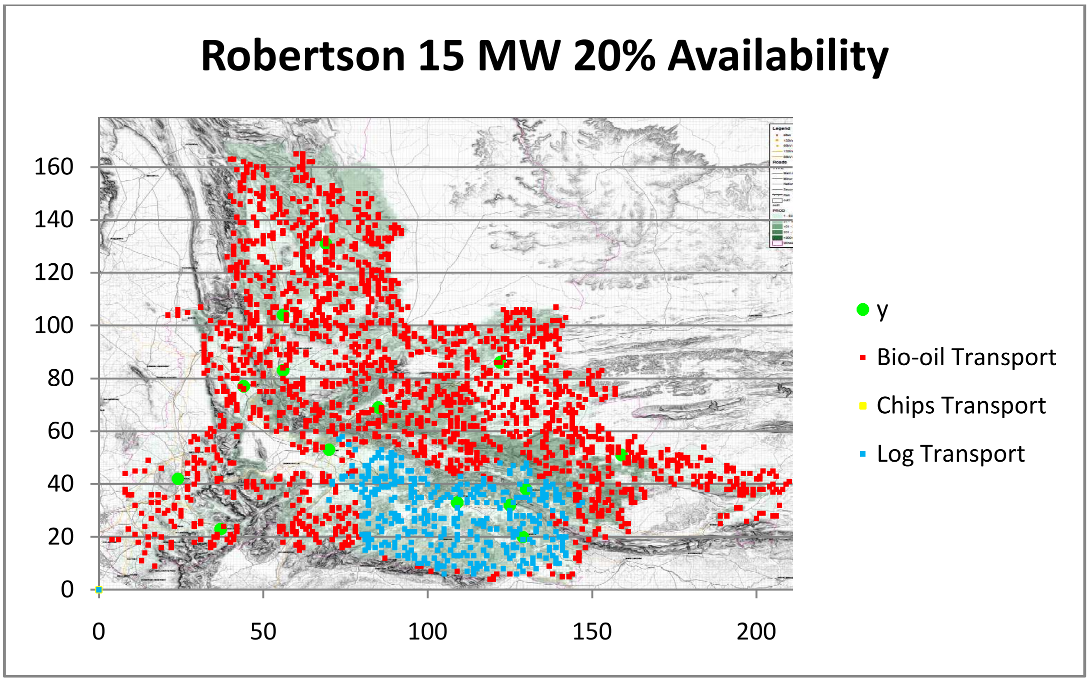
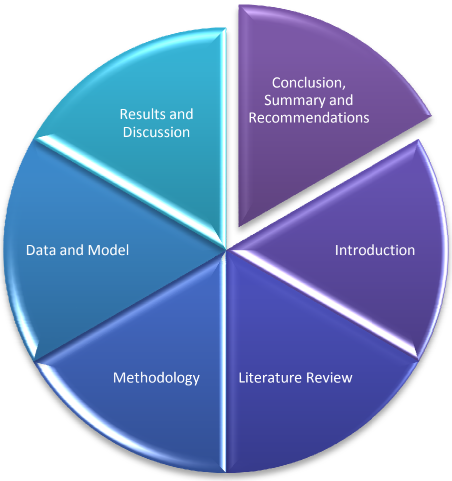


Figure 38: Bio-oil vs log transportation for a 15 MW plant for Robertson

For the other figures from the model results for Robertson refer to Appendix 11. Considering the previous graphs and the associated data, it is reasonably clear that the generation of electricity from woody biomass is feasible. It can be argued that when considering the farm gate prices from Figure 32, the lowest risk option would be to build a 5 MW plant. From all the options, it would seem that the potential gain to be made from building a larger plant would be offset against the higher risk involved, should a lower percentage of farmers choose to participate.

The final chapter gives a summary of general conclusions and some indications for potential future work on the CWDM project.



6. CONCLUSIONS, SUMMARY AND RECOMMENDATIONS

Worldwide energy consumption is at an all time high, causing serious concern about the depletion of energy sources. The negative effect this has on the environment is also causing concern and the world is determined to find cleaner, renewable energy sources.

The CWDM project seeks to address these issues. It is concerned with producing energy, specifically electricity from renewable sources, without jeopardising the already fragile environment.

Energy from lignocellulosic biomass has been identified as a possible energy source. However it is important to assess the economic feasibility of such a project. The purpose of this thesis was to find the most profitable area, considering the associated life cycle cost, including establishment and maintenance of the crops, harvesting, transport, conversion and generation. An important focus area was determining the most realistic transport cost.

To determine the life cycle cost the process was analysed from start to end over 20 years. A GIS analysis was done to determine the most suitable areas within the CWDM region. Results from this analysis together with ESKOM and other industry relevant data were used to identify demand locations. In the end, 14 possible plant locations were identified. After this, a last GIS analysis was performed to determine the height, distances and other relative information required to calculate equivalent yearly life cycle costs for each of the 14 plant locations.

The transport costs were determined by means of the RFA`s VCS, as well as the work of Prof. C.J. Bester. These costs and all the other costs associated with the life cycle were combined with the GIS results into an EXCEL data file. The LINGO model was developed and runs were done to optimise the equivalent yearly life cycle cost of each plant location.

The results indicate that the three most profitable locations to build 2.5 MW capacity plants are Montagu, Bonnievale and Robertson. The reasons for this are the high production within this region and also, the advantages from income of heat sales and accessibility to substations and transmission lines.

To illustrate the effect of building larger plants and farmer participation in the project it was decided to perform optimisation on the LINGO model for Robertson. Results indicate that building a 5 MW capacity plant is the best option, since the price that can be paid to farmers are higher than for a 2.5 MW plant. It was also apparent that more farmer participation would lower the life cycle costs, especially the transport cost.

Therefore, it is recommended to build the first 5 MW plant in Robertson. Although its life cycle costs are not the lowest, none of the supply areas of Robertson are situated on the other side of a watershed as is the case in Montagu. Another important consideration is the sensitivity analysis of farmer participation as this will have a great effect on life cycle costs especially when one considers building larger plants. Choosing a 5 MW plant also minimises the risk associated with potential low farmer participation. The model also indicated that the transport of Bio-oil will only become efficient over large distances.

Potential risks to consider include the lack of previous benchmarks. There is at this moment no biomass conversion plants of this scale present in South Africa, making it difficult to find information and solutions to problems unique to South Africa. There is also a lack of skilled labour in terms of the new processing technologies such as pyrolysis and gasification. Also, the effects that a fleet of trucks will have on road infrastructure must also be addressed and planned for.

Future work:

Future work should include carbon and energy balances as well as the overall life cycle assessment of the CWDM project which is currently being done by Mr. C.C.C. von Doderer. The carbon and energy efficiency of trucks should also be determined.

Other work should include:

- An in-depth study on the harvesting of biomass and costs associated with it as illustrated in the article: Logistics for forage harvest to biogas products (Gunnarsson, Vagström and Hansson 2008).
- The use of torrefaction as an energy conversion process as illustrated in the article: Pre-treatment technologies and their effects on international bioenergy supply chain logistics (Uslu, Faaij and Bergman 2008).
- The development of a user interface together with LINGO and EXCEL to make the model more user-friendly. This could be the topic of an undergraduate study in the future.
- A more combined approach to using GIS and LINGO could yield more accurate results. This could be the topic of a PhD study in the future.
- Competition for biomass between plants should also be simulated, for instance what would the effect be on the supply areas when building a 5 MW

capacity plant in Robertson and building a 5 MW capacity plant in Bonnievale, especially once farmer participation has been taken into account.

- It can be considered to divide CWDM area into smaller areas in the GIS model. In this way more detail can be considered, making analyses` more accurate.
- The development of a complete business plan for the CWDM project is also of high importance. Technology transfers, training of personnel as well as project management are areas that will be crucial to the successful completion of such a project. It is also important to determine the short term and long term strategies as well as forming an expert group that will make decisions based on the most relevant knowledge at hand. This will lead to sound decisions and consistency over all disciplines of the project.

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APPENDICES

Appendix 1: Maximum Dimensions, 2009

	Maximum	Regulation
Overall Length		
Trailer with one axle or one axle unit.	11.3m	221 (b) (i)
Trailer with two axles or one or more axle units.	12.5m	221 (c)
Any other vehicles.	12.5m	221(f)
An articulated motor vehicle.	18.5m	221(d)
Combination of vehicles.	22m	221(g)
Overall Width		
Goods vehicle, the gross vehicle mass of which does not exceed 12 000 kg.	2.5m	223(b) & (c)
Goods vehicle, the gross vehicle mass of which exceed 12 000 kg.	2.6m	223(a)
Overall Height		
All goods vehicle.	4.3m	224(b)
Turning Radius		
Maximum at full lock.	13.1m	225(a)
Wheelbase		
Semi-trailer. Trailer.	10.0m	

	Maximum	Regulation
All other goods vehicles.	8.5m 8.5m	225(b)
Front Overhang Semi-trailer. Goods vehicle, 60 % of wheelbase, or (a) If the driver`s seat is not more than 1.7 m from the front end – (b) Any other goods vehicle (including a trailer) – In the case of a front axle unit, the front overhang is measured from the foremost axle and not the centre of the axle unit.	1.8m 6.2m - ½ wb 2.8m - ½ wb	226(1)(a) and (b)
Rear Overhang Refuse collectors, road making and road construction vehicles, and farming vehicles – 70 % of wheelbase. A trailer with one axle or one axle unit (excluding a semi-trailer) 50 % of body lenghth. Any other vehicle 60 % of wheelbase. The rear overhang is measured from the rear most axle.	70 % 50 % 60 %	226(2)(a) 226(2)(b) 226(2)(c)
Load Projections Load projection must not be confused with overhang.		

	Maximum	Regulation
Basically, overhang is part of the vehicle, whereas projection is that part of the load which extends beyond the front end and/or rear end of the vehicle.		
Maximum load projections are –		
Side Load Projections		
In the case of a goods vehicle which has a GVM exceeding 12 000 kg, maximum each side longitudinal centre line.		
In the case of any other goods vehicle.		
Front Load Projection	1.3m	227(aa)
All goods vehicle, the projection of the load beyond the front end of the vehicle.	1.25m	227(bb)
or		
The front overhang plus the front load projection must not exceed the front overhang as prescribed in Regulation 226.	300mm	227(a)(ii)
Rear Load Projection		
All goods vehicles, the projection of the load beyond the rear end of the vehicle.		227(b)(i)
NOTE: The combined length of a vehicle or combination of vehicles plus any front or rear load projection must not exceed the prescribed overall length of the vehicle or combination.	1.8m	227(1)(a)(iii)
Drawbar Length Maximum length of conventional drawbar – The		

	Maximum	Regulation
length of an underslung drawbar – the maximum drawbar length is not prescribed, but the maximum distance between the rear end of the towing vehicle and the front end of the trailer must not exceed	2m	222(2)(b)
	2.5m	222(2)(b)

Source: Fictitious data, for illustration purposes only (Freightliner 2008) (Hino 1994).

Appendix 2: Common energy units and conversions

Energy units

Quantities

1.0 joule (J) = one Newton applied over a distance of one meter (= 1 kg m^2/s^2).

1.0 gigajoule (GJ) = 10^9 joules = 278 kWh

Power

1.0 watt = 1.0 joule/second

1.0 kilowatt (kW) = 1.341 horsepower

1.0 kilowatt-hour (kWh) = 3.6 MJ

1.0 horsepower (hp) = 745.7 watts = 0.746 kW

Some common units of measure

1.0 metric tonne (tonne) = 1000 kilograms

Areas and crop yields

1.0 hectare = 10,000 m^2 (an area 100 m x 100 m)

1.0 km^2 = 100 hectares

100 g/m^2 = 1.0 tonne/hectare

Biomass energy

1.0 metric tonne wood = 1.4 cubic meters (solid wood, not stacked)

Energy content of wood fuel (HHV, bone dry) = 18-22 GJ/t

Energy content of wood fuel (air dry, 20% moisture) = about 15 GJ/t

Fossil fuels

Note that the energy content (heating value) of petroleum products per unit mass is fairly constant, but their density differs significantly – hence the energy content of a liter, gallon, etc. varies between gasoline, diesel, kerosene.

Metric tonne coal = 27-30 GJ (bituminous/anthracite); 15-19 GJ (lignite/sub-bituminous)

Carbon content of fossil fuels and bioenergy feedstocks

coal (average) = 25.4 metric tonnes carbon per terajoule (TJ)

1.0 metric tonne coal = 746 kg carbon

oil (average) = 19.9 metric tonnes carbon / TJ

carbon content of bioenergy feedstocks: approx. 50% for woody crops or wood waste; approx. 45% for graminaceous (grass) crops or agricultural residues

Appendix 3: Growth performance per relatively homogeneous farming area

Relatively homogeneous farming area	Growth performance (exotic species) 80 % MC			Growth performance (indigenous species) 80 % MC		
	minimum	mean	maximum	minimum	mean	maximum
Drakenstein/Groenberg	8.0	13.0	18.0	6.0	9.0	12.0
Eersteriviervallei	8.0	13.0	18.0	6.0	9.0	12.0
Franschhoek/Simonsberg	8.0	13.0	18.0	6.0	9.0	12.0
Villiersdorp/Vyeboom	8.0	13.0	18.0	6.0	9.0	12.0
Goudini/Breërivier	7.0	11.5	16.0	6.0	9.0	12.0
Tulbagh/Wolseley	7.0	11.5	16.0	6.0	9.0	12.0
Winterhoek	7.0	11.5	16.0	6.0	9.0	12.0
Agter-Paarl	7.0	11.5	16.0	6.0	9.0	12.0
Bergrivier/Paarl	7.0	11.5	16.0	6.0	9.0	12.0
Bottelary	7.0	11.5	16.0	6.0	9.0	12.0
Gemengde Boerderygebied	7.0	11.5	16.0	6.0	9.0	12.0
Gouda/Hermon	7.0	11.5	16.0	6.0	9.0	12.0
Hoë Reenval Saaigebied	7.0	11.5	16.0	6.0	9.0	12.0
Hottentotsholland	7.0	11.5	16.0	6.0	9.0	12.0
Middel-Swartland Saaigebied	7.0	11.5	16.0	6.0	9.0	12.0
Vier-en-Twintig Riviere	7.0	11.5	16.0	6.0	9.0	12.0
Bergplase	4.0	8.0	12.0	5.0	7.5	10.0
Breëriviervallei	4.0	8.0	12.0	5.0	7.5	10.0
Langeberg Saaigebied	4.0	8.0	12.0	5.0	7.5	10.0
Overhex/Moordkuil	4.0	8.0	12.0	5.0	7.5	10.0
Riviersonderendvallei	5.0	8.5	12.0	5.0	8.0	11.0
Ruens	4.0	8.0	12.0	5.0	7.5	10.0
Berge	4.0	8.0	12.0	5.0	7.5	10.0
Hexvallei	4.0	8.0	12.0	5.0	7.5	10.0

Koo/Concordia/Bo-Vlakte	4.0	8.0	12.0	5.0	7.5	10.0
Montagu-Bergplaas	4.0	8.0	12.0	5.0	7.5	10.0
Montagu-Kom	4.0	8.0	12.0	5.0	7.5	10.0
Montagu-Rivierplaas	4.0	8.0	12.0	5.0	7.5	10.0
Stockwell	4.0	8.0	12.0	5.0	7.5	10.0
Twisniet/Barrydale/Doornrivier 1	4.0	8.0	12.0	5.0	7.5	10.0
Koue Bokkeveld	3.0	7.5	12.0	5.0	7.5	10.0
Montagu-Saaigebied 1	3.0	7.5	12.0	5.0	7.5	10.0
Suid-Oostelike Platogebied	3.0	7.5	12.0	5.0	7.5	10.0
Warm Bokkeveld	3.0	7.5	12.0	5.0	7.5	10.0
Langeberg Voetheuwels	3.0	6.5	10.0	3.0	6.5	10.0
Montagu-Saaigebied 2	3.0	6.5	10.0	3.0	6.5	10.0
Montagu-Saaigebied 3	3.0	6.5	10.0	3.0	6.5	10.0
Touw/Ladismith-Karoo	3.0	6.5	10.0	3.0	6.5	10.0
Twisniet/Barrydale/Doornrivier 2	3.0	6.5	10.0	3.0	6.5	10.0
Ceres Karoo	2.0	3.5	5.0	3.0	5.5	8.0
Groot Karoo	2.0	3.5	5.0	3.0	5.5	8.0

Appendix 4: Availability factors per relatively homogeneous farming area and land use type

Relatively homogeneous farming areas	Availability factor [%]	Land use – description
Agter-Paarl		extensive dry land and improved grassland
Agter-Paarl		forest plantations
Agter-Paarl	10 %	fynbos, shrubland and bushland
Agter-Paarl		intensive permanent and temporary farmland
Berge	0 %	CCP agricultural land
Berge	0 %	CCP forest plantation
Berge		CCP protected area
Berge	0 %	extensive dry land and improved grassland
Berge		forest plantations
Berge	10 %	fynbos, shrubland and bushland
Berge	0 %	intensive permanent and temporary farmland
Bergplase	100 %	extensive dry land and improved grassland
Bergplase	20 %	fynbos, shrubland and bushland
Bergplase	100 %	intensive permanent and temporary farmland
Bergrivier/Paarl		extensive dry land and improved grassland
Bergrivier/Paarl		forest plantations
Bergrivier/Paarl	0 %	fynbos, shrubland and bushland
Bergrivier/Paarl		intensive permanent and temporary

Relatively homogeneous farming areas	Availability factor [%]	Land use – description
		farmland
Bottelary		extensive dry land and improved grassland
Bottelary		forest plantations
Bottelary	0 %	fynbos, shrubland and bushland
Bottelary		intensive permanent and temporary farmland
Breëriviervallei	100 %	extensive dry land and improved grassland
Breëriviervallei	20 %	fynbos, shrubland and bushland
Breëriviervallei		intensive permanent and temporary farmland
Ceres Karoo		extensive dry land and improved grassland
Ceres Karoo	0 %	fynbos, shrubland and bushland
Ceres Karoo		intensive permanent and temporary farmland
Drakenstein/Groenberg	0 %	CCP forest plantation
Drakenstein/Groenberg		extensive dry land and improved grassland
Drakenstein/Groenberg		forest plantations
Drakenstein/Groenberg	10 %	fynbos, shrubland and bushland
Drakenstein/Groenberg		intensive permanent and temporary farmland
Eersteriviervallei	0 %	CCP forest plantation
Eersteriviervallei	0 %	CCP forest plantation
Eersteriviervallei		extensive dry land and improved grassland

Relatively homogeneous farming areas	Availability factor [%]	Land use – description
Eersteriviervallei		forest plantations
Eersteriviervallei	10 %	fynbos, shrubland and bushland
Eersteriviervallei		intensive permanent and temporary farmland
Franschhoek/Simonsberg	0 %	CCP forest plantation
Franschhoek/Simonsberg		CCP protected area
Franschhoek/Simonsberg		extensive dry land and improved grassland
Franschhoek/Simonsberg		forest plantations
Franschhoek/Simonsberg	10 %	fynbos, shrubland and bushland
Franschhoek/Simonsberg		intensive permanent and temporary farmland
Gemengde Boerderygebied		extensive dry land and improved grassland
Gemengde Boerderygebied		fynbos, shrubland and bushland
Gemengde Boerderygebied		intensive permanent and temporary farmland
Gouda/ Hermon		extensive dry land and improved grassland
Gouda/ Hermon		forest plantations
Gouda/ Hermon	0 %	fynbos, shrubland and bushland
Gouda/ Hermon		intensive permanent and temporary farmland
Goudini/Breërivier	100 %	extensive dry land and improved grassland
Goudini/Breërivier		forest plantations
Goudini/Breërivier	50 %	fynbos, shrubland and bushland
Goudini/Breërivier		intensive permanent and temporary

Relatively homogeneous farming areas	Availability factor [%]	Land use – description
		farmland
Groot Karoo	0 %	fynbos, shrubland and bushland
Hexvallei	100 %	extensive dry land and improved grassland
Hexvallei		forest plantations
Hexvallei	10 %	fynbos, shrubland and bushland
Hexvallei		intensive permanent and temporary farmland
Hoë Reënval Saaigebied		extensive dry land and improved grassland
Hoë Reënval Saaigebied		forest plantations
Hoë Reënval Saaigebied	50 %	fynbos, shrubland and bushland
Hoë Reënval Saaigebied		intensive permanent and temporary farmland
Hottentotsholland		extensive dry land and improved grassland
Hottentotsholland		forest plantations
Hottentotsholland	0 %	fynbos, shrubland and bushland
Hottentotsholland		intensive permanent and temporary farmland
Koo/Concordia/Bo-Vlakte	100 %	extensive dry land and improved grassland
Koo/Concordia/Bo-Vlakte	20 %	fynbos, shrubland and bushland
Koo/Concordia/Bo-Vlakte		intensive permanent and temporary farmland
Koue Bokkeveld	100 %	extensive dry land and improved grassland
Koue Bokkeveld		forest plantations

Relatively homogeneous farming areas	Availability factor [%]	Land use – description
Koue Bokkeveld	20 %	fynbos, shrubland and bushland
Koue Bokkeveld		intensive permanent and temporary farmland
Langeberg Saaigebied	0 %	fynbos, shrubland and bushland
Langeberg Voetheuwels		extensive dry land and improved grassland
Langeberg Voetheuwels	50 %	fynbos, shrubland and bushland
Langeberg Voetheuwels		intensive permanent and temporary farmland
Middel-Swartland Saaigebied		extensive dry land and improved grassland
Middel-Swartland Saaigebied	0 %	fynbos, shrubland and bushland
Montagu-Bergplaas	100 %	extensive dry land and improved grassland
Montagu-Bergplaas	50 %	fynbos, shrubland and bushland
Montagu-Bergplaas		intensive permanent and temporary farmland
Montagu-Kom	100 %	extensive dry land and improved grassland
Montagu-Kom	50 %	fynbos, shrubland and bushland
Montagu-Kom		intensive permanent and temporary farmland
Montagu-Rivierplaas	100 %	extensive dry land and improved grassland
Montagu-Rivierplaas	20 %	fynbos, shrubland and bushland
Montagu-Rivierplaas		intensive permanent and temporary farmland
Montagu-Saaigebied 1	100 %	extensive dry land and improved

Relatively homogeneous farming areas	Availability factor [%]	Land use – description
		grassland
Montagu-Saaigebied 1	50 %	fynbos, shrubland and bushland
Montagu-Saaigebied 1		intensive permanent and temporary farmland
Montagu-Saaigebied 2	100 %	extensive dry land and improved grassland
Montagu-Saaigebied 2	50 %	fynbos, shrubland and bushland
Montagu-Saaigebied 2		intensive permanent and temporary farmland
Montagu-Saaigebied 3	100 %	extensive dry land and improved grassland
Montagu-Saaigebied 3	50 %	fynbos, shrubland and bushland
Montagu-Saaigebied 3		intensive permanent and temporary farmland
Overhex/Moordkuil	100 %	extensive dry land and improved grassland
Overhex/Moordkuil	20 %	fynbos, shrubland and bushland
Overhex/Moordkuil		intensive permanent and temporary farmland
Riviersonderendvallei	0 %	fynbos, shrubland and bushland
Ruens		extensive dry land and improved grassland
Ruens	0 %	fynbos, shrubland and bushland
Ruens		intensive permanent and temporary farmland
Stockwell	100 %	extensive dry land and improved grassland
Stockwell	30 %	fynbos, shrubland and bushland

Relatively homogeneous farming areas	Availability factor [%]	Land use – description
Stockwell		intensive permanent and temporary farmland
Suid-Oostelike Platogebied	30 %	fynbos, shrubland and bushland
Suid-Oostelike Platogebied		intensive permanent and temporary farmland
Touw/Ladismith-Karoo		extensive dry land and improved grassland
Touw/Ladismith-Karoo	5 %	fynbos, shrubland and bushland
Touw/Ladismith-Karoo		intensive permanent and temporary farmland
Tulbagh/Wolseley		CCP agricultural land
Tulbagh/Wolseley		CCP forest plantation
Tulbagh/Wolseley		CCP protected area
Tulbagh/Wolseley	100 %	extensive dry land and improved grassland
Tulbagh/Wolseley		forest plantations
Tulbagh/Wolseley	20 %	fynbos, shrubland and bushland
Tulbagh/Wolseley		intensive permanent and temporary farmland
Twisniet/Barrydale/Doornrivier 1	0 %	extensive dry land and improved grassland
Twisniet/Barrydale/Doornrivier 1	40 %	fynbos, shrubland and bushland
Twisniet/Barrydale/Doornrivier 1		intensive permanent and temporary farmland
Twisniet/ Barrydale/ Doornrivier 2	0 %	extensive dry land and improved grassland
Twisniet/ Barrydale/	30 %	fynbos, shrubland and bushland

Relatively homogeneous farming areas	Availability factor [%]	Land use – description
Doornrivier 2		
Twisniet/ Barrydale/ Doornrivier 2		intensive permanent and temporary farmland
Vier-en-Twintig Riviere	0 %	extensive dry land and improved grassland
Vier-en-Twintig Riviere		forest plantations
Vier-en-Twintig Riviere	50 %	fynbos, shrubland and bushland
Vier-en-Twintig Riviere		intensive permanent and temporary farmland
Villiersdorp/Vyeboom	0 %	extensive dry land and improved grassland
Villiersdorp/Vyeboom	0 %	fynbos, shrubland and bushland
Villiersdorp/Vyeboom		intensive permanent and temporary farmland
Warm Bokkeveld		extensive dry land and improved grassland
Warm Bokkeveld		forest plantations
Warm Bokkeveld	20 %	fynbos, shrubland and bushland
Warm Bokkeveld		intensive permanent and temporary farmland
Winterhoek		extensive dry land and improved grassland
Winterhoek		forest plantations
Winterhoek	10 %	fynbos, shrubland and bushland
Winterhoek		intensive permanent and temporary farmland

Appendix 5: Summary of GIS phase three results

Area No	Site No	No of Hexa-gons	Tot Pro-duction	Total Area	Average P/A	Average Dist	Max Dist	Avg Dist to Road	Min Dist to Road	Max Dist to Road	Average Slope (D)	Min Slope (D)	Max Slope (D)	Average Slope (P)	Min. Slope (P)	Max. Slope (P)	Density Distance	Total Distance	Total Dist to Road
0	12919	884	37751.64	229662	0.1644	29051.3	69347.0	1917.2	2.0	9799.0	9.79	0.46	35.47	21.76	1.02	78.82	19.3852	25681314	1694796
1	12926	461	30987.75	119814	0.2586	18313.4	37510.0	2641.8	10.0	9741.0	10.18	0.59	33.49	22.63	1.31	74.42	16.5297	8442499	1217878
2	13094	203	33922.00	52768	0.6429	10313.3	18735.0	4360.7	7.0	8772.0	12.95	0.51	26.25	28.77	1.13	58.33	10.2151	2093610	885228
3	13532	258	34380.60	67062	0.5127	10326.4	21633.0	4414.8	8.0	14205.0	9.89	0.62	27.01	21.97	1.38	60.02	10.6727	2664207	1139019
4	14096	236	34132.00	61354	0.5563	11870.1	24062.0	4172.5	10.0	15860.0	8.64	0.69	24.78	19.20	1.53	55.07	11.7616	2801335	984711
5	14387	412	33796.10	107108	0.3155	18754.9	47085.0	3721.4	12.0	11464.0	14.67	0.48	34.55	32.60	1.07	76.78	11.5896	7727036	1533217
6	14472	161	33223.35	41882	0.7933	8358.9	18330.0	4878.5	77.0	13196.0	12.32	2.35	26.40	27.38	5.22	58.67	8.4767	1345786	785443
7	14689	168	34071.20	43712	0.7794	8361.0	17059.0	4866.7	5.0	15186.0	8.16	0.57	19.90	18.13	1.27	44.22	8.0483	1404651	817612
8	14872	138	22260.01	35892	0.6202	7763.1	15100.0	3963.8	35.0	11580.0	18.81	0.97	36.93	41.80	2.16	82.07	7.2523	1071311	547009
9	15002	228	20655.82	59322	0.3482	10270.0	20421.0	3414.1	14.0	10331.0	11.16	0.76	36.03	24.81	1.69	80.07	10.3545	2341557	778415
10	15322	229	33836.46	59548	0.5682	10479.8	21000.0	1841.1	1.0	9672.0	7.71	0.55	30.89	17.14	1.22	68.64	9.5097	2399881	421621
11	15727	123	33364.90	31998	1.0427	7681.7	16703.0	5446.8	100.0	14015.0	7.94	1.67	21.01	17.64	3.71	46.69	7.2834	944854	669958
12	15912	149	32004.66	38720	0.8266	8434.5	19287.0	3452.5	21.0	10202.0	14.05	1.09	33.98	31.23	2.42	75.51	7.1872	1256744	514417
13	15931	214	34628.21	55642	0.6223	10119.6	22113.0	4528.5	10.0	15061.0	11.14	0.75	26.13	24.75	1.67	58.07	9.5357	2165594	969089
14	15996	163	32816.80	42352	0.7749	8618.5	16703.0	2640.4	18.0	7678.0	8.85	0.73	21.60	19.66	1.62	48.00	8.1554	1404816	430392
15	18906	297	24319.06	77198	0.3150	12494.1	30716.0	4426.7	1.0	14216.0	6.73	0.40	20.68	14.95	0.89	45.96	11.4167	3710734	1314738
16	16944	53	33008.95	13760	2.3989	5423.3	9644.0	3868.5	166.0	8172.0	5.71	1.02	13.92	12.68	2.27	30.93	5.5600	287435	205029
17	16950	52	28539.45	13518	2.1112	4745.0	9644.0	2079.7	7.0	6777.0	5.20	1.34	10.90	11.55	2.98	24.22	4.2004	246739	108145
18	17028	147	31767.21	38172	0.8322	7933.9	16523.0	2827.7	29.0	9288.0	11.13	2.47	29.83	24.74	5.49	66.29	7.0681	1166279	415674
19	17154	169	36084.00	43890	0.8221	8400.7	15395.0	1608.5	4.0	6016.0	8.43	0.74	27.69	18.73	1.64	61.53	8.0018	1419718	271838
20	17414	143	24455.25	37088	0.6594	9588.2	19975.0	3692.7	158.0	9797.0	8.22	0.38	18.75	18.27	0.84	41.67	9.0920	1371112	528051
21	17745	69	33558.55	17900	1.8748	5210.2	9165.0	3173.4	65.0	7664.0	8.93	2.06	22.14	19.86	4.58	49.20	5.0559	359501	218966
22	16934	145	33542.10	37678	0.8902	8496.1	17326.0	2703.5	3.0	9596.0	13.18	1.41	32.82	29.29	3.13	72.93	9.7355	1231930	392011

Area No	Site No	No of Hexa-gons	Tot Pro-duction	Total Area	Average P/A	Average Dist	Max Dist	Avg Dist to Road	Min Dist to Road	Max Dist to Road	Average Slope (D)	Min Slope (D)	Max Slope (D)	Average Slope (P)	Min. Slope (P)	Max. Slope (P)	Density Distance	Total Distance	Total Dist to Road
23	18404	132	33180.00	34312	0.9670	8942.4	21071.0	1567.7	11.0	5233.0	6.97	0.84	25.42	15.48	1.87	56.49	9.0361	1180403	206930
24	18425	72	32525.05	18704	1.7389	5394.0	9644.0	3892.7	89.0	8979.0	16.02	5.12	29.39	35.60	11.38	65.31	5.8630	388365	280276
25	18460	153	35418.80	39764	0.8907	7796.6	15000.0	2829.7	29.0	8453.0	8.20	0.70	18.70	18.21	1.56	41.56	7.8731	1192873	432944
26	19108	85	30925.85	22104	1.3991	7270.9	16116.0	1712.4	15.0	6517.0	10.88	2.81	30.15	24.17	6.24	67.00	7.2963	618026	145551
27	19126	154	33110.03	40032	0.8271	9081.9	21000.0	3234.3	2.0	9641.0	6.46	0.59	17.86	14.35	1.31	39.69	7.2945	1398616	498077
28	19215	156	32698.10	40542	0.8065	9798.4	21071.0	1318.9	0.0	4842.0	8.07	0.63	31.63	17.93	1.40	70.29	9.1391	1528556	205751
29	19463	61	33809.35	15842	2.1342	5114.2	9165.0	3389.3	13.0	9340.0	8.82	2.52	16.85	19.60	5.60	37.44	5.0016	311966	206749
30	19573	50	30123.75	12998	2.3176	4899.5	10817.0	4153.1	26.0	12056.0	10.94	4.11	17.61	24.31	9.13	39.13	4.9043	244974	207657
31	20252	89	35622.50	23096	1.5424	7030.9	15395.0	4751.5	31.0	13044.0	11.33	4.89	21.03	25.19	10.87	46.73	7.7539	625753	422880
32	20615	142	34000.70	36860	0.9224	7518.6	14177.0	4782.9	10.0	14228.0	5.38	1.42	16.33	11.96	3.16	36.29	7.8188	1067648	679166
33	22337	317	32863.44	82362	0.3990	16509.8	33045.0	3204.7	17.0	12903.0	8.54	0.65	30.86	18.97	1.44	68.58	17.0249	5233598	1015889

Appendix 6: Theoretical explanation of Winter`s method

When forecasting from data using Winter`s method, the following notation is used:

c = the number of periods in the length of the seasonal pattern (c = 4 for quarterly data, and c = 12 for monthly data).

s_t = estimation of a seasonal multiplicative factor for month t, obtained after observing x_t.

L_t = estimation of the base level.

T_t = estimation of the per-period trend.

α, β and γ are smoothing constants, each of which is between 0 and 1.

$$L_t = \alpha \frac{x_t}{s_{t-c}} + (1-\alpha)(L_{t-1} + T_{t-1})$$

$$T_t = \beta(L_t - L_{t-1}) + (1-\beta)T_{t-1}$$

$$s_t = \gamma \frac{x_t}{L_t} + (1-\gamma)s_{t-c}$$

The first equation updates the estimate of the series base by taking a weighted average of the following two quantities:

- $L_{t-1} + T_{t-1}$, which is the base level estimate before observing x_t
- The deseasonalised observation x_t/s_{t-c}, which is an estimate of the base obtained from the current period.

The second equation is used to update the trend estimate.

The third equation updates the estimate of month t`s seasonality by taking a weighted average of the following two quantities:

- Our most recent estimate of month t`s seasonality (s_{t-c})
- X_t/L_t which is an estimate of month t`s seasonality, obtained from the current month.

NOTE: Every ‘c’ period, the indices s must be normalised so that their average is one.

At the end of period t, the forecast ($f_{t,k}$) for month t + k is given by

$$f_{t,k} = (L_t + kT_t)s_{t+k-c}$$

Thus, for the forecast value of the series during period t + k, we multiply our estimate of the period (t + k)'s base ($L_t + kT_t$) by our most recent estimate of month (t + k)`s seasonality factor (s_{t+k-c}).

Obtaining good forecasts with Winter`s method is dependant on obtaining good initial estimates of base, trend and all seasonal factors.

The mean absolute deviation (MAD) is the tool used to measure the forecasting accuracy. Together with the MAD, a forecast error is used. The forecast error, e_t is calculated by the following equation:

$$e_t = x_t - (forecast\ for\ x_t)$$

The MAD is then simply the average of the absolute values of all the errors, which is minimised to achieve the best smoothing constants and consequently the best forecasts.

Remarks on Winter`s method:

- The use of three smoothing constants in Winter`s method makes it quite a tedious task to determine the best combination of α, β and γ that will yield the smallest MAD.
- The values of α and β that leads to a minimisation of MAD will usually not exceed 0.5, whereas the best value of γ may exceed 0.5. This is due to the fact that for monthly data, each monthly seasonal factor is updated during only a 1/12 of all periods. Since the seasonality factor is updated so infrequently, it may be necessary to add more weight to each observation, therefore γ > 0.5 is quite a common occurrence.
- It is important to consider the data which forecasting is done on, more specifically its applications and continuing to update the data as new data arrive. If any uncommon trends do occur this will make it easier to determine why this happened which will lead to more accurate forecasts.

Initialisation: *(need 2 cycle's data)*

- Find average level of oldest cycle - L_{old}

- Find average level of latest cycle - L_{new}
- Calculate
- Determine: $L_{-1} = L_0 - T_0$

  $L_{-2} = L_{-1} - T_0$ etc

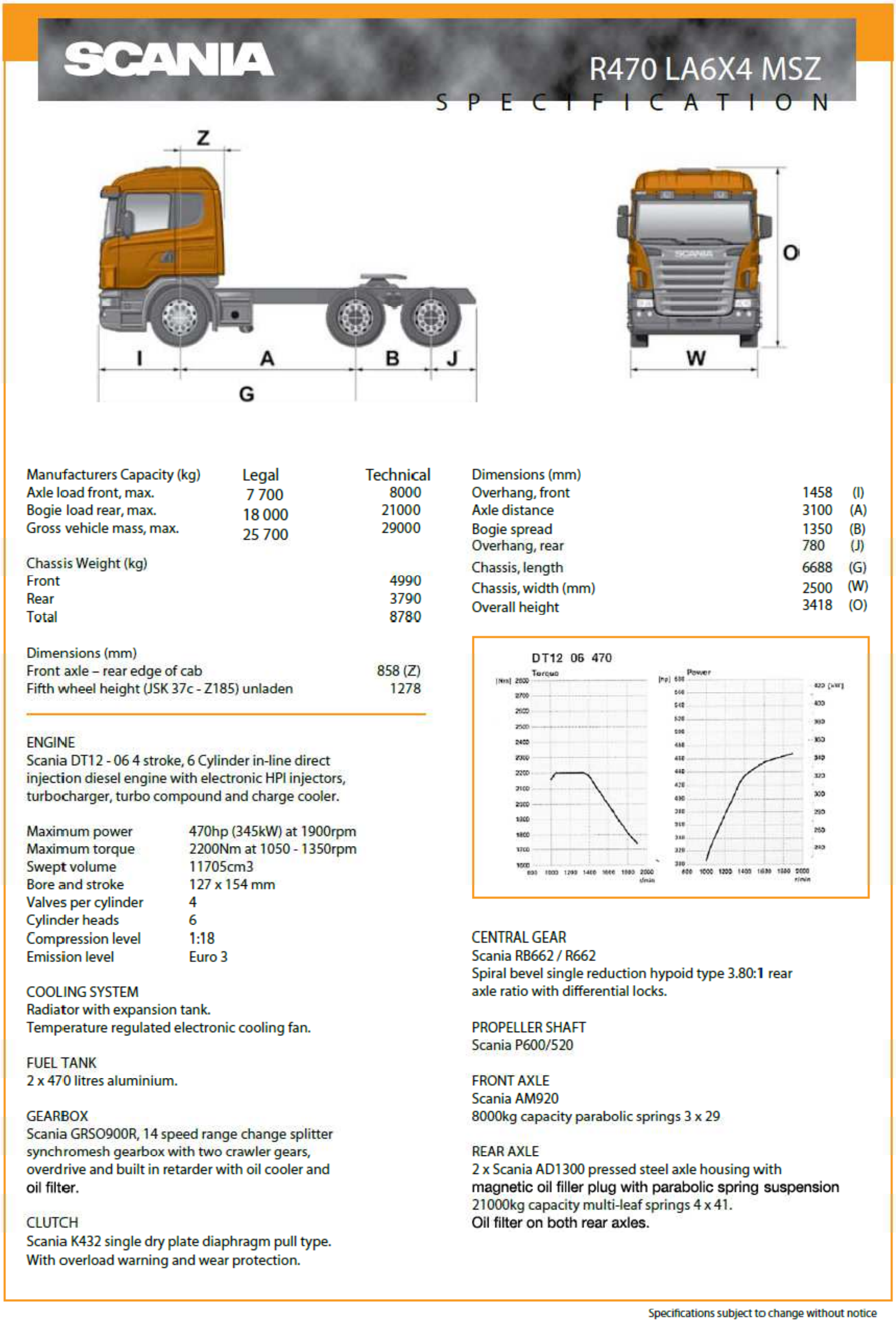
  until the base levels of all historical data is known.
- Divide the actual series values by the corresponding base level values to obtain 2 estimates for each seasonal index.

  Combine the two estimates of each seasonal index into one by taking the average of the 2 estimates.
- Finally, normalise the seasonal indices so that their average equals 1.

Disadvantages:

- In its standard form only good for multiplicative cycles - but can be adapted for additive cycles
- Difficult (almost impossible) to optimize three smoothing constants (a, b, g)

Appendix 7: Scania brochure



R470 LA6X4 MSZ

SPECIFICATION

Manufacturers Capacity (kg)	Legal	Technical
Axle load front, max.	7 700	8000
Bogie load rear, max.	18 000	21000
Gross vehicle mass, max.	25 700	29000

Chassis Weight (kg)	
Front	4990
Rear	3790
Total	8780

Dimensions (mm)	
Front axle – rear edge of cab	858 (Z)
Fifth wheel height (JSK 37c - Z185) unladen	1278

ENGINE
Scania DT12 - 06 4 stroke, 6 Cylinder in-line direct injection diesel engine with electronic HPI injectors, turbocharger, turbo compound and charge cooler.

Maximum power	470hp (345kW) at 1900rpm
Maximum torque	2200Nm at 1050 - 1350rpm
Swept volume	11705cm3
Bore and stroke	127 x 154 mm
Valves per cylinder	4
Cylinder heads	6
Compression level	1:18
Emission level	Euro 3

COOLING SYSTEM
Radiator with expansion tank.
Temperature regulated electronic cooling fan.

FUEL TANK
2 x 470 litres aluminium.

GEARBOX
Scania GRSO900R, 14 speed range change splitter synchromesh gearbox with two crawler gears, overdrive and built in retarder with oil cooler and oil filter.

CLUTCH
Scania K432 single dry plate diaphragm pull type.
With overload warning and wear protection.

Dimensions (mm)		
Overhang, front	1458	(I)
Axle distance	3100	(A)
Bogie spread	1350	(B)
Overhang, rear	780	(J)
Chassis, length	6688	(G)
Chassis, width (mm)	2500	(W)
Overall height	3418	(O)

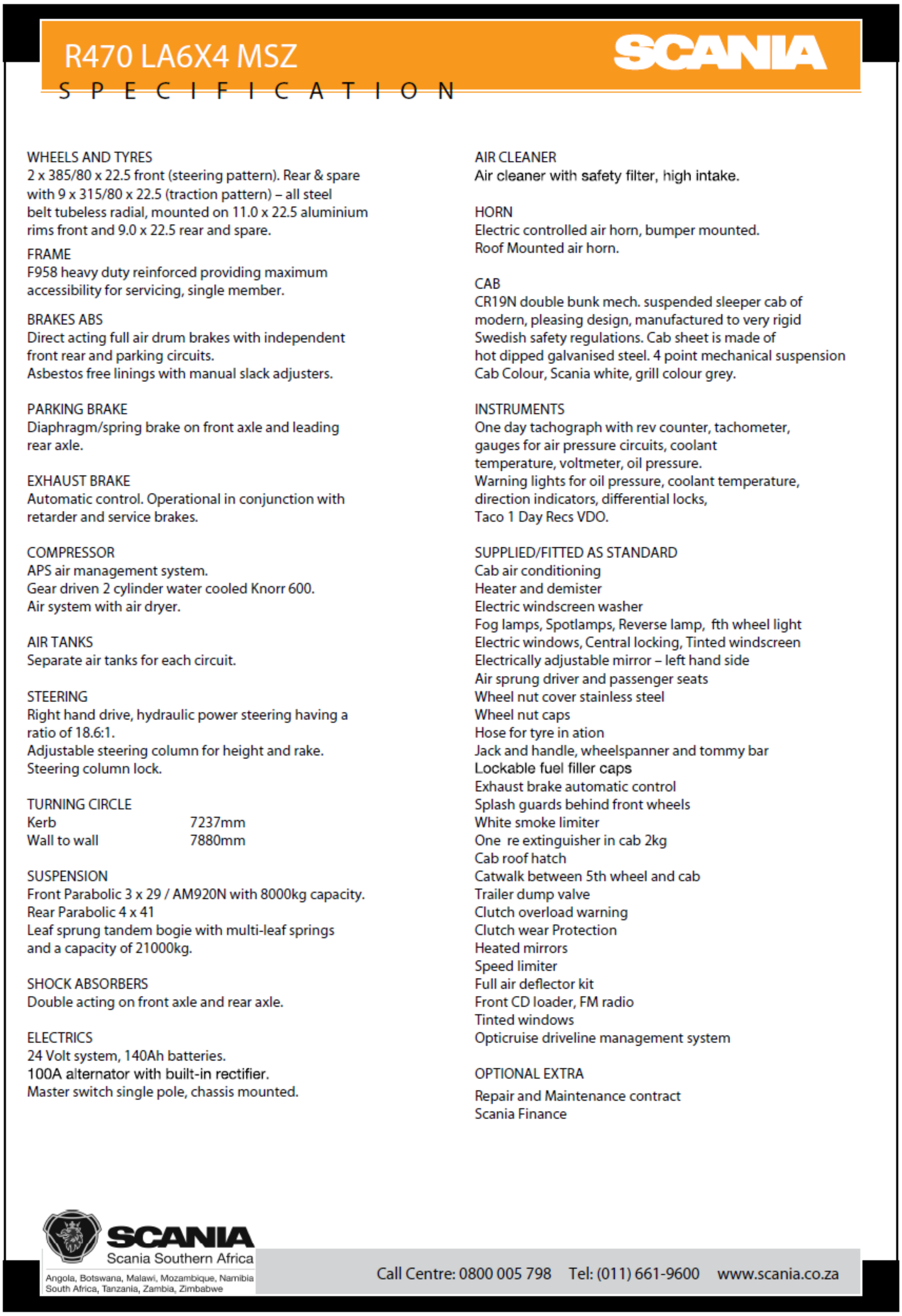
CENTRAL GEAR
Scania RB662 / R662
Spiral bevel single reduction hypoid type 3.80:1 rear axle ratio with differential locks.

PROPELLER SHAFT
Scania P600/520

FRONT AXLE
Scania AM920
8000kg capacity parabolic springs 3 x 29

REAR AXLE
2 x Scania AD1300 pressed steel axle housing with magnetic oil filler plug with parabolic spring suspension 21000kg capacity multi-leaf springs 4 x 41.
Oil filter on both rear axles.

Specifications subject to change without notice



R470 LA6X4 MSZ

SPECIFICATION

SCANIA

WHEELS AND TYRES
2 x 385/80 x 22.5 front (steering pattern). Rear & spare with 9 x 315/80 x 22.5 (traction pattern) – all steel belt tubeless radial, mounted on 11.0 x 22.5 aluminium rims front and 9.0 x 22.5 rear and spare.

FRAME
F958 heavy duty reinforced providing maximum accessibility for servicing, single member.

BRAKES ABS
Direct acting full air drum brakes with independent front rear and parking circuits.
Asbestos free linings with manual slack adjusters.

PARKING BRAKE
Diaphragm/spring brake on front axle and leading rear axle.

EXHAUST BRAKE
Automatic control. Operational in conjunction with retarder and service brakes.

COMPRESSOR
APS air management system.
Gear driven 2 cylinder water cooled Knorr 600.
Air system with air dryer.

AIR TANKS
Separate air tanks for each circuit.

STEERING
Right hand drive, hydraulic power steering having a ratio of 18.6:1.
Adjustable steering column for height and rake.
Steering column lock.

TURNING CIRCLE

Kerb	7237mm
Wall to wall	7880mm

SUSPENSION
Front Parabolic 3 x 29 / AM920N with 8000kg capacity.
Rear Parabolic 4 x 41
Leaf sprung tandem bogie with multi-leaf springs and a capacity of 21000kg.

SHOCK ABSORBERS
Double acting on front axle and rear axle.

ELECTRICS
24 Volt system, 140Ah batteries.
100A alternator with built-in rectifier.
Master switch single pole, chassis mounted.

AIR CLEANER
Air cleaner with safety filter, high intake.

HORN
Electric controlled air horn, bumper mounted.
Roof Mounted air horn.

CAB
CR19N double bunk mech. suspended sleeper cab of modern, pleasing design, manufactured to very rigid Swedish safety regulations. Cab sheet is made of hot dipped galvanised steel. 4 point mechanical suspension
Cab Colour, Scania white, grill colour grey.

INSTRUMENTS
One day tachograph with rev counter, tachometer, gauges for air pressure circuits, coolant temperature, voltmeter, oil pressure.
Warning lights for oil pressure, coolant temperature, direction indicators, differential locks,
Taco 1 Day Recs VDO.

SUPPLIED/FITTED AS STANDARD
Cab air conditioning
Heater and demister
Electric windscreen washer
Fog lamps, Spotlamps, Reverse lamp, fifth wheel light
Electric windows, Central locking, Tinted windscreen
Electrically adjustable mirror – left hand side
Air sprung driver and passenger seats
Wheel nut cover stainless steel
Wheel nut caps
Hose for tyre inflation
Jack and handle, wheelspanner and tommy bar
Lockable fuel filler caps
Exhaust brake automatic control
Splash guards behind front wheels
White smoke limiter
One fire extinguisher in cab 2kg
Cab roof hatch
Catwalk between 5th wheel and cab
Trailer dump valve
Clutch overload warning
Clutch wear Protection
Heated mirrors
Speed limiter
Full air deflector kit
Front CD loader, FM radio
Tinted windows
Opticruise driveline management system

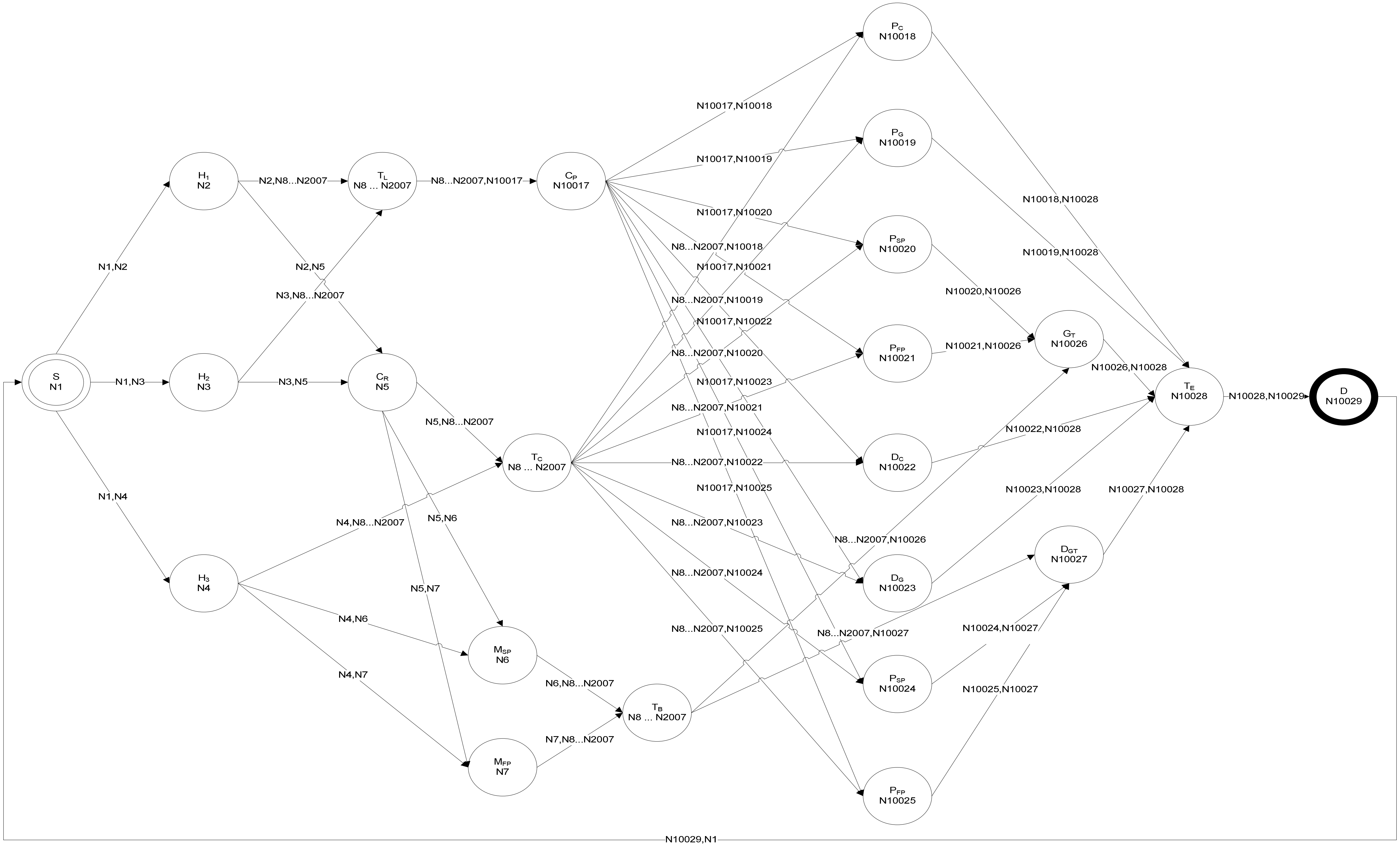
OPTIONAL EXTRA
Repair and Maintenance contract
Scania Finance

SCANIA
Scania Southern Africa
Angola, Botswana, Malawi, Mozambique, Namibia
South Africa, Tanzania, Zambia, Zimbabwe

Call Centre: 0800 005 798 Tel: (011) 661-9600 www.scania.co.za

Specifications subject to change without notice

Appendix 8: CWDM network diagram



Appendix 9: Other considerations for efficient transport

Transport efficiency

Optimal payload ability:

Transport efficiency resides in optimising the legal payload as a percentage of gross mass and the extent to which it is utilised. Optimum payload ability begins with choosing vehicles that provide the best payload to gross mass ratio without compromising the ability to achieve acceptable average speeds at an acceptable cost.

Payload should, wherever possible, be more than 50% of the legal gross mass in the case of rigid vehicles and somewhere between 60% and 67% for articulated vehicles, depending on trailing equipment requirements. Unladen mass in road-ready condition is fundamental to the objective and a studied approach to vehicle size for any given task. There are many new makes, models and specification options available to suit almost any on-road transport task.

In order to take full advantage of optimum payload capability, vehicles must be able to travel at average speeds of not less than 70% to 75% for urban areas and 75%, to 80% on highways and regional roads of the allowable speed limit. This is no longer difficult for modern trucks. However, it is important to take time to establish beyond doubt the amount of kW power needed to complete a job and how much fuel will be consumed in the process.

Calculating the number of ton-km produced:

It is more meaningful to calculate and estimate the level of productivity to be achieved and the difference between what is actually achieved (this can be done for each vehicle in the fleet) by calculating the number of ton-km produced.

Ton-km is the product of distance (kilometres) and tons (the payload tons). The following simple example illustrates the point:

Total kilometres travelled (include the return trip) – say 100 km
Payload tons transported – say 10 ton
Load factor – say 50% (this means the payload of 10 tons was carried only one way and the return trip was an empty leg)

Calculations:
100 km x (10 tons x 0.5) = 500 ton-km
If a truck travels at 50 km/hr, it can be said that the production rate is 500 ton-km/hr when transporting a 10-ton payload. Assuming a 100-km round trip is planned four times a month for a full year with a payload of 10 tons one way only. What would the productivity factor be?

Total kilometres = 4 x 12 x 100 = 4 800
Payload tons = 10
Load factor = 50%
Total ton-km = 4 800 x (0.5 x 10) = 2 4000
When load factor = 100%
Total ton-km = 48 000
% Productivity = 50%

Opportunities for improving productivity lie in obtaining a return load, therefore consider sourcing additional loads that offer a full or partial return leg. Also, consider taking steps to improve the workload during the day and contemplate the possibility of night runs.

The majority of vehicles engaged in secondary distribution achieve productivity levels of less than 20% of the vehicle`s capability when measured in ton-kms; steps to improve such low productivity by 15% to 20% would make a significant difference to actual productivity and a more efficient use of energy. This level of productivity improvement would still be below 20% of the vehicle`s capability.

There are opportunities for improving transport efficiency, provided a more flexible and innovative approach to achieving more of the economic potential offered by modern trucks is adopted.

Transport productivity

The objective of any task is to achieve the best performance. This can be done by achieving the desired level of productivity at the lowest cost possible. For transport performance this is usually expressed in any unit of work applicable to the task at hand. These units of work could be anything from tons to cubic metres, litres or even passengers. These units are then expressed together with the distance needed to move them, such as ton-km, litre-km and so on. Max Braun, Fleetwatch correspondent, suggests: "think of trucks as factories that produce a transport commodity such as a ton-km or whatever suits your business."

Calculation for a hypothetical workload.

The Task – transport 100 tons 50 kilometres. Assume no return load.

Workload – 100 x 50 x 2 = 10 000 ton/km

Time on the road – 10 hours (excluding turnaround time)

Production rate – 10 000/10 = 1000 ton/km-hour

The two factors making up transport production are tons (units) and the distance travelled per hour.

A truck is defined as follows:

- When it is fully loaded and is standing still – it is a warehouse.
- When a truck is empty and standing – it is a monument.
- When a truck is empty and moving – it is a job opportunity for the driver.
- Only when a truck is fully loaded and moving – is it a TRUCK.

Only now can it be decided what would be the best way to transport 1 000 ton/km-hr. It can either be transported with one large truck or perhaps two or more smaller capacity vehicles.

For example: One large vehicle with a payload of approximately 21 tons capable of travelling at an average speed of 48 km/h will successfully complete the task:

21 x 48 = 1 008 ton/km-hr

If a vehicle that can carry 24 tons is chosen, an average speed of 42 km/h will be sufficient to do the job:

24 x 42 = 1 008 ton/km-hr

Assume both vehicles offer a legal GVM/GCM of 43 000 kg. The larger payload vehicle provides a GVM:payload ratio of 56%. The 21-ton payload yields a ratio of 49%. A payload to GVM ratio must, if at all possible, exceed 50% if it is to be economical to operate. The capital cost per payload ton of larger vehicles is more beneficial than smaller payload units. Lower average speeds contribute to fuel efficiency, less tyre wear and damage, and longer economic life. One large truck costs less than even three smaller trucks. However, smaller trucks for this operation would be favoured if there were logistical reasons to do so.

Workload (the transport task) should be clearly identified and defined before deciding on the type and size of truck. Unfortunately, in practise, it is almost always the other way around.

In choosing a truck to achieve a particular workload in a given time, there are two elements to consider. These are payload and average speed.

Over-the-road performance is governed by the drive-line components to overcome resistance – these include rolling resistance, air-drag, gradients and gross mass.

Average speed is limited to the vehicle`s tractive capability, road traffic conditions and – by legislation – speed limits.

Where road conditions permit, an economical average speed to achieve is 70 % to 80 % of the speed limit. Below this figure, more vehicles will be required. In excess of 80% is uneconomical in terms of fuel usage and ownership costs, due to reduced economic life expectancy.

When a truck is acquired for full-time use, there is a commitment to pay the standing costs (also known as fixed costs) whether it is used or not. This is so whether it is owned or leased. Most fleet owners expect their vehicles to be available for work at least 90% of the available hours. This leaves sufficient time to service and maintain them.

Theoretically speaking, the vehicle is available 24 hours, 365 days of the year, or 8760 hours a year. A 90% availability suggests an availability of 7884 hours a year. In the real world, ability to use the vehicle will be impacted by a variety of factors, some of which cannot be controlled.

Regardless of the reasons why, the fleet owner pays for the lost ton/km that could have been produced. Assume 65% of the available hours per year. This equates to 5125 hours a year.

Assume the truck is operating in a 60 km/h zone. Assume further that 70% of the speed limit can be maintained, at say 42 km/h, making it possible to cover 215 250 km a year. At an average of 80% of an 80 km/h speed limit, the potential is 328 000 km a year. As is known, multi-drop vehicles working in metropolitan areas frequently cover 30 000 km a year or less. When this is so, efficiency is less than 14%. When the overall productivity measured in ton/km-hr is considered, the result is absurdly low:

Assume a 6-ton payload:

215 250 km x 6 tons = 1 291 500 ton/km

30 000 km x 3 tons = 90 000 ton/km
6.9 % efficiency (assumes full load but empty return leg)

The above example illustrates why transport is seen to be expensive by so many financial and other managers not informed about vehicle use and efficiency.

To achieve 1000 ton-km/hr at 48 km/h, a 20,83 ton payload capacity truck would be needed, or 2 x 10,41 ton trucks, or 3 x 6, 95 ton trucks, 4 x 5,2 ton trucks (decimals to be rounded off according to the task; turnaround time not included). If the average speed was 70% of the 60 km/h, one 23,8 ton truck would be needed, or three 7.94 ton trucks, and so on.

The example highlights possibilities for trading- ff average speed against payload. Invariably, high payload capacity contributes to economical transport. This is particularly so in long haul, big-rig operations.

Payload factors:

Two factors contribute to payload. The first is the tar (or unladen mass) when the vehicle is road ready and the second is the gross vehicle mass (GVM). The GVM is limited by the vehicle manufacturer's specification or by legal limits set by legislation.

Payload has a considerable impact on ownership costs – the capital cost per payload ton. Large trucks cost less than smaller vehicles. Smaller trucks are chosen for logistical reasons. Here are a few current examples of capital cost per payload ton (figures sourced from Fleetwatch's operating cost benchmarks, and correct at the time of writing):

Payload capacity (tons)	cost per payload ton
3	R75 000 – panel van
5,5	R130 000 – insulated volume van
8,5	R60 000 – flat-deck truck

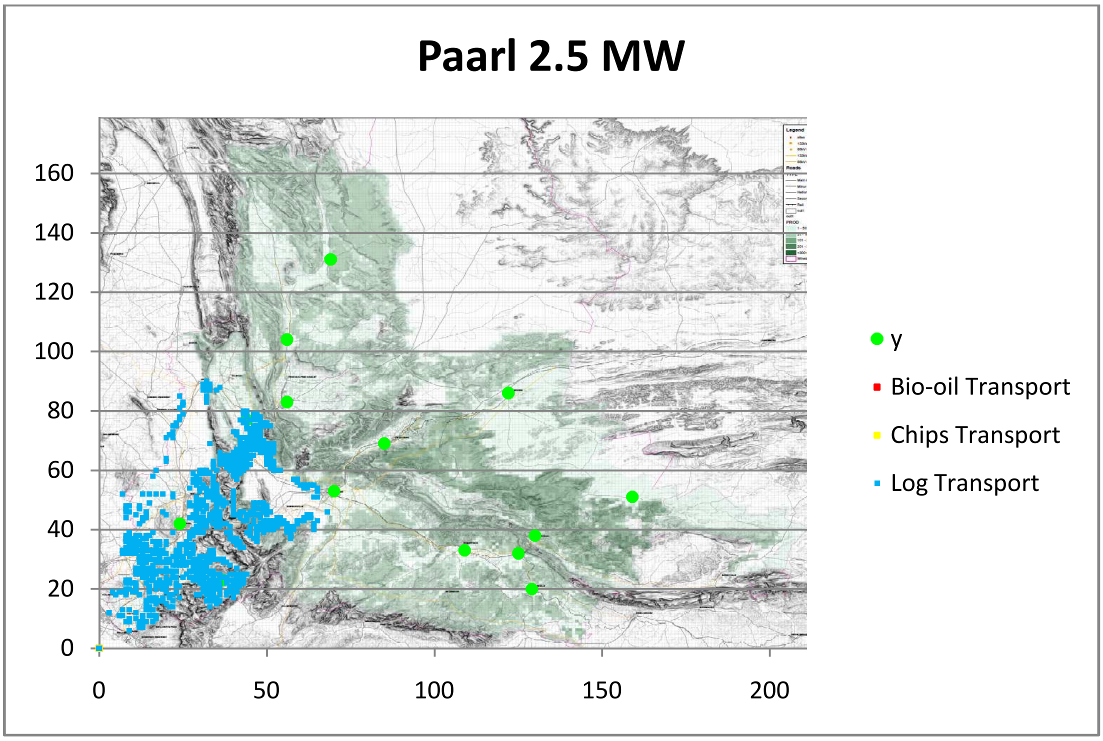
30	R39 000 – 6-axle articulated rig
35	R37 000 – 7-axle interlink

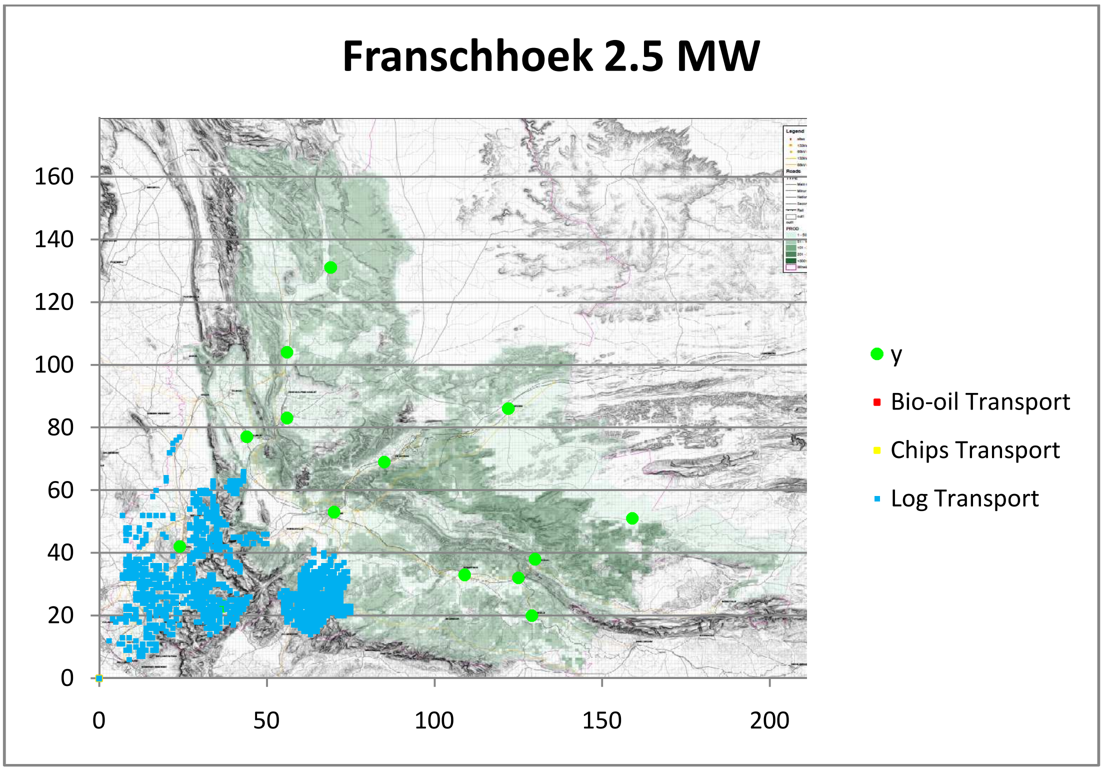
Tare and gross allowable mass are the determining factors. Therefore, when evaluating a truck, its payload efficiency should be examined. A measure of payload efficiency is striving for the optimum payload GVM ratio.

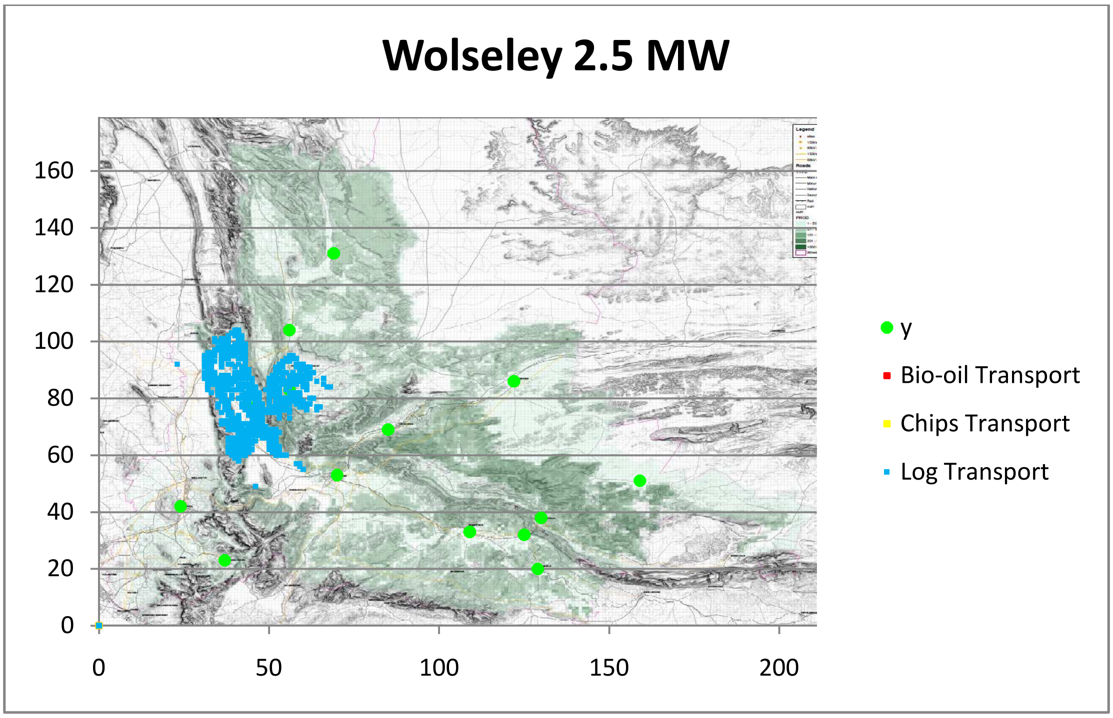
Rigid vehicles: > 55% to 60% of GVM

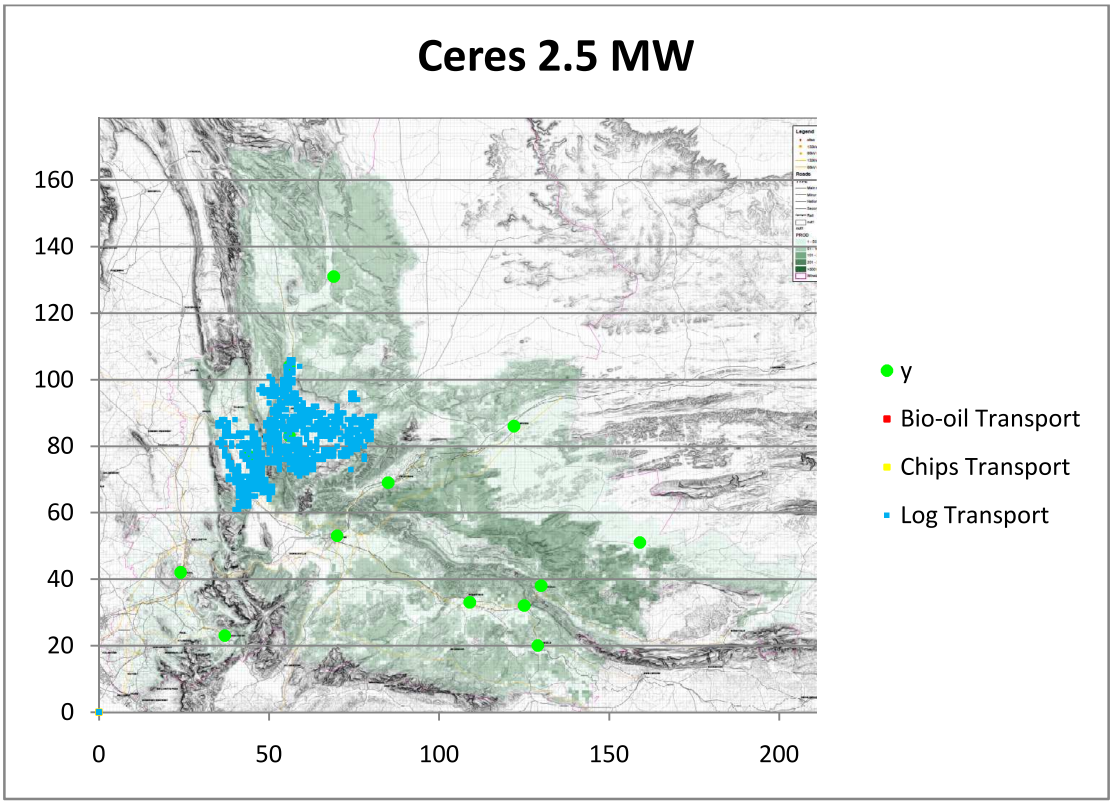
Articulated: > 60% of GCM.

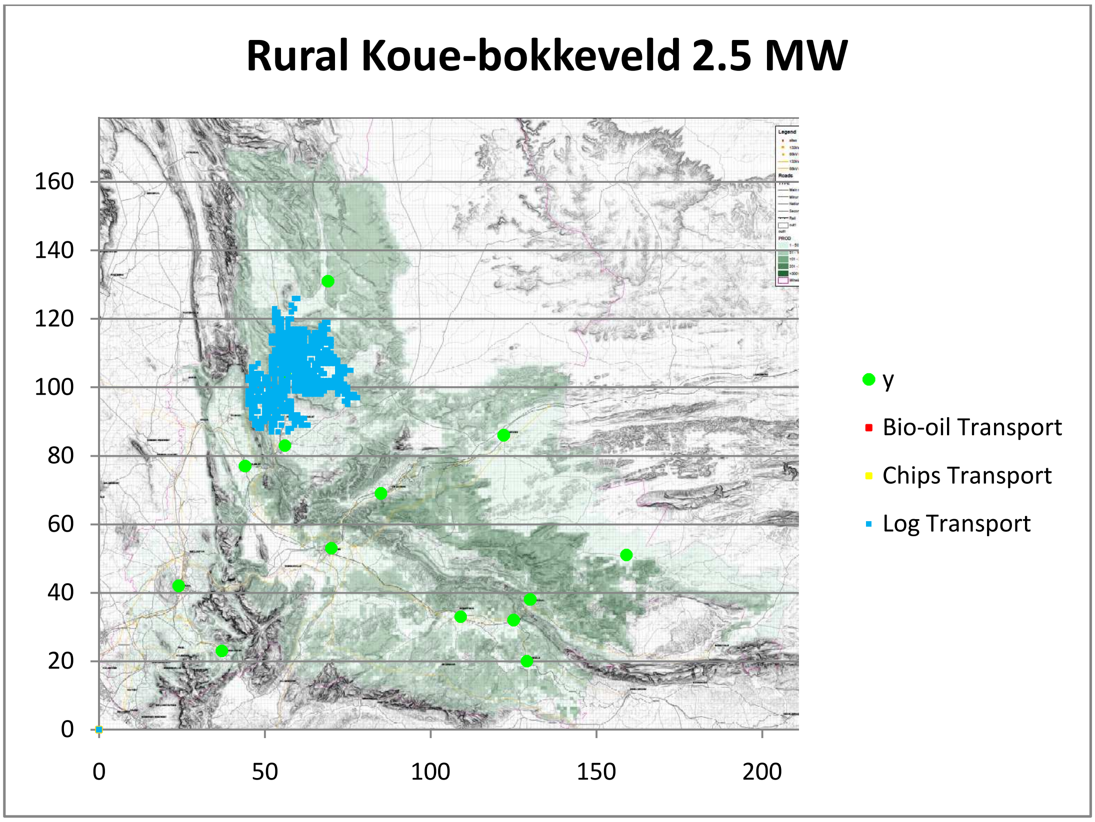
Appendix 10: 2.5 MW plant production areas for each demand point

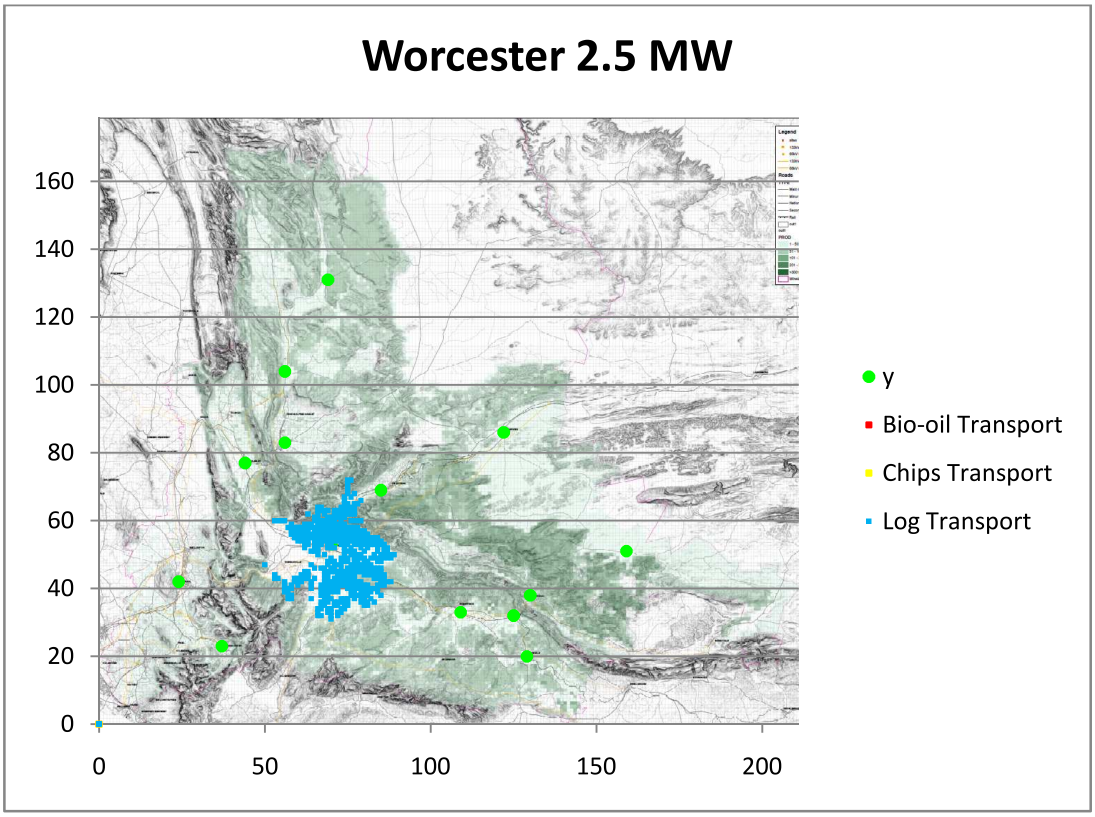


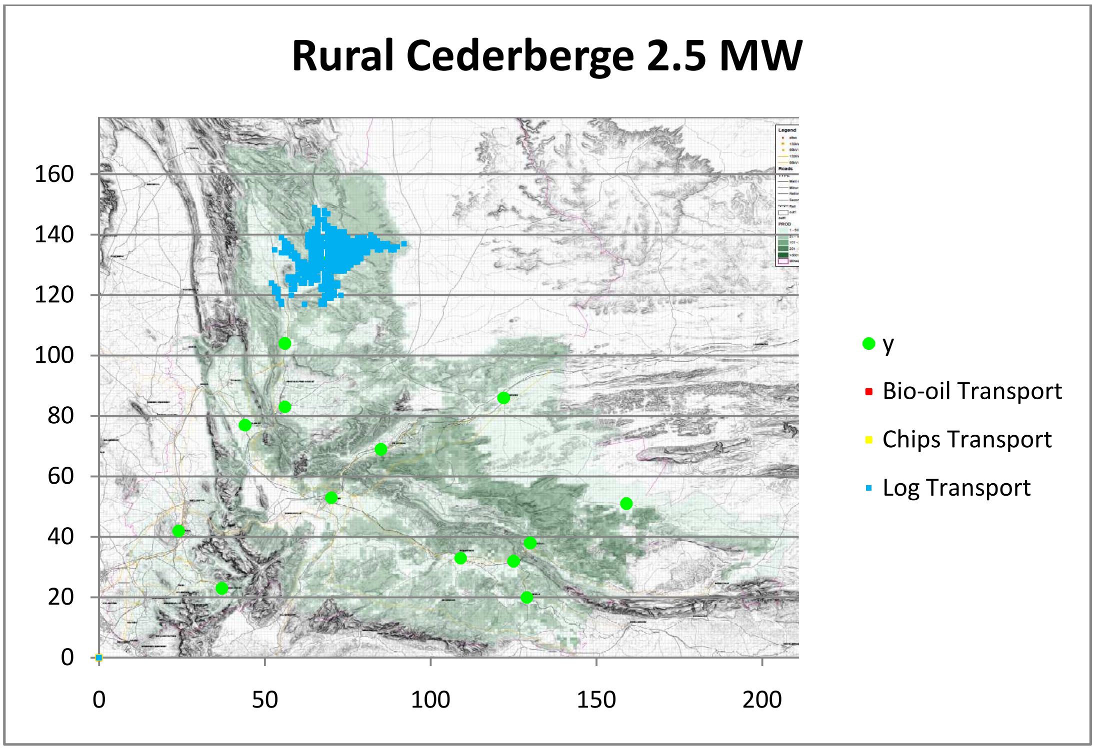


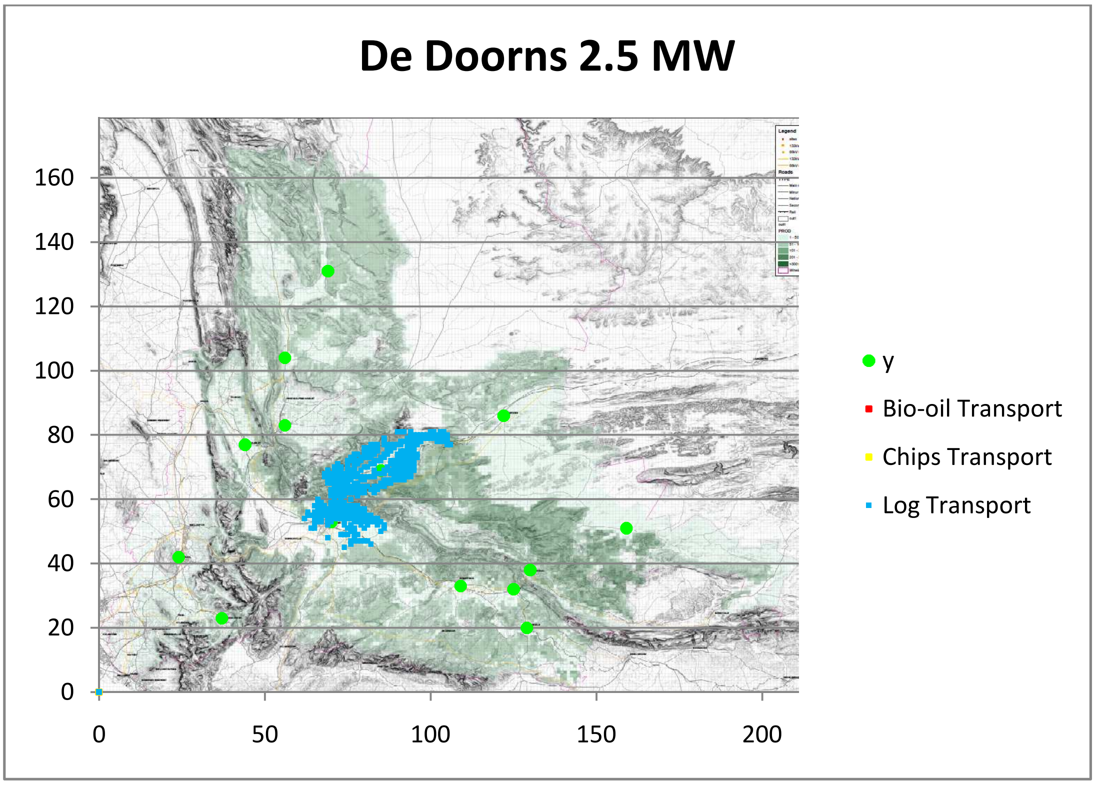

Wolseley 2.5 MW
160
140
120
100
80
60
40
20
0
0
50
100
150
200
y
Bio-oil Transport
Chips Transport
Log Transport

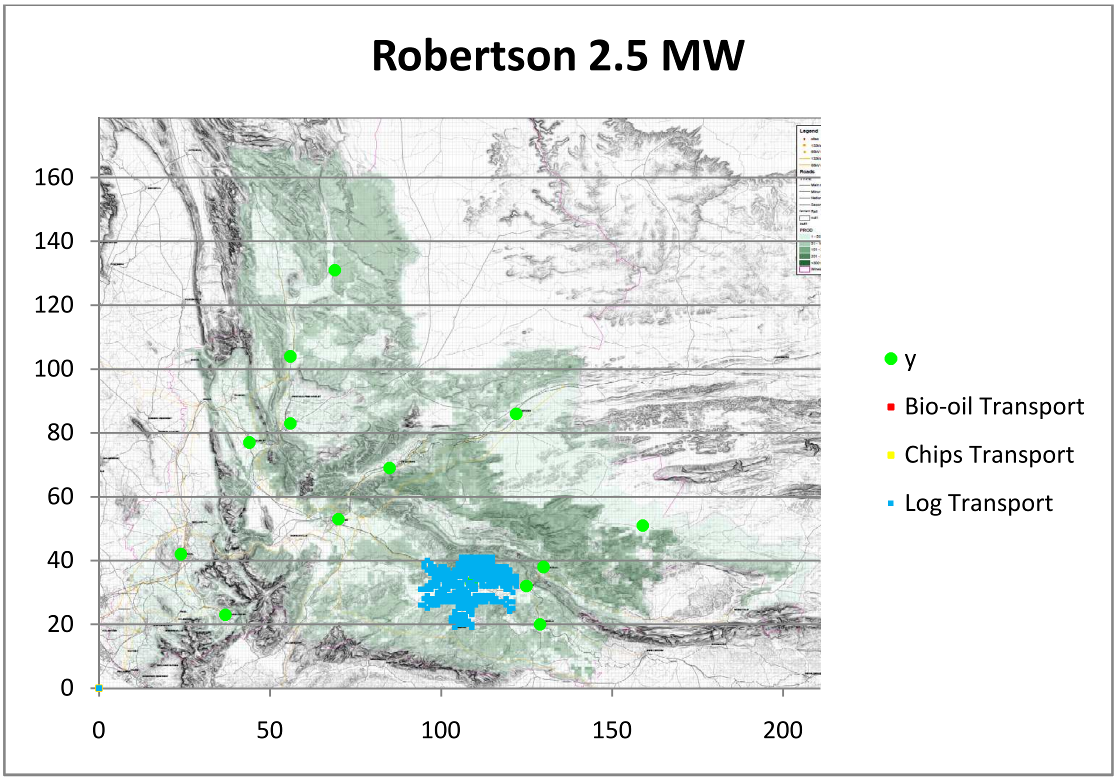

Ceres 2.5 MW
160
140
120
100
80
60
40
20
0
0
50
100
150
200
y
Bio-oil Transport
Chips Transport
Log Transport

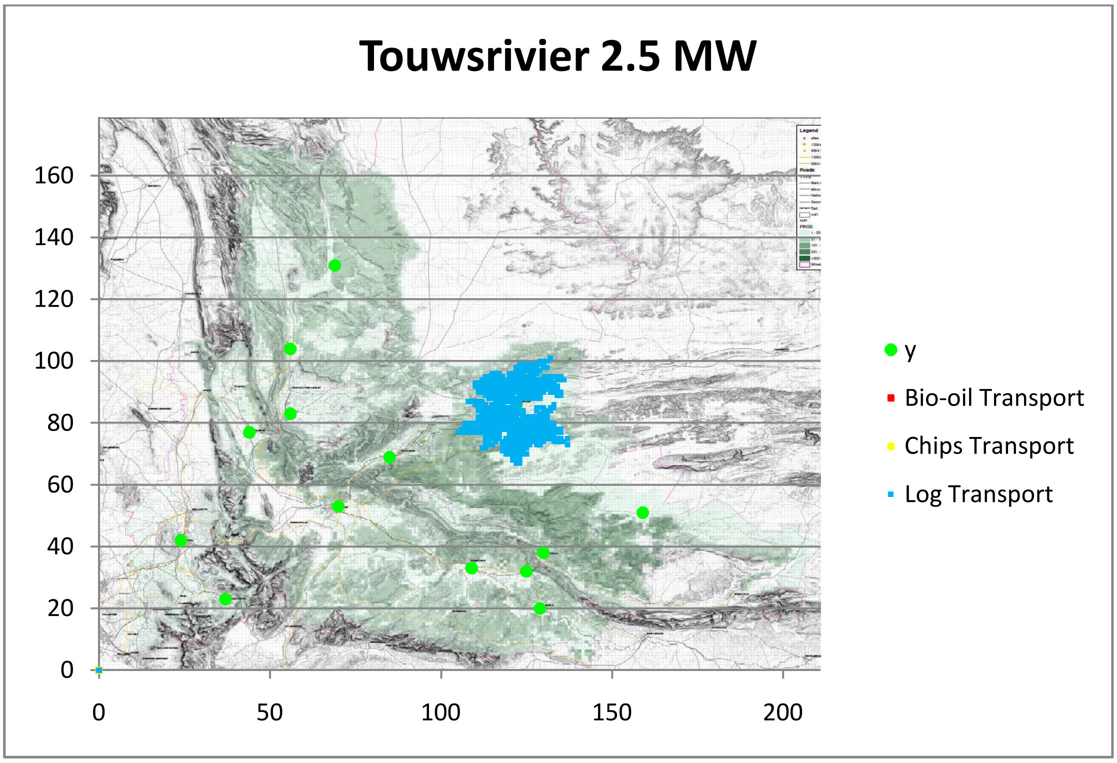

Rural Koue-bokkeveld 2.5 MW
160
140
120
100
80
60
40
20
0
0
50
100
150
200
● y
■ Bio-oil Transport
■ Chips Transport
■ Log Transport

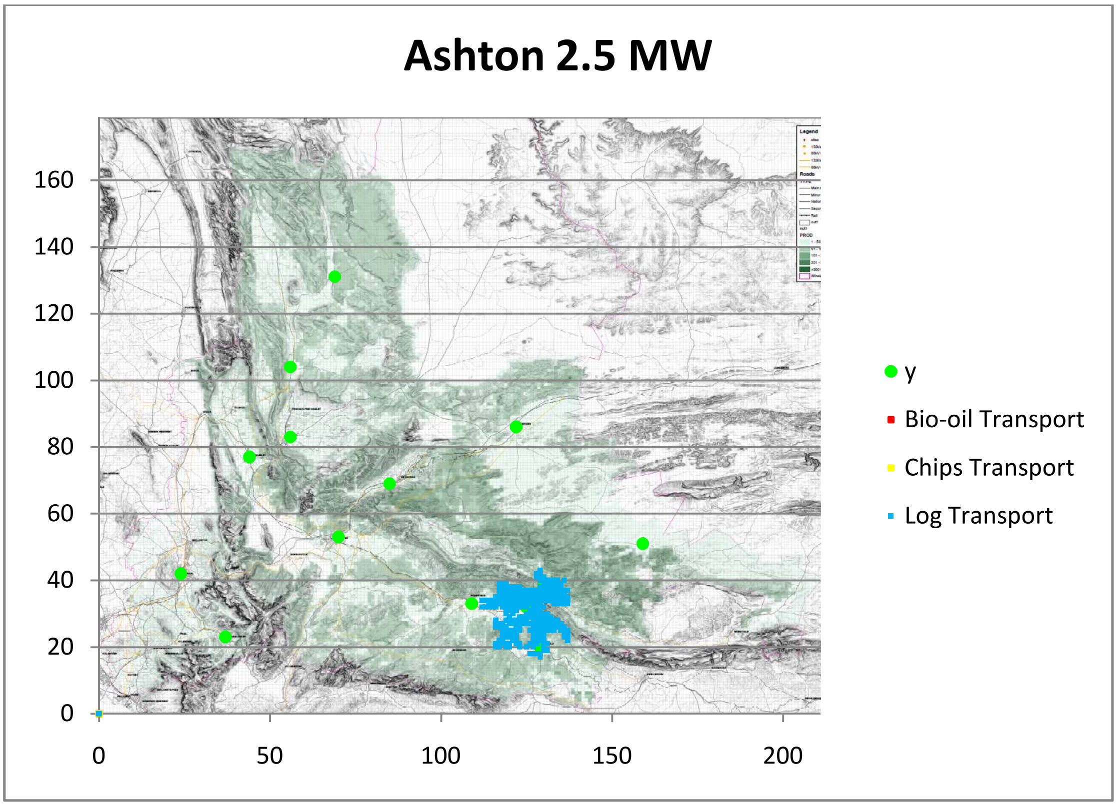

Worcester 2.5 MW
160
140
120
100
80
60
40
20
0
0
50
100
150
200
● y
■ Bio-oil Transport
■ Chips Transport
■ Log Transport

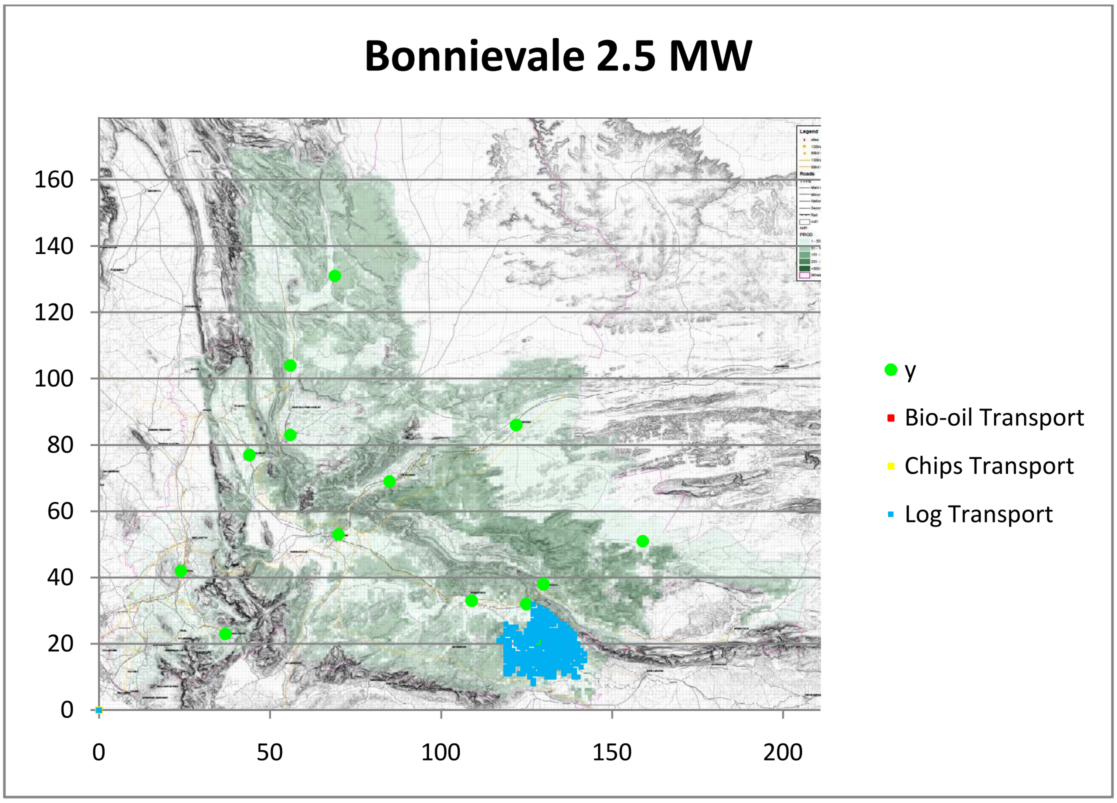

Rural Cederberge 2.5 MW
160
140
120
100
80
60
40
20
0
0
50
100
150
200
● y
🟥 Bio-oil Transport
🟨 Chips Transport
🟦 Log Transport

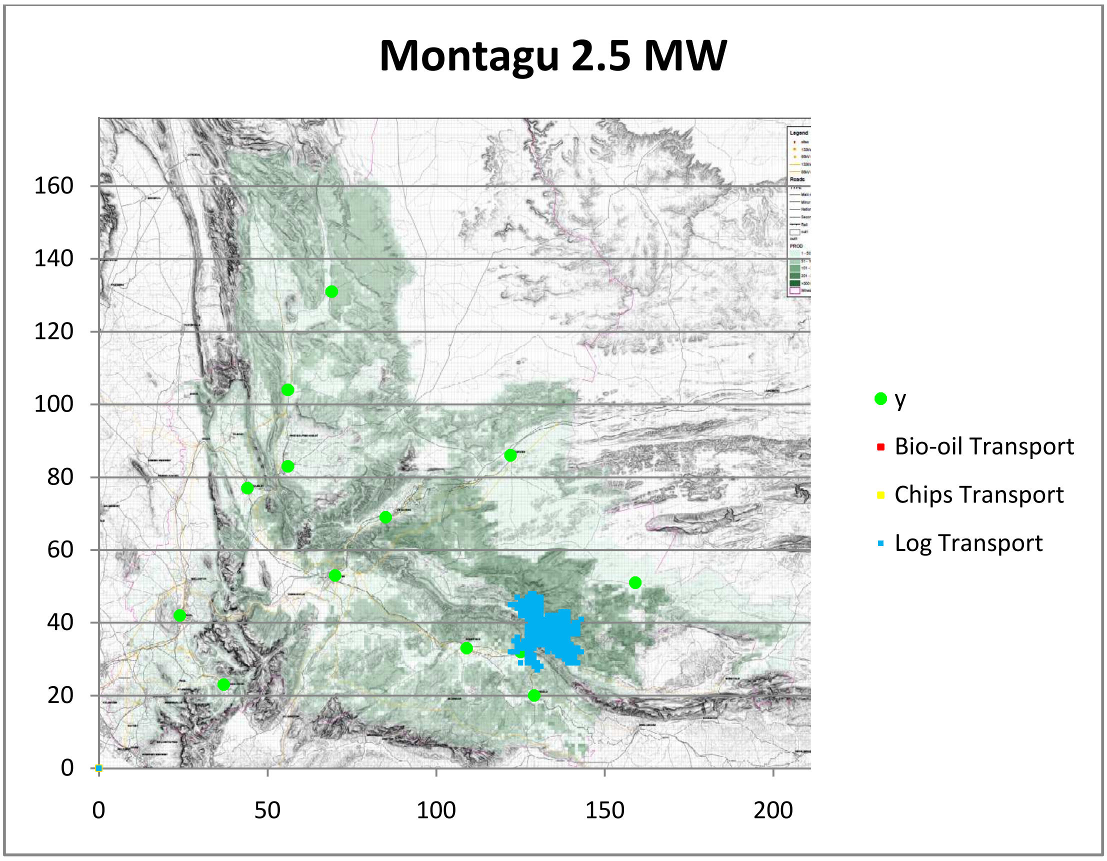

De Doorns 2.5 MW
160
140
120
100
80
60
40
20
0
0
50
100
150
200
● y
🟥 Bio-oil Transport
🟨 Chips Transport
🟦 Log Transport

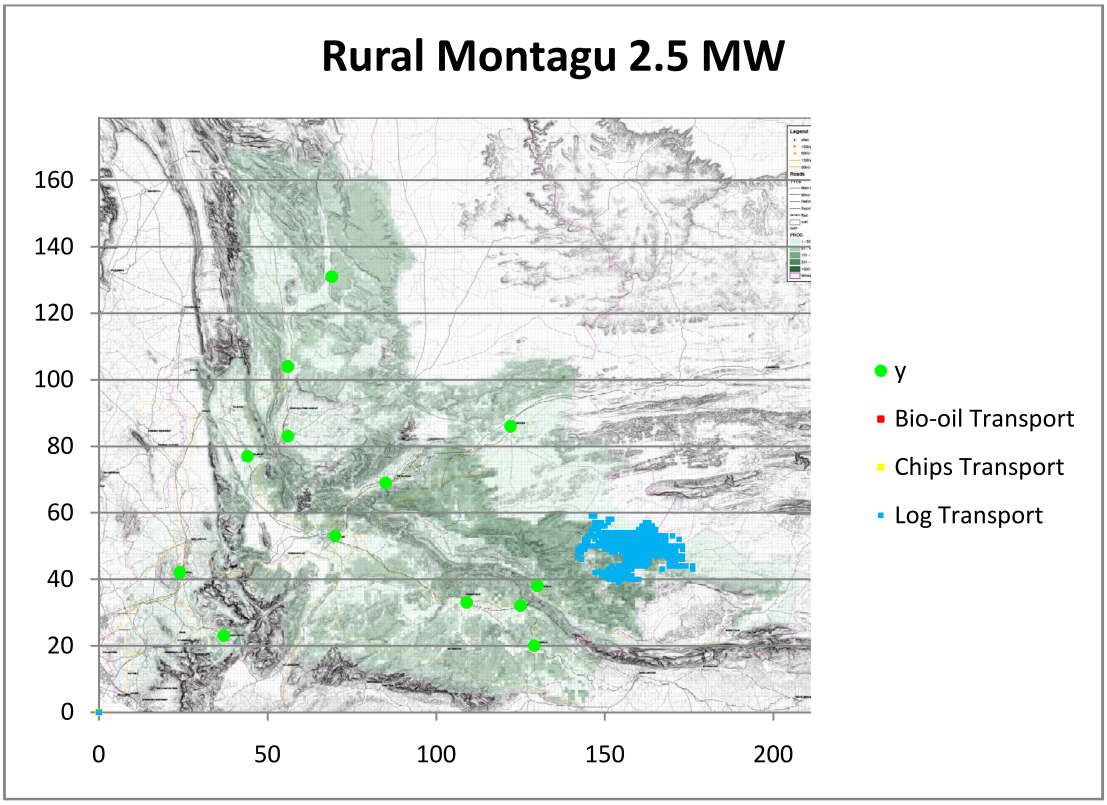

Robertson 2.5 MW


Touwsrivier 2.5 MW

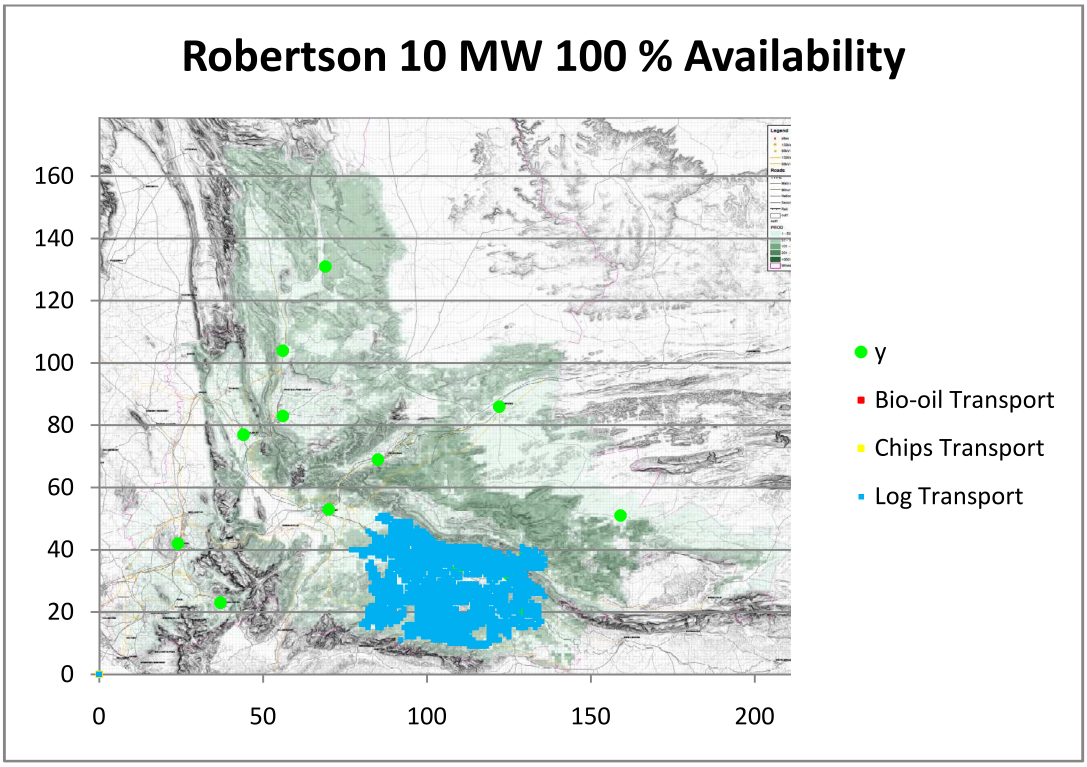

Ashton 2.5 MW
160
140
120
100
80
60
40
20
0
0
50
100
150
200
● y
■ Bio-oil Transport
■ Chips Transport
■ Log Transport

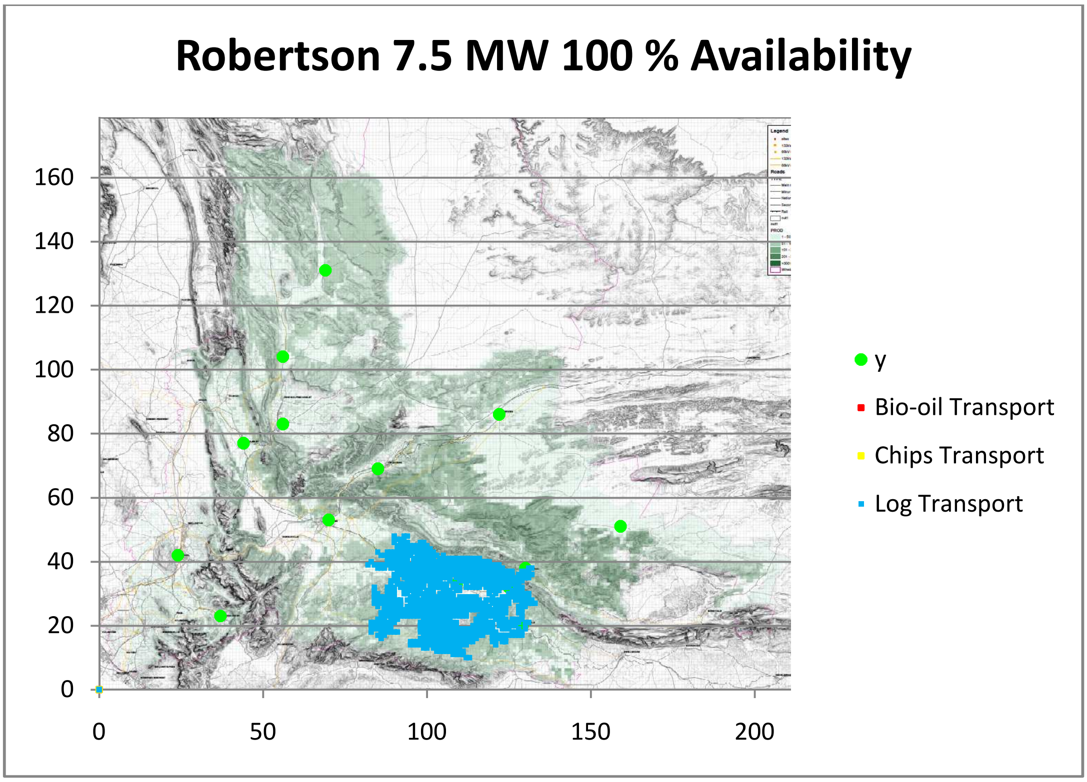

Bonnievale 2.5 MW
160
140
120
100
80
60
40
20
0
0
50
100
150
200
● y
■ Bio-oil Transport
■ Chips Transport
■ Log Transport

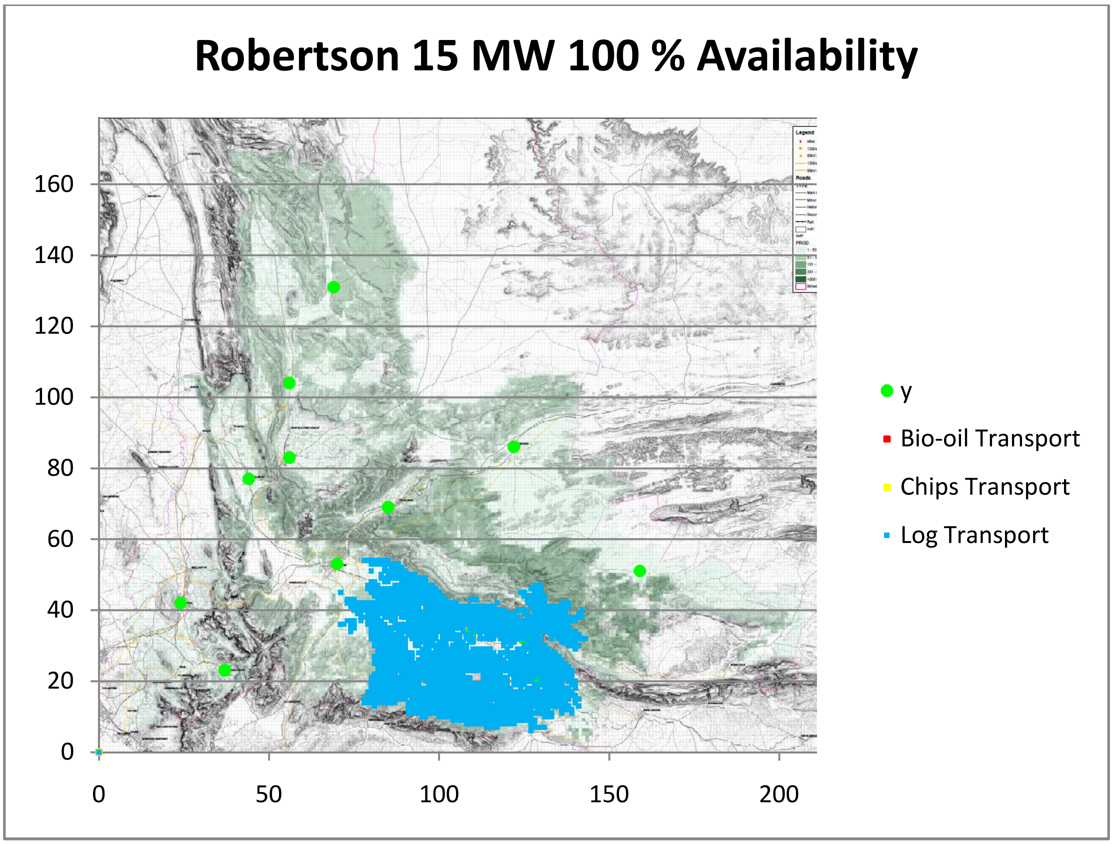

Montagu 2.5 MW
160
140
120
100
80
60
40
20
0
0
50
100
150
200
● y
🟥 Bio-oil Transport
🟨 Chips Transport
🟦 Log Transport

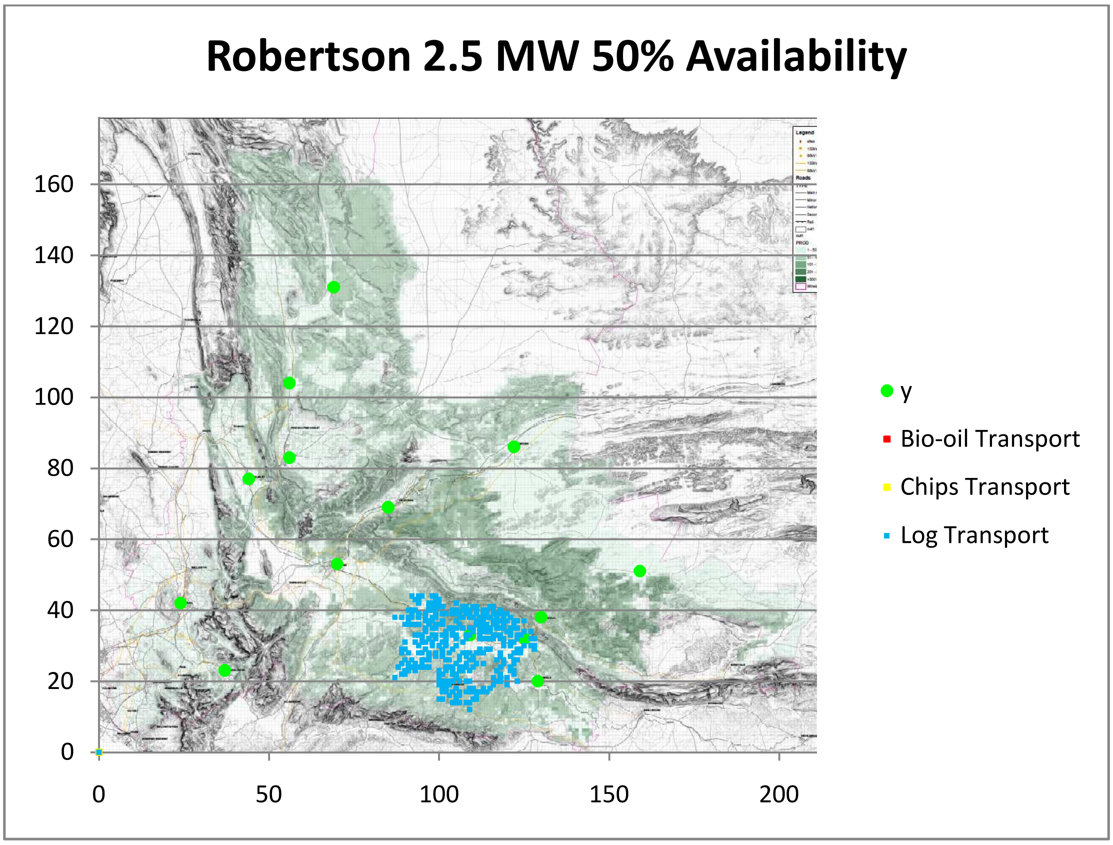

Rural Montagu 2.5 MW
160
140
120
100
80
60
40
20
0
0
50
100
150
200
● y
🟥 Bio-oil Transport
🟨 Chips Transport
🟦 Log Transport

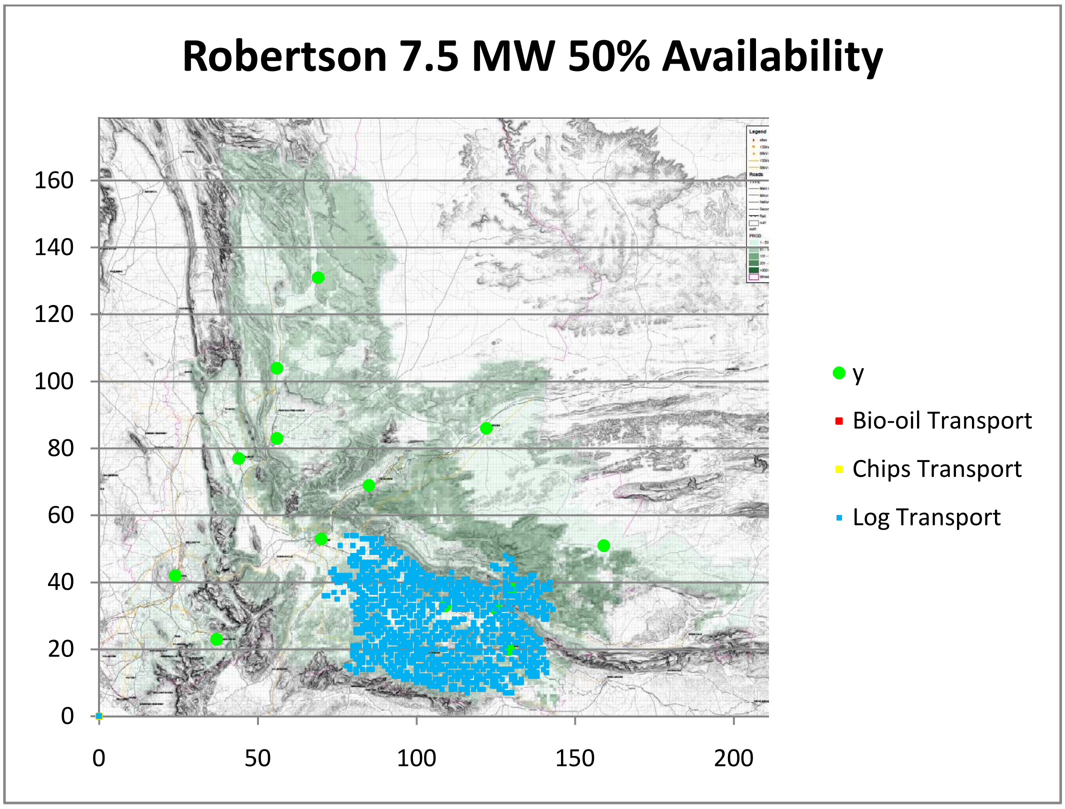
Appendix 11: Production areas for different plant sizes at different participation factors

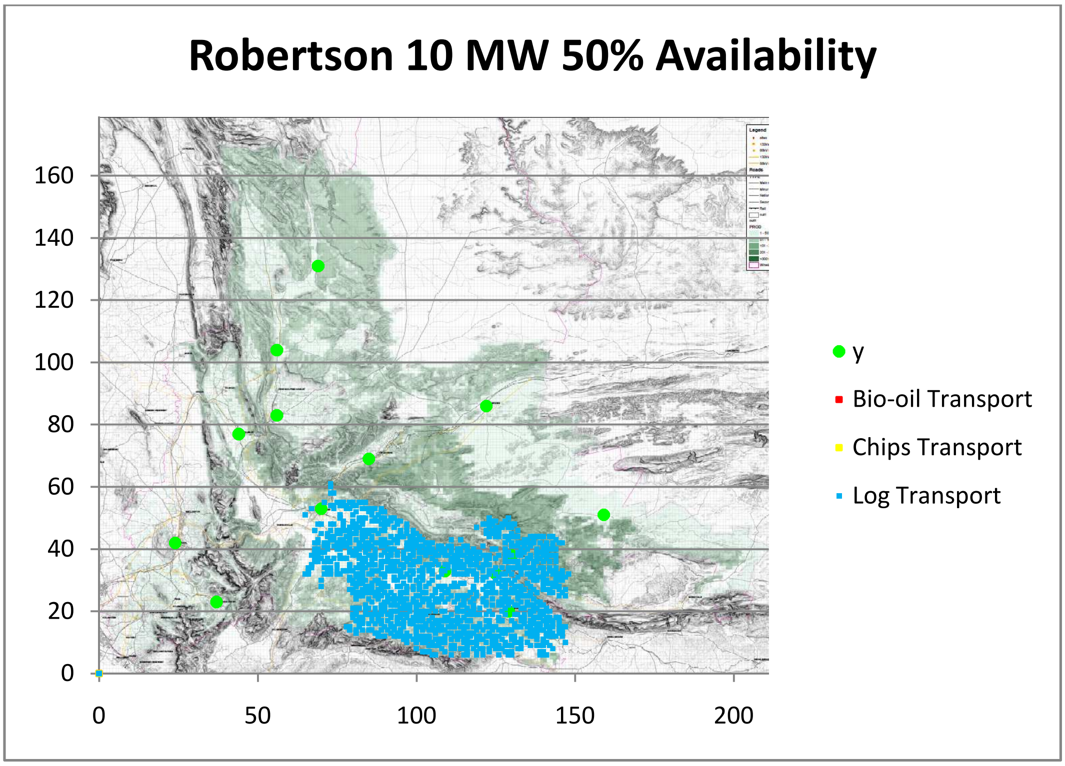


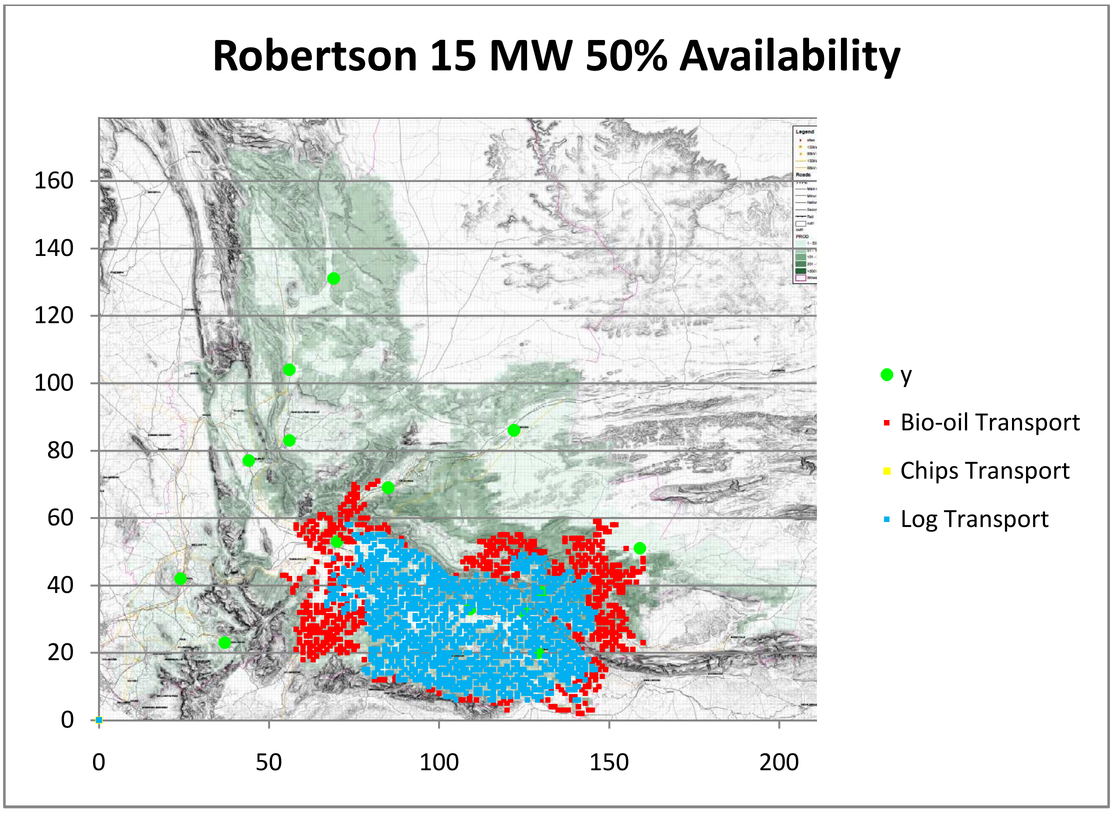


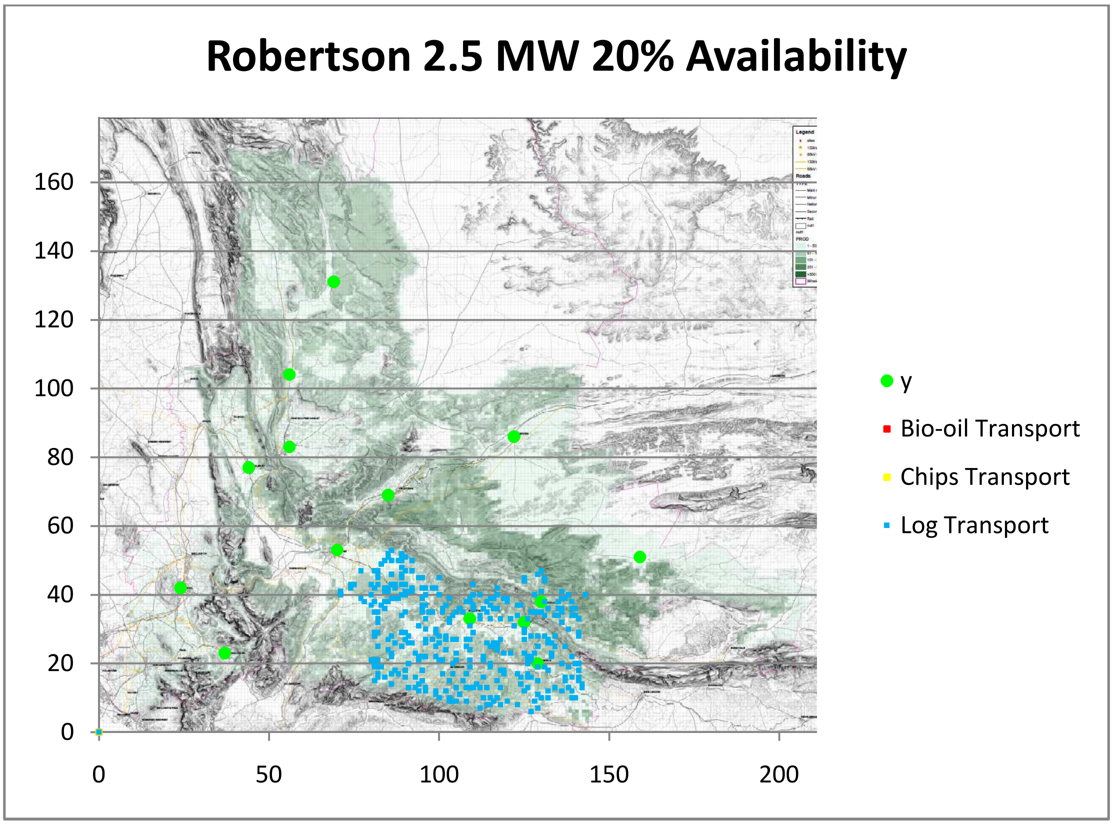

Robertson 15 MW 100 % Availability
160
140
120
100
80
60
40
20
0
0
50
100
150
200
● y
🟥 Bio-oil Transport
🟨 Chips Transport
🟦 Log Transport


Robertson 2.5 MW 50% Availability
160
140
120
100
80
60
40
20
0
0
50
100
150
200
● y
🟥 Bio-oil Transport
🟨 Chips Transport
🟦 Log Transport


Robertson 7.5 MW 50% Availability
160
140
120
100
80
60
40
20
0
0
50
100
150
200
y
Bio-oil Transport
Chips Transport
Log Transport


Robertson 10 MW 50% Availability
160
140
120
100
80
60
40
20
0
0
50
100
150
200
y
Bio-oil Transport
Chips Transport
Log Transport


Robertson 15 MW 50% Availability
160
140
120
100
80
60
40
20
0
0
50
100
150
200
● y
▪ Bio-oil Transport
▪ Chips Transport
▪ Log Transport


Robertson 2.5 MW 20% Availability
160
140
120
100
80
60
40
20
0
0
50
100
150
200
● y
▪ Bio-oil Transport
▪ Chips Transport
▪ Log Transport

CD 1: Additional information and data CD