Utrecht University

The potential of sugar beet for the biobased economy in the south west of The Netherlands

Energy Science Master Thesis (30 ECTS)

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Abstract

The Netherlands has been cultivating sugar beet in large agro-industrial co-operatives since the 19th century. In recent years, the sugar quota has limited sugar beet cultivation but the quota will expire in 2017. At the same time, the Dutch government aims to stimulate the biobased economy, therefore increasing the demand for biomass. For example, the proposed biorefinery project REDIFINERY is expected to consume four million tonnes of feedstock per year.

Several studies indicate that, with the increase in demand, large amounts of biomass are imported to The Netherlands, while locally cultivated biomass shows economic potential at world market prices. Therefore, in this research, the geographic potential of locally cultivated sugar beet as a biomass resource for non-food purposes in the south west of The Netherlands is determined up to 2030. This is achieved by using ArcGIS software, creating maps of the sugar beet yields and costs. These cover the whole research area of the south west of The Netherlands, and, then in more detail, the province of South Holland. Scenarios from PBL/CPB (WLO scenarios) are used to determine agricultural land availability for non-food purposes, and KWIN AGV data is used to determine the cost of cultivation. To determine the transport costs, a demand node is assumed on the Maasvlakte. Other important inputs in to the model are; soil type, experience with sugar beet cultivation and transport distance. To determine the potential, the findings are benchmarked against imported lignocellulosic biomass sources. The supply costs found are extrapolated until 2030 to determine the future of sugar beet as a biomass source and as a stepping stone for the Dutch biobased economy. Finally, the greenhouse gas (GHG) emissions of the locally grown sugar beets are compared to imported biomass.

In the south west of The Netherlands, the theoretical potential is estimated to be 198.8PJ (52Mt sugar beet, 8,946kt fermentable sugar). The technical potential, limited by the crop rotations and WLO scenarios, is estimated to be 1.9PJ (0.490Mt sugar beet, 84kt fermentable sugar). The economic potential, limited by the technical potential, is estimated to be 1.9PJ (0.490Mt sugar beet, 84kt fermentable sugar). If the province of South Holland is examined in detail, the theoretical potential is estimated to be 39.2PJ (10.3Mt sugar beet, 1.76Mt fermentable sugar); the technical potential, limited by crop rotations and land availability without harming the food and feed supply, is estimated to be 0.4PJ (0.094Mt sugar beet, 16kt fermentable sugar). The economic potential, again limited by the technical potential, is estimated to be 0.4PJ (0.094Mt sugar beet, 16kt fermentable sugar). The net present value (NPV) of the business as usual (BAU) and bio economy crop rotations are compared in South Holland and they show that the NPV would increase when sugar beet is increased in the rotation. The data, with the addition of lower and higher limits, is shown in table 1. The 0.49Mt of sugar beet cultivated for non-food purposes in the south west of The Netherlands makes a large contribution to the 1.6Mt currently cultivated. The 0.094Mt of sugar beet cultivated for non-food purposes in the province of South Holland also substantially contributes to the 0.3Mt currently cultivated. However, when the potentials found in the south west of The Netherlands are compared to the demand, which is set to rise, by the REDIFINIERY project for example, it will only be a small contribution.

Table 1 Theoretical, Technical and Economic potential of sugar beet cultivation found in this thesis

	Area	Reference case PJ (total yield[1])	Lower limit PJ (total yield[1])	Higher limit PJ (total yield[1])
Theoretical Potential	SW-N[3]	198.8 (52 - 8,946)	N.A.	N.A.
	SH[2]	39.2 (10 - 1,763)	N.A.	N.A.
Technical Potential	SW-N[3]	1.9 (0.49 - 84)	1.0 (0.253 - 43)	1.9 (0.490 - 84)
	SH[2]	0.4 (0.094 - 16)	0.2 (0.063 - 11)	0.4 (0.094 - 16)
Economic Potential	SW-N[3]	1.9 (0.490 - 84)	0.1 (0.029 - 5)	21.9 (5.7 - 986)
	SH[2]	0.4 (0.094 - 16)	0.1 (0.018 - 3)	4.4 (1.2 - 200)

The costs calculated are benchmarked against sugar production costs from imported lignocellulosic biomass and global raw sugar prices until 2030. The results show that Dutch sugar beet cultivation costs are projected to remain below global market prices for raw sugars, fermentable sugars derived from woodchips, and fermentable sugars derived from wood pellets until 2030. Lastly, the GHG emissions of ethanol from sugar beet are compared to those of woodchips, assuming that ethanol will be produced. The GHG emissions of sugar beet ethanol range from 38 to 40g CO_2-eq/MJ ethanol and a GHG-saving performance of between 52% and 53%. This is insufficient to meet the EU Renewable Energy Directive (RED) (2009/28/EC) threshold for liquid biofuel installations installed after 2018 (60%).

Sugar beet cultivation in the south west of The Netherlands can compete economically until 2030 in the world biomass market. It has a total potential of 0.49Mt of sugar beet cultivated at or below world market prices. This increases even further if technical constraints on competition with the food supply are not taken into account.

[1] Mt Sugar beet - kt fermentable sugar
[2] Province of South Holland
[3] Southwest Netherlands

List of abbreviations

BAU: Business As Usual

CO_2-eq: Carbon dioxide equivalent, standardised measurement of greenhouse gasses.

CPB/PBL: Centraal Plan Bureau/Plan Bureau Leefomgeving - governmental bureaux analysing Dutch society.

Fermentable sugars: a platform molecule which can be used for different applications in the biobased economy.

GHG: Greenhouse Gas

ha: hectare (10,000 m^2)

LCA: Life Cycle Assessment, a technique to assess environmental impacts associated with all the stages of a product's life from cradle to grave

LHV: Lower Heating Value, throughout this thesis the LHV is used unless mentioned otherwise.

NPV: Net Present Value, the sum of the present values of incoming and outgoing cash flows over a period of time.

t: tonne (1,000kg)

wb: wet based

WLO: Welvaart en Leefomgeving - scenarios used to determine the amount of land available for sugar beet cultivation for non-food purposes

WM: Wet Material

Table of Content

1. Introduction

Large-scale cultivation of sugar beet and processing into sugar by growers and beet-processing co-operatives dates back to the 19th century (Suikerunie, 2015). While production increased from the 19th century onwards, in the late 20th and early 21st centuries, sugar production facilities in Halfweg (Sugar City, 2015), Breda (Vrij Nederland, 2005), and Groningen (Trouw, 2008) were closed mainly due to economies of scale and the sugar quota. The Dutch sugar beet industry cultivated 4.8Mt per year on $58*10^3$ ha of the 2 million ha of arable land in The Netherlands in 2015 (CBS, 2015). The average yield of sugar beet today in The Netherlands ranges from 78 t/ha (FAOSTAT, 2015) to 91 t/ha (IRS, 2014). Yields of sugar beet cultivation in The Netherlands are high due to the good soil conditions, advanced levels of agricultural management, and cultivation techniques used by farmers. (Deloitte, 2014). Today, sugar beets are mainly used to make edible sugar. However, recent technological improvements have enabled further conversion of sugars into biofuels and chemicals like bioplastics (Harmsen, et al., 2014) (Deloitte, 2014). A small fraction of the total sugar beet production is used for biofuels (ethanol) in The Netherlands today. See appendix A-5 (Goh & Junginger, 2015).

In 2014, 111PJ of renewable energy was generated in The Netherlands of which 79PJ came from biomass. While biomass is imported to reach these targets, in total 75% of all biomass used in The Netherlands is domestic. The remaining 25% of the biomass is imported: 10% from the EU and 15% from non-EU countries. The imported biomass primarily consists of biofuels and wood pellets for firing in power plants (Agentschap NL, 2013). More information on the domestic and imported biomass is provided in appendices A-3 and A-4. The total contribution of renewable energy must increase from 5.6% today up to 14% as agreed on in the Renewable Energy Directive (EU RED, 2009). Furthermore, the Dutch government has set a target that 16% of total generated energy should come from renewable origins by 2023, as laid down in the Energy Agreement (Energieakkoord) (Agentschap NL, 2013). Biomass is expected to remain the largest source of renewable energy and import levels will increase but this will also create opportunities for domestic supply. In 2007 the Ministry of Agriculture, Nature and Food set out a vision to create a biobased economy. This vision included plans to reduce the CO_2 emissions, link the biobased economy with Dutch chemistry, logistic and agro sectors - and play an active role in international co-operation (Verburg, 2007). This ambition was specified further in 2012 when the government finalised an innovation contract for the biobased economy, elevating the biobased economy above regulatory barriers that were hampering innovation (Werkgroep biobased economy 2.0, 2012).

An example of increasing the Dutch interest in bio energy is the Bio Port of Rotterdam initiative. This initiative was set out to make the port of Rotterdam a main hub in the global bio energy trade. The Port of Rotterdam has planned to cluster CO_2 storage; biochemical and fuel production facilities; jetty storage; and mixing facilities. Building these facilities will increase efficiency, synergy, and knowledge spill-overs (Port of Rotterdam, 2014). The Bio Port of Rotterdam plans to create a biorefinery using fermentable sugars from lignocellulosic, called REDIFINERY. See text box.

The increasing demand of biomass for non-food purposes potentially increases the demand for fermentable sugars. Pre-treatment technologies designed to make fermentable sugars from lignocellulosic biomass are still in the early stages (technology readiness level four to seven) of commercialisation (TKI BBE, 2015). The sugar quota[4] will expire in 2017 while recent studies on the cost of Dutch sugar beet production show that The Netherlands can compete with Brazilian sugar cane. While next-generation biomass sources are not yet capable of coping with the demand, sugar beet can be cultivated at this moment. This creates a simultaneity in production and demand and, therefore, creates opportunities for increasing sugar beet cultivation in The Netherlands (Deloitte, 2014) (Todd, 2015). This means that sugar beet could be used as a stepping stone until other biomass sources become fully commercial.

REDIFINERY project

The project consists of multiple partners in the biobased cluster Rotterdam, aiming to establish a biomass refinery on the Maasvlakte in 2020. Its design allows it to run on multiple sources of biomass, from lignocellulosic wood residues to sugar beet and sugar corn. The total investment in the project is budgeted at 4 billion euros, with a capacity of 4 million tonnes of lignocellulosic biomass input per year. This biomass refinery creates a stepping stone towards a biobased economy in The Netherlands. There is expected to be a total CO_2 emission reduction of 6-8Mtpa per biorefinery with a 4Mtpa lignocellulosic biomass input by 2030 (REDIFINERY, 2015). The REDIFINERY project’s size, demand, and location is used as a reference for the biorefinery throughout this thesis.

1.1 Problem definition

In recent years, significant research has been carried out on determining crop potentials. However, due to non-heterogeneity in the methodologies, results from the same area have varied. To solve this problem, two guidelines have been released: first of all *Harmonising bioenergy resource potentials - Methodological lessons from review of state of the art bioenergy potential assessments* (Batidzirai, Smeets, & Faaij, 2012), and secondly the *Best Practices and Methods Handbook* (Biomass Energy Europe, 2010). Batidzirai, Smeets, and Faaij (2012) focus on the short-comings of earlier research, and on what problems commonly arise with bioenergy potential assessments. Biomass Energy Europe (BEE) is an EU FP7 project with 16 partners with the objective to improve the accuracy and comparability of bioenergy assessment research. BEE provides methods in four categories of biomass: forest biomass, energy crops, agricultural residues, and organic waste.

Bioenergy potential assessments are conducted worldwide. Batidzirai, Smeets, and Faaij (2012) gave example articles in five regions including the US, China, India, Indonesia, and Mozambique. Their study focussed on giving an overview of what was done for these countries. Single studies assessing the bioenergy potential commonly use either geographical information systems (GIS), or a land-use model. Diego et al. (2014) and Fischer et al. (2010) are an example of using a land-use model to assess the potential. These models focus on what possible land use

[4] The sugar quota sets creates two prices, one sugar price for consumer purposes, which is set by the quota, and one for industrial purposes, set by global market prices. With the expiration of the quota set for 2017 it is expected that the consumer price will decrease since the EU will not be paying the price premium set by the quota. In contrary, the industrial price will increase since the price difference between the consumer price and industrial price will seize to exist. (Harmsen, et al., 2014). The higher sugar price for non-food purposes will increase the profitability of sugar beet cultivation, which could spike the interest of farmers.

changes could occur, and on which soils offer opportunities for other bioenergy. Articles based on GIS commonly are more comprehensible because of their inputs, and calculations. For example, Graham, English, and Noon (2000) study the potential of crops in the U.S. by using GIS. For this thesis, the article by van der Hilst et al. (2010) has more relevance because of its use of sugar beet and because of the authors' location which is The Netherlands. Since the research area of this thesis is relatively small, the spatial explicit method of GIS is the most suitable.

Besides differences in methodology, the research differs in scope. As noted previously, the scope of research carried out by Batidzirai, Smeets, and Faaij (2012) and the BEE (2010) was global. However, with a global scope, only a general assessment of the potential can be made. To be more precise, the scope would need to be narrowed. For example, the article by de Wit and Faaij (2010) on biomass potentials and costs in Europe offers more detail on the different countries, sources, and prices of biomass. This study, however, still lacks precise data on the potential for sugar beet as a biomass source in The Netherlands. The study of Koppejan et al. (2009) narrows the study area even further and takes The Netherlands as its scope, but focusses on biomass sources other than sugar beet. In accordance with the recommendations from BEE (2010), greater detail is used in the the article by van der Hilst et al. (2010), which examines the north of The Netherlands. This research has a focus on the feedstock potential of miscanthus and sugar beet, which are also useable in the biobased chemical industry. Assessing the complex matter of the economic potential is carried out by comparing the spatial NPV (Net Present Value) of the crop. However, transportation from the north of The Netherlands to the Bio Port of Rotterdam is a considerable expense. Therefore, biomass potentials in closer proximity to the bio port should be examined in great spatial detail.

Different spatial scopes create different spatial detail on biomass potentials. the *Outlook on spatial biomass chains in EU28* done by Elbersen et al. (2015), for example, covers an extensive amount of biomass types and regions. Their research focusses on the total biomass potential for the EU at NUTS2 level for agriculture biomass, primary forestry, secondary forestry, landscape biomass, and waste. The total biomass potential for all sectors in these 28 EU countries in 2010 accumulates to 9,219PJ, increasing to 10,722PJ in 2020 and 11,393PJ in 2030. The total biomass potential for The Netherlands was estimated at 139.1PJ in 2010, increasing to 141.7PJ in 2020 and 142.7PJ in 2030, with waste being the primary Dutch source of biomass. The report also estimates an increase in first-category crops, especially sugar beet, from 1PJ in 2010 to 4.8PJ in 2030. Therefore, Elbersen et al. (2015) predict a modest but growing role for Dutch energy crop production. While the report is extensive in its scope, in some areas its explicit spatial information is limited to NUTS2 level, and it only mentions sugar beets briefly.

More detailed research on The Netherlands has been done by Koppejan et al. (2009). This research aimed to map the total biomass potential of The Netherlands. It concluded that the total potential of The Netherlands in 2009 was 124PJ[5]. This leaves a difference of 15.1PJ between the research done by Elbersen et al. (2015) and the research done by Koppejan et al. (2009). Koppejan included four different growth scenarios which gave biomass potentials ranging from 169PJ to 179PJ in 2020. These future scenarios increase the difference from 27.3 to 37.3PJ in comparison to Elbersen et al. (2015). The primary difference between them is the level of detail with Koppejan et al. (2009) investigating the Dutch biomass potential in greater detail.

[5] All values reported are LHV unless stated otherwise

However, the report by Koppejan et al. (2009) lacks explicit spatial detail and little importance is given to the biobased economy, especially sugar beet potentials.

Van der Hilst et al. (2010) determined the potential of miscanthus and sugar beet in the north of The Netherlands by using a spatial explicit approach. One of the results shows the technical potential if the total surface of arable land in the region were to be covered in sugar beet (134PJ) or miscanthus (155PJ). The total coverage of the arable land would not be a realistic scenario and so the NPV of the crops in rotation were determined in a spatially explicit way, showing locations with great potential for the crops. Lastly, the feedstock production costs were calculated for both miscanthus (€ 5.4/GJ) and sugar beet (€ 9.7/GJ).

While extensive research has been carried out in the north of The Netherlands, the south west of The Netherlands has not yet been investigated at such a level of detail. This region is in close proximity to the Bio Port of Rotterdam, which minimises the costs of transport. Furthermore, high yields are reported and, therefore, there is significant potential for bioenergy in this region (Todd, 2015) (Deloitte, 2014).

This thesis, therefore, investigates the potential for the bio energy sugar beet crop in the south west of The Netherlands. This is carried out using a GIS-based method that combines the knowledge gained from previous research (Hilst, et al., 2010) with available methodical guidelines (Biomass Energy Europe, 2010) (Batidzirai, Smeets, & Faaij, 2012). The cost of locally cultivated sugar beets is compared in this thesis with imported biomass today and in the future up to 2030.

1.2 Main question

Main research question

What is the economic potential for the locally grown biomass source sugar beet for non-food purposes (i.e. bioenergy and novel biobased materials), in comparison to importing biomass, in the south west of The Netherlands?

Sub questions:

1) What is the potential for sugar beet cultivation in the south west of The Netherlands?
   a) What is the theoretical potential of sugar beet cultivation in the south west of The Netherlands? With a focus on the Dutch province of South Holland.
   b) What is the technical potential of sugar beet cultivation for non-food purposes in the south west of The Netherlands? With a focus on the Dutch province of South Holland.
   c) What is the economic potential of sugar beet cultivation for non-food purposes in the south west of The Netherlands? With a focus on the Dutch province of South Holland.
2) When comparing the cost of sugar beet cultivation, found in the economic potential, to importing fermentable sugar, could the sugar beet cultivation in south west of The Netherlands be cost competitive?
3) What are the projected ranges of future prices of fermentable sugar and how do they compare with lignocellulosic biomass sources in the case study area up to 2030?

1.3 Scope

Cultivation - this research focusses on the cultivation of dedicated energy crops with particular attention paid to sugar beet. Therefore, it does not investigate the different possibilities relating to refining the biomass. Pre-processing carried out by the farmers, such as removing dirt and leaves, is taken into account.

Import - both the world sugar price and the fermentable sugar prices from lignocellulosic sources are used for comparison. Starch and other sources of imported biomass are not included.

Time period - the comparison of sugar beet and imported biomass takes place from 2015 to 2030, taking into account developments in agriculture and technological change (learning) of lignocellulosic biomass pre-treatment technologies.

South west of The Netherlands - with the Bio Port of Rotterdam in close proximity, the combination of the provinces of South Holland, Zealand, and North Brabant is chosen as the research area. Appendix A-6 shows a map of the area.

1.4 Relevance of the research

This thesis provides potentials in demand from different sources:

1. Local Dutch farmers have experience with growing sugar beet, and with high yields per hectare. This creates opportunities for locally grown fermentable sugars. With the results of this research they can compare the profitability of their own production to the projections given here.
2. The Port of Rotterdam has made considerable investment in the Bio Port of Rotterdam. They would, therefore, be interested in the biomass potential of the local area.
3. Dutch and European legislation is increasing the demand for renewable energy sources and this is, therefore, increasing the demand of biomass for non-food purposes. This legislation contains, in some cases (SDE+)[6]. The research can give them an insight into the extent to which biomass must be subsidised in order to make it economically feasible. The research could also contribute to investigating whether the targets set by the legislators are achievable.
4. The owners of the new opportunities of end-use applications (REDIFINERY, DSM, Biochemicals) for fermentable sugar from sugar beet can use the results of this research to glean an insight into the costs of the production of the raw material.

[6] The most significant support instrument to reach the targets for renewable energy generation in The Netherlands is SDE+ (Stimulering duurzame energieproductie plus) which subsidizes all renewable energy sources. A total of 3.5 billion euros is spent by the Dutch government in order to stimulate renewable energy production (Agentschap NL, 2013).This policy has resulted in a largely domestic production of biomass in The Netherlands.

2. Methodology

2.1 Overview

This thesis determines the potential of sugar beet cultivation in The Netherlands. Figure 1 gives an overview of the questions answered and the input they need:

1) The potential of Dutch sugar beet cultivation was determined. This was achieved by creating an ArcGIS model to calculate sugar beet's potential as a biomass source. In this thesis, this was done in accordance with the Biomass Energy Europe (BEE) *Best Practices and Methods Handbook* (2010) for agricultural products. The ArcGIS model used a reference biorefinery at the Maasvlakte as the demand node, inspired by the REDIFINERY project. The model was used on the provinces of South Holland, Zealand and North Brabant. The province of South Holland was inspected in greater detail due to its close proximity to the biorefinery.
2) The costs found by the model were compared to world raw sugar prices (FAO, 2014) and imported wood chip prices (van Meijl, et al., 2016) in order to see how local sugar beet cultivation competes with imported biomass sources.
3) The previous findings were extrapolated into the near future using FAO agricultural outlook and scientific research from the MEV II project.
4) The GHG emissions of Dutch sugar beet cultivation were calculated and compared to their RED (2009/28/EC) input values. Combining all the answers found that the potential for sugar beet, cultivated as a biomass source for the bio economy now and in the future, was determined.

The intermediate results of the sugar beet potential found through this study were discussed with two experts in the field in order to test the results in relation to their own experience. Interviews were held with Gert Jan van den Born from the PBL and Bert Smit and Edward Smeets from LEI-Wagengen UR. Suikerunie declined the opportunity to make a statement.

GHG emission reduction is one of the primary reasons for sugar beet cultivation for non-food purposes. This thesis, in addition to answering the main question, assesses the GHG balance of sugar beet cultivation. This has been done using the BioGrace tool from the EU-funded Intelligent Energy Europe research project, which is also used to calculate RED emissions. This was mainly done for comparability and to investigate the CO_2-eq reduction in local sugar beet cultivation - and to see if it is compliant with the GHG reduction requirements as set in the RED[7].

[7] The EU Renewable Energy Directive (RED) establishes that a minimum of 10% biofuels or other renewable fuels for transport. The Fuel Quality Directive (FQD) is aimed towards fuel suppliers, obliging them to reduce greenhouse gas (GHG) emissions with 6% by 2020 (F3, 2013). These biofuels now are required reduce the GHG emissions of the fuel they replace by 35% increasing to; 50% in 2017, and 60% in 2018.

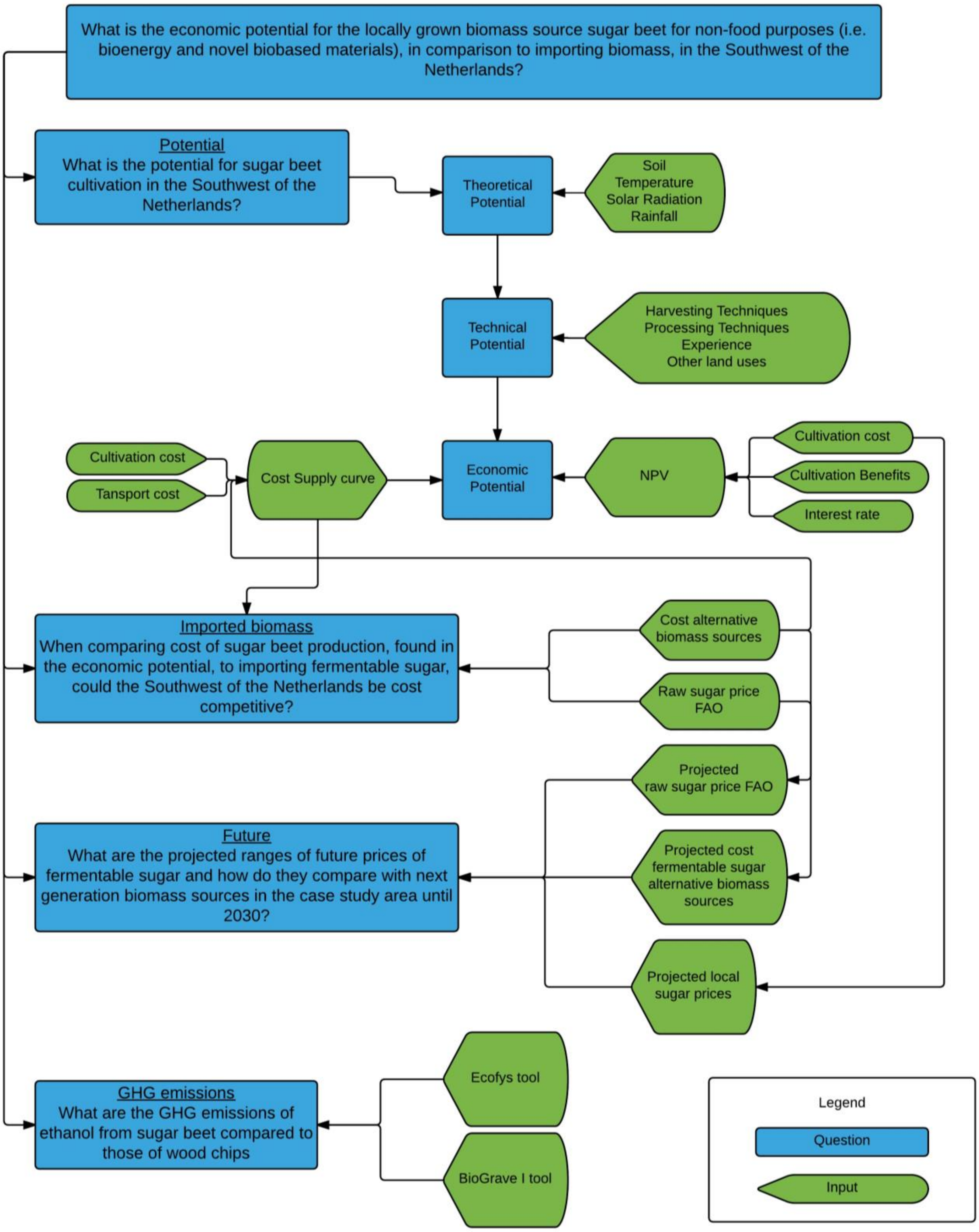

Figure 1 Methodology of the thesis showing questions and input needed

2.2 South west of The Netherlands

The province of South Holland is a densely populated province, with large cities, industry, horticulture, and natural parks. All of these consume a large portion of the available subsurface. This has an impact on the potentials found, and so the south west of The Netherlands is investigated for its sugar beet cultivation potential. A map of the area is shown in appendix A-6. With the reference biorefinery plant aiming for an input of four million tonnes of biomass per year, the surface area of the south west of The Netherlands is chosen to substantially contribute to the biorefinery demand. In Zealand and, to a lesser extent, North Brabant, there are large numbers of sugar beet farmers. Figure 2 shows that North Brabant and Zealand together contribute to 26% of the total sugar beet cultivation subsurface. With the 6% from South Holland added, this thesis covers 32% of the total sugar beet cultivation subsurface (CBS, 2015).

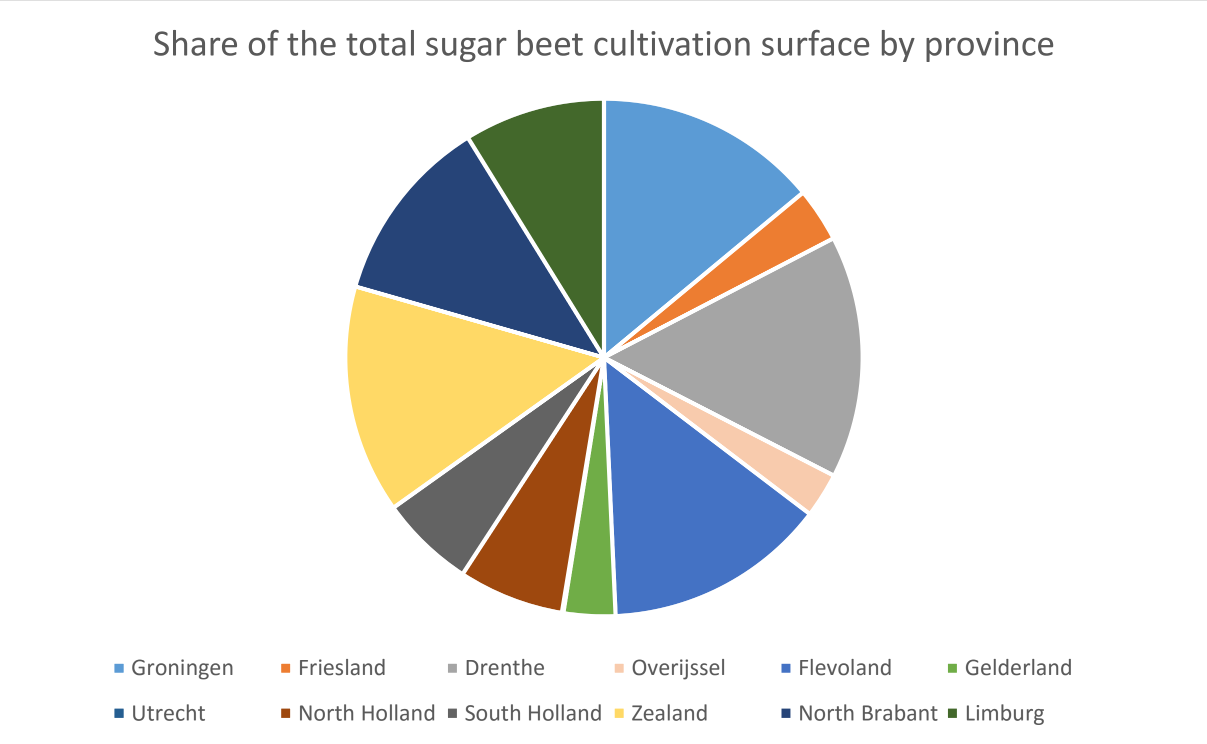

Figure 2 Share of the total sugar beet cultivation surface by province (CBS, 2015)

The introduction to this thesis mentions that 4.8Mt of sugar beet was cultivated on $58.4*10^3$ ha in The Netherlands in 2015 The south west of The Netherlands cultivates 1.6Mt of sugar beet on $18.7*10^3$ ha, of which most comes from Zealand, followed by North Brabant and South Holland (CBS, 2015). In table 2, the total yields and areas used for sugar beet cultivation are given.

Table 2 Sugar beet cultivation in the south west of The Netherlands (CBS, 2015)

	Netherlands	south west Netherlands	South Holland	Zealand	North Brabant
Area ($*10^3$ ha)	58.4	18.7	3.47	8.35	6.87
Yield (Mt)	4.8	1.6	0.3	0.8	0.6

2.3 Scenarios

The scenarios are based on both the "Cahier Landbouw" (CPB/PBL, 2015) and the extent to which The Netherlands has shifted towards a biobased economy. They show how much arable land is likely to become available for other land uses in 2050. Depending on the scenario, this ranges from 3.7% to 6.2%. These scenarios are then used as an indication of the land availability for sugar beet cultivation without harming the food and feed supply.

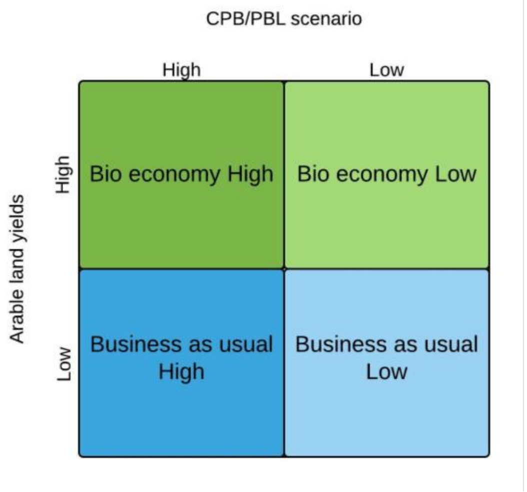

Figure 3 Technical potential scenarios

Bio economy High

In the bio economy high scenario, high preference is given to the bio economy, and so sugar beet is cultivated on arable land with the highest yields. Furthermore, in comparison, the low scenarios additional land becomes available for sugar beet cultivation in this scenario (6.2%). This scenario depends on both legislative impulses and high demand for biobased products.

Bio economy Low

In the bio economy low scenario, high preference is still given to the bio economy, and so sugar beet is grown on the high-yielding grounds. However, in contrast to the previous scenario, there is less land available for sugar beet cultivation (3.7%-4.7%). This scenario would be carried out only if appropriate legislation was introduced to enable high-yielding land to be claimed for sugar beet production, but with a CPB/PBL low scenario the economy demands fewer biobased products.

BAU High

In the business-as-usual high scenario, no real preference is given to the biobased economy. In order to not compete with the food-and-feed supply, sugar beet cultivation takes place on low-yielding soils. Due to the high CPB/PBL scenario, the demand for bio economy products is still high, resulting a substantial amount of land becoming available for sugar beet cultivation (6.2%). So this scenario has minimal legislative impulse but high demand due to the CPB/PBL scenario.

BAU Low

In the business-as-usual low scenario, little preference is given to the biobased economy and the low growth of the CPB/PBL also results in minimal demand. The consequence of this is low-yielding soil on less available land (3.7%-4.7%). This scenario involves minimal legislative impulse and low demand for bio economy products.

2.4 Potential of sugar beet cultivation for non-food purposes

To determine the potential of sugar beet cultivation, this study uses the hierarchy of potentials from theoretical and technical to economic. Each potential is a fraction of the previous potential, as is shown in figure 4 (Biomass Energy Europe, 2010). The research does not investigate different options for refining the biomass, and its different applications. Transport depends on the distance to the Bio Port of Rotterdam. All of the constraints used in the ArcGIS models are listed below, both for the south west of The Netherlands and South Holland.

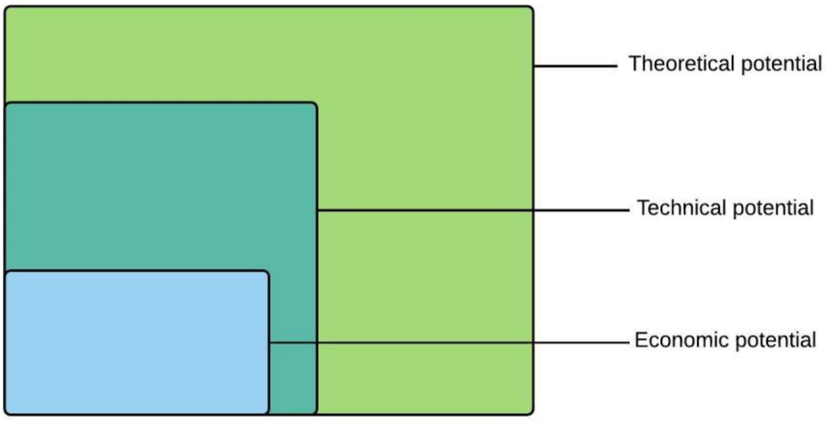

Figure 4 Different types of potentials (modification of Batidzirai et al. (2012))

2.4.1 Theoretical potential

The theoretical potential is the overall maximum amount of terrestrial biomass that can be considered to be theoretically available for bioenergy production within fundamental bio-physical limits. (BEE, 2010). The following bio-physical constraints are considered:

- Soil
- Temperature
- Solar radiation
- Rainfall
- Land use

In order to calculate the potential, certain constraints were imposed. For the theoretical potential, these were primarily soil type and land use. The constraints and their implications are listed below.

Soil type

The different soil types were classified using the Physical Geographic regional map of The Netherlands (Fysisch-Geografische Regios Kaart,), and this can be seen in appendix A-7. This map classifies the different types of soil in The Netherlands. For sugar beet cultivation in the south west of The Netherlands the most important soil types[8] (Bal & Looise, 2013) are:

1) River clay - clay deposited from the different rivers flowing through the province of South Holland. These clay formations are mostly deposited by the *Maas* and the *Rijn*, and are suitable for sugar beet cultivation.
2) Sea clay - clay deposited from the sea. This is mostly clay soil from the bottom of the sea and, when the land was reclaimed on the sea, it became the top soil layer. Therefore, it is to be found within the boundaries of dikes. Sea clay is very suitable for sugar beet cultivation, with 60% of Dutch sugar beet cultivation taking place on sea clay.
3) Bog/low peat - low-lying peat formation formed during the Holocene epoch. This consists of a small layer of clay on top of a layer of peat. Due to the saggy nature of the soil, it is difficult to manoeuvre agricultural equipment on it. Therefore, after consolidation with LEI and PBL it was excluded from the theoretical potential (B. Smit & E. Smeets, personal communication, January 3, 2016) (G. van den Born, personal communication, January 21, 2015). Furthermore, using the LGN (Landelijk Grondgebruik Nederland) map and the soil map in ArcGIS, no sugar beet cultivation on bog/low Peat was found.
4) Dunes - these naturally formed sand formations are the barrier between the sea and the low-lying land behind them. However, dunes are not suitable for sugar beet cultivation and are, therefore, excluded from the theoretical potential.
5) Higher sand grounds - found throughout The Netherlands, mainly above sea-level. These consist of all sand soils with soil development (podlzolgronden). Higher sand grounds are suitable for sugar beet cultivation but they have lower yields in comparison to clay soils.

Sea clay is the main soil used for sugar beet cultivation, followed by sand and river clay (Suikerunie, 2015). Some Sugar beet cultivation takes place on peat and valley grounds but, according to a PBL researcher (G. van den Born, personal communication, January 21, 2015), these soils are not comparable with the bog soil in the province of South Holland. Figure 5 shows on which soil types sugar beet is cultivated.

[8] North Sea, closed estuary and not classified soil types are excluded from the list.

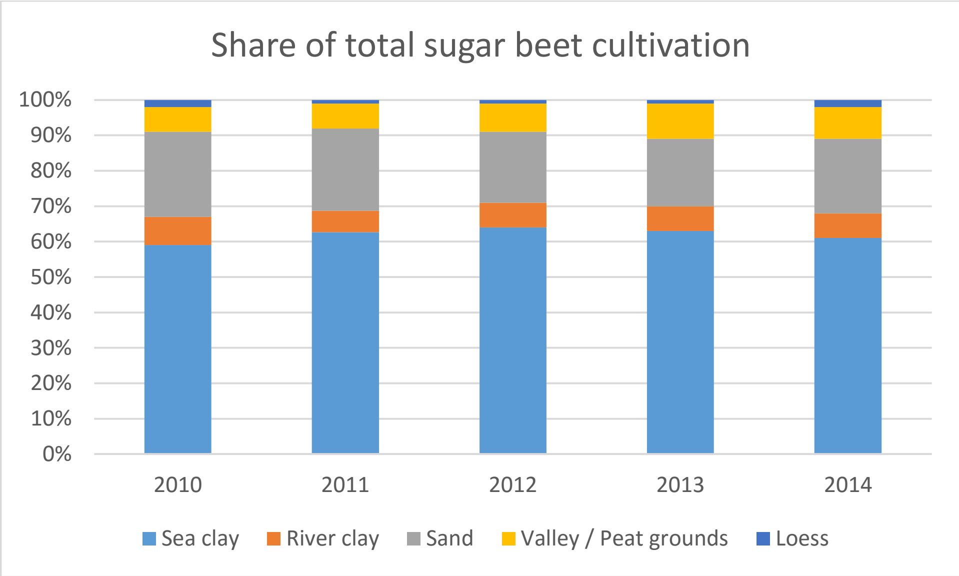

Figure 5 Share of total sugar beet cultivation (Suikerunie, 2015)

Each of these soil types has a corresponding yield given by the most recent KWIN AGV report (2015), Suikerunie's "bietenstatistiek" (2015) or extrapolation. How the extrapolation of river clay was calculated is shown in appendix A-3. In table 3 below, the correlation between the different soil types found and their corresponding maximum yields is shown. Sea clay, river clay and sand are used in the various models. Clay from the IJselmeerpolder was added for comparison.

Table 3 Soil types and their corresponding maximum yields

Soil type	Soil type translation	yield (t/ha)	Source
rivierengebied	river clay	80.16	Extrapolation (see appendix, A-3)
zeeklei	sea clay	81.39	kleigrond zuidwest ned suikerbiet (KWIN-AGV 2015)
hogere zandgronden	higher sand grounds	78.54	zandgrond suikerbiet (KWIN-AGV 2015)
Duinen	dunes	0.00	(G. van den Born, personal communication, January 21, 2015)
Laagveengbied	bog (low peat)	0.00	(G. van den Born, personal communication, January 21, 2015)
klei IJselmeer	clay IJselmeer	92.20	IJselmeerpolder (KWIN-AGV 2015). N.A. outside scope

Land use

Sugar beet will not be grown in urbanised areas and the current land use is taken into account. The land-use map (BBG 2010) from the central statistical office (CBS) is used to determine the current land use in the research area. The map is shown in appendix A-5. In the technical potential, the following land uses are included: parks, sports fields, forests, other agricultural lands, recreational terrain, and allotments. The other 31 land uses marked on the BBG map are excluded from sugar beet cultivation in the technical potential.

Meteorology

The climate in the south west of The Netherlands is aggregated to a single climate region by the KNMI (KNMI, 2015). Therefore, no quantitative differences in the region are observed. This means that no meteorological differentiation within the model is made. This is an important limitation to the model but it keeps the model comprehensible and limits input.

Determining the theoretical potential in ArcGIS

With the constraints listed above, the ArcGIS model was constructed:

1) All data was cut to the size of the research area.

2) The land-use map (BBG layer) was used to create a layer without the built-up areas and water bodies. This layer was then used to create a map of the soil at all possible locations for sugar beet cultivation.

3) The corresponding maximum yields were added, creating a map showing the theoretical potential of the research area. An overview of the model can be seen in appendix A-8.

2.4.2 Technical potential

Technical potential is defined as the fraction of the theoretical potential which is available under current technological possibilities, taking into account harvesting techniques, soil, land use, accessibility, processing techniques, and other land uses (Batidzirai, Smeets, & Faaij, 2012).

- Cultivation
- Harvesting techniques
- Infrastructure and accessibility
- Other land uses

These limits were used to alter the maximum yields found in the theoretical potential. Harvesting techniques include crop rotations and this limits the maximum yield. Other land uses will limit the technical potential since they eliminate potential surface area for sugar beet cultivation.

Table 4 Sugar beet properties

Sugar beet properties	
Average rotation (years between rotations)	5.16
Moisture content (water %)	76.5%
Recoverability index (recoverable from yield)	91.2%
Yield loss without experience (%)	10%

Cultivation and harvesting techniques

Sugar beet is usually cultivated in a rotation with other crops. Table 4 shows the number of years between the rotations of sugar beet (Suikerunie, 2015). The average years between rotations is 5.16. Therefore, the yields, from the theoretical potential, are divided by 5.16 to get the technical yield per soil type. An overview of the data gathered on the years between rotations is given in Appendix A-8. The calorific value and moisture content of the sugar beet is taken to express the energetic value of the sugar beet (BioGrace, 2015). The technical potential takes into account the recoverability of cultivated sugar beets. In 2014 the recoverability was 91.2% of the total yield. This means that 91.2% of the total yield was able to be processed further (Suikerunie, 2015).

Soil types

In contrast to the theoretical potential, the technical potential only uses land identified as "arable land" on the BBG 2010 map. This limits the possible locations for sugar beet cultivation. These locations are then coupled with the corresponding soil types and yields. Future land use change is not taken into account, other than the WLO scenarios.

Infrastructure and accessibility

The infrastructure of the research area is well developed, with the Port of Rotterdam in close proximity to multiple transport routes. This creates an efficient way to transport sugar beets to the biorefinery. Therefore, the issue of accessibility does not limit the possible locations of sugar beet cultivation. However, distance could become a determining factor involved in reaching the environmental and profitability goals of the sugar beet farmers. This is mainly due to the high moisture content of the sugar beet (76.5%) (BioGrace, 2015).

Previous experience

In addition to the differences of soil type, experience with sugar beet cultivation has an influence on the yields. After consultation with a PBL researcher (G. van den Born, personal communication, January 21, 2015), it was revealed that experience is an important factor in sugar beet cultivation. Therefore, this thesis takes previous experience into account by combining four data sets of previous sugar beet cultivation. These data sets are LGN (Landelijk Grondgebruikbestand Nederland) 4 to 7, and are used to create a mosaic of locations with sugar beet cultivation between 2003 and 2014. See figure 6. The assumption is made that these places would be able to reach the yields set in the previous section, and the locations without experience would be able to reach 90% of those yields. An overview of the model used in ArcGIS can be found in appendix A-10.

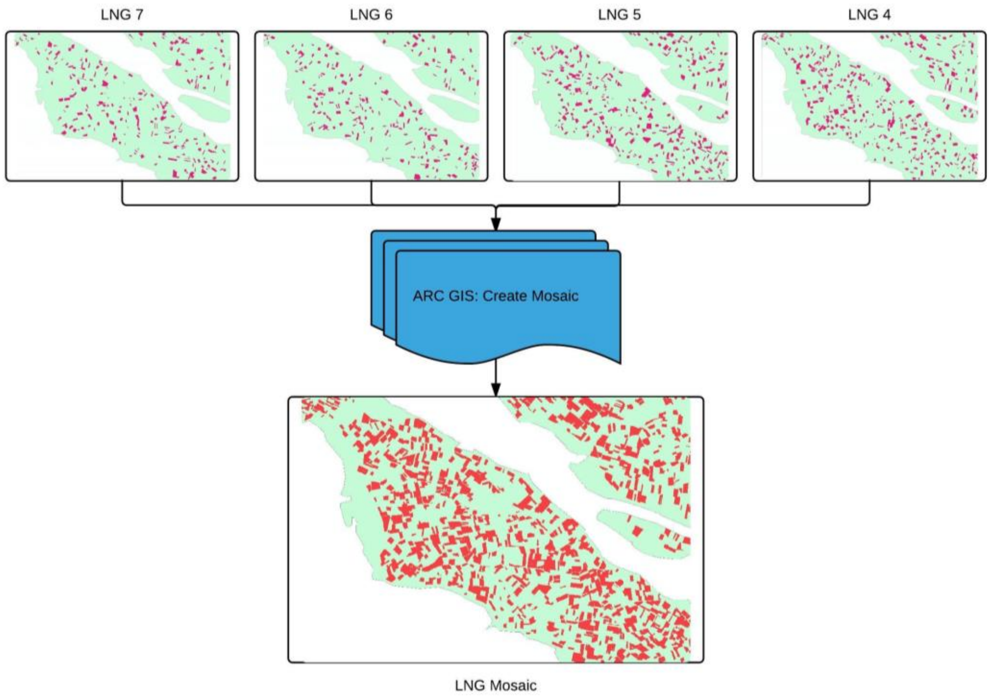

Figure 6 creating the experience map: LGN mosaic creation

Other land uses

In comparison with the theoretical potential, only the other agricultural land from the BBG map is taken into account. In order to determine how much land is available for sugar beet cultivation for non-food purposes without competing with other land uses, the CPB/PBL report on agriculture has been used (CPB/PBL, 2015). In this report, two WLO (Welfare and Environment) scenarios from 2015 are used. One assumes low economic growth and one assumes high economic growth. The scenario estimates land use changes in The Netherlands to 2050 and shows how much arable land will shift to other land uses in these scenarios. In this case, how much land shifts to sugar beet cultivation? While 2050 is outside the scope of this thesis, the WLO scenarios give an indication as to how much land will become available without harming the food and feed supply. Therefore, these scenarios are used to determine the present day-technical potential.

The percentages from the CPB/PBL report have been converted to surface areas, after which these total areas have been converted back to a percentage of the total arable land. An overview of the calculations is given in appendix A-14. The percentages gathered are lower in comparison to van der Hilst et al. (2010). This difference could be related to the population density in the south west of The Netherlands and especially South Holland. It is higher in these areas than in the north of The Netherlands. The data CPB/PBL used in their report is summarised in tables 5 and 6 below:

Table 5 Results of the WLO scenarios for arable land in South Holland (CPB/PBL, 2015)

Scenario South Holland	Low	High
Increase in arable land used by sugar beet SH	4%	25%
Decrease in horticulture SH	-30%	-10%
Decrease agriculture and horticulture Netherlands	-3.50%	-5%
Total arable land becoming available	4.7%	6.2%

Table 6 Results of the WLO scenarios for arable land in south west of The Netherlands (CPB/PBL, 2015)

Scenario south west of The Netherlands	Low	High
Increase in arable land used by sugar beet	4%	25%
Decrease agriculture and horticulture	-3.50%	-5%
Total arable land becoming available	3.7%	6.2%

While the increase in arable land for sugar beet cultivation for non-food purposes is determined, it is not specified where this land would be. Therefore, the assumption is made that either land becomes available on soils with the highest yields, or on soils with the lowest yields. In combination with the two scenarios of the WLO. This gives four solutions, also shown in chapter 2.3 which covers creating a spectrum in which the technical potential was found.

ArcGIS

Figure 7 below incorporates all of the constraints listed above into the ArcGIS model. The land-use map (BBG 2010) has been used and, in contrast to the theoretical potential, only the arable land was selected. This selection was then cut out of the soil map and the yields were added to each soil type. The limitations of both the harvesting and processing techniques were added to the map, further limiting the yields. The model used to create this map in ArcGIS can be found in appendix A-10.

This map then uses the WLO scenarios showing how much arable land comes available to determine how much of the land indicated on the map could be used for sugar beet cultivation. This has been done by determining with the WLO scenario data what percentage of land would become available. This percentage of either the highest or the lowest yielding soils was used to geographically locate the sugar beet cultivation area. This results in the creation of four scenarios from both the WLO scenarios and the authorities' influences.

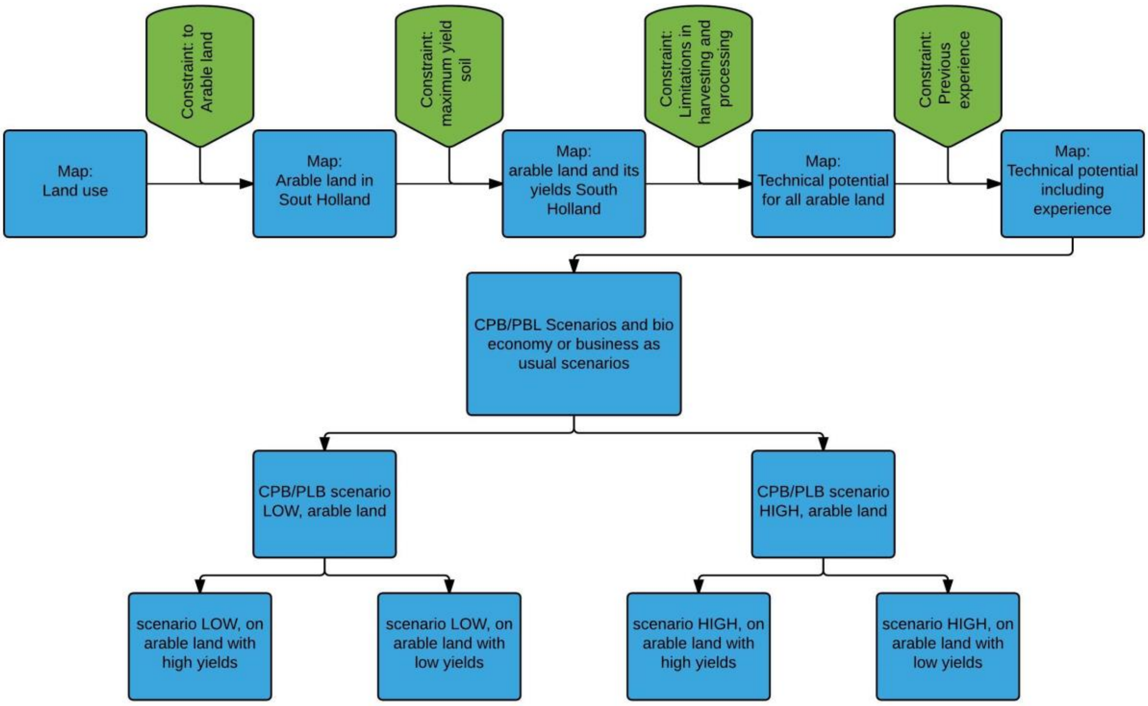

Figure 7 Technical potential flowchart

The flowchart shows that this will deliver four different scenarios presenting the technical potential. The difference is made by determining which arable land is chosen as well as which CPB/PBL WLO scenario is selected. An overview of the scenarios is given in chapter 2.3.

2.4.3 Economic Potential

The economic potential is the share of the technical potential which meets the criteria of economic profitability within the given framework conditions (Biomass Energy Europe, 2010). Given this limitation, either finding the Net Present Value (NPV) of a crop rotation, or benchmarking the cultivation costs against import cost, gives the best representation of the profitability. In the south west of The Netherlands the costs were benchmarked against import costs. When the province of South Holland was researched, the NPV and benchmark techniques were used to achieve a greater level of detail in the findings.

To determine the economic potential, data on the costs and benefits of sugar beet cultivation is needed. The data on benefits were gathered in correlation with the yields found in the technical potential. The yields were multiplied by the price of the sugar beet giving the benefits for a certain surface. The costs were more comprehensive to calculate: data from the KWIN-AGV, suitability, and yields were incorporated to find the yearly costs. In the cost supply curve, the costs of cultivation were compared to the world raw sugar prices and lignocellulosic biomass sources.

Calculating the Economic potential with NPV

In ArcGIS, the NPV found for every grid cell shows in what grid cells the potential for growing sugar beet is economically viable. Adding up all the economically viable grid cells gave the total economic potential of the province of South Holland.

Constraints

Determining the economic potential was carried out by comparing the NPV of a normal rotation scheme with a rotation scheme that has increased sugar beet cultivation. The benefits of these rotation schemes are largely determined by the yields, which are associated with the soil type. The NPV method is chosen because it illustrates the farmer's choice as to which rotations he or she will be likely use in the near future. Costs associated with land use, labour, and increasing yields were not taken into account because they are not concerned with the cultivation directly, and were therefore, deemed out of scope.

The costs of cultivation have been revealed by the KWIN-AGV 2015 report. This report includes all the different possible sources of costs. Sugar beet cultivation on sea clay and higher sand grounds are given in appendix A-14 as an example. This overview is also used to determine the GHG emissions of sugar beet cultivation, and to determine whether Dutch sugar beet cultivation stays within the limits of RED.

Rotation schemes

Farmers have to differentiate their crops in order to keep sufficient nutrition levels in their soils, and minimise crop sicknesses. Therefore, farmers use rotation schemes that ensure that the same crop only returns to a certain soil area after a given time. Sugar beet, for example, can only grow every four years on the same soil (B. Smit & E. Smeets, personal communication, January 3, 2016). The technical potential shows that, on average, there have been 5.16 years between rotations, which has been rounded to five years in the normal scheme. This leaves room to increase the amount of sugar beet cultivation from every five years to every four years. With information from LEI-Wageningen UR, two rotation schemes have been constructed.

Table 7 Rotation schemes

year	Normal scheme	Bio economy scheme
1	Sugar beet	Sugar beet
2	Potato	Potato
3	Union	Union
4	Spring barley	Spring barley
5	Winter wheat	

Table 6 shows the two different rotation schemes. Winter wheat is left out in the bio economy rotation scheme. All of the crops have their costs and benefits listed in the KWIN AGV and, each year, these are added to the NPV. The NPV calculation stretches back 20 years. Both schemes will simultaneously end their rotation.

$$NPV = \sum \frac{(Benefits_y - Cost_y)}{(1+a)^y}$$

$Benefits = yield * price_{sugar\ beet}$

$Costs = Cost_{cultivation}$

$a = discount\ rate\ (5.5\%\ KWIN\ AGV\ 2015)$

$y = annuity\ period\ (year)$

The costs and benefits on each of the soil types and both of the scenarios is given below:

Table 8 Costs and benefits normal rotation scheme

	Normal scheme	
crop	costs	benefits
Sugar beet		
Sea clay experience	€ 1,342.00	€ 4,557.00
Sea clay	€ 1,342.00	€ 4,101.30
River clay experience	€ 1,348.03	€ 4,197.42
River clay	€ 1,348.03	€ 3,777.67
Potato	€ 4,059.00	€ 10,387.00
Onion	€ 2,753.95	€ 6,636.00
Spring barley	€ 430.00	€ 1,617.00
Winter wheat	€ 693.00	€ 2,099.00

Table 9 Costs and benefits bio economy scheme

Bio economy scheme		
crop	cost	benefits
Sugar beet		
Sea clay experience	€ 1,342.00	€ 4,557.00
Sea clay	€ 1,342.00	€ 4,101.30
River clay experience	€ 1,348.03	€ 4,197.42
River clay	€ 1,348.03	€ 3,777.67
Potato	€ 4,059.00	€ 10,387.00
Onion	€ 2,753.95	€ 6,636.00
Spring Barley	€ 430.00	€ 1,617.00

The rotation schemes show that potato has the highest benefits but also the highest costs, followed by onion and sugar beet. Spring barley and the added winter wheat in the business-as-usual scheme need little investment from the farmer but they gross few benefits.

Other constraints

The constraints used for the economic potential are identical to the technical potential. Therefore, only arable land was taken into account and harvesting losses were taken into account. Taxes were not taken into account as sugar beet cultivation is a business-to-business operation. The assumption was made that farmers' expenses are exempted from taxes.

Calculating the economic potential by benchmarking against import

In order to benchmark the locally cultivated sugar beet against the imported woodchips, the cost of sugar beet cultivation has been calculated. The cost price of sugar beet cultivation and transport has been calculated using the technical potential, ArcGIS network analysis and KWIN AGV data, as is shown in appendix A-12. The cost of cultivation is expressed both in €/GJ to assess its energy content, and in tonnes of fermentable sugar in order to compare it to imported biomass sources. Imported sources of biomass are the world raw sugar price given by the FAO, and fermentable sugar prices from woodchips and wood pellets (van Meijl, et al., 2016). More on the fermentable sugar prices from woodchips and wood pellets can be found in the next section on price projections of fermentable sugar. When the cost of locally cultivated sugar economically competes with the cost of the imported wood chips and fermentable sugars, potential locations for sugar beet cultivation were found. Since not all of the costs that the farmer incurs were included in the cultivation costs, two cost supply curves have been added with profit margins of 20% and 40%. According to the U.S. Department of Agriculture, typical operational profit margins for American midsize to large farms range from 18% to 23% (Hoppe, 2014).

Transport

The transport costs have been calculated using ArcGIS's network analyst. Using the ESRI Street map 2008 and the reference biorefinery as a demand node, network areas with the same costs of transportation have been constructed. Each area shows the transport cost in € per tonne of sugar beet. Costs have been calculated in accordance with the article by Hoefnagels et al. (2014). Fuel consumption was calculated in accordance with the European input values for bioenergy pathways (2015).

Other constraints

Other constraints on the yield correspond with the technical potential, with the exception that the limitations on the rotations are increased from every 5.16 years of the normal scheme, to four years of the bio economy scheme. Following the example of the NPV calculations, taxes are not taken into account.

Processing cost

The processing costs associated with converting sugar beet to fermentable sugars is assumed to be non-existent. This simplification was made since the cost associated with the process are low and the allocation of costs creates difficulties. This is because fermentable sugar is an unconventional end product of the production chain. Normally, it is processed further to raw sugar. The process from sugar beet to fermentable sugar is shown in the Deloitte study (2015), and entails washing, slicing, and juice extraction. These processes are fairly simple and do not need much capital investment, aside from the investments already made for a sugar refinery or biorefinery.

2.5 Fermentable sugar price projections

To assess the future of the Dutch sugar beet cultivation, the projected future prices of sugar beet cultivation were compared to the projected future prices of raw sugar and fermentable sugars from wood pellets. With growing yields in The Netherlands and the expiration of the sugar quota, Deloitte (2014) and Harmsen et al. (2014) have predicted economically competitive biomass from sugar beet. To test these claims, world raw sugar prices and the prices of lingo cellulosic sugar from sugar beet, wood pellets and wood chips have been compared, and projected up to 2030. The comparison is made in euros per tonne of fermentable sugar which is in compliance with previous research.

Local sugar price projections

To project the price of sugar beet cultivation from 2015 to 2030, historic data from KWIN AGV and Suikerunie's "bietenstatistiek" has been used. In conversation with LEI researchers (B. Smit & E. Smeets, personal communication, January 3, 2016), the assumption has been formulated that sugar beet yields will keep their linear growth at least until 2030. Next, the yields, benefits, and costs of sugar beet cultivation on sea clay in the south west of The Netherlands have been taken from the KWIN AGV data from: 1997-1998, 2000, 2002, 2006, 2009, and 2015. Sea clay has also been taken into account since most sugar beet cultivation takes place on this soil type (Suikerunie, 2015). To obtain a better understanding of the increasing yields, all available data, ranging from 1996-2012 has been taken from Suikerunie's "bietenstatistiek" (Suikerunie, 2015). These yields are then linearly extrapolated using excel to give an indication on future sugar beet yields. They are based on the same constraints used in the technical potential, regarding yield loss, sugar content, and water content. The average sugar content has been used to determine the fermentable sugar price.

Import sugar price projections

For comparison, prices of raw sugar (FAO, 2014) and prices of fermentable sugar (van Meijl, et al., 2016) have been used. Fermentable sugar prices have been chosen because they present a second-generation biomass source (ECN, 2014). Both the prices of raw and fermentable sugar have been given in U.S. dollars and they have been converted to euros using the conversion table in the FAO report.

The MEV II study by van Meijl et al. (2016) uses a Markal model to project future prices of fermentable sugar. These calculations have been carried out for wood pellets and they differentiate between high and low technological growths. The model distinguishes the cost of the fermentable output in three categories: a) capital costs, b) feedstock costs and c) Operation & Maintenance (M&O) costs. Feedstock costs are the primary contributor to the total, followed by either capital costs or M&O costs depending on the technological growth. In the final price, the credit from the lignin waste stream is included. With the feedstock costs being the primary contributor to the total price, a cheaper alternative is found in wood chips. The wood chip conversion process to lingo cellulosic sugar is similar to the wood pellets process. Therefore, the assumption has been made that the feedstocks are replaceable. Lastly, the price is divided into a marginal cost price of production (M&O and Feedstock costs) and total costs price (M&O, Feedstock and Capital costs). In this thesis, the prices of the high technical growth scenario are shown, with the biobased economy driving the technological growth.

2.6 GHG balance

To assess the environmental impact of sugar beet cultivation in The Netherlands, the BioGrace I tool was used. This tool from the EU-funded Intelligent Energy Europe research project is made to harmonise calculations of biofuel greenhouse gas emission in the European Union. The calculations have been made in order to determine whether ethanol from Sugar beet meets the RED criteria. Processing and other production steps are outside the scope of this thesis and their inputs are left as default. The calculations for the cultivation step have been carried out with input from KWIN AGV data and a report on greenhouses gasses by Smit et al. 2011. No specific data on seeding material, of N_2O emissions was found, and therefore these values were left default. Table 10 shows the data used as input data in the BioGrace I tool;

Table 10 Input data GHG balance

	Sand	Sea Clay	River Clay	Default	Unit
Yield					
Sugar beet	72,390	81,390	80,160	68,860	kg ha^{-1} $year^{-1}$
Moisture content	75%	75%	75%	75%	
Energy consumption					
Diesel	4,043	4,221	4,221	6,331	MJ ha^{-1} $year^{-1}$
Agro chemicals					
N-fertiliser (kg N)	149	149	149	120	kg N ha^{-1} $year^{-1}$
Manure	-	-	-	-	kg N ha^{-1} $year^{-1}$
CaO-fertiliser (kg CaO)	373	72	72	400	kg CaO ha^{-1} $year^{-1}$
K_2O-fertiliser (kg K_2O)	160	40	40	135	kg K_2O ha^{-1} $year^{-1}$
P_2O_5-fertiliser (kg P_2O_5)	20	50	56	60	kg P_2O_5 ha^{-1} $year^{-1}$
Pesticides	11	15	15	1	kg ha^{-1} $year^{-1}$
Seeding material					
Seeds-sugar beet	6	6	6	6	kg ha^{-1} $year^{-1}$
Field N_2O emissions	3	3	3	3	kg ha^{-1} $year^{-1}$

Comparison wood chips

In order to compare the GHG emissions, the emissions of wood chips have been calculated using the report of Hamelinck & Hoogwijk (2007). This was used to calculate the GHG emissions of ethanol from wood chips as a biomass source. This was done in four scenarios, with a time frame either in 2005 or 2020, and either the ethanol from wood chips was produced in Rotterdam, so the ethanol was not shipped. Or the assumption was made that ethanol was shipped from overseas, in this case Savannah, with $7.3*10^3$ km of shipping to the Port of Rotterdam.

3. Results

The results discuss the theoretical, technical, and economic potential of sugar beet cultivation for non-food/feed purposes in the south west region of The Netherlands, followed by the province South Holland in further focus. Finally, the price projections and GHG emissions are shown.

3.1 Theoretical potential

The theoretical potential shows the potential if all land was used for sugar beet cultivation. Firstly, the theoretical potential is assessed for the south west of The Netherlands. Secondly, the theoretical potential is assessed for the province of South Holland.

3.1.1 Theoretical potential - south west of The Netherlands

The theoretical potential of the south west of The Netherlands accumulates to 198.8PJ or 52.3Mt of sugar beet (wb) per year. This sugar beet is cultivated on $655*10^3$ ha of the $725*10^3$ ha available within the constraints in the area. The largest contribution comes from the higher sand ground in the province of North Brabant, with 94.6PJ or 24.9Mt of sugar beet (wb). These soils have the lowest yields in comparison but, due to the large surface area, they make the largest contribution to the theoretical potential. The second largest contribution comes from the sea clay soils in the provinces of South Holland and Zealand, contributing 89.2PJ or 23.5Mt of sugar beet (wb) per year. Lastly, the river clay soils contribute 14.9PJ or 3.9Mt sugar beet (wb), to the theoretical potential. An overview of the data found is given in table 11 and shown in figure 8.

Especially in the province of South Holland, large amounts of the surface are devoted to other land uses. The cities of Rotterdam and Den Haag and the Port of Rotterdam all take up much of the subsurface. Other limitations to sugar beet cultivation are unsuitable soils, bogs, and dunes. These soils, together with the built-up areas, make up $70*10^3$ ha which is 9.7% of the total researched area.

Table 11 Theoretical potential for sugar beet cultivation in the south west of The Netherlands

Soil type	Area ($*10^3$ ha)	Yield (t/ha)	Total Yield (Mt)	Energy (PJ)
River clay	49	80.16	3.9	14.9
Sea clay	289	81.39	23.5	89.2
Higher sand grounds	317	78.54	24.9	94.6
Unsuitable soils	70	N.A.	0	0
Total	725	N.A.	52.3	198.8

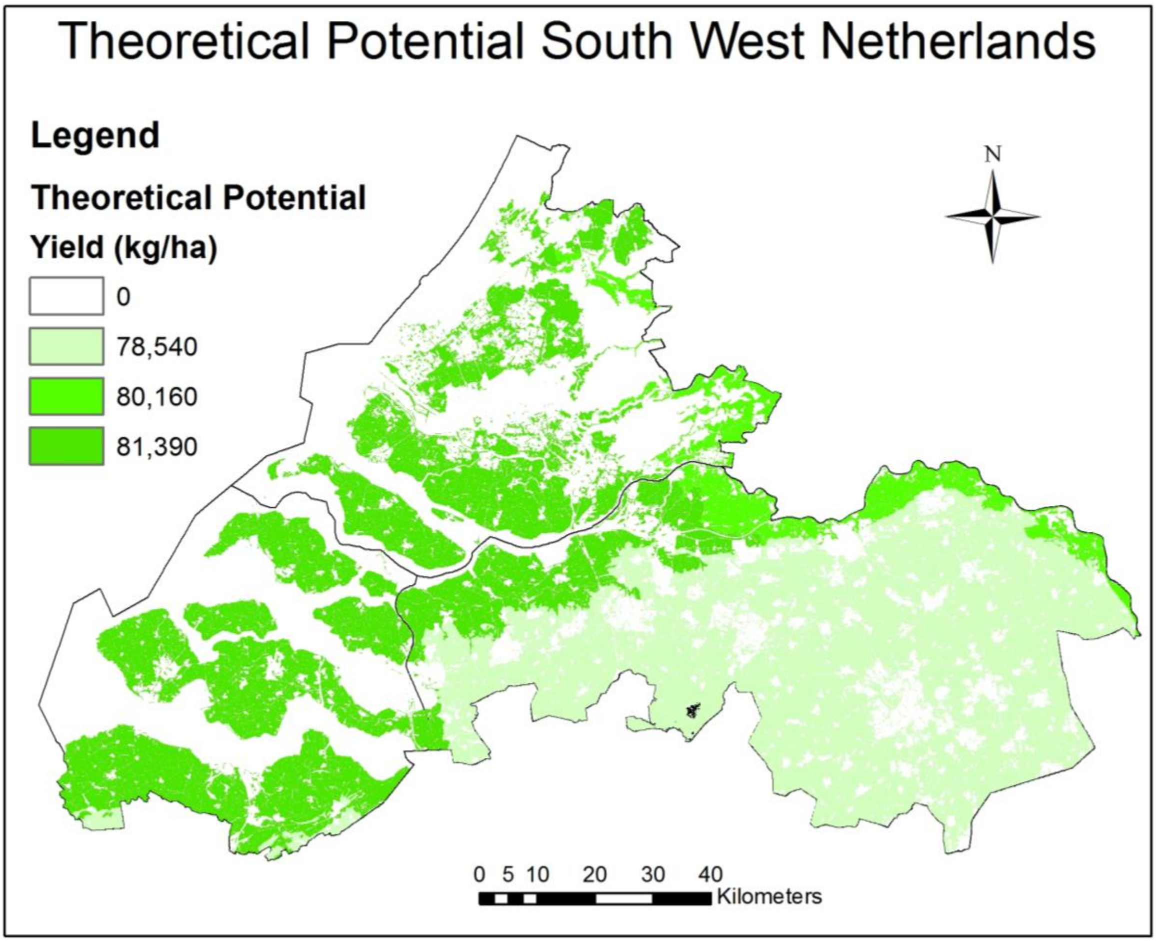

Figure 8 Theoretical potential in the south west of The Netherlands

3.1.2 Theoretical potential - South Holland

The total theoretical potential of sugar beet cultivation in the province of South Holland accumulates to 39.2PJ or 10.3Mt of sugar beet (wb) per year. The biggest contribution comes from areas with a soil type consisting of sea clay, with 33.9PJ or 8.92Mt wb per year. With the largest total area of $110*10^3$ ha and the highest annual yield of 81 t/ha/year, this was expected. Due to a small total area of $17.4*10^3$ ha, river clay only contributes 5.3PJ or 1.39Mt wb per year to the theoretical potential. All figures are ordered in the table 12, and shown geographically in figure 9.

The main limitations of the potential are the exclusion of bog and dune soil, which means that $64.4*10^3$ ha are excluded from sugar beet cultivation. Other limitations are due to the dense population in the south west of The Netherlands, which takes up large portions of the available surface area.

Table 12 Theoretical potential for sugar beet cultivation in South Holland

Soil type	Area ($*10^3$ ha)	Yield (t/ha)	Total Yield (Mt wb)	Energy (PJ)
River clay	17.4	80	1.38	5.3
Sea clay	110	81	8.92	33.9
Bog	46.4	0	-	-
Dunes	18.0	0	-	-
Total	**192**	**N.A.**	**10.31**	**39.2**

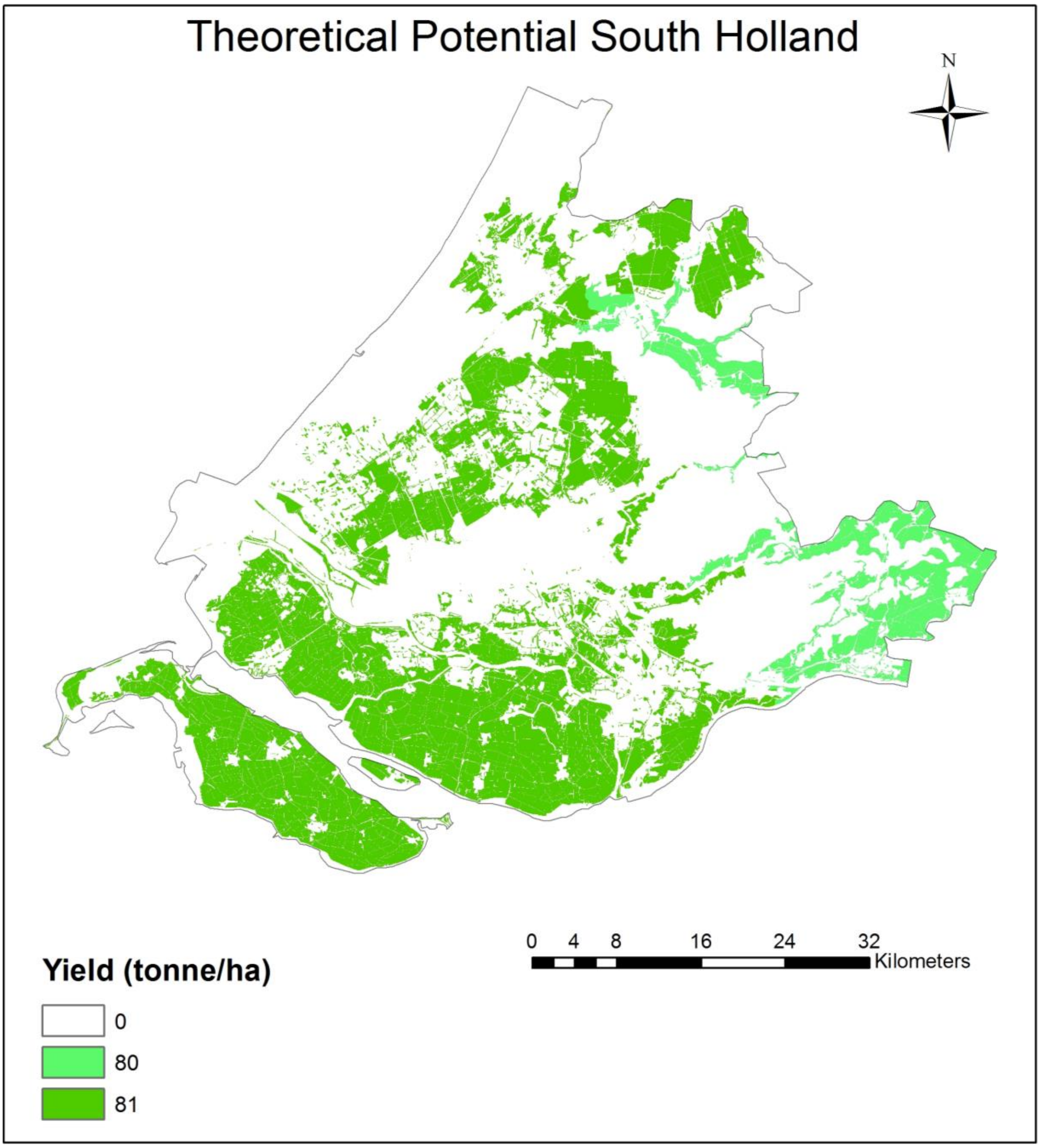

Figure 9 Theoretical potential for sugar beet cultivation in South Holland

3.2 Technical potential

The technical potential incorporates more constraints when compared to the theoretical potential and, thus, comes closer to reality. By using the WLO scenarios on how much land is becoming available for other land uses, the potentials found show sugar beet cultivation for non-food purposes. In contrast, the theoretical potential shows the total theoretical potential of sugar beet cultivation, not taking into account non-food, experience, or crop recoverability limitations.

3.2.1 Technical potential - south west of The Netherlands

If all the arable land in the south west of The Netherlands were to be used for sugar beet cultivation, a total of 7.14Mt (27.1PJ) could be produced. This would require a total of more than 549*10^3 ha, with annual yields ranging from 12.5 t/ha to 14.4 t/ha. The sandy soils of North Brabant (235*10^3 ha) and the sea clay in Zealand and South Holland (267*10^3 ha) are the largest contributors to the technical potential, while river clay (46*10^3 ha) only contributes marginally. In line with figure 5 in the methodology, sea clay is the most used soil for sugar beet cultivation. An overview of the data is given in the table 13, and shown in figure 10.

In comparison with the theoretical potential, the technical potential is most limited by the crop rotations. This decreases the yield by 1/5.16 of the original yield per year. To a lesser extent, the technical potential is limited by the yield loss from inexperienced farmers and the recoverability of the sugar beet. The further limitation that sugar beet cultivation only takes place on arable land has little effect on the results.

Table 13 Technical Potential - south west of The Netherlands

Soil	Yield (t/ha)	Area (*10^3 ha)	Total Yield (Mt)	Energy (PJ)
Sand no experience	12.5	216	2.69	10.2
River clay no experience	12.8	43.8	0.55	2.1
Sea clay no experience	13.0	194	2.51	9.5
Sand experience	13.9	20.1	0.28	1.1
River clay experience	14.2	3.32	0.05	0.2
Sea clay experience	14.4	73.8	1.06	4.0
Total	N.A.	549	7.14	27.1

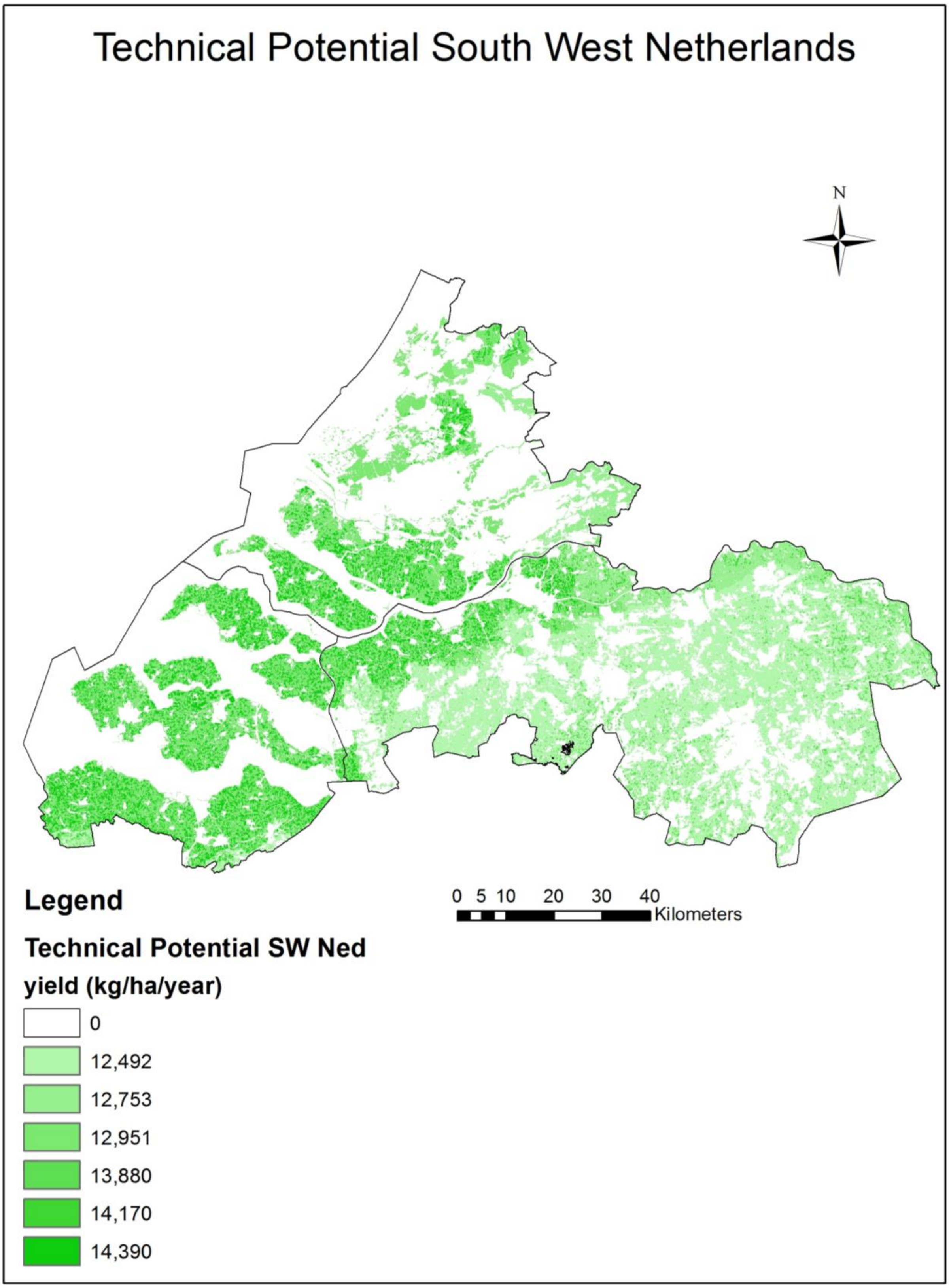

Figure 10 Technical potential - south west of The Netherlands

In comparison to the province of South Holland, the WLO scenarios used for the south west of The Netherlands increase the difference between the high and low scenarios. This is mainly due to a decrease in the area used by the cluster of horticulture in the province of South Holland, which has a small effect on the total land becoming available in the south west of The Netherlands.

Table 14 Technical potential - sugar beet cultivation in the south west of The Netherlands

Scenario	Area (*10^3 ha)	Yield (t/ha)	Total Yield (Mt)	Energy (PJ)
Bio economy high	34.1	14.4	0.49	1.86
Bio economy low	20.3	14.4	0.29	1.11
BAU high	34.1	12.5	0.43	1.62
BAU low	20.3	12.5	0.25	0.96

Table 14 shows the technical potential of each scenario. On a total area of 34.1*10^3 ha, 0.49Mt of sugar beet is cultivated in the bio economy high scenario with 1.86PJ of potential energy. On the same amount of area in the BAU high scenario, 0.43Mt of sugar beet is cultivated with a potential of 1.62PJ of energy. In both the bio economy low and the BAU low scenarios, 20*10^3 ha of land is used for sugar beet cultivation. This area would yield 0.25Mt of sugar beet in the BAU low scenario, with 0.96PJ of energy. In the Bio economy low scenario this area would yield 0.29Mt with a potential of 1.11PJ energy. Since the WLO scenarios show the land becoming available for other lands uses, these potentials show the added sugar beet cultivation for non-food purposes.

3.2.2 Technical potential - South Holland

The results show that, with all the constraints listed in the methodology but without the scenarios, the total area of 106*10^3 ha could produce 5.0PJ or 1.4Mt wb/year. Highest yields can be achieved on sea clay soils by experienced farmers. On an area of 19.4*10^3 ha, a total of 0.28Mt of sugar beet could be cultivated. Lowest yields are found on river clay soils by farmers without experience with sugar beet cultivation. It is interesting to note the small area of 65 ha taken by farmers with experience of sugar beet cultivation on river clay. All figures are listed in table 15. The map shown in Figure 11 shows the different yields resulting from the constraints of the technical potential. The map shows that the island of Goeree-Overflakkee and the area south of Rotterdam have experience with sugar beet cultivation and are achieving high yields. The experience of the farmers could be explained by the close proximity of Suikerunie's Sugar Factory in Dinteloord. The largest limitations on the technical potential are, again, the crop rotations, followed by the yield loss, and the experience.

Table 15 Technical Potential of sugar beet if it is assumed that the whole area is available for sugar beet cultivation.

Soil type	Area (*10^3 ha)	Yield (t/ha)	Total Yield (kt)	Energy (PJ)
Sea clay experience	19.4	14.4	278	0.6
Sea clay no experience	70.8	13.0	917	1.9
River clay experience	0.1	14.2	1	0.0
River clay no experience	15.8	12.8	201	0.4
Total	106	N.A.	1.39*10^3	5.0

This being the technical potential, only a fraction of the subsurface can be used for sugar beet cultivation for the biobased economy. The WLO scenarios are used to determine how much land is becoming available for other types of land use. In comparison to the south west of The Netherlands, the difference between the high and low scenarios is smaller. When the scenarios are imposed upon the total potential listed in table 15, they show the technical potential of sugar beet cultivation for non-food purposes.

Table 16 Technical Potential in the WLO scenarios in 2050

Scenario	Area ($*10^3$ ha)	Yield (t/ha)	Total yield (Mt)	Energy (PJ)
Bio economy high	6.58	14.4	0.094	0.36
Bio economy low	4.99	14.4	0.071	0.27
BAU high	6.58	12.8	0.083	0.32
BAU low	4.99	12.8	0.063	0.24

In Table 16, the results are summarised for the different scenarios. The bio-economy high has the highest potential, with 0.36PJ on $6.58*10^3$ ha of land. The BAU low scenario has the lowest potential with 0.24PJ on almost $4.99*10^3$ ha of land. Note that these scenarios have limitations: for example, it would be illogical to grow sugar beet on low-yielding grounds without experience. However, they do provide an example of the spectrum of the technical potential in the province of South Holland.

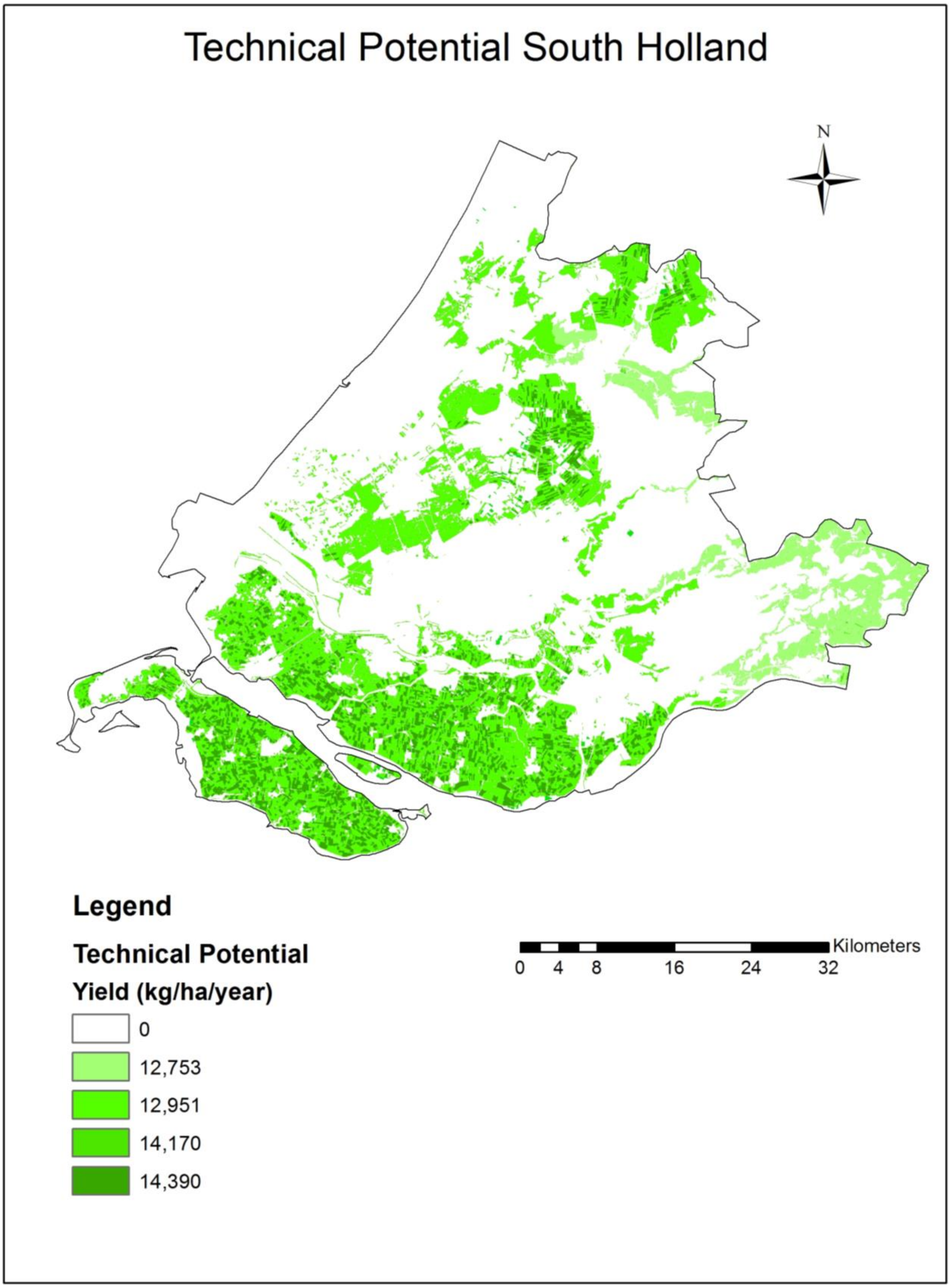

Figure 11 Technical Potential – South Holland

3.3 Economic potential

The economic potential is defined as the share of the technical potential which, under certain economic constraints, is shown to be profitable. Therefore, the economic potential is largely determined by the cost of production and the price of sugar beet (Batidzirai, Smeets, & Faaij, 2012). In this thesis, the cost of imported biomass is benchmarked against the cost-supply curve of local sugar beet cultivation. To gather more detail in the province of South Holland, the NPV of both the BAU and the biobased economy rotation schemes are compared.

3.2.1 Economic potential - south west of The Netherlands

In the south west of The Netherlands the economic potential was determined by constructing a cost-supply curve. To construct the information needed, the model shown in appendix A-12 is used and the resulting map is shown as figure 12.

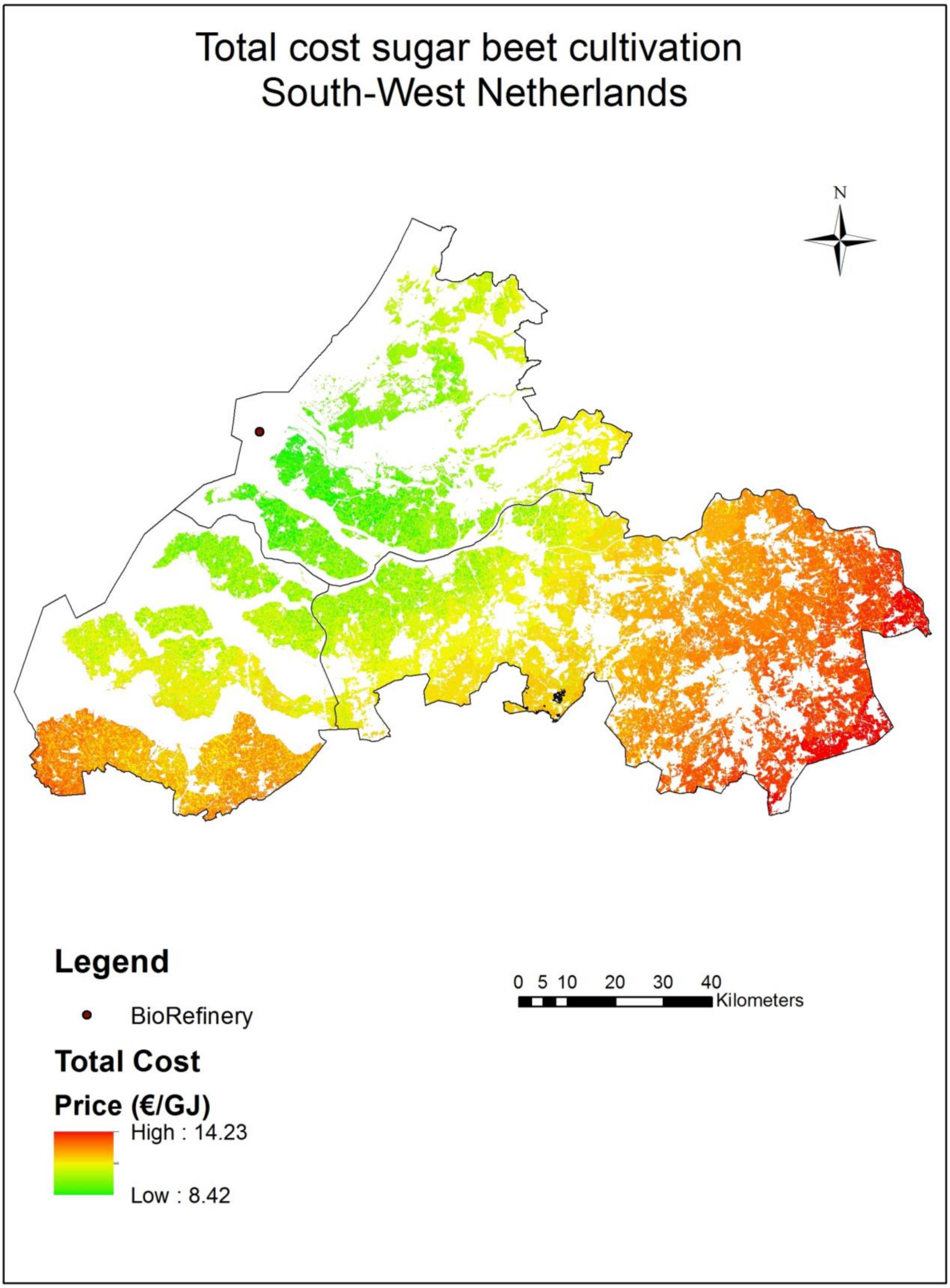

Figure 12 Total cost cultivation including transport in the south west of The Netherlands

The map shows that the province of South Holland is the cheapest place to cultivate sugar beet, and transport it to the reference biorefinery on the Maasvlakte. The area adjacent to the province of South Holland is also able to cultivate sugar beet at competitive prices. The islands of Gouwe Duiveland and Noord Beveland, consist of sea clay soils and are in close proximity to the Port of Rotterdam. On the mainland, the north-western corner of Brabant consists of sea clay and is also in close proximity to the Port of Rotterdam. In comparison, the most southern islands of Zealand and the remaining parts of Brabant seem less suitable for sugar beet cultivation. This is mainly due to poor soil conditions and large transportation costs.

Soil conditions and transport costs are the most important factors to calculating the price of sugar beet cultivation. The soil conditions are largely responsible for the yields, which are covered in both the theoretical and technical potential. Transport costs make a substantial contribution to the total cost. These added costs range from 1 €/tonne of sugar beet in close proximity to the biorefinery plant to 20 €/tonne of sugar beet in the eastern parts of Brabant. These factors make the arable land in close proximity to the reference biorefinery the cheapest place to cultivate.

The cost-supply curve of sugar beet cultivation in the south west of The Netherlands is shown in figure 13. It shows that a total of 1.28PJ can be cultivated for under € 9.50/GJ, and 2.68PJ could be cultivated for less than € 10.00/GJ. The maximum cultivation costs in the province of South Holland are € 11.60/GJ, at which price the total potential is 13.59PJ in the south west of The Netherlands. After this point the price increases rapidly to € 14.23/GJ.

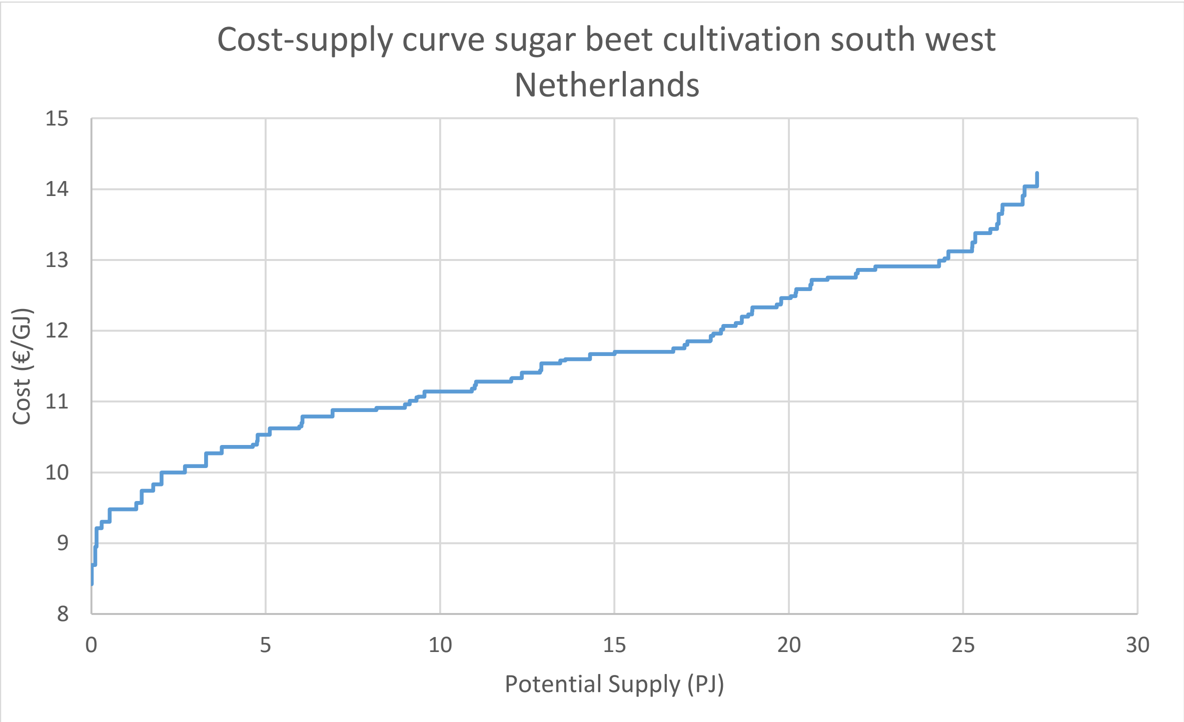

Figure 13 Cost-supply curve of sugar beet cultivation in the south west of The Netherlands

In table 17 and figure 14, the price of fermentable sugar from sugar beet cultivation in the south west of The Netherlands is compared to imported biomass sources. When compared to the raw sugar price set by the FAO, sugar beet cultivation in the south west of The Netherlands can produce 303kt of fermentable sugar (1.77Mt sugar beet, 6.7PJ) under or at world prices. If farmers set a 20% profit margin, they would be able to produce 7kt of fermentable sugar (0.04Mt sugar beet, 0.2PJ).

Local fermentable sugar price is compared to the fermentable sugar price from wood pellets in 2030 with high technological growth. This shows that 817kt of fermentable sugar (4.78Mt sugar beet, 18.2PJ) is produced economically. If farmers go for a 20% profit margin they would produce 118kt of fermentable sugar (0.690Mt sugar beet, 2.6PJ) economically. If they increase their margin further to 40%, a total of 5kt of fermentable sugar (0.03 Mt sugar beet, 0.1PJ) is producible economically.

Comparing locally cultivated farmable sugar prices to those from wood pellets in 2025 with high technological growth gives a total of 986kt of fermentable sugar (5.77Mt sugar beet, 21.9PJ) economically produced. With a margin of 20% this would decrease to 266kt (1.56Mt sugar beet, 5.9PJ) of fermentable sugar. If a margin of 40% is chosen, it decreases further to 13kt of fermentable sugar (0.08Mt sugar beet, 0.3PJ).

For comparison as to how these prices compare to current prices given by the Suikerunie, the KWIN AGV 2015 prices are added to the graph. These prices are the highest in comparison, and are set to decrease with the expiration of the sugar quota. At current prices, the entire research area of the south west of The Netherlands is able to cultivate sugar beet. If a 20% margin is taken, 792kt of fermentable sugar (4.63Mt sugar beet, 17.6PJ) could be cultivated. With a 40% margin, this would decrease to 164kt of fermentable sugar (0.959Mt sugar beet, 3.6PJ). All of the intersections are shown in figure 14 and an overview is given in table 17.

Table 17 Overview of economic potentials given profit margins and biomass sources in the south west of The Netherlands

	Fermentable Sugar (kt)	Sugar Beet (Mt)	Energy (PJ)	Profit Margin
Raw sugar FAO	303	1.77	6.7	0%
	7	0.04	0.2	20%
Woodchips 2030	817	4.77	18.2	0%
	118	0.69	2.6	20%
	5	0.03	0.1	40%
Woodchips 2025	986	5.77	21.9	0%
	266	1.56	5.9	20%
	13	0.08	0.3	40%
KWIN AGV 2015	792	4.63	17.6	20%
	164	0.96	3.6	40%

Finally, the intersection between fermentable sugar from sugar beet with a 20% margin and fermentable sugar woodchips in 2030 is chosen as the best representation of the economic potential. This leaves the farmers with sufficient profit margin to cover external costs while economically competing with the cheapest imported biomass source. The 20% margin corresponds with other reports (Hoppe, 2014). This would set the economic potential at 118kt of fermentable sugar (0.69Mt sugar beet, 2.6PJ) and would mean that the economic potential is greater than the technical potential. Since the economic potential is not limited to the WLO scenarios, it cannot be said with certainty that this is the potential for non-food purposes. Therefore, the economic potential for non-food purposes is limited by the technical potential. Meaning that a total of 84kt of fermentable sugar (0.49Mt sugar beet, 1.9PJ) can economically be produced for non-food purposes. This is a substantial addition to the 1.6Mt of sugar beet currently cultivated in the south west of The Netherlands (CBS, 2015).

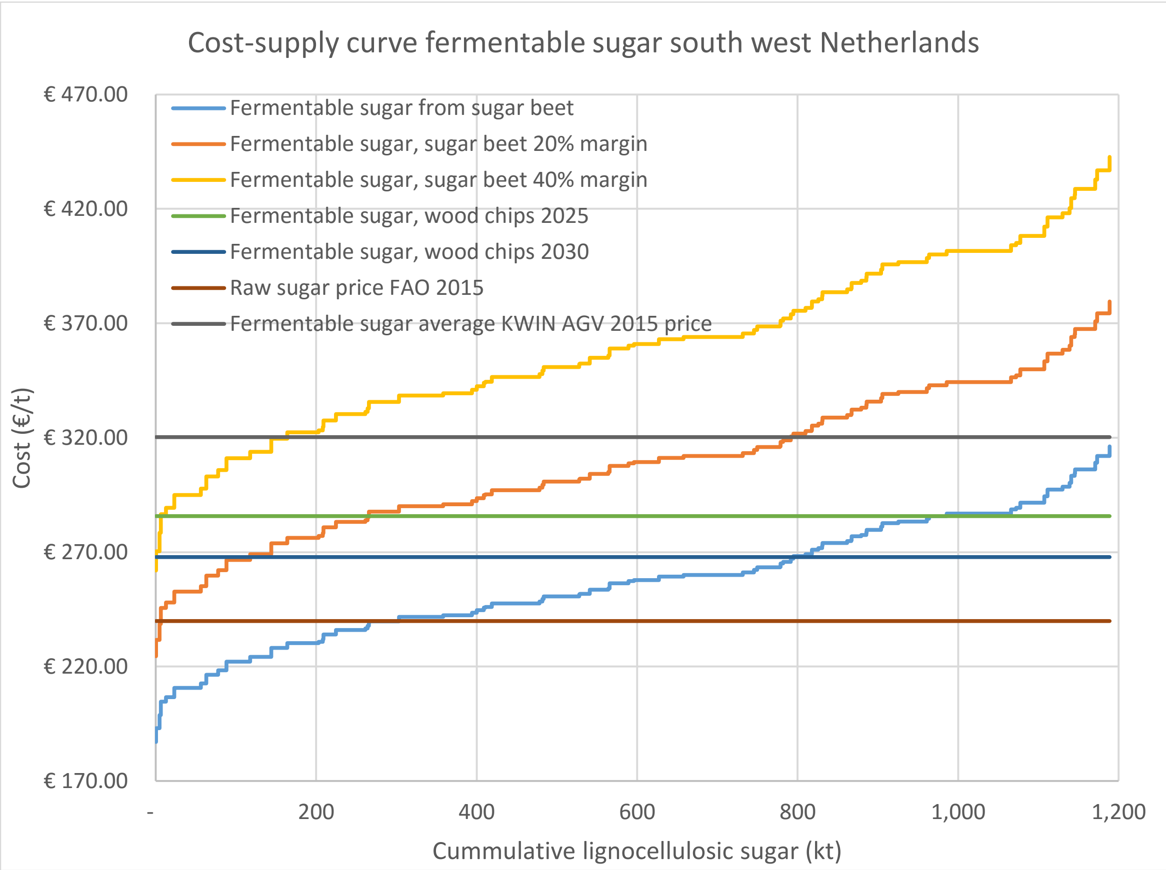

Figure 14 Cost-supply curve for fermentable sugar in the south west of The Netherlands

3.3.2 Economic potential - South Holland: NPV

Two NPV's are calculated over a period of 20 years, and compared to one other: a) the NPV of a BAU rotation scheme, and b) the NPV of a biobased economy with an increased sugar beet rotation scheme. The results are shown below.

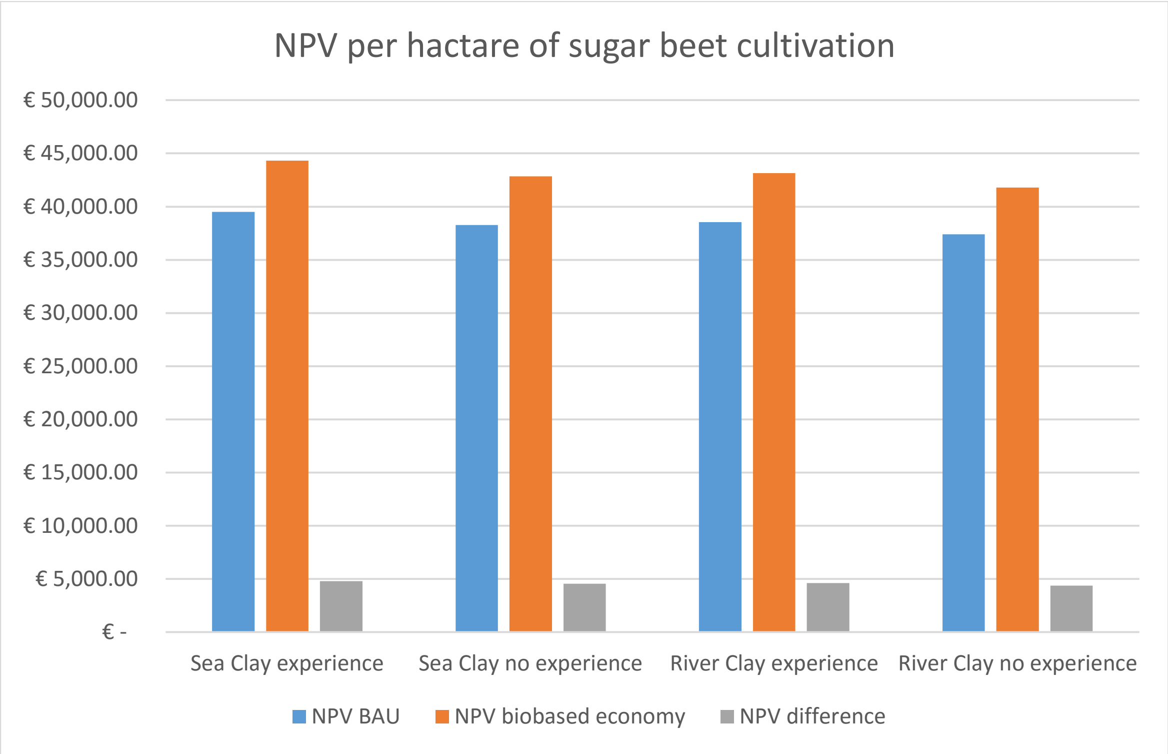

Figure 15 NPV of sugar beet cultivation

The results show that every farmer would increase their NPV by increasing the sugar beet rotation from every five years to every 4 years. The increased NPV per hectare ranges from € 4,379 on river clay soils to € 4,802 on sea clay soils. The largest contributors to the NPV are potatoes, followed by onion and sugar beet. Winter wheat and spring barley add little to the NPV in the rotation scheme and this explains the improved NPV of the biobased economy case. In these calculations, sugar beet is the only crop which is differentiated across the subsurface. Therefore, sugar beet is solely responsible for the differences in NPV. Since all the soil types, with or without experience, could increase their NPV by switching to the biobased economy scheme, no geographically substantial differences are noticed. This means that the determination of the economic potential by NPV comparison is difficult.

3.3.3 Economic potential - South Holland: cost-supply curve

The economic potential is also determined by comparing the production cost of sugar beet to the import cost of its competitors. This indicates where the economic potential lies as the share of the technical potential which, under economic constraints, shows profitable. "Profitability" can be defined as occurring when the production of sugar beet is cheaper than its imported biomass rivals.

In figure 16, the total production and transport costs towards the reference biorefinery plant on the Maasvlakte is shown. The arable land in close proximity to the biorefinery location is able to cultivate and transport the sugar beet cheaply. This area consists of arable land, with sea clay soil, west of Rotterdam and the island Goeree Overflakkee. Production costs range from € 8.16/GJ on sea clay soil in close proximity to the biorefinery plant to € 11.60/GJ on river clay soils in the east. Since the same methodology is applied to the province of South Holland as was applied to the south west of The Netherlands, both soil conditions and distance are the most important constraints responsible for the prices.

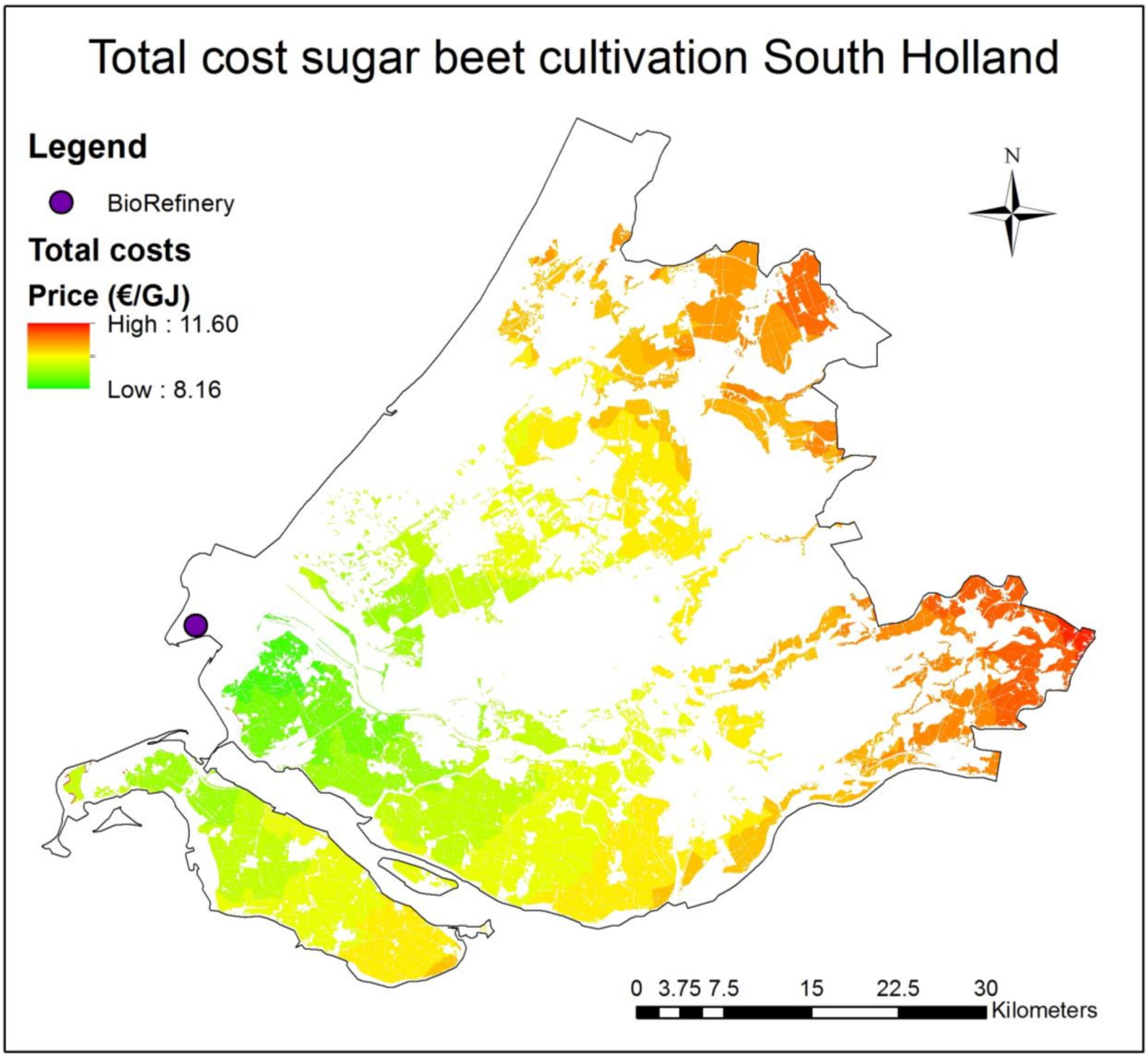

Figure 16 Total cost of cultivation (including transport)

The cost-supply curve depicted in figure 17 shows that costs rise rapidly from € 8.16/GJ to € 9.00/GJ at 0.15PJ as a result of high transport costs. This indicates that only a small fraction of the land would be able to compete economically with imported biomass sources. The majority of the province is able to cultivate sugar beet at a cost of between € 9.50/GJ and € 10.50/GJ with with a potential of 2,7PJ in that price range.

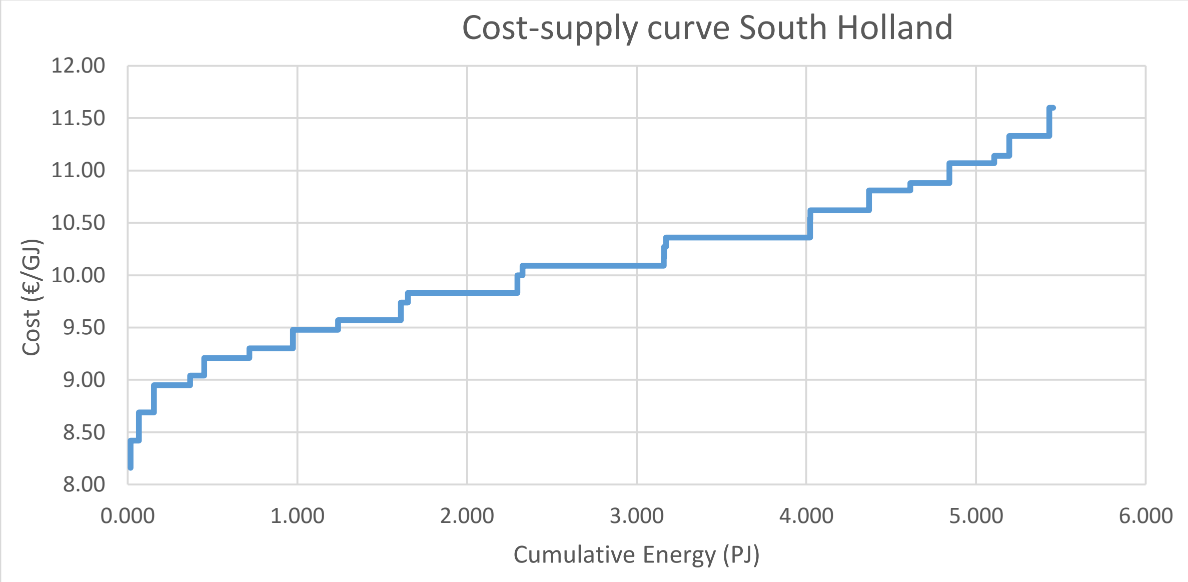

Figure 17 Cost-supply curve in South Holland

Figure 18 and table 18 show the comparison between sugar beet cultivation in the province of South Holland and the cost of imported biomass sources. When compared to the price of imported biomass, sugar beet cultivation in South Holland can produce up to 200kt of fermentable sugar (1.17Mt sugar beet, 4.4PJ) below or at world raw sugar prices. When the farmers take a profit margin of 20% for external expenses, the economic potential drops to 16.5kt of fermentable sugar (0.965Mt sugar beet, 0.4PJ). With a 40% margin, sugar beet cultivation in the province of South Holland cannot economically compete with world raw sugar prices.

When compared to the projected prices of fermentable sugars derived from wood chips in 2030, all of the farmers are able to produce below that price. When a farmer takes a 20% profit margin, 103kt of fermentable sugar (0.604Mt sugar beet, 2.3PJ) could economically be cultivated in the province of South Holland. Some farmers could even take a 40% profit margin. They would be able to produce 3.0kt of fermentable sugar (0.0175Mt sugar beet, 0.1PJ).

If fermentable sugar prices from Dutch sugar beet cultivation are compared to the projected fermentable sugar prices from wood chips in 2025, two intersections are found. Firstly, the farmers who take a 20% profit margin are able to produce 196.6kt of fermentable sugar (1.15Mt sugar beet, 4.4PJ) at that price. Secondly, farmers who take a 40% profit margin produce 20.3kt (0.119Mt sugar beet, 0.5PJ). An overview of the intersection is given in table 18.

Suikerunie's prices, as given in the KWIN AGV 2015 data, indicate that with or without a 20% margin, the entire province of South Holland is able to cultivate sugar beet economically. When a margin of 40% is selected, 142kt of fermentable sugar (0.831Mt, 3.2PJ) is economically cultivated.

Table 18 Overview of economic potentials given profit margins and biomass source in South Holland

	Fermentable Sugar (kt)	Sugar Beet (Mt)	Energy (PJ)	Profit Margin
Raw sugar FAO	200	1.17	4.4	0%
	16.5	0.10	0.4	20%
Woodchips 2030	103	0.60	2.3	20%
	3.0	0.02	0.1	40%
Woodchips 2025	197	1.15	4.4	20%
	20.3	119	0.5	40%
KWIN AGV 2015	142	0.83	3.2	40%

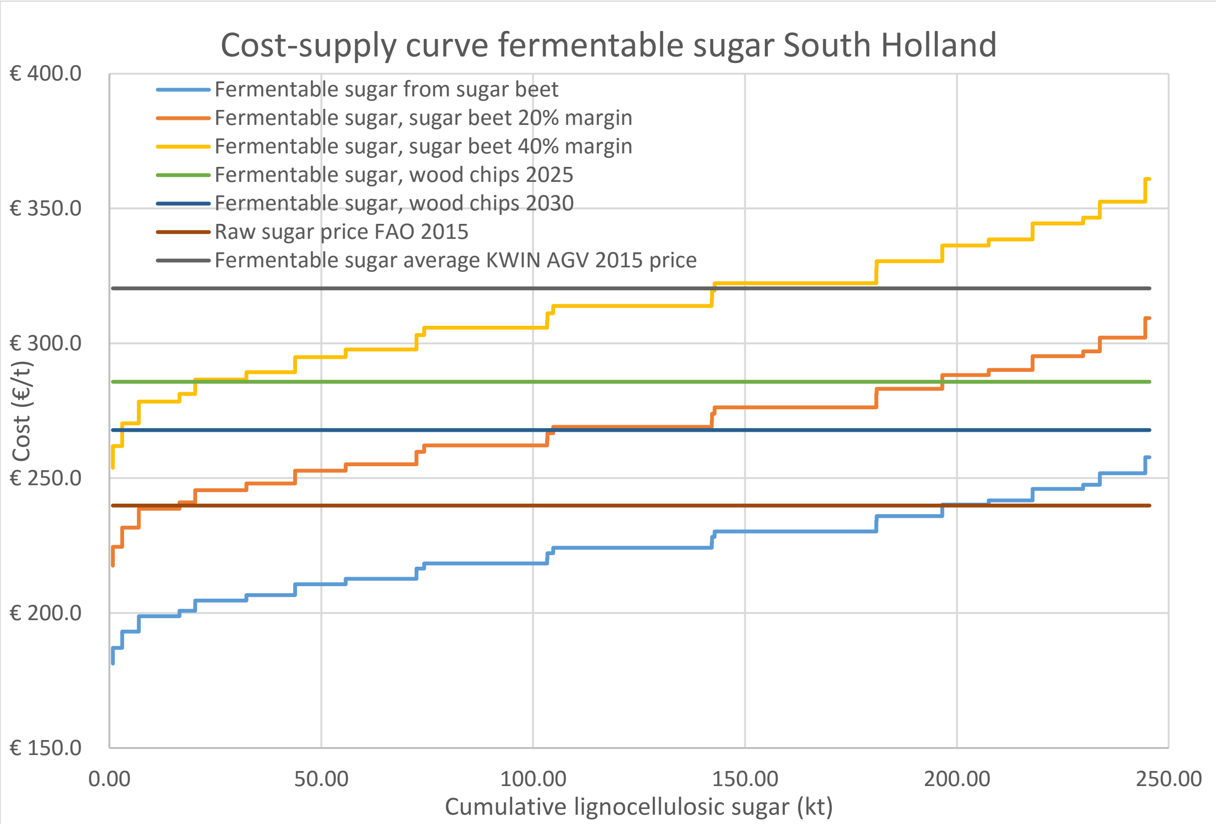

Figure 18 Cost-supply curve for fermentable sugar in South Holland

In line with the south west of The Netherlands, the best representation is taken from the intersection between the fermentable sugars from wood chips 2030 price and the sugar beet cultivation with 20% margin price. As in the south west of The Netherlands, this results in the economic potential being greater than the technical potential. Therefore, the economic potential is limited by the technical potential for the same reason. The economic potential is found at 0.4PJ (0.094Mt sugar beet, 16kt fermentable sugar), which is a substantial addition to the 0.3Mt of sugar beet currently cultivated in the province of South Holland (CBS, 2015).

3.4 Price projections - fermentable sugar

When calculating the price projections of fermentable sugar beet, both the data from KWIN AGV and Suikerunie show growing yields. KWIN AGV yields increase from 81 t/ha in 2015 to 97.2 t/ha in 2030. Yield projections using data from Suikerunie show that yields could increase from 79 t/ha in 2012 to 106 t/ha in 2030. The average of these two is then used to indicate a yield of 102 t/ha in 2030. While the yields have increased in recent times, so too, did the labor and cultivation costs. To achieve the higher yield, more pesticides, sowing material and labour is used per hectare. Therefore, the price of the fermentable sugar only marginally decreases.

The price projections of sugar beet cultivation are compared to the FAO raw sugar price projections, and the Markal lignocellulosic biomass projections. The FAO raw sugar price projections show the world raw sugar price and this gives an indication of the price the farmers will receive after the quota is lifted. The Markal projections used are with the high technological growth scenarios, both for wood pellets and wood chips. Due to the high technological growth the price per tonne fermentable sugar decreases.

Projections of world raw sugar prices show a decline towards 2017 as a result of the expiration of the sugar quota. Beyond 2017, the price is projected to increase again. With this increase, the marginal cost (Feedstock and O&M costs) of fermentable sugar from wood chips would become comparable (€ 240/t) to raw sugar (€ 237/t). If all costs are included in the price of woodchips, a price drop due to the technological improvements is also apparent. While capital costs are decreasing, bringing the total price closer to the marginal price, the total price is still considerably higher at € 267/t. The price of wood pellets follows the same decrease as wood chips. Due to the higher feedstock prices, the price of fermentable sugar from wood pellets stays higher in comparison to all other biomass sources. The marginal price of the wood chips would economically compete with the raw sugar price in 2030. With the assumption that the raw sugar price is an indication of the price farmers get for their sugar beet, this would indicate economic competition between wood pellets or chips and sugar beet cultivation in 2030. An overview of the data descriped is shown in figure 19.

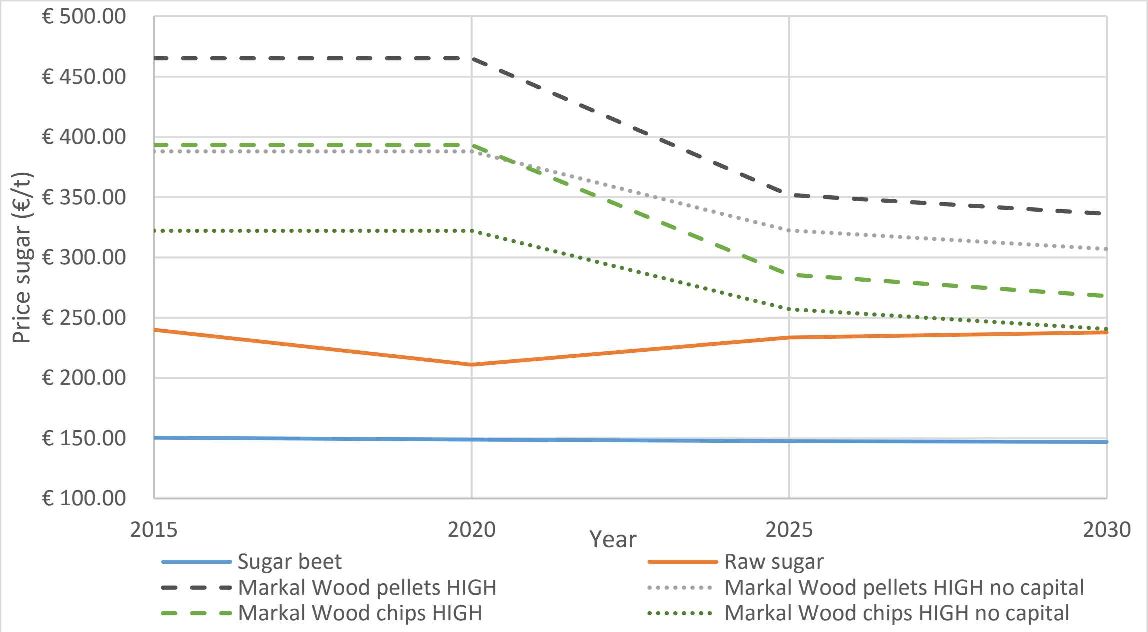

Figure 19 Future sugar price projections

3.5 GHG balance

The environmental impact from sugar beet cultivation used for liquid biofuels has to meet RED regulations. Therefore, liquid biofuels used in transport have to meet binding sustainability criteria, including a minimum GHG-saving performance compared to fossil fuels. Liquid biofuels have to outperform the fuels that they replace with a 35% GHG emission decrease. This figure increases to 50% in 2017 and 60% in 2018. When sugar beet is used for other biobased purposes, these criteria do not have to be met.

The BioGrace I tool calculates the environmental impact of sugar beet cultivation, given the inputs in the methodology. Dutch sugar beet cultivation on sand, sea clay and river clay soils outperforms the default RED sugar beet calculation. In BioGrace's default settings 35.62g CO_2-eq/kg sugar beet is emitted. The input data for sea clay in found by this research suggest it is expected to emit the least CO_2-eq, at 30.48g CO_2-eq/kg, while both sand (34.53g CO_2-eq/kg) and river clay (31.06g CO_2-eq/kg) also emit less than the default settings.

The BioGrace I tool allocates these emissions between the end product and by-products using energy allocation. With production of ethanol, sugar beet pulp is created, which is used by various other sources. Therefore, 76.5% of the CO_2-eq emissions are allocated to the ethanol, and are included in the RED totals (BioGrace, 2015).

The biggest contribution to the environmental impact comes from the ethanol production of sugar beet. While this is outside the scope of the research, it is crucial to reaching the RED criteria, and, therefore, its CO_2-eq emissions are examined here briefly. During the process, a total of 38.82g CO_2-eq/MJ of ethanol (26.26g CO_2-eq/MJ ethanol allocated) are emitted. The bulk of the cultivation emissions range from 16.08 to 13.76g CO_2-eq/MJ (12.30g to 12.52g CO_2-eq/MJ ethanol allocated). These allocated production emissions (26.26g CO_2-eq/MJ ethanol) are therefore emitting 31% of the emissions of comparable fossil resources (petrol 83.8g CO_2/MJ). With the RED criteria demanding a 60% GHG decrease, this would leave less than 9% or 7.54g CO_2 eq/MJ coming from cultivation. An overview of the data is given in tables 19 and 20, and a comparison between ethanol from sugar beet, wood chips and petrol is given in figure 20.

Table 19 Environmental impact of sugar beet cultivation

	Sand	Sea Clay	River Clay	Default	unit
Per kg sugar beet	34.53	30.48	31.06	35.62	g CO_2-eq
per ha per year	2499.4	2481.1	2489.9	2452.8	kg CO_2-eq
Per MJ ethanol	15.59	13.76	14.02	16.08	g CO_2-eq/MJ Ethanol
RED criteria	53%	54%	54%	52%	GHG reduction

Comparison

For comparison, ethanol production from sugar beet is compared to ethanol production from woodchips and petrol. The ethanol from wood chips emits less CO_2-eq per MJ and this is primarily due to the fact that Hamelinck & Hoogwijk (2007) does not incorporate any conversion emissions. Due to the willow feedstock, the production of wood chips in 2005 is considerably higher at 26.6g CO_2-eq/ MJ. If the feedstock production in 2020 is taken, instead of 2005, the emissions are lower at 12.8g CO_2-eq/ MJ. If other lignocellulosic feedstocks are used, these emissions are lower (Chum, et al., 2011). Transport emissions from the ethanol from Savannah to Rotterdam are regarded as relatively low considering the distance at 0.7g CO_2/MJ. In total, the reduction of GHG emissions from wood chips would be 63% of the petrol it replaces. Figure 20 and table 20 give an overview of the emissions of ethanol from different sources of biomass and petrol (83.8g CO_2/MJ).

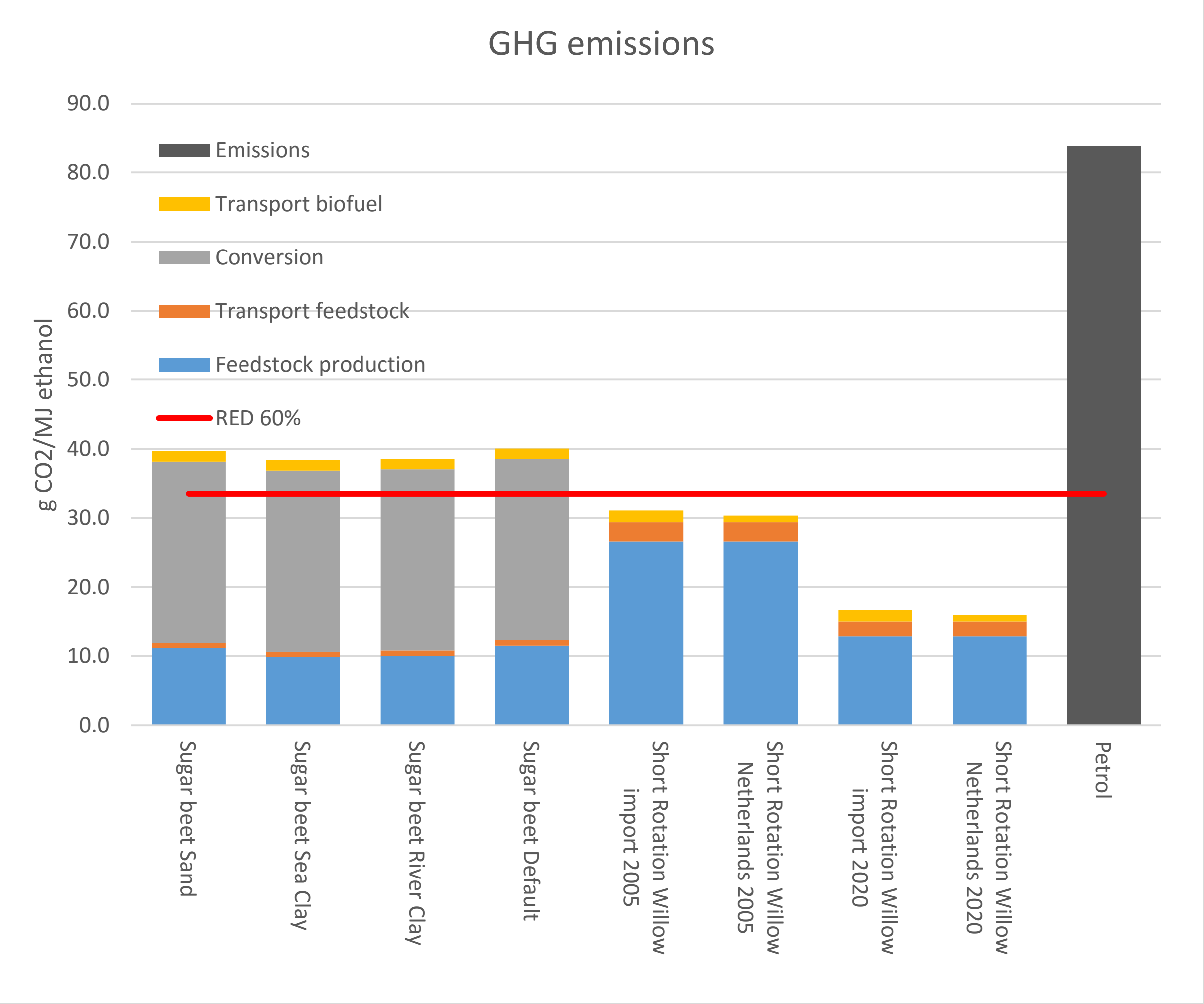

Figure 20 GHG emissions sugar beet, wood chips and fossil gasoline, based on energy allocation and given in g CO_2-eq/MJ Ethanol

Table 20 GHG emissions - sugar beet and wood chips (all values are allocated and given in g CO_2-eq/MJ Ethanol)

	Sugar beet Sand	Sugar beet Sea Clay	Sugar beet River Clay	Sugar beet Default	Short Rotation Willow import 2005	Short Rotation Willow NL 2005	Short Rotation Willow import 2020	Short Rotation Willow NL 2020
Feedstock production	11.1	9.8	10.0	11.5	26.6	26.6	12.8	12.8
Transport feedstock	0.8	0.8	0.8	0.8	2.8	2.8	2.2	2.2
Conversion	26.3	26.3	26.3	26.3	0.0	0.0	0.0	0.0
Transport biofuel	1.5	1.5	1.5	1.5	1.7	0.9	1.7	0.9
Emissions	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RED	53%	54%	54%	52%	63%	64%	80%	81%

4. Discussion

This discussion consists of three parts. Firstly, the results are compared to existing studies. Secondly, the limitations of the model and the results are discussed. Finally, recommendations on further research are provided.

4.1 Comparison with other studies

In the upcoming section, articles are examined and compared to the present study with attention being focussed on the different methods applied to determine the theoretical, technical, and economic potential and the results found.

Van Hilst et al. (2010) calculated the potential of sugar beet cultivation in the north of The Netherlands and this was represented by the cost-supply curves made for both miscanthus and sugar beet. The total amount of arable land according to the CBS (2016) in the north of The Netherlands ($5.8*10^3$ km^2) is comparable to the total amount of arable land in the south west of The Netherlands ($5.3*10^3$ km^2). The theoretical potential of sugar beet cultivation in the north of The Netherlands accumulates to 134PJ. This is low in comparison to the 198.8PJ of accumulated energy from sugar beet in the south west of The Netherlands. The technical potential found by van Hilst et al. (2010) used the EU Refuel study (de Wit & Faaij, 2010) to determine the amount of land available for bioenergy cultivation without harming food security. The Refuel project estimated 1.7% to 4.3% of arable land was available for bioenergy cultivation in 2015, and that there will be 6.1% to 10.2% in 2030. This thesis uses the WLO scenarios to assess the amount of land that will become available for the biobased economy in 2050. While 2030 and 2050 are difficult to compare, the 3.7% to 6.4% estimated in this thesis, is considerably lower than estimated by the Refuel project. The article by van Hilst et al. (2010) also calculated the cost of cultivating sugar beet. In the north of The Netherlands the costs start at € 9.7/GJ. The estimated lowest cost of sugar beet in this thesis is slightly lower (8.17 €/GJ) as found for South Holland. One factor contributing to this difference could be the improved sugar beet yields in The Netherlands as Van Hilst et al. (2010) base their figures on a yield of 73 t/ha.

Koppejan et al. (2009) focus on the total potential of biomass (forest, agriculture, waste) for energy purposes and they do not explicitly report on the theoretical, technical, and economic potentials. Furthermore, there is little focus on sugar beet cultivation for the biobased economy. The study mentions 100,000 ha reserved for all energy crop cultivation in The Netherlands in 2020. While 2050 and 2020 are difficult to compare, the 20.325 to 34.059 ha projected to be available for sugar beet cultivation in the south west of The Netherlands in this thesis, the 100,000 ha in the entire Netherlands for all energy crops seems conservative. Koppejan et al. (2009) further assume 10 tonnes of dry matter per ha, while sugar beet yields as high as 80 tonnes per ha (wb) are found in this study. Koppejan et al. (2009) regard sugar beet as too expensive for energy crop cultivation, while the results in this thesis show a large economic potential when compared to imported biomass.

In correspondence with Koppejan et al. (2009), Elbersen et al. (2015) use market and demand constraints to determine the bioenergy potential in the EU28 at NUTS-2 level. The theoretical, technical, and economic potentials are not assessed separately. Elbersen et al. (2015) use a combination of CAPRI[9] and PRIMES[10] to determine the technical potential. The article assumes that sugar beet is mainly used for fermentable sugars, but its leaves are also available for lignocellulosic biomass production. This is something which is left out of the scope of this thesis. The demand for first- and second-generation biomass is taken from the PRIMES model and added to the market demand of the CAPRI model. The CAPRI model then determines the best mix of biomass production and distribution in accordance with several market constraints internal to the CAPRI model. Supply of sugar beet is only driven by demand projections of first-generation biofuels. Since Elbersen et al. (2015) uses market prices and demand constraints in the determination of their potentials, these potentials are economic. The scope and the models that are used are very elaborate which leaves opportunities for further research into specific biomass sources and potentials, such as in this thesis.

The Deloitte study (2014) focusses on the entire fermentation industry, investigating the many applications of fermentable sugars. One of the findings of the study shows that the crop costs are 281$/t for white sugar equivalent, not including transport, and that the total costs would amount to 429$/t for white sugar equivalent in 2014. These costs correspond with the cultivation costs calculated in this thesis. The Deloitte study (2014) also predicts $47*10^3$ ha of arable land being returned to cultivating sugar beet in The Netherlands. This was the number of hectares lost when the sugar quota started. This amount of land becoming available for sugar beet cultivation in the entire Netherlands, corresponds with the amount of land becoming available in the south west of the Netherlands in this thesis. With the south west of The Netherlands being in close proximity to the Dinterloord or a reference biorefinery plant, most of the area regained by sugar beet cultivation is expected to be in this area. The study also assumes sugar yields to increase from 14 to 18 t sugar/ha which corresponds to 105 tonnes sugar beet per hectare in 2020. The yield projections in this thesis are similar, with 97 and 106 tonnes of sugar beet cultivated per hectare in 2030. The Deloitte study also predicts ethanol from sugar beet will become competitive with fossil fuels, but this is not relevant to present-day fossil fuel prices.

In comparison with previous research, the overall approach of the thesis is set out to be comprehensible. This created limitations on the amount of constraints taken into account, but also limits the amount of input needed. Moreover, the input data is easily accessible for any future researcher who wishes to run the model for any other area. With the insight given in the methodology, constraints can be added or altered for further research.

4.2 Limitations of the model, input data and results

While the model is comprehensible and the data easily accessible, some factors which are too complex for the model are left out. For example, the suitability of areas for sugar beet cultivation primarily depends on the soil types available, which are included in the model. However, irrigation, precise meteorological statistics and farmers' preferences also play a role. Precise meteorological and irrigation data require elaborate models and large amounts of data

[9] The CAPRI (Common Agricultural Policy Regionalised Impact) model is a tool for ex ante impact assessment of agricultural and international trade policies with a focus on the European Union.
[10] The PRIMES energy model simulates the European energy system and markets on a country-by-country basis and across Europe for the entire energy system. The model provides projections of detailed energy balances, both for demand and supply, CO2 emissions, investment in demand and supply, energy technology penetration, prices and costs.

to be included. Other data such as farmers' preferences are incorporated by creating a mosaic of the LNG maps in order to determine how much experience they have.

Determining the technical potential with the different scenarios, created limitations within the scenarios. The BAU high scenario has 6.3% of arable land becoming available for sugar beet cultivation on soils that are least suitable for sugar beet cultivation. In reality, this combination of high biobased economy drivers and low-yielding grounds would not be likely to occur, but it does give a spectrum in which the technical potential should be expected. Also, the scenarios used give an indication as to how much land will become available in 2050, which is outside the scope of this research. Therefore, they are used as an indication as to how much land could be used without harming the food and feed supply. These WLO scenarios lack the spatial detail on where this land will become available. Due to the suitability in the region, sugar beet cultivation in the south west of The Netherlands could push out other crops, creating more land used by sugar beet cultivation for non-food purposes, than predicted by the WLO scenarios. Clear data on how much land is needed to meet the food demand of the research area does not exist, mainly because large amounts of food are imported and exported. Therefore, the WLO scenarios are the best indication in this case, and form a clear limitation for the potentials found.

The primary source of the geographic differentiation of yields on arable lands comes from the soil type used. These soil types were coupled to the KWIN AGV data, which created limitations to the results. Other sources, such as Suikerunie (2015) and IRS (2014), gave yields exceeding those of the KWIN AGV. These sources lacked extensive data on the costs and benefits of cultivation. This would indicate that the potentials found in this thesis are conservative when the sugar beet yields are compared to the 93 t/ha suggested by Suikerunie (2015), or 90.8 t/ha suggested by the IRS (2014). With the annual update of the KWIN AGV and the experience and knowledge of the Wageningen-UR and LEI-WUR constructing it, it is the best source available for the calculations. While more comprehensible geographic differentiations should be aspired to by future research, the soil types and KWIN AGV data create a solid basis for calculating the potentials.

Constructing the cost-supply curve indicated limitations to the data used. For example, only the costs given in the KWIN AGV where taken into account. Therefore, profit margins, capital costs, and land costs could not be taken into account. This was solved by incorporating profit margins into the cost-supply curve and by investigating how the cost-supply curve, including the margins, would perform against imported biomass. In the cost-supply curve, the price that the Suikerunie gives to the farmers according to the KWIN AGV is incorporated. After research, it became clear that this price depends on an intricate system involving the global market price, shareholders, the sugar quota, and further processing. When Suikerunie was contacted to explain this pricing system and the results of this thesis, they declined to make a statement. Another limitation, given the KWIN AGV costs used, is the non-monetisable gains of some of the crops in the rotation. Crops such as winter wheat and spring barley increase the soil quality, while very little profit is made with them. Other factors, such as personal preference, could also encourage farmers to make non-economic decisions.

To be able to put the potentials into perspective, the GHG emissions were estimated and price projections were made. The cost price projections of sugar beet rely on the simplified assumption that the yields will grow linearly. The raw sugar price and fermentable sugar price from wood pellets were taken from extensive research. The fermentable wood chips price is constructed with the simplified assumption that the production process of wood chips and wood pellets is interchangeable. While this is a simplification, it gives an outlook to future price movements. The GHG emissions are found using different tools: this has resulted in dissimilarity of the assumptions. The comparison between the different biomass sources could still be made and so the environmental impact could be assessed. More biomass sources such as forestry residues, oil crops, and perennial grasses, should be added to investigate its potential supply, and the environmental impact. Currently an LCA study on sugar beet cultivation is being conducted by Alex Werner at the Utrecht University and this could resolve the discrepancy.

4.3 Recommendations

With the limitations listed in the previous section in mind, future research and recommendations are made. The first of these deals with the issue of market penetration by REDIFINERY. Due to the market domination by Suikerunie - including infrastructure, transport network, contracts, and contacts - penetrating the market will bring difficulties for REDIFNERY. Establishing a network of farmers and their deliveries to the plant will be difficult for a new entrant. With Suikerunie being the first choice of the farmers, REDIFNERY would have to create a bold strategy to persuade farmers to deliver sugar beet to them. This could be done by competitive pricing, or a guaranteed amount purchased. There is, however, a probability that there will always be farmers who are excited to sell their crops to a different buyer.

This thesis mainly focusses on determining the potentials of sugar beet cultivation, with the addition of future projections and GHG emissions. Both of these subjects could be studied in greater detail. The price projections are researched in greater detail in the MEV II study, which focuses on multiple sources of biomass. Further price projections focused on the biobased economy with fermentable sugars as an input source could be done in order to assess the feasibility of the biobased economy. With the increasing yields of sugar beet in The Netherlands, an LCA study of sugar beet cultivation could indicate whether RED criteria are feasible. As noted in the GHG section, the emissions primarily originate from the processing of the sugar beet. Further research could indicate whether technological improvement could decrease the GHG emissions that are part of the process.

Further research on the potential of sugar beet cultivation in The Netherlands should investigate two topics. Firstly, the models created should be run for the whole of The Netherlands. This could show regions suitable for intensive sugar beet cultivation. The IJselmeer polder in the province of Flevoland is one example. This province had, according to multiple sources, the highest yields in The Netherlands at 92.2 t/ha in 2015. Secondly, more constraints should be added to create more geographical differentiation in the results. The article by van der Hilst et al. (2010) can be taken as an example. With this added differentiation, the NPV comparison in the economic potential would show results as to where to economically cultivate sugar beet.

5. Conclusion

This thesis answers the following question: *What is the economic potential for the locally grown biomass source sugar beet for non-food purposes (i.e. bioenergy and novel biobased materials), in comparison to importing biomass, in the south west of The Netherlands?* Answering this question has been achieved by creating a model to determine the potential of sugar beet cultivation in the south west of The Netherlands, benchmarking the cost of cultivation, and comparing the GHG emissions to those of imported biomass sources. This thesis assesses the economic potential for non-food purposes. To avoid interference with the food and feed supply, they are prioritised over energy and non-energy purposes.

In order to determine the economic potential of sugar beet cultivation for non-food purposes available today, the theoretical and technical potential must first be determined. The theoretical potential is estimated to be 198.8PJ (52Mt sugar beet, 8.9Mt fermentable sugar) in the south west of The Netherlands, of which 39.2PJ (10Mt sugar beet, 1.7Mt fermentable sugar) comes from the province of South Holland. However, technical constraints including the amount of arable land available for non-food purposes and rotation schemes significantly reduce the potential. The technical potential is estimated to be 1.9PJ (0.49Mt sugar beet, 84kt fermentable sugar) for the south west of The Netherlands, and 0.4PJ (0.094Mt sugar beet, 16kt fermentable sugar) in the province of South Holland. The economic potential is assessed in two ways: by comparing the NPV of crop rotation schemes, and by a comparison to imported biomass sources in a cost-supply curve. Due to the high profits that can be generated by sugar beet cultivation, the economic potential is similar to the technical potential in the assessed region. Therefore, the economic potential is estimated at 1.9PJ (0.49Mt Sugar beet, 84kt fermentable sugar) in the south west of The Netherlands and 0.4PJ (0.94Mt Sugar beet, 16kt fermentable sugar) in the province of South Holland. Currently 1.6Mt of sugar beet is cultivated in the south west of The Netherlands, and 0.3Mt of sugar beet in the province of South Holland. The economic potentials for non-food purposes found in this thesis indicate that a substantial addition to the currently cultivated sugar beet industry can be made.

The economic potential, limited by the technical potential, shows that there is a large potential for sugar beet cultivation in the south west of The Netherlands. It shows sugar beet cultivation for non-food purposes is limited by the land availability and, to a lesser extent, to the economic feasibility of the crop cultivation. An example is when the NPV of a rotation scheme with increased sugar beet cultivation is compared to a BAU scheme. The results show an increase between € 4,379 and € 4,802 in favour of the increased sugar beet cultivation scheme throughout the province of South Holland. This economic feasibility makes sugar beet a suitable source of biomass for the biobased economy. When Dutch sugar beet cultivation costs, starting from € 8.16/GJ in the province of South Holland, are compared to the costs of imported biomass, the cost of cultivation in certain locations is lower than the cost of the imported biomass. This indicates that, at current biomass prices, sugar beet is a cheap, available and local option for the biobased economy. It is important to note that while the demand for biomass is set to rise in the coming years, the production must also rise. This would create demand for a biomass source which simultaneously could increase its production. While other sources are trying to significantly increase biomass production, sugar beet could serve as a stepping stone towards future-generation biomass sources. However, while sugar beet cultivation can increase at the same time the demand is rising, it is unlikely to produce more than a fraction of the total demand.

Although sugar beet can be used as a stepping stone for now, this study shows that, in 2030, fermentable sugar from wood pellets or wood chips is projected to be economically competitive. In the high technological growth scenarios, the price of fermentable sugar from wood pellets and wood chips is decreasing. The marginal costs of wood chips would compete with the raw sugar price (240 €/t) in 2030. Therefore, non-economic aspects will be considered by the end users of the biomass. Firstly, the GHG emissions of both the lignocellulosic biomass sources and the sugar beet can be compared. Both biomass sources are used for ethanol production. The comparison in the south west of The Netherlands shows that ethanol from woodchips creates lower GHG emissions (30.3 to 31.0g CO_2-eq/MJ) than ethanol from sugar beet (38.4 to 39.7g CO_2-eq/MJ). Furthermore, it shows that, for ethanol from sugar beet (53% to 54% decrease) there are difficulties in reaching the RED criteria, which are set at decreasing 60% of the GHG emissions of the fuel it replaces. This could indicate that when wood chips and wood pellets are cost-competitive with sugar beet, the lignocellulosic biomass sources are preferred due to their low GHG emissions. In the meantime, however, sugar beet can be used as a driver for the biobased economy.

To investigate the capabilities of sugar beet as a stepping stone and driver of the biobased economy, further research is required. The total demand of the bio cluster at Rotterdam has to be mapped in detail, along with the different biomass sources which could be used. This would indicate the amount of sugar beet that would need to be cultivated to meet the demand. Further research could also be undertaken by increasing the research area, such as by including the province of Flevoland. This would indicate possible economic locations for sugar beet cultivation for non-food purposes beyond the south west of The Netherlands.

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References

Agentschap NL. (2013). *Statusdocument bio-energie 2012.* Utrecht: ministerie van economische zaken.

Bal, D., & Looise, B. (2013). Toelichting opde Fysische-Geografische regio's kaart van Nederland.

Batidzirai, B., Smeets, E., & Faaij, A. (2012). Harmonising bioenergy resource potentials - Methodological lessons from review of state of the art bioenergy potential assessments. *Renewable and Sustainable energy reviews*, 6598-6630.

BioGrace. (2015). BioGrace I excel tool. *BioGrace I excel tool*. Intellegent energy Europe.

Biomass Energy Europe. (2010). *Best practices and methods handbook.* Freiburg: University of Freiburg.

CBS. (2015, october 28). *CBS: Minder suikerbieten, meer pootaardappelen*. Opgehaald van Centraal bureau voor de statistiek: http://www.cbs.nl/nl-NL/menu/themas/landbouw/publicaties/artikelen/archief/2015/minder-suikerbieten-meer-pootaardappelen.htm

CBS. (2015, october 20). *Hernieuwbare energie; verbruik naar energiebron, techniek en toepassing*. Opgehaald van Centraal bureau voor de statistiek: http://statline.cbs.nl/StatWeb/publication/?DM=SLNL&PA=83109ned

CBS. (2015, october 16). *Vloeibare biotransportbrandstoffen; aanbod, verbruik en bijmenging*. Opgehaald van statline.cbs.nl: http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLNL&PA=71456ned&D1=0,2-3&D2=a&D3=a&HD=080616-1119&HDR=T,G2&STB=G1

Cengel, Y. A., & Boles, M. A. (2011). *Thermodynamics an engineering approach.* New York: McGraw - Hill Education.

Chum, H., Faaij, A., Moreira, J., Berndes, G., Dhamija, P., Dong, H., . . . Pingoud, K. (2011). *Chapter 2 Bionenergy, Renewable Energy Sources and Climate Change Mitigation (IPCC).* Cambridge: Cambridge University Press.

CPB/PBL. (2015). *Toekomstverkenning Welvaart en Leefomgeving Cahier Landbouw.* Den Haag: Plan bureau voor de leefomgeving.

de Wit, M., & Faaij, A. (2010). European biomass resource potential and costs. *Biomass and bioenergy*, 188-202.

Deloitte. (2014). *Opportinities for the fermentation-based chemival industry.* Deloitte.

Diogo, V., van de Hilst, F., van Eijck, J., Verstegen, J., Hilbert, J., & Carballo, S. (2014). Combining empirical and theory-based land-use modelling approaches to assess economic potential of biofuel production avoiding iLUC: Argentina as a case study. *Renewable and sustainable energy reviews*, 208-224.

ECN. (2014). *Verkenning van biomassamarkten en hernieuwbare-energiebeleid.* Petten: ECN.

ECN, CBS, PBL, RVO. (2015). *Nationale Energieverkenning 2015.* Petten: ECN.

Elbersen, B., Staritsky, I., Hengeveld, G., Jeurissen, L., & Lesschen, K.-P. (2015). *Outlook of spatial biomass value chains in EU28 (draft).* Brussel: Intelligent energy Europe.

EU. (2015, 12 10). *Fuel Quality*. Opgehaald van european commission : http://ec.europa.eu/clima/policies/transport/fuel/index_en.htm

EU RED. (2009). *RICHTLIJN 2009/28/EG VAN HET EUROPEES PARLEMENT EN DE RAAD.* Brussel: EU.

European Commissioin & Joint Research Centre. (2015). *Solid and gaseous bioenergy pathways: input values and GHG emissions.* Luxemburg: Publications Office of the European Union.

F3. (2013, January). *EU sustainability criteria for biofuels.* Opgehaald van F3 the swedish knowledge centre for renewable transportation fuels: http://www.f3centre.se/renewable-fuels/fact-sheets/eu-sustainability-criteria-biofuels

FAO. (2014). *OECD-FAO Agrictultural Outlook 2014-2023.* OECD Publishing.

FAOSTAT. (2015, 10 20). *Yield information sugar beet*. Opgehaald van statistical data website FAO: http://faostat3.fao.org/browse/Q/QC/E

Fischer, G., Prieler, S., van Velthuizen, H., Berndes, G., Faaij, A., Lando, M., & de Wit, M. (2010). Biofuel production potentials in Europe: Sustainable use of. *Biomass and Bioenergy* , 173-187.

Goh, C. S., & Junginger, M. (2015). *Sustainable biomass and bioenergy in the Netherlands: Report 2014.* Utrecht: Copernicus institute Utrecht University.

Graham, R. L., English, B. C., & Noon, C. E. (2000). A Geographic Information System-based modeling system for evaluating the cost of delivered energy crop feedstock. *biomass and bioenergy*, 309-329.

Hamelinck, C., & Hoogwijk, M. (2007). *Future scenarios for first and second generation biofuels.* Utrecht: Ecofys.

Harmsen, P., Lips, S., Bos, H., Smit, B., van Berkum, S., Helming, j., & Jongeneel, R. (2014). *Suiker als grondstof voor de Nederlandse chemische industrie; gewassen, proces, beleid.* Wageningen: Wageningen UR food & biobased research.

Hilst, v. d., F, D., V, S. J., B, G., A, T., W.C., E., . . . A.P.C. (2010). Potential, spatial distribution and economic performance of regional biomass chains, the North of the Netherlands as example. *Agricultural Systems*, 403-417.

Hoefnagels, R., Searcy, E., Cafferty, K., Cornelissen, T., Junginger, M., Jacobson, J., & Faaij, A. (2014). Lignocellulosic feedstock supply systems with intermodal and overseas transportation. *Biofuels Bioproducts & Biorefining*, 794-818.

Hoppe, R. A. (2014). *Structure and Finances of U.S. Farms: Family Farm Report, 2014 Edition.* Washington: U.S. Department of Agriculture.

ICTSD. (2013, January 28). *European Commission Proposes Duties on Imports of US Biofuels*. Opgehaald van website International Centre for Trade and Sustainable Development:

http://www.ictsd.org/bridges-news/biores/news/european-commission-proposes-duties-on-imports-of-us-biofuels

IRS. (2014). *Jaarverslag 2014.* Bergen op Zoom: Stichting IRS.

KNMI. (2015). *Jaaroverzicht van het weer in Nederland.* Zeist: KNMI.

Koppejan, J., Elbersen, W., Meeusen, M., Bindraban, P., & van Erp, F. (2009). *Beschikbaarheid van Nederlandse biomassa voor elektriciteit en warmte in 2020.* SenterNovem.

Mainville, N., Bernadet, P., bloome, B., Brooks, R., Cotter, & Janet. (2011). *Fuelling a biomess.* Montreal: Greenpeace Canada.

Neste oil. (2006). NExBTL. *Renewable Synthetic Diesel* (pp. 1-4). Canada: Neste Oil.

Port of Rotterdam. (2014). *Bio Port Rotterdam.* Rotterdam: department energy and inustry.

REDIFINERY. (2015). *Blauwdruk voor ketenintegratie rond bioraffinage, om de transitie naar een biobased economy te versnellen.* Rotterdam: REDIFINERY.

SER. (2013). *Energieakkoord voor duurzame groei.* Den haag: Sociaal-economische raad.

Smit, A., Janssens, S., Conijn, J., Jager, J., Prins, H., & Luesink, H. (2011). *Parameters to calculate green house gas emissions of Dutch arable crops.* The Hague: LEI.

Sugar City. (2015, November 20). *Over ons Suagr city*. Opgehaald van Website Sugar City: http://www.sugarcity.com/nl/over-ons

Suikerunie. (2014). *Naturally Sustainable (Sustainability Report 2014).* Dinterloord: Suiker unie.

Suikerunie. (2015, 12 17). *Bietenstatistiek.* Opgehaald van Bietenstatistiek: http://www.bietenstatistiek.nl/default.aspx?year=2015&item=Rooiverloop&showIRS=true#chart

Suikerunie. (2015, 10 15). *suikerunie historie*. Opgehaald van suikerunie: http://www.suikerunie.nl/History.aspx

TKI BBE. (2015). *B4B: biobased voor bedrijven, burgers.* tki bbe.

Todd, M. (2015, October 6). Presentation on sugar beet potential research by LMC international. *Agri meets chemicals*. Utercht, Utrecht, Netherlands.

Trouw. (2008, januari 16). Suiker Unie sluit deuren Groningse fabriek. *Trouw*, p. 1.

van der Hilst, F., & Faaij, A. P. (2012). Spatiotemporal cost-supply curves for bioenergy production in Mozambique. *Biofuels, Bioprod. Bioref*, 405-430.

van Meijl, H., Tsiropoulos, I., Vartelings, H., van den Broek, M., Hoefnagels, R., van Leeuwen, M., . . . Faaij, A. (2016). *Macro economic outlook of suistainable energy and biorenewable innovations (MEV II).* Wageningen: LEI Wageningen UR.

Verburg, G. (2007). *Overheidsvisie op de biobased economy in de energietransitie.* Den haag: het rijks.

Vrij Nederland. (2005, November 19). Leven na de suikerbiet, De mannen van de CSM-fabriek. *Vrij Nederland*, p. 1.

Werkgroep biobased economy 2.0. (2012). *Innovatiecontract biobased economy 2012-2016; Groene groei van biomassa naar business.* den haag: het rijks.

World bank. (2015). *Commodity market outlook.* Washington: The World Bank.

A. Appendix

A-1 Conversion table

Substance	*Density (kg/L)*	*Energy density (MJ/kg)*	*Energy density (GJ/t)*
Diesel[11]	0,823	43,1	43,1
Gasoline	0,745	44,0	44,0
Sugar beet dry[12]	N.A.	16.3	16.3
Sugar beet wet [13](76,5% water)	N.A.	3.8	3.8

A-2 Definitions

LHV: Lower Heating Value, throughout this thesis the LHV is used unless mentioned otherwise

Fermentable sugars: Sugars that can be easily digested in the human digestive system.

GHG: Green House Gas

WM: wet material

BAU: Business as usual

A-3 Extrapolation river clay

opbrengst/ha (kg)	2009	2015	verandering (%)
klei ijselm	74000	92200	25%
zand zo ned	63000	78540	25%
klei zw ned	68000	81390	20%
klei n ned	65000	78640	21%
zand n	63000	73920	17%
rivierklei	66000	80159,69	21%

[11] Data taken from the range of data given by Cengel and Boles (2011)
[12] Data from Biograce I excel tool (2015)
[13] Data from the Renewable energy directive excel conversion tool (2009)

A-4 Textbox domestic and imported biomass

Import

Dutch demand for biomass is mainly driven by regulations. Because The Netherlands are an open market country the demand for biomass will be met economically. Thus buyers will look for the cheapest option. This resulted in importing certain biomass sources (sugarcane, wood pellets) from all over the world. In order to meet the targets set in the energy agreement (*Energieakkoord*), The Netherlands has to generate 16% renewable energy in 2023 (Agentschap NL, 2013). This will be done in a number of ways, one of which is to co-fire existing coal power plants with biomass (SER, 2013). Secondly the EU renewable energy directive demands road fuels to be blended with biofuels, ramping up to 10% of the fuels used in transport being renewable in 2020 (EU RED, 2009). In The Netherlands this contributed to a total biofuel consumption of 478 million kg (approximately 17 407 TJ) per year in 2014 (CBS, 2015). With the Dutch and EU legislators trying to increase biomass use and reducing greenhouse gas emissions. New products like bioplastics, biojet fuel and other biochemicals will likely induce new legislation, demanding the industry to use them. This would increase the demand of biomass in The Netherlands even further.

To cope with these increasing demands The Netherlands has to import biomass from different sources. Three main sources of imported biomass can be distinguished:

- Wood pellets; Wood pellets are primarily used for co firing in existing power plants. However, new technologies are emerging which could proof useful for the chemical, - and biofuel industry (Harmsen, et al., 2014). In 2011 one Mt of wood pellets was imported to The Netherlands, 40% of the pellets came from the U.S. and 26% came from Canada, making North America the largest exporter to The Netherlands (Agentschap NL, 2013). The North American industry has grown over 700% in the last 8 years, with an expected growth in demand of 600% in 2020 (Mainville, et al., 2011). However, the use of North American wood pellets has been criticized for creating a Carbon debt, as the CO_2 emitted by co firing is not taken up directly by the forest, but over a time period depending on the wood sources of the pellets.
- Sugar and food crops; Sugar cane, corn, sugar starch and sugar beet are crops which have historically been used for food purposes, and more recently for biofuel production (ECN, 2014). Two groups of biofuel can be distinguished; bio diesel, a blend stock for fossil diesel, and bio ethanol, a blend stock for fossil gasoline. The Netherlands are a net exporter of biodiesel and the biodiesel feedstocks are produced locally. On the contrary, Bio ethanol is imported. Therefore, The Netherlands either needs to import pure Ethanol, or the feedstock crops; corn from the U.S., sugar cane from South America or sugar beet from other EU members (Agentschap NL, 2013). However, using food crops for energy purposes has given rise to concerns about food scarcity and rising food prices. Other research states that food crops used for energy purposes would have had insufficient quality to be used for consumption (Todd, 2015).
- Rapeseed, palm oil and other vegetable oils; Vegetable oils are primarily used for bio diesel (i.e. methylesters) production. In comparison to rapeseed, palm oil and soy oil both have very little market share as a bio energy source in The Netherlands (Agentschap NL, 2013). The Netherlands mainly imports rapeseed from other EU member (ECN, 2014). In the Rotterdam bio port Neste Oil has made a NExBTL refinery capable of producing 0.8 million tons of renewable diesel (i.e. hydrotreated diesel) a

year, running on vegetable oils and waste fats (Neste oil, 2006). These oils have similar concerns as towards deforestation and competition with the food supply.

The price of this imported biomass is subjected to currency exchange rates. With the Brazilian real peaking in 2010-2012, importing sugar cane was relatively expensive. This enabled European farmers to economically compete with Brazil and created new opportunities for locally produced biomass in Europe. However, with the Brazilian real at its lowest point in 2015 sugar cane from Brazil has become a cheaper option again (Todd, 2015). Other mechanisms operating on the price are the taxes the EU imposes on importing ethanol from non EU countries. For example the anti-dumping duties imposing a 9.5% tax on ethanol fuel from the US (ICTSD, 2013).

Domestic

As was previously stated, the Dutch government has made a commitment to the EU with RED II to produce 16% renewable energy by 2023 (Agentschap NL, 2013) (EU RED, 2009). And while biomass is imported to reach these targets, The Netherlands is also cultivating biomass for non-food purposes. The most significant legislation to reaching the RED II commitment with production in The Netherlands is SDE+ (Stimulering duurzame energieproductie plus) which subsidizes all renewable energy sources. A total of 3.5 billion euros is spent by the Dutch government in order to stimulate renewable energy production (Agentschap NL, 2013).

This policy has resulted in a largely domestic production of biomass in The Netherlands. In total 75% of all biomass used in The Netherlands is domestic. The remaining 25% of the biomass is imported, 10% from the EU and 15% from non-EU countries. The imported biomass primarily consists of biofuels and wood pellets for firing (Agentschap NL, 2013).

An example of increasing the Dutch interest in bio energy is the Bio port Rotterdam initiative. This initiative was set out to make the port of Rotterdam a main hub in the global bio energy trade. The Port of Rotterdam has planned to cluster CO_2 storage, biochemical and - fuel production facilities, jetty storage and mixing facilities. Building these facilities will increase efficiency, synergy and knowledge spill overs (Port of Rotterdam, 2014).

In addition to most of the policies covered in the previous section this research will also be influenced by the expiration of the sugar quota. With the quota the price of sugar is divided into two prices. One sugar price for consumer purposes, which is set by the quota, and one for industrial purposes, set by global market prices. With the expiration of the quota set for 2017 it is expected that the consumer price will decrease since the EU will not be paying the price premium set by the quota. In contrary the industrial price will increase since the price difference between the consumer price and industrial price will seize to exist. (Harmsen, et al., 2014). The higher sugar price for non-food purposes will increase the profitability of sugar beet cultivation, which will spike the interest of the farmers.

Besides the sugar prices for non-food purposes, which are projected to increase. The yields per hectare of arable land of sugar beet are also increasing. Dutch beet yields with 78 ton/ha are the highest in the world (FAOSTAT, 2015). With high prices, high yields and an increasing demand of biomass the potential for Dutch sugar beet cultivation should be increasing.

A-5 Sankey diagram carbon hydrates netherlands 2013

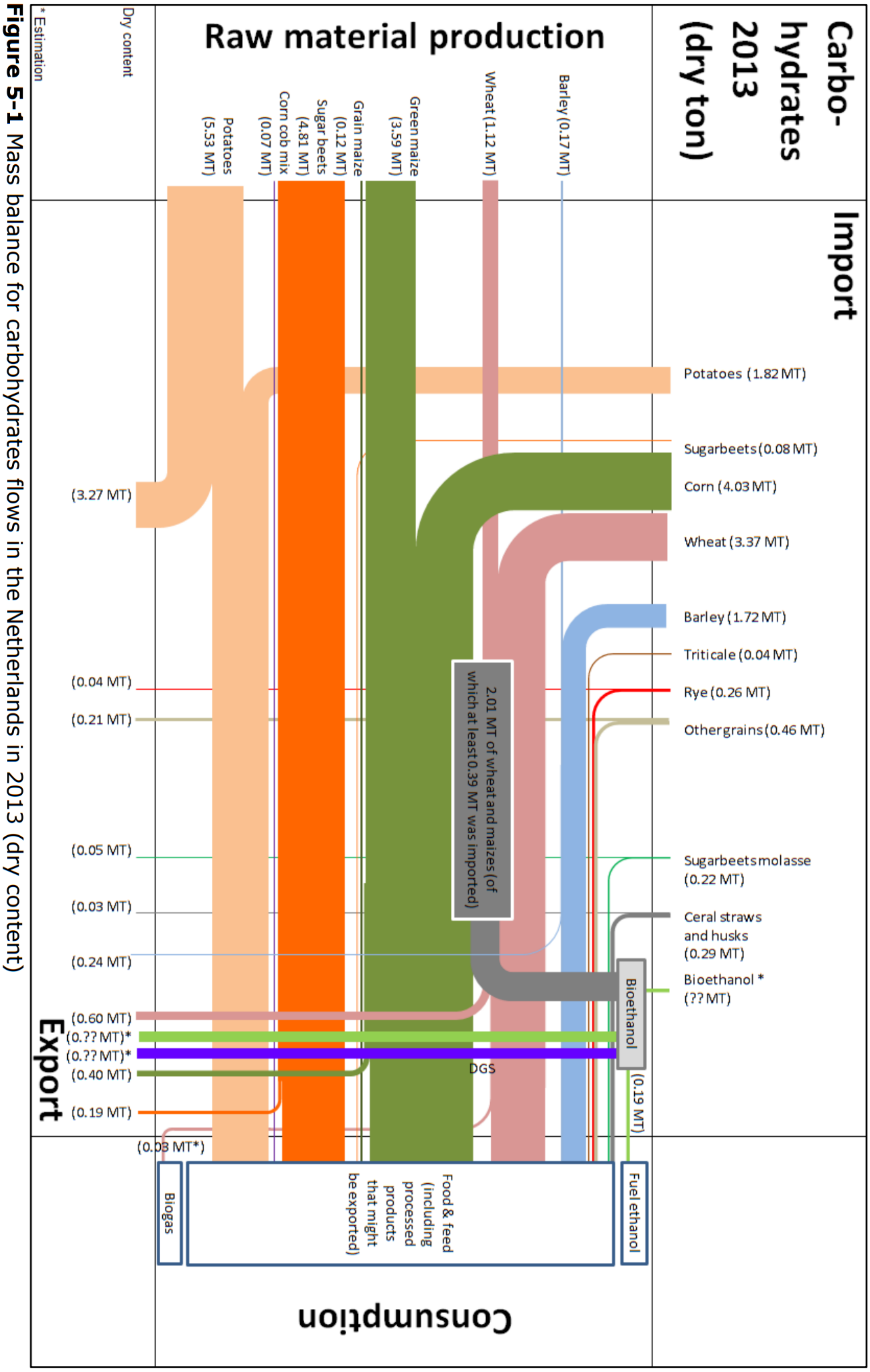

Figure A-21 Sankey diagrams Netherlands

A-6 Map of the south west of The Netherlands

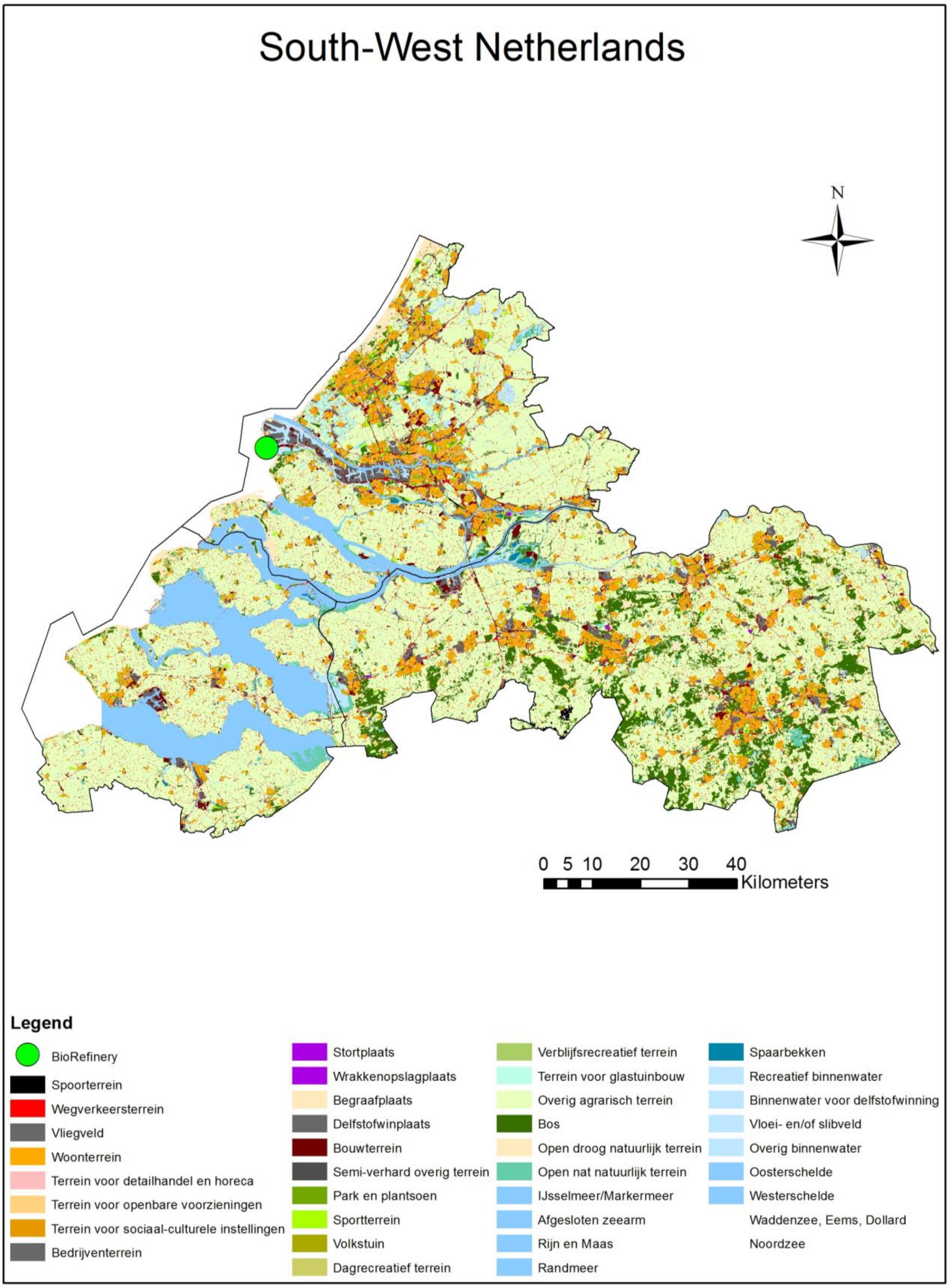

Figure A-22 Research are province of South Holland

A-7 Map of the Soil types South Holland

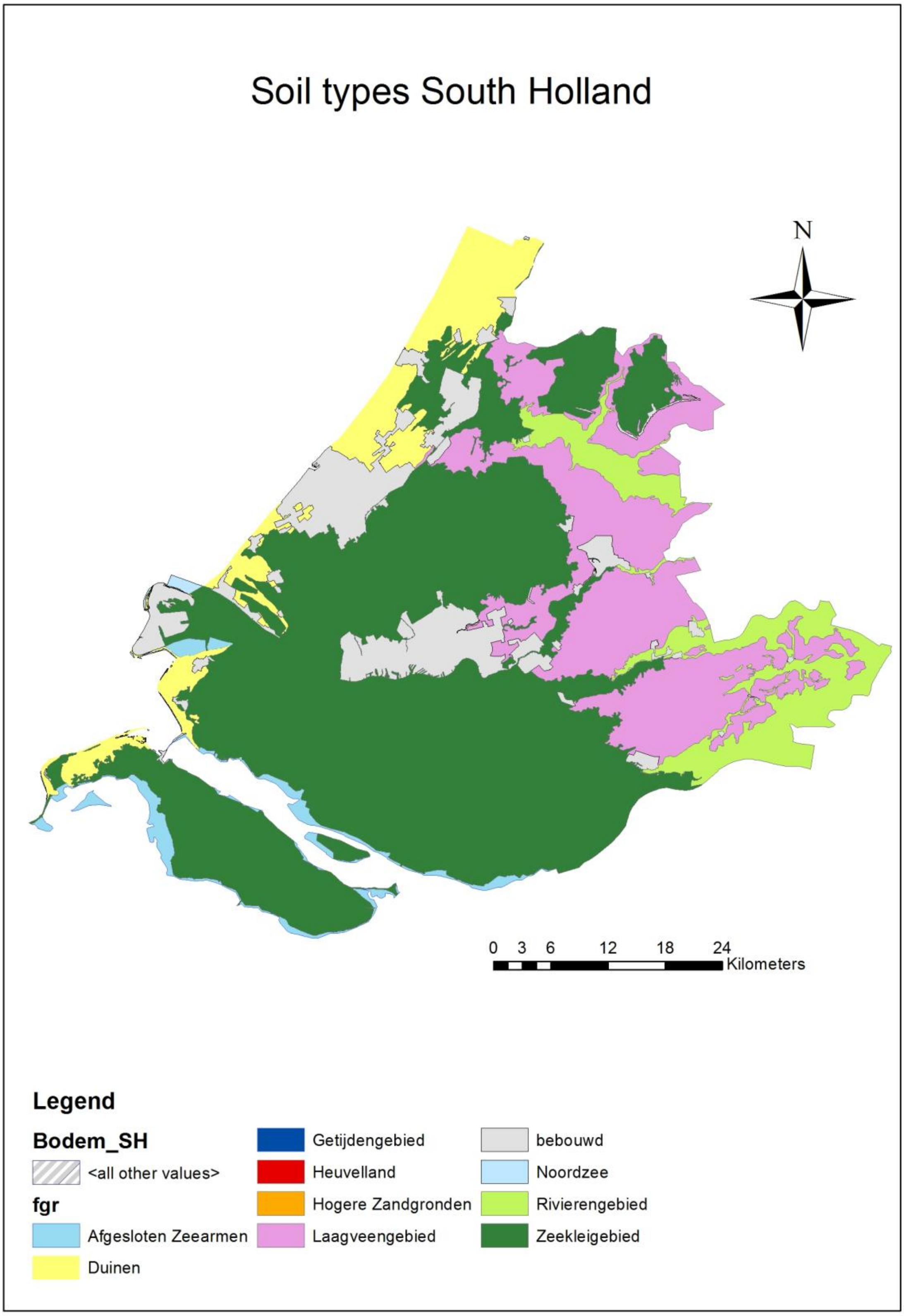

Figure A-23 Soil types South Holland

A-8 Years between rotations Sugar beet cultivation

Table A-21 Years between sugar beet cultivation

Number of years since last sugar beet cultivation (%)	2008	2009	2010	2011	2012	2013	2014	avg (2008-2014)
1	1	1	1	1	1	-	-	1%
2	3	2	1	2	1	2	2	2%
3	12	10	9	9	9	8	7	9%
4	29	30	29	28	29	29	27	29%
5	17	19	17	16	17	17	13	17%
6	16	15	17	14	16	16	13	15%
7	24	24	26	29	27	27	38	28%

A-9 Theoretical potential ArcGIS model

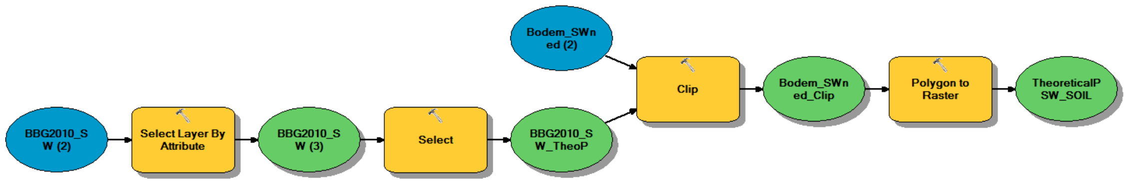

Figure A-24 ArcGIS model Theoretical Potential

A-10 LNG mosaic ArcGIS model

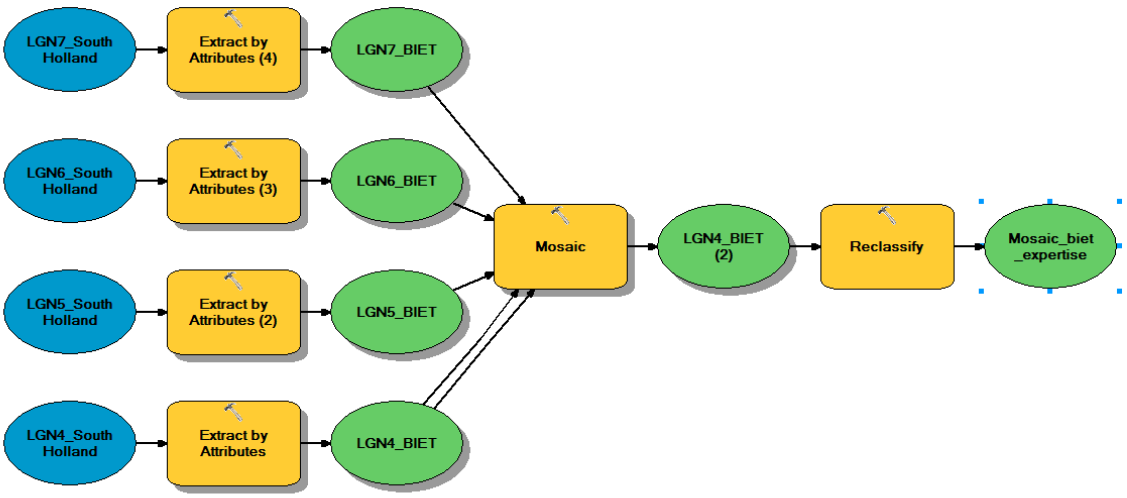

Figure A-25 ArcGIS model LNG mosaic

A-11 Technical potential ArcGIS model

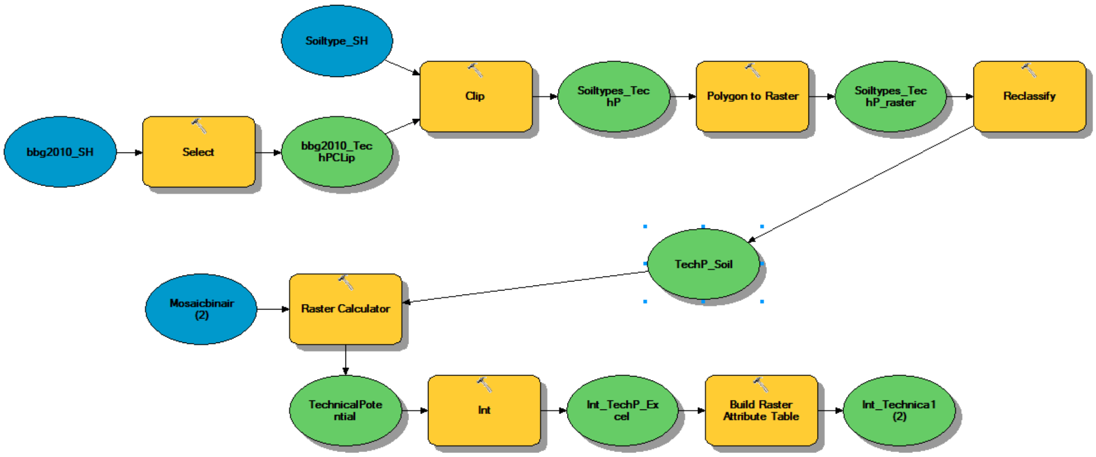

Figure A-26 ArcGIS model Technical Potential

A-12 Economic Potential ArcGIS model

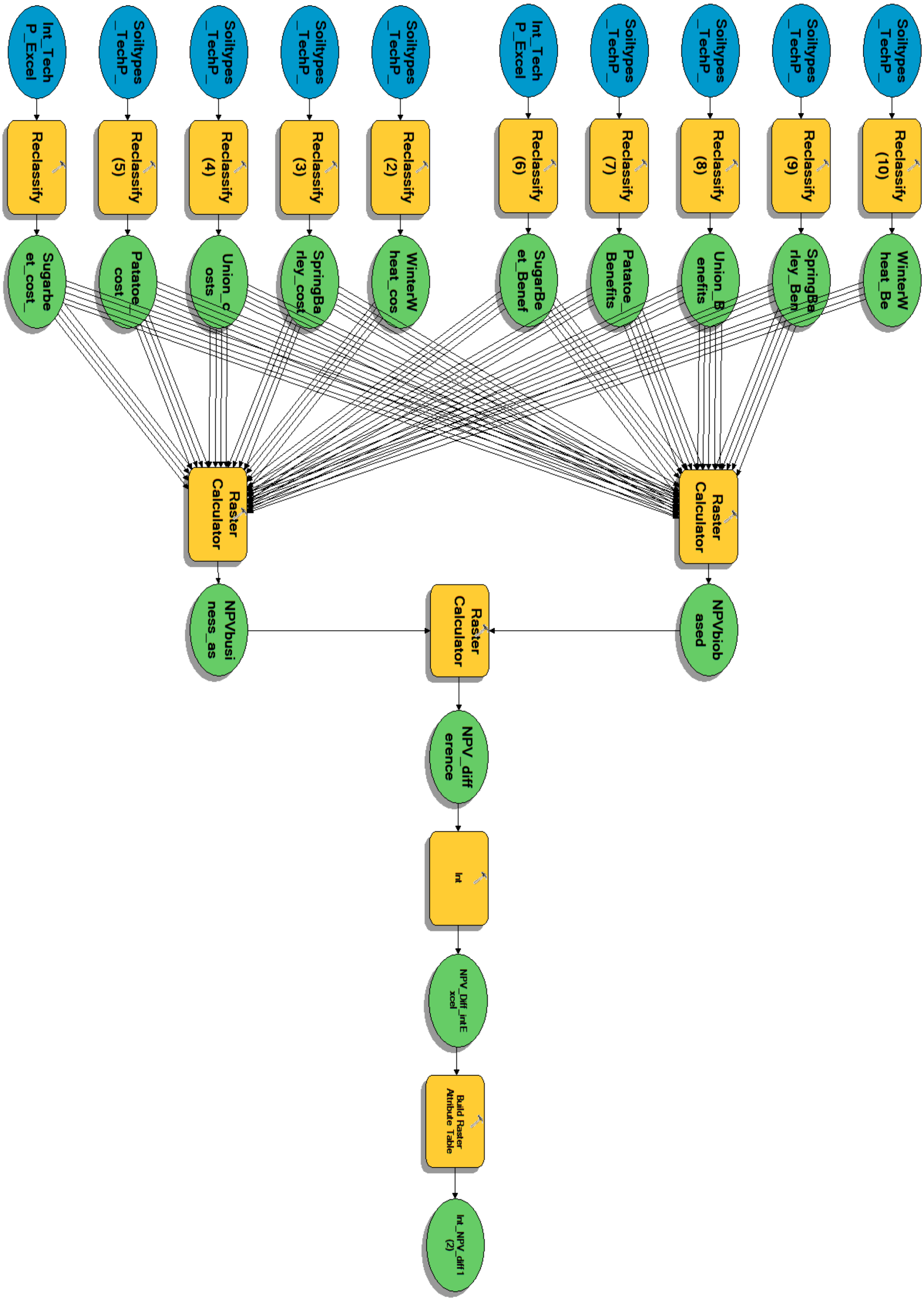

Figure A-27 ArcGIS model Economic Potential

A-13 Cost including transport model

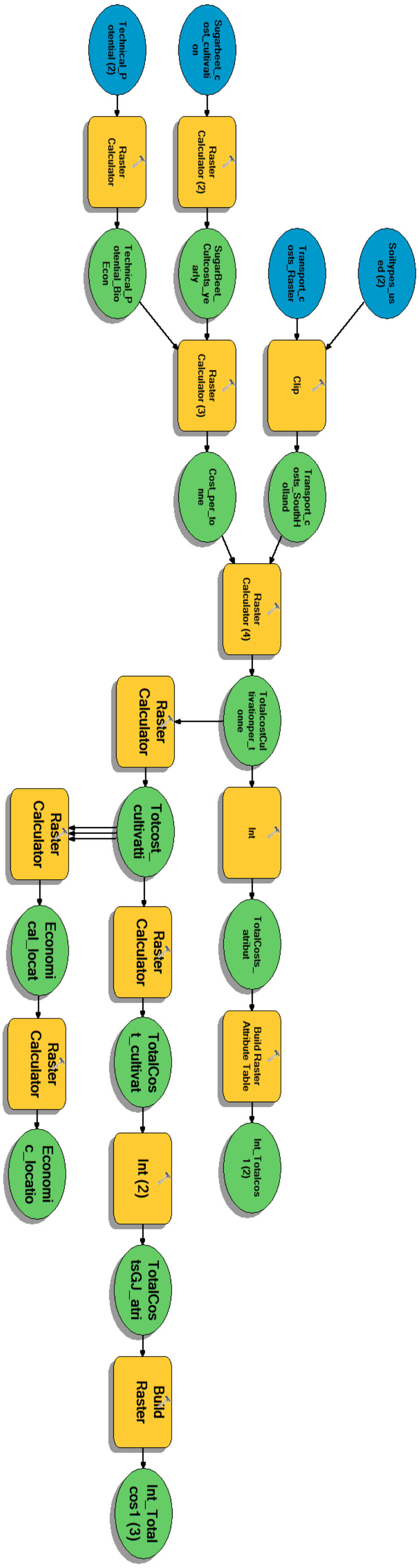

Figure A-28 ArcGIS model Cost

A-14 WLO scenarios

Table 22 WLO scenario inc surface area South Holland

Scenario SH	Low	High	surface low	surface high
Increase in arable land used by sugar beet SH	4%	25%	199	1,241
Decrease in horticulture SH	-30%	-10%	1,561	520
Decrease agriculture and horticulture Netherlands	-3.50%	-5%	5,075	7,250
Total arable land becoming available	4.7%	6.2%	6,835	9,012

Table 23 WLO scenario inc surface area south west Netherlands

Scenario south west Netherlands	Low	High	surface low	surface high
Increase in arable land used by sugar beet	4%	25%	997	6,230
Decrease agriculture and horticulture	-3.50%	-5%	18,911	27,016
Total arable land becoming available	3.7%	6.2%	19,908	33,246

Table 24 Surface are WLO scenarios

2005-2015	Average	Average SH	Average ZL	Average NB
Horticulture	10,074	5,203	177	1,362
Sugar beet	74,944	4,966	10,805	9,148
Agriculture	2,037,343	145,003	125,387	269,932

A-15 KWIN AGV Data sugar beet cultivation

	Sea Clay		Sand	
Usage	Quantity/ha	Amount (€)	Quantity/ha	Amount (€)
Benefits				
Yield (sugar beet)	81390	€ 4,557.00	78540	€ 4,397.00
Costs				
Seedlings		€ 240.00		€ 240.00
Fertilizers				
N	149	€ 157.00	149	€ 157.00
P2O5	40	€ 40.00	0	€ -
K2O	50	€ 32.00	140	€ 89.00
Pesticides				
Epoxiconazool	0.75	€ 46.00	0.75	€ 46.00
Kresoxim-methyl				
Ethofumesaat	2	€ 27.00	2	€ 27.00
Fenmedifam	2	€ 15.00	2	€ 15.00
Fenpropimorf	1	€ 32.00	1	€ 32.00
Glysofaat	2	€ 11.00		
Metamitron	4	€ 134.00	2	€ 67.00
Mineral oil	2	€ 6.00	2	€ 6.00
S-metochloor	1	€ 26.00	1	€ 26.00
Quizalafop P ethyl			1	€ 40.00
Energy				
Diesel	119	€ 131.00	114	€ 125.00
Miscellaneous				
Interest	5.50%	€ 18.00		€ 17.00
N-mineral monster		€ 22.00		€ 22.00
Labour				
Sowing		€ 75.00		€ 75.00
Grubbing		€ 330.00		€ 330.00
Total		€ 1,342.00		€ 1,314.00
Net Total		€ 3,215.00		€ 3,083.00