BIOPOL

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D 5.1.2. Prospects for further demonstration

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PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
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Content

Management summary

This report was produced to serve as a reference for biorefinery development in Europe. It contains an analysis of the current states of biorefinery and a model to estimate biorefinery establishment in Europe. The costs of pilot and demonstration scale biorefinery projects were estimated. Recommendations were formulated.

Current status of biorefinery

Four different biorefinery types were defined and evaluated based on information from work package 1 to 4. The following topics were reviewed:

- Technical and economical evaluation of 4 different biorefinery types
- Opinion of industry on biorefinery concept
- Opinion of consumers on biorefinery processes
- Opinion of politicians on biorefinery
- Presence of factors that will enhance future biorefinery establishment

The information from work package 1-4 was collected, processed, combined and presented in graphs. Through these graphs the strengths and weaknesses of biorefinery in Europe were visualized. General results, biorefinery type specific results and region specific results were derived.

Results of general analysis

The general opinion (from industry, consumers and politicians) on biorefineries is positive. Some improvement is possible on the following issues:

- Regulations
- Economic issues (profitability)
- Feedstock/raw material problems
- Plant/mill/manufacturing problems
- (Perception of) Eco-friendliness of biorefineries
- Acceptance of use of agricultural products for non food non feed applications
- Opinion of several political stakeholders on biorefineries
- Food and feed competition.

Results of biorefinery type specific analysis

Whole crop biorefinery

- Ready for demonstration, high feedstock costs for crops, low feedstock costs for currently underutilized fractions such as straw, technological improvement expected for processing of lignocellulosic feedstocks
- High availability of crops and straw in Western Europe, good side markets present in Western Europe

Lignocellulosic biorefinery

- Technical feasibility is currently low, further development might well result in much better feasibility, low feedstock costs for biomass that is currently left behind on the field or in the forest
- High availability of straw and wood in Western Europe and high availability of wood in Northern Europe, Western and Eastern Europe, good side markets present in Western Europe

Green biorefinery
- Ready for demonstration, improvement expected, low capital costs, low feedstock costs.
- High production of grass in Western Europe

Syngas biorefinery
- Ready for full scale implementation, high capital costs, low feedstock costs for biomass that is currently left behind on the field or in the forest, little technical improvement is expected
- High availability of straw and wood in Western Europe and high availability of wood in Northern Europe, Western and Eastern Europe, good side markets present in Western Europe

Region specific analysis
- Western Europe has the best prospects for biorefinery development. It has: high agricultural yields, vast amounts of ligno-cellulosic agricultural side streams, considerable forestry and good possibilities to sell biorefinery side products
- The countries in the East of Europe have good opportunities to improve agricultural yields. Therewith they could become interesting countries for biorefinery establishment.
- Northern Europe is currently a natural market leader of lignocellulosic biorefinery due to the presence of large forests.

Likeliness of biorefinery establishment

A model was produced to estimate likeliness of biorefinery establishment based on establishment factors. The establishment of new biorefineries in a certain region will depend on numerous establishment factors such as land use in surrounding area, presence of animal husbandry, presence of oil refineries and chemical industry and transport possibilities.
As a test, the model was used to 'predict' the establishment of current biofuel production facilities and pulp and paper facilities. The current biofuel production facilities and paper and pulp facilities are indeed situated in countries with high biorefinery establishment likeliness.
The model was then used to estimate the likeliness of biorefinery establishment in all the countries of Europe.
- Whole crop biorefinery will develop in traditional areas of wheat, potato or sugar beet production (France and Germany) and near harbours and where feed is needed (Belgium and The Netherlands). Wheat is more easily transported over large distances than potatoes and sugar beets (which have far larger water content). Therefore, wheat is more likely to be processed in harbour areas such as Rotterdam and Antwerp and potatoes and sugar beets are more likely to be processed in the area where they are grown. The analysis shows opportunities for whole crop biorefinery in Belgium, Czech Republic, Denmark, France, Germany, Hungary and the United Kingdom.
- Lignocellulosic biorefinery will mainly develop in straw regions (e.g. France and Germany) and possibly in wood regions (like Sweden and Finland). Lignocellulosic biorefineries might also develop in countries with large harbours that can import lignocellulosic feedstocks and countries with well developed oil refineries and base chemical production sites (like The Netherlands and Belgium). The likeliness of lignocellulosic biorefinery in the analysis is high in Austria, Belgium, Czech Republic, Denmark, Estonia, France, Germany, Hungary, Latvia, The Netherlands, Slovak Republic and Sweden.
- Green biorefinery will develop in regions where grass and clover are produced (wet agricultural land) and where feed for animals is needed. These areas can be found in

the whole of Europe, but mostly in Western Europe. Countries that show high opportunities for green biorefinery in the analysis are Belgium, France, Germany, Ireland, The Netherlands and the United Kingdom.
- Syngas biorefinery will preferentially develop in an area with large availability of lignocellulosic raw materials (wood or straw), harbours (supply of feedstocks) and traditional oil refineries and base chemical production (to further process the synthesis gas). The transport of lignocellulosic raw material is relatively easy (no decay) and therefore, syngas biorefinery might also develop in regions with less lignocellulosic biomass, but better harbour facilities. Syngas biorefineries have high chances of development according to the analysis in the countries Austria, Belgium, Czech Republic, Estonia, Finland, France, Germany, Latvia, The Netherlands, Slovak Republic and Sweden.

Cost estimates

Costs of pilot and demonstration scale biorefineries were estimated from a full scale plant point of view, from a research project point of view and from real world pilot and demonstration scale biorefineries.
- The costs of demonstration plants can be estimated from the fixed capital investment, the costs of raw materials and the costs of utilities. Adaptation will be needed to account for higher labor costs.
- The fixed capital costs will be higher for stand alone plants than for plants alongside another plant
- The costs of pilot plants should be calculated from the research point of view
- The real world pilots and demos show a huge spread of investment costs ranging from 3 to 200 M€.

Recommendations

The following general recommendations could help the establishment of biorefineries
- Improve regulations
- Improve profitability (cut costs, increase revenues)
- Solve technological issues
- Improve image of biorefineries
- Tackle food and feed issue

It the last two issues are tackled, it is expected that the negative opinion of some political stakeholders will also change.

Establishment and type of biorefinery should depend on the local circumstances (establishment factors).

The North of Europe could attract more chemical industry to increase the efficiency of their lignocellulosic biorefineries. This way, the presence of lignocellulosic biorefineries could become an establishment factor for the chemical industry instead of the other way around.

In the East of Europe the agricultural yield could be increased. This would also increase the likeliness of biorefinery establishment.

1 Introduction

The potential and costing for the introduction of pilot or demonstration biorefinery plants a) alongside existing facilities and b) for the implementation of new plants has been determined in task 5.1 of WP5. For this purpose an appropriate generic methodology has been described containing the following elements:

- Input data supplied by WP1-WP4.
- Taking into account technical (WP1), social & environmental (WP2), and political criteria (WP3).
- Based on the current implementation status (WP4).
- Using scenario analysis, where several relevant factors will be varied like the rate of acceptance by consumers, policy makers and industry; the development and introduction rate of new biorefinery technologies; etc.
- A calculation method to estimate the future potential of biorefinery plants in regions of the European Union.
- An economic evaluation tool to determine the approximate costs of new pilot or demonstration biorefinery plants.

The current implementation status of the biorefinery concept (WP4) has been taken as starting point to identify the potential for pilot or demonstration biorefinery plants alongside the identified existing facilities, e.g. food-based biorefineries such as sugar, oil and grain processing facilities. The model of the ‘whole crop’ biorefinery concept, that has been developed in WP1, has been used to determine the major requirements of pilot or demonstration plants. These requirements were then translated into relevant criteria. Together with all partners probable scenarios were determined in WP3.2 that were also used to calculate the future potential. The economic evaluation was performed for the most relevant biorefinery types that were identified in work packages 1 and 4.

So the first goal of task 5.1 was to compare the prospects of biorefineries using the values of the key parameters that were determined in work packages 1 to 4. A generic methodology was developed to determine the potential of different biorefinery types from the data that were acquired in work package 1 to 4. Social and political acceptance, economic feasibility, environmental issues, biorefinery type adequacy and current status of biorefineries were measured. The types of results from work packages 1 to 4 are very diverse. Some parameters have a quantitative value (calculation based), others are more qualitative of nature (opinion based). The evaluated parameters also have very different characteristics and scales. Therefore, the different parameters cannot simply be added up to yield one final evaluation number to compare different biorefinery types or different regions. So therefore a special scaling approach was followed to anable a comparison between these parameters. In the analysis four biorefinery types (green biorefinery, whole crop biorefinery, lignocellulosic biorefinery and syngas biorefinery) and four regions (North, West, East and South) were distinguished.

The second goal of task 5.1 deals with the potential and costing of biorefinery pilot and demonstration plants. Several calculation methods are described with their strong and weak points.

In Chapter 2 some basic definitions are described that are used throughout the report. The data processing and results for the individual workpackages is described in Chapter 3. The integration of the results of the workpackages represented in spider plots is given in Chapter 4. The indications of revenues and costs of pilot and demo scale biorefineries is described in Chapter 5. Finally conclusions and recommendations are given in Chapter 6.

2 Definitions

In this chapter definitions are given for the main items that are involved in task 5.1:

- regions where biorefinery could be implemented;
- crops that could be used as a feedstock for biorefinery;
- biorefinery types;
- intuitive scores that were used to judge the potential of biorefinery;
- key parameters that were used;
- scale of pilot and demo biorefinery;
- alongside versus stand-alone.

2.1 Description of regions

Four European regions were defined based on geography and climate (in brackets the total surface area of the region):

North
Finland, Sweden, Norway and Denmark (132 Mha).

East
Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia (108 Mha).

South
Cyprus, Greece, Italy, Malta, Portugal and Spain (104 Mha).

West
Austria, Belgium, France, Germany, Ireland, Luxembourg, the Netherlands, Switzerland and the United Kingdom (142 Mha).

Denmark was allocated to the Northern region, which agrees with the classification used in work package 4 and many other EU documents. However, from a climatological (and agricultural) point of view, Denmark would fit far better into the Western region. The other Northern countries have very large areas in cold (non-arable) regions, whereas Denmark is almost fully arable.

2.2 Description of crops

In this section several crops that could be used as a raw material for biorefineries are briefly described and characterized. The data for these crops mainly originate from WP 4.

Sugar beets and wheat
Wheat and sugar beets cannot be grown in regions with insufficient growth season (the North of Sweden, Finland and Norway).

Maize
Maize can be grown up to Denmark and the south of Sweden. It is sensitive to water shortage in summer. Therefore, it cannot be grown in dry climates (Mediterranean) without sufficient opportunities for irrigation. In the South, maize is usually grown to yield kernels. In the North, the complete plant is often used to prepare silage fodder for cattle.

Potato
Potatoes can be grown on arable land all over Europe, but not in the extreme North of Sweden, Finland and Norway.

Rapeseed
Rapeseed can be grown on arable land all over Europe, but not in the extreme North of Sweden, Finland and Norway.

Wood
Wood is mainly grown in places where cultivation, growth or harvest of other crops is impossible or uneconomic (short growth season, mountainous area, wet (peat) soils, too dry) or to immobilize sand dunes. Especially Sweden, Norway and Finland have vast amounts of woodland.

Grass
Grass is often grown in places where intensive soil cultivation is impossible or uneconomic (mountainous area, wet (peat) soils, poor soils, very dry soils) or where lands are susceptible to flooding (river banks). Grass is often grown in regions where cattle is bred (one could pose this the other way around: cattle is often bred in regions with much grass land, i.e. where other crops are not grown).

2.3 Description of biorefinery types

In this work four biorefinery types will be distinguished (Kamm *et al.*, 2006):

- Whole crop biorefinery (WCBR);
- Ligno Cellulosic Feedstock Biorefinery (LCBR);
- Green Biorefinery (GreenBR);
- Syngas Platform Biorefinery (SyngasBR).

These types will be briefly described in the next sections. A biorefinery type that was not taken into account is e.g. the Marine Biorefinery (based on algaea).

2.3.1 Whole Crop Biorefinery (WCBR)

The Whole Crop Biorefinery is based on dry or wet milling of biomass (Figure 1). Raw materials are typically cereals, such as: rye, wheat, and maize. The first step is the mechanical separation into a grain and straw fraction. Both streams will be further processed separately. The grain will deliver starch. The straw (a mixture of chaff, nodes, ears and leaves), represents a lignocellulosic feedstock, and may be further processed in a lignocellulosic biorefinery (see section 2.3.2).

Both fractions can be processed further to result in a portfolio of end products (Figure 2).

In case of wet milling the grain is swelled and pressed afterwards, releasing value-added products. The advantages of using a wet milling system are that natural structure elements, such as: starch, cellulose, and proteins are saved. Furthermore, known basic technologies can be used.

In this report also the processing of oilseed crops is included in whole crop biorefineries. The oil seeds are pressed to produce oil and press cake. The straw could be used in a lignocellulosic borefinery.

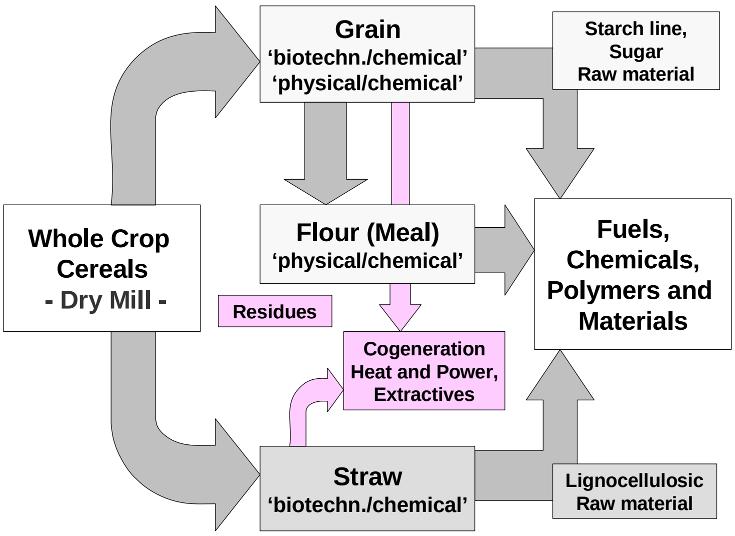

Figure 1. Whole Crop Biorefinery (dry milling) (Kamm *et al.*, 2006).

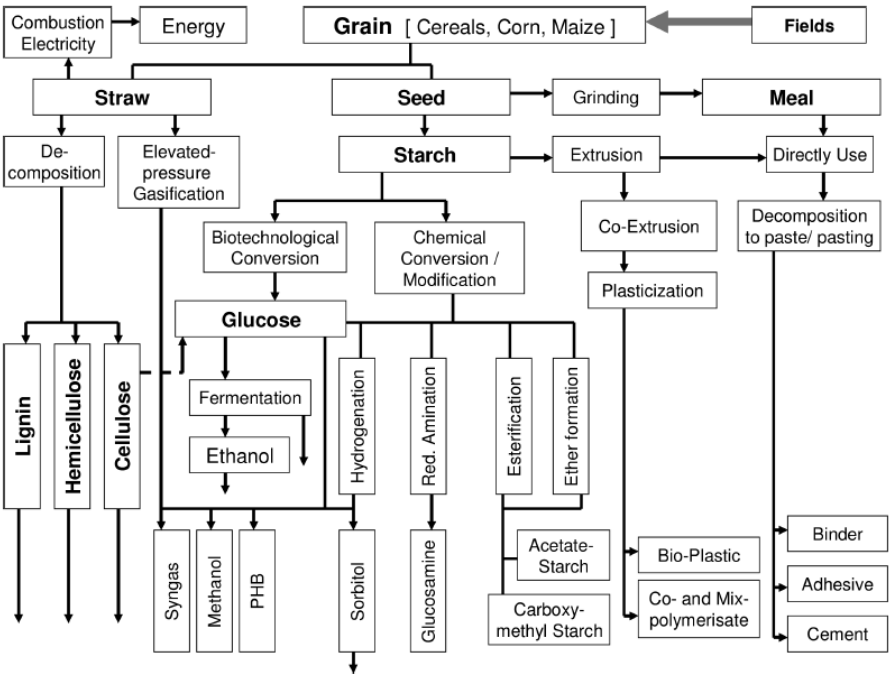

Figure 2. Potential products from a Whole Crop Biorefinery (dry milling) (Kamm *et al.*, 2006).

Wheat straw (Figure 3) is an example of a low-value and high-volume agricultural by-product that can be used for the co-production of materials, chemicals, fuels and power/heat by an integrated biorefinery approach.

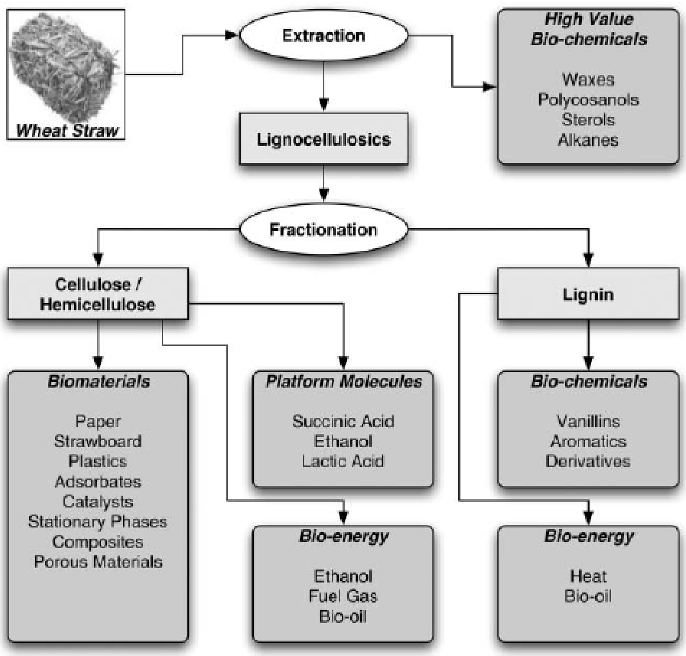

Figure 3. Wheat Straw Biorefinery Concept (Clark *et al.*, 2006).

2.3.2 Ligno Cellulosic Feedstock Biorefinery (LCBR)

The LCFBR is based on the fractionation of lignocellulosic-rich biomass sources into the intermediate output streams cellulose, hemicellulose and lignin (Figure 4), which can then be further processed into a portfolio of bio-based end-products, materials, chemicals, fuels and power and/or heat (Figure 5). These bio-based products will have a good position on both the traditional petrochemical and the expected future bio-based markets. Lignocellulosic-rich biomass is expected to become the most important biomass source of the future, because it will become widely available at moderate costs, and its cultivation and use compete less with food and feed crops. However, when lignocellulosic biomass can be processed to ethanol, it can also be used as feed. So in the future different biomass value chains (food, feed, fuels and chemicals) will be largely linked together. In the definition used in task 5.1 the emphasis for the LCBR is on the biochemical route (in contrast to the Syngas Platform Biorefinery in section 2.3.4 that covers the thermochemical route).

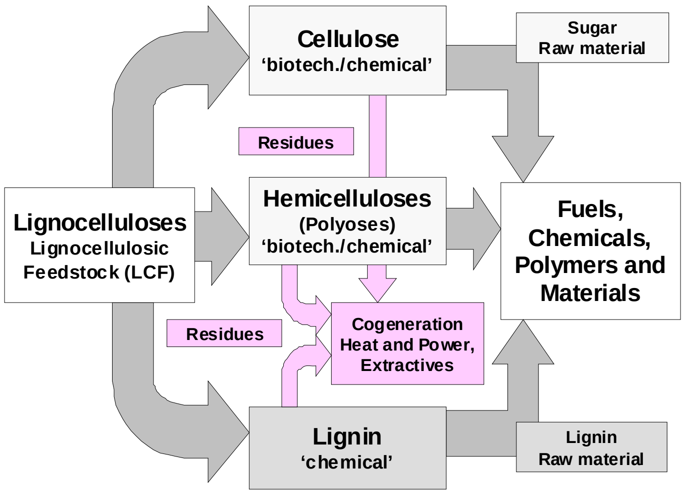

Figure 4. Lignocellulosic Feedstock Biorefinery (Kamm *et al.*, 2006).

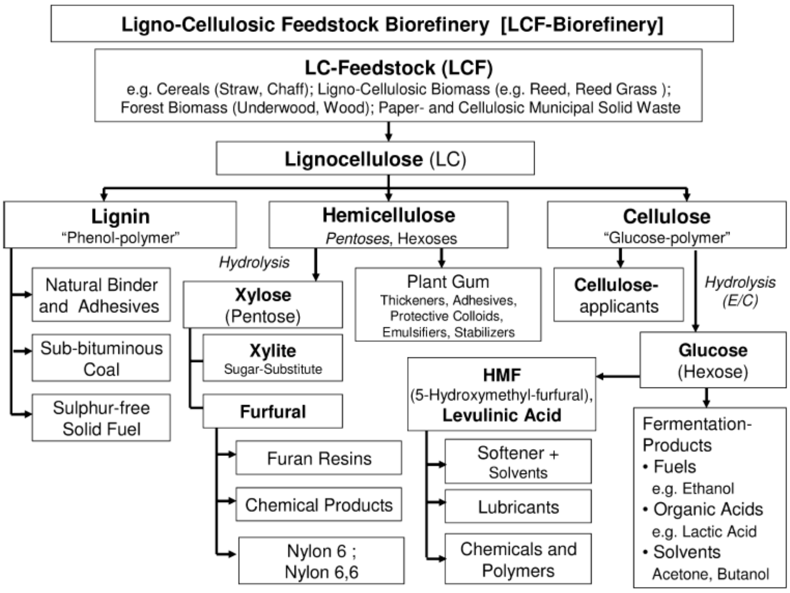

Figure 5. Potential products from a Lignocellulosic Feedstock Biorefinery (Kamm *et al.*, 2006).

2.3.3 Green Biorefinery (GreenBR)

The Green Biorefinery is based on pressurisation of wet biomass, such as green grasses and green crops (lucerne, clover), resulting in a fibre-rich press cake and a nutrient-rich press juice (Figure 6). This biorefinery concept differs from the others because fresh biomass is processed. This means that specific points of interest have to be taken into account, e.g. rapid primary processing or use of preservation methods (i.e. silage) is necessary to prevent degradation of the harvested materials.

Often the economy of bioprocesses is still a problem because in the case of bulk products, the price is highly affected by raw material costs. The advantages of the Green Biorefinery are a high biomass profit per hectare and a good link with the agricultural production; whereas the price segment of the raw materials is still low. Simple base technologies can be used and pass a good biotechnical and chemical potential for further conversions.

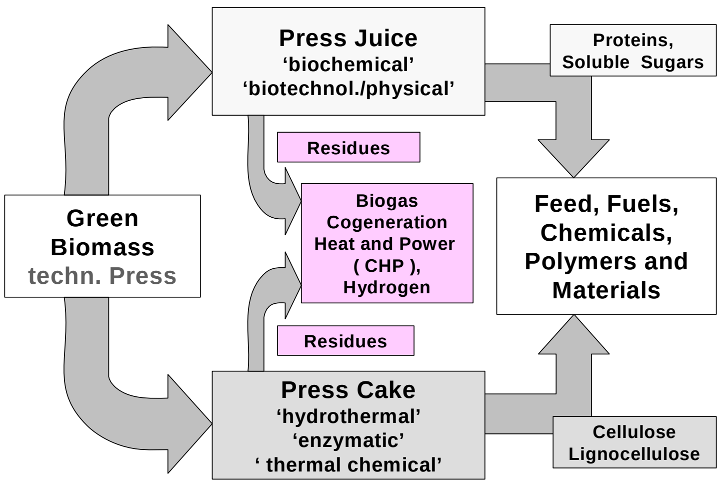

Figure 6. Green Biorefinery (Kamm *et al.*, 2006).

A portfolio of end-products can be produced of both the fibre fraction in the press cake and the green juice fraction (containing a.o.: proteins, free amino acids, and minerals; Figure 7).

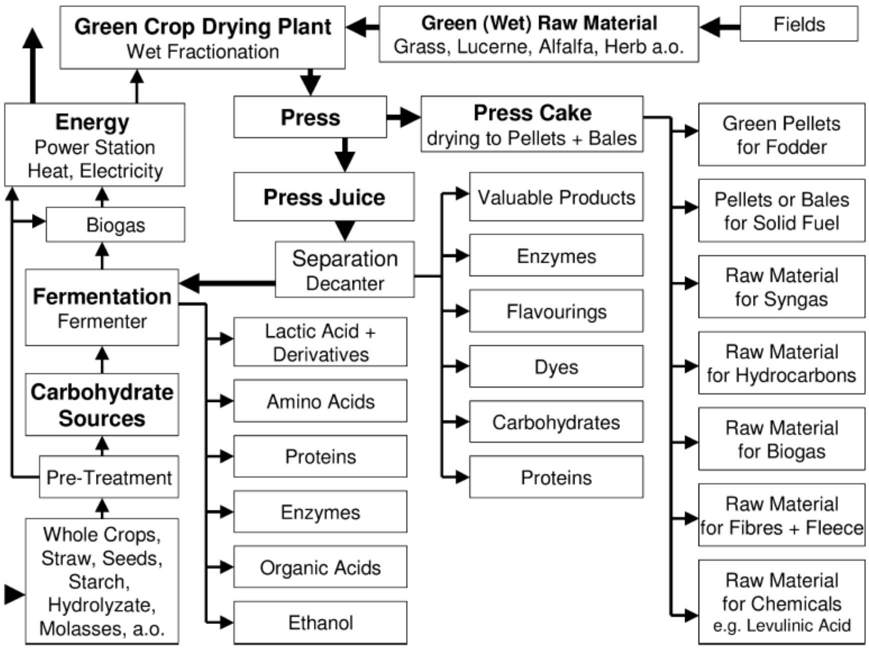

Figure 7. Potential products from a Green Biorefinery (dry milling) (Kamm *et al.*, 2006).

2.3.4 Syngas Platform Biorefinery (Syngas BR)

Biomass will be thermochemically converted using a so called “syngas platform” into a syngas for the potential production of a spectrum of bio-based products, including power and/or heat, to meet the internal process power and heat requirements.

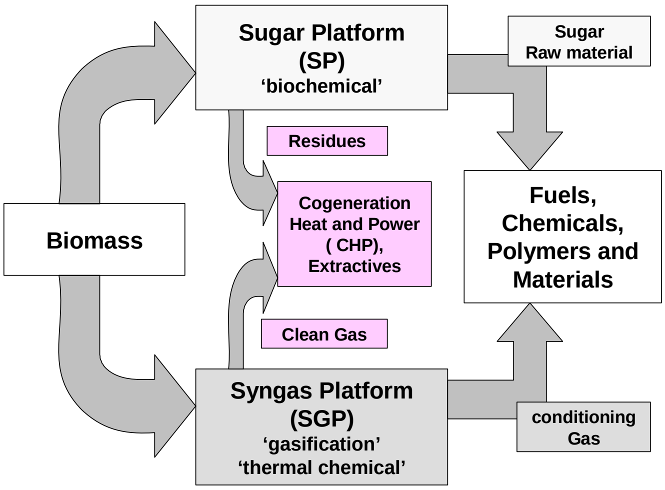

Figure 8. Two Platform Concept Biorefinery, containing the Syngas Platform (Kamm *et al.*, 2006).

2.4 Intuitive scores

Since the key parameters of the various workpackages have different scales, a comparison is difficult. Therefore, all parameters were valued on a 1 to 5 scale. A value 5 on the scale means that the conditions are favourable for biorefinery establishment and a value 1 means that biorefinery establishment is not to be expected. Examples of these intuitive scores are mapped in Table 1.

Table 1. Intuitive scores for key parameter analysis

Score	Conditions	Opinions	Costs	Profitability
1	highly unfavourable	not a chance	very high costs	very unprofitable
2	unfavourable	unlikely	high costs	unprofitable
3	neutral	neutral	neutral	neutral
4	favourable	likely	low costs	profitable
5	very favourable	very likely	very low costs	very profitable

2.5 Preliminary list of key parameters

Depending on the availability and quality of the data from work packages 1 to 4, the following parameters were taken into account in the analysis of workpackage 5.

Techno-economic status of biorefineries (work package 1):
- Technical maturity
- Technological improvement potential
- Cost reduction potential

Opinion of industry on biorefineries (work package 2):
- Concept
- Process economy
- Implementability
- Interesting markets
- Regulations

Opinion of consumers on biorefineries (work package 2):
- General attitude
- Pros and Cons
- Willingness to pay

Political legitimacy of biorefineries (work package 3):
- Stakeholder opinion
- Contribution to CO_2 reduction targets
- Contribuition to energy security
- Food and feed competition
- Contribution to (rural) economy

Biorefinery establishment factors (work package 4):
- Crop production
- Presence of feed industry
- Presence of chemical industry
- Presence of oil refinery

2.6 Definition of pilot, demo and full scale biorefineries

The delineation of pilot and demonstration scale plants is not well defined. Some processes cannot be scaled down easily and, therefore, sometimes pilot scale plants can be quite large (i.e. in the case of gasification). On the other hand, demonstration phase research is sometimes carried out in abandoned pilot scale plants. In such a case, not the scale but the purpose of the plant has altered. On the internet, press releases were found that show that the terms ‘pilot’ and ‘demonstration’ are applied inconsistently. As examples a pilot plant of 43 Ml/yr was reported by Abengoa (2007) and BP reported a demo plant of 0.02 Ml/yr (2008).

Generally pilot, demonstration and full scale facilities can be characterized as shown in Table 2, adapted from VTT (2007).

Table 2. Pilot, demonstration and full scale characteristics.

	Pilot	Demonstration	Full scale	Unit
Investment	<1	1-10	>10	M€
Lifespan	<1	1-5	>5	year
Throughput (fresh weight)	<10	10-100	>100	kton/year
Scale factor (compared to full scale)	0.01	0.1	1	-
Goal	R&D	Proof of concept	Profit	
Investor	R&D	Mixed	Industry	
Location	R&D facility	Next to full scale plant	Industrial site	
Scope	Testing process sections with largest uncertainty	Demonstrating full process		

2.7 Alongside vs. stand alone

Biorefineries can be built as stand alone or alongside an existing plant. The investment costs will be lower if the plant is built alongside: it can share utilities (steam, cooling water, canteen, weigh-bridge, forklift truck, warehouse) and services (gatekeeper, surveillance, technical service). For this reason, pilot and demo plants are almost always built alongside another plant. Full scale plants are also preferentially built alongside. Stand alone facilities are only built if there are no other options (no space available at the old site) or if the new site has considerable advantages over the old site (good accessability by road, train and/or boat, old site has been surrounded by densely populated areas).

3 Results of data processing for individual work packages

This chapter will discuss the results of the data processing per individual work package. The processing of data to come to the results on a 1 to 5 scale will briefly be discussed. A more detailed elaboration is found in Appendix A (WP2), Appendix B (WP3) and Appendix C (WP4). In chapter 4 the results of the various work packages will then be combined .

3.1 Technical and economical evaluation (WP1)

Unfortunately Deliverable 1.3 was not ready in time. So the technical and economical evaluation was partly derived from the assessment that was made in the article of Kamm *et al.* (2009) and a draft article on the whole crop biorefinery. Furthermore, the scores were produced by combining expert judgements of the project partners with available literature. The final results of the assessment are given in Table 3.

Table 3. Technological and economical aspects of 4 different biorefinery types.

Aspects	WCBR	LCBR	GreenBR	Syngas
Technical feasibility	3	2.5	3.5	4.5
Capital costs not a problem	3	2.5	4	2
Feedstock costs not a problem	3	3.5	4	3.5
Technological & feedstock efficiency improvement potential	3.5	4	3.5	2.5

The reasoning of the experts behind the scores on different aspects in Table 3 is given below.

Technical feasibility

- Syngas: ready for full scale implementation.
- Green biorefinery: successful demonstrations.
- Lignocellulosic biorefinery: proof of principle, but low yields and high reactor retention times.
- Whole crop biorefinery: half of the crop (e.g. wheat) is already processed at full scale, half of the crop (straw) needs to go through lignocellulosic biorefinery which is far from ready.

Capital costs not a problem

- Syngas: not implemented yet because of high capital costs.
- Green biorefinery: simple equipment so capital costs are relatively low.
- Lignocellulosic biorefinery: high reactor retention times cause high capital costs.
- Whole crop biorefinery: half of the crop (wheat) is processed with traditional equipment that probably already has been built, half of the crop (straw) needs to go through lignocellulosic biorefinery which has high capital costs.

Feedstock costs not a problem

- Syngas and lignocellulosic biorefinery: waste wood and straw are relatively cheap, however specially grown wood is more expensive. The feedstock will be a mix of these biomass types.
- Whole crop biorefinery: Half of the crop (wheat) is very expensive, half of the crop (straw) is currently available at just above harvest cost.
- Green biorefinery: Grass is easily grown (seeding and ploughing only once in 3 or 4 years) and has a very high yield. Therefore this crop is relatively cheap.

Technological improvement potential

- Syngas: the yield is already very high, the residence time is very short, FT-technology is well developed: little improvement is expected.
- Lignocellulosic biorefinery: low yield and high residence time. A new technology with plenty of room for improvement of the technology.
- Green biorefinery: the technology is new, and improvements are still to be expected.
- Whole crop biorefinery: half of the crop (wheat) is processed very efficiently (so hardly any improvement is expected), half of the crop (straw) goes through lignocellulosic biorefinery with high improvement opportunities.

3.2 Industry and consumer survey (WP2)

Work package 2 has performed an industry survey and a consumer survey. This has supplied data about the market acceptance of biorefinery concepts by industry (section 3.2.1) and a consumer opinion on biorefineries (section 3.2.2).

3.2.1 Market acceptance of biorefinery concepts by industry

The market acceptance of biorefinery concepts in industry is of crucial importance to the establishment of biorefineries. Without investments from the industry, no establishment will occur. In work package 2, the market acceptance of biorefineries was assessed via surveys and interviews with industry (Deliverable 2.1.2). The survey gave some propositions about biorefineries that could be judged by respondents from industry. Respondents also had the chance to indicate the major barriers and disadvantages/ problems. These issues will be discussed consecutively below.

Propositions about biorefineries
The respondents were asked for their opinions on a list of propositions. The following 5 propositions from this survey were assumed relevant to the future prospects of biorefineries:

- Biorefinery is a promising concept
- Biorefinery makes good economic sense
- Biorefinery is implementable
- Biorefinery offers interesting markets
- Biorefinery fits well in existing regulations

After processing the answers to a 1-5 scale (see Appendix A), Table 4 resulted. It can be concluded that the market acceptance of biorefineries is generally very good. However, industry experiences some problems with existing regulations.

Table 4. Market acceptance of biorefineries in industry.

Proposition	Score
Is promising concept	4.5
Makes good economic sense	4.6
Is implementable	4.1
Offers interesting markets	4.6
Fits well in existing regulations	3.7

Barriers for biorefineries
The respondents were asked to respond to eleven issues where they foresee barriers. In order to cut down the number of issues for our analysis, these eleven barriers were grouped into economic issues (economic barriers, market conditions and negative opinion of stakeholders), political/legal issues (political framework, legal framework and environmental regulations), technological issues (technological barriers) and other issues (behaviour of clients, qualification /knowledge of staff, co-operations of the actors and knowledge transfer).

After processing the answers again to a 1-5 scale (see Appendix A), Table 5 resulted. Generally, no large barriers are seen by the majority of respondents. The respondents see slightly larger barriers from economic and technological issues, but still these are only minor.

Table 5. Barriers indicated by industry on 1 to 5 scale (1 is very big problem, 5 is no problem).

Barriers	Score
Economic issues	3.8
Political/legal issues	4.1
Technological issues	3.8
Other issues	4.6

Disadvantages/problems concerning the implementation of biorefineries
The respondents were asked to indicate a number of issues where they foresee disadvantages or problems concerning the implementation of biorefineries. The disadvantages were grouped to feedstock/raw material problems (variable quality of feedstock, deficient availability of feedstock), plant/mill/manufacturing problems (high investment costs, immature technology, expensive production process) and problems with market conditions (established regulations, deficient consumer acceptance, fossil feedstock is too cheap). The same approach as for the *barriers* issue was used, and Table 6 resulted. Little disadvantages or problems were indicated by the respondents. The scores for feedstock/raw material and plant/mill/manufacturing issues were indicated less positive than the market conditions. However, none of the issues are considered to be a real barrier (all scores are higher than 3).

Table 6. Disadvantages or problems indicated by industry on 1 to 5 scale (1 is a very big problem, 5 is no problem).

Disadvantage or problem	Score
Feedstock/raw material problems	3.7
Plant/mill/manufacturing problems	3.5
Market conditions	4

3.2.2 Consumer opinion on biorefineries

The succes of biorefineries will also depend on the opinion of the consumers. If they are willing to pay more for the products from biorefineries than for fossil alternatives, that could be a driver for the biorefinery industry. At the same time, each consumer (buyer) is also a civilian (member of society). If a united group of civilians opposes a certain technology, they can slow down the establishment through all sorts of formal procedures (building permit, hindrance permit, environmental effect report). Thus, it is important that consumers acknowledge the benefits of the new technology, and do not threats from the technology. People that are willing to pay equal or more for products produced at biorefineries, do obviously not oppose to this new technology. The general consumer attitude towards biorefineries, the pros and cons of biorefinery concepts, and willingness to pay were evaluated in work package 2 based on a consumer survey.

General consumer attitude towards biorefineries
The general consumer attitude towards biorefineries was measured on a 1 to 5 scale. The score was positive (Table 7).

Table 7. Consumer acceptance of biorefineries (1 is very opposing, 5 is very supportive).

General attitude	Score
Consumer acceptance of biorefineries	4.1

Pros and cons
In work package 2, a list of 10 pros and cons was evaluated by the respondents. The consumer survey has also revealed the most important issues for the consumers: eco-friendliness, conservation of resources and health reasons. The number of pros and cons was therefore reduced to the responses that were related to these themes:

- Biorefineries are eco-friendly
- It is positive that agricultural products are also used for technical raw materials
- Biorefineries are odourless (do not smell and poison the air)

All issues were rephrased to positive statements in order to allow the 1-5 scaling (where 1 is very opposing and 5 is very supportive). Table 8 shows that the consumers are positive on all these issues.

Table 8. Consumer opinion biorefineries (1 is very opposing, 5 is very supportive).

Pros of biorefineries	Score
Biorefineries are eco-friendly	3.7
It is positive that agricultural products are also used for technical raw materials	3.4
Biorefineries are odourless	3.3

Willingness to pay
The consumer survey has revealed that 85% of the respondents is willing to pay equal or more to get renewable products. This clearly shows that the far majority of people do not feel objections to buy renewable products and that some are even willing to pay extra. After scaling to the 1-5 scale, a score of 4.4 resulted (Table 9).

Table 9. Consumer willingness to pay (1 is not willing to pay, 5 is very willing to pay).

Willingness to pay	Score
Renewable products	4.4

3.3 Political survey (WP3)

In work package 3, the political legitimacy of biorefineries was assessed via a web-based survey at the end of 2007 within the policy community. The opinion of policy makers on the following issues was assessed in the questionnaire and assumed relevant for the prospects of biorefineries:

a) Percieved opinion of different categories of stakeholders on biorefinery
b) Credibility and usefulness of information from these categories of stakeholders
c) Effect of biorefineries on CO_2 reduction
d) Effect of biorefineries on Security of Supply
e) Barriers or drivers caused by competition with food
f) Barriers or drivers caused by competition with feed
g) Development of rural economy
h) Development of farmer income
i) Development of employment

These parameters were determined both for current and advanced biorefineries. In the political survey, biofuel production was used as an example case for biorefineries. Current biorefineries produce biofuels from grains or seeds and advanced biorefineries produce biofuels and other bioproducts (also using the straw besides the grains). The data from the questionnaire (as made available by work package 3), were processed, combined, averaged and transferred to a 1 to 5 scale (1 is very opposing biorefineries, 5 is very supporting biorefineries) to generate 5 key parameters (containing one or more of the issues (a) – (i)):

1. The perceived opinion of each category of stakeholders (a) was weighed with the credibility of the respective stakeholder category (b) to estimate the influence of the respective stakeholder category according to the politician's opinion.
2. Effect on CO_2 reduction (c).
3. Effect on Security of Supply (d).
4. The competition with food (e) and feed (f) was averaged.
5. Parameters developement of rural economy (g), of farmer income (h) and of employment (i) were averaged to produce one parameter on (rural) economy

The calculations that led to the data in Table 10 can be found in Appendix B.

Table 10. Political opinion on current biorefineries and advanced biorefineries (1 is very opposing biorefineries, 5 is very supporting biorefineries).

Issue	current	advanced
Influence of stakeholder opinion on politicians	3.1	3.6
CO_2 reduction	3.6	4.5
Security of supply	3.7	4.3
Food and feed competition	2.5	3.0
(Rural) economy	3.9	4.1

It can be seen that the opinion of policy makers on advanced biorefineries is better than on current biorefineries on all aspects. In general, their opinion on biofuel production facilities is positive. The food/feed competition is seen as a mildly negative aspect of curent biorefineries, but it is seen as a neutral aspect with advanced biorefineries.

The questionnaire has also assessed the significance of some reputational and general acceptance issues. The results were again transferred to a 1 to 5 scale, where 1 indicates that the issue is a strong barrier and 5 that the issue is a strong driver (Table 11). The low scores indicate that all issues could be potential barriers to the development and implementation of biorefineries according to the respondents. Especially the competition for food, deforestration in the rest of the world an GMO issues could form potential barriers. However, (as seen from Table 10) the respondents expect less problems with advanced biorefineries on the food and feed competition issue.

Table 11. Political significance of reputational and acceptance issues (1 indicates that the issue is a strong barrier and 5 that the issue is a strong driver; calculations in Appendix B).

Issue	Score
GMO	1.9
Competition with food	1.7
Competition with forestry	2.3
Deforestation in rest of world	1.9

3.4 Mapping of existing biorefineries and establishment factors (WP4)

Work package 4 has mapped existing biorefineries. Furthermore it has determined some parameters that might encourage biorefinery establishment such as: availability of relevant crops, presence of (side) product markets (feed industry, chemical industry and oil refineries) and presence of transport facilities (harbours). First, all data from work package 4 were converted to comparable units (paragraph 3.4.1). The establishment factor weighing procedure is explained in paragraph 3.4.2. The processed results are shown in paragraph 3.4.3 per country and in paragraph 3.4.4 per region. The discussion and conclusions can be found in paragraph 3.4.5.

3.4.1 Data preprocessing

The following original data were supplied by work package 4:

- agricultural crop production volumes of sugar beet, wheat, maize potato, rape seed, roundwood and grass (Mton of fresh material/year)
- production volumes of milk and meat (Mton of fresh material/year)
- production of basic chemicals (M€/yr)
- oil refineries (Mton/yr)
- harbours (Mton/yr)

Before the analysis in this report, some data preprocessing was performed in order to transform all available original data to comparable units, in this case weight (Mton of dry matter/year).

All agricultural crop production volumes were recalculated from fresh weight to dry matter (DM) production volumes (by multiplying with the respective dry matter contents; Figure 9).

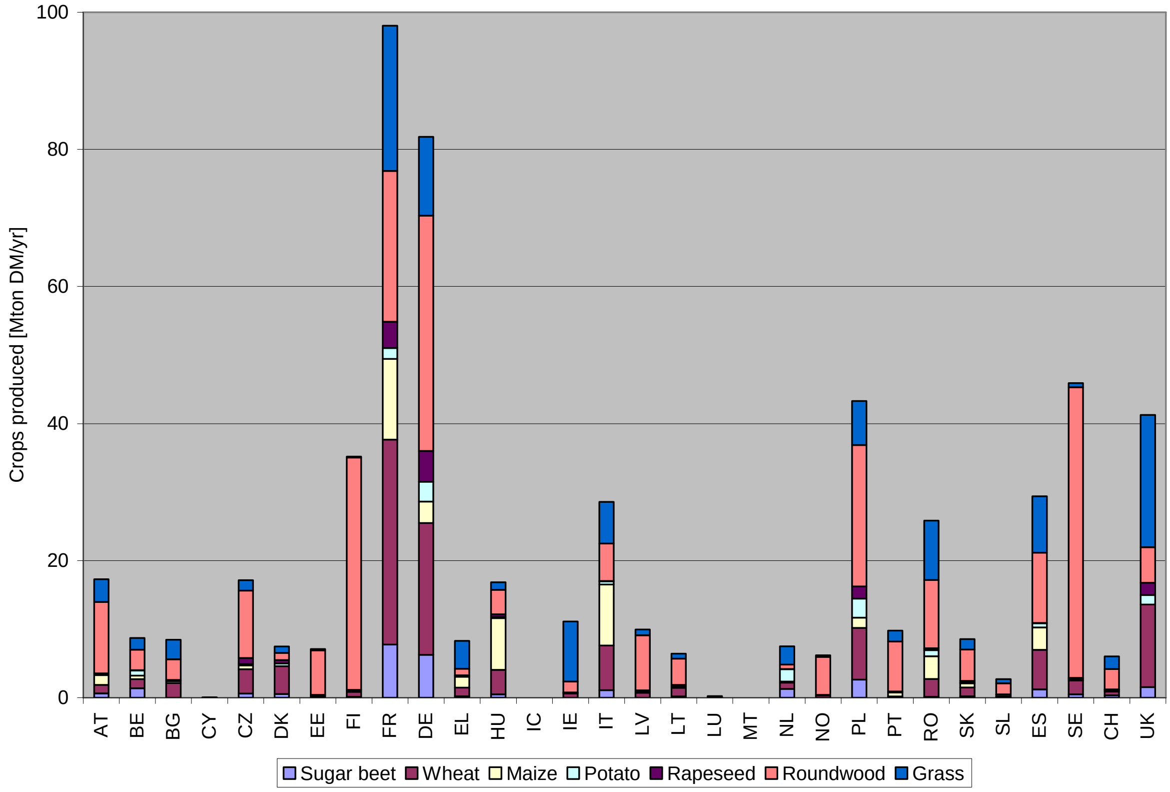

Figure 9. Absolute production volumes of agricultural crops, wood and grass

A remark should be made with regard to the maize data: only kernel maize is included, not maize for silage purposes. Especially in the northern countries this can make a considerable difference: in 2006 almost 9 Mton of silage maize was harvested in the Netherlands. If maize for silage would have been included, the calculated likeliness of whole crop, lignocellulosic and syngas biorefineries would increase in countries with high silage maize production. European statistics on maize silage production are, unfortunately not available.

Some large countries (such as France and Germany) have a high absolute production volume, thus appearing relatively often at the top of the assessments. Therefore, in order to compare large and small countries in a different way, also values per Mha (the surface of each country as found in Eurostat) were used (Figure 10). Thus, also smaller countries like Belgium, Denmark and The Netherlands will appear higher in the ratings.

The production volumes of milk and meat were recalculated to required feed dry matter consumption volumes. For milk a yield of 0.5 kgDM/kgDM and for meat a yield of 0.33 kgDM/kgDM was assumed. As a result, all data ended up in comparable units.

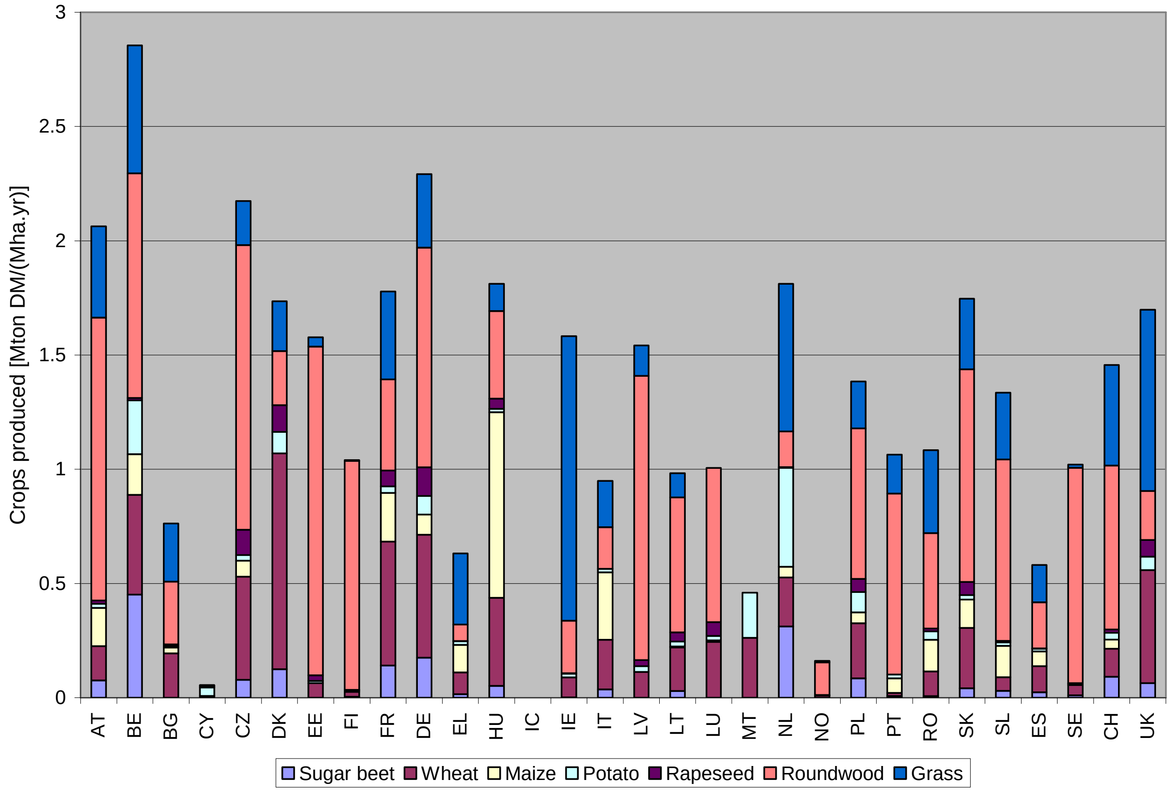

Figure 10. Production volume of agricultural crops, wood and grass per Mha

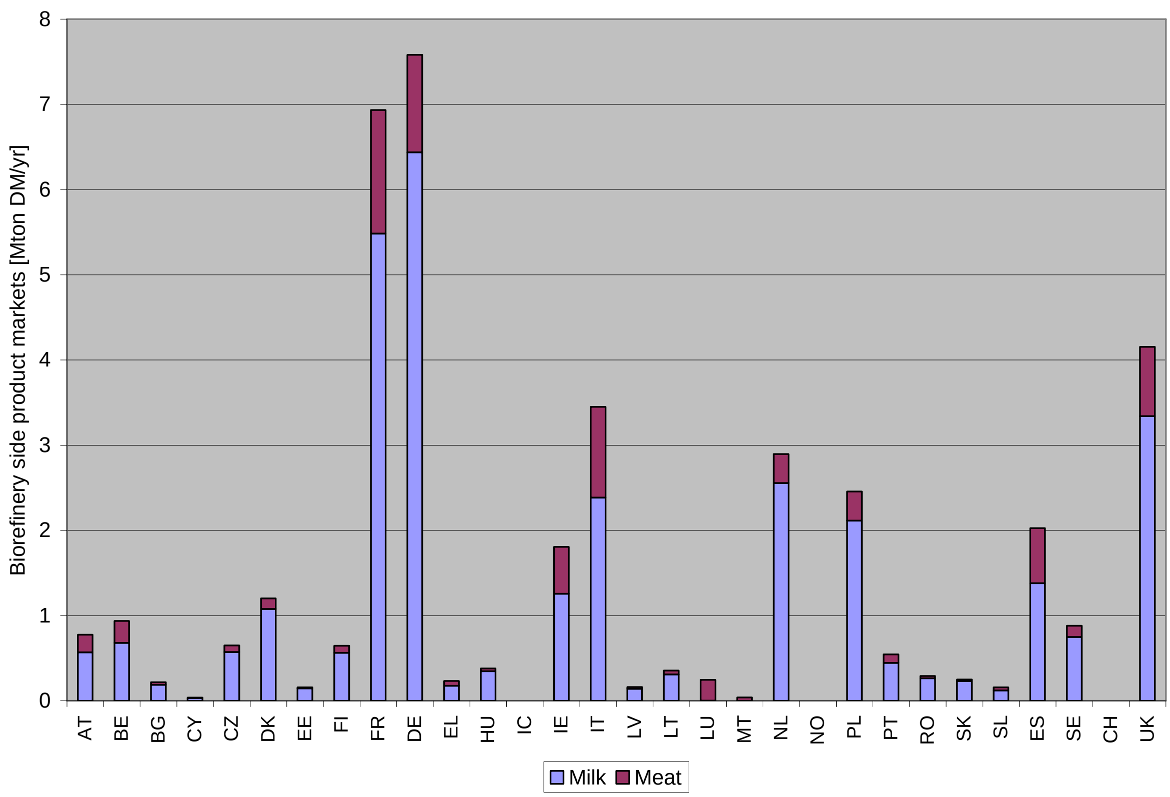

Figure 11. Side product markets from milk and meat industry

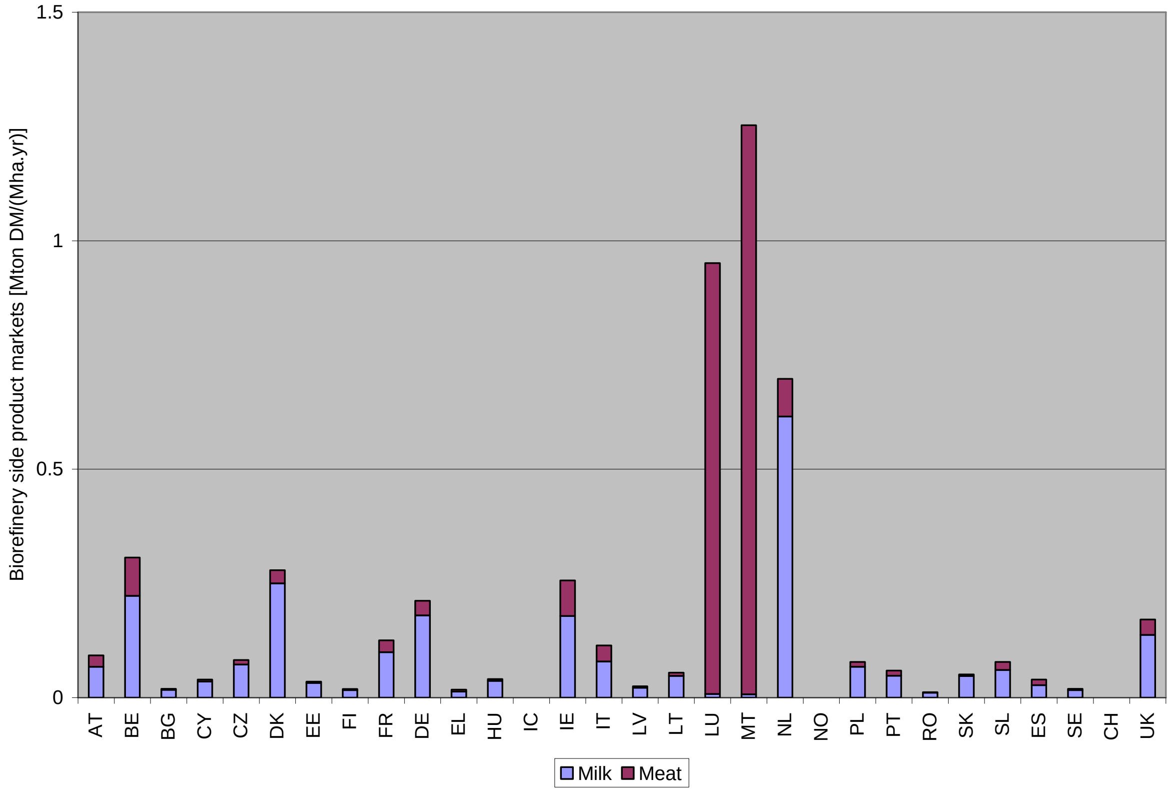

Figure 12. Side product market from milk and meat industry per Mha

The production volume the basic chemistry was estimated from the financial data assuming an average product price of 2 €/kg. The results for the capacity of basic chemistry and oil refineries per EU-country are shown in Figure 13. The capacities were also converted to per Mha values as shown in Figure 14.

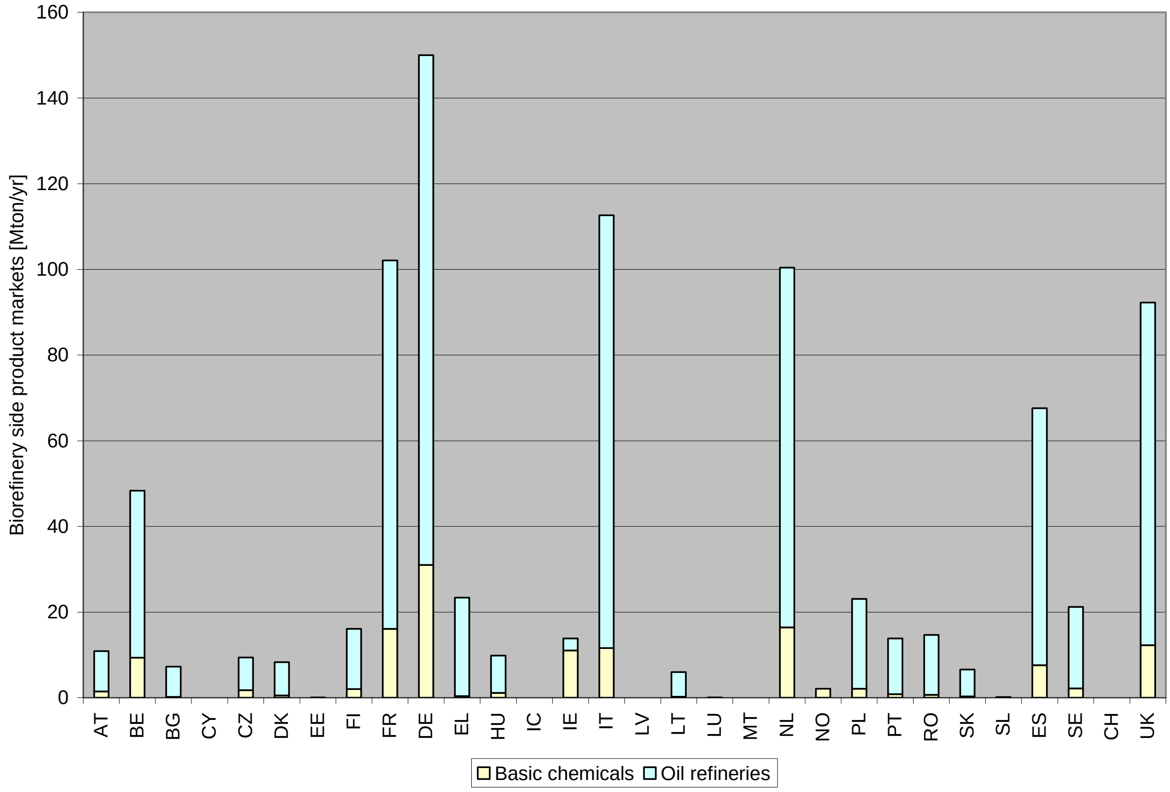

Figure 13. Estimate of oil refinery and basic chemical production capacity in Mton/yr.

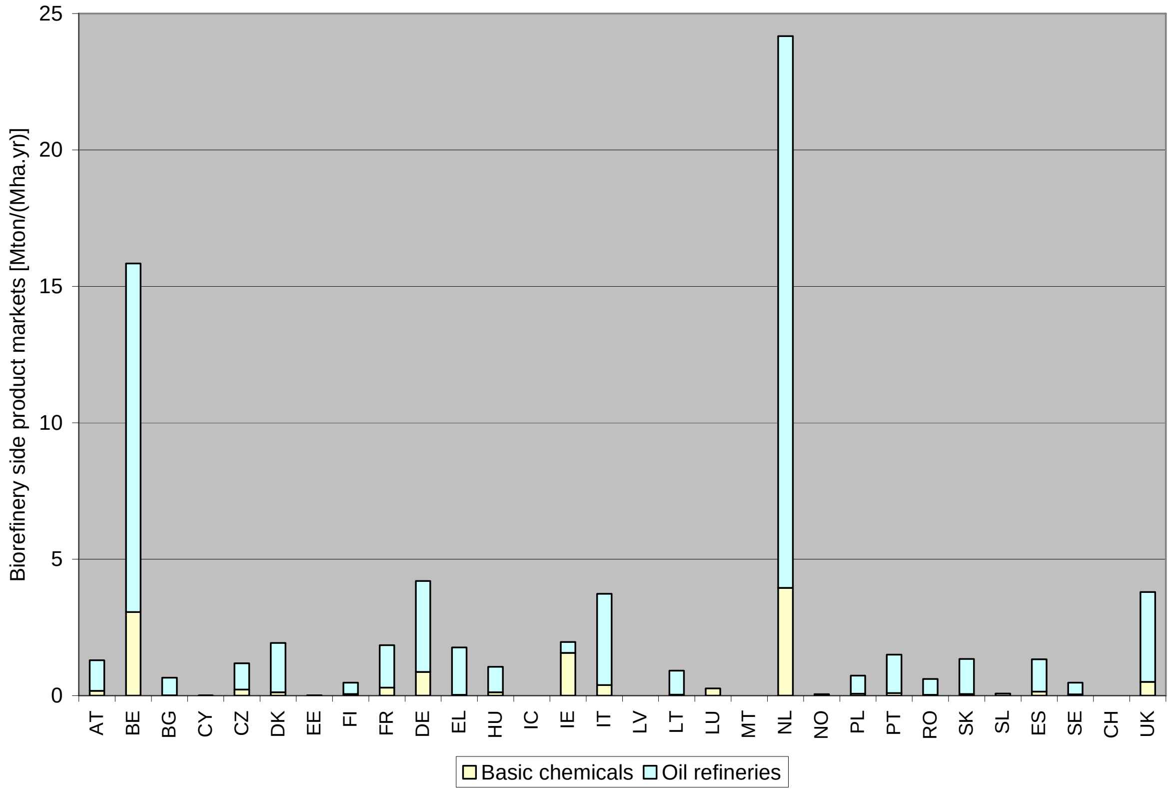

Figure 14. Estimate of oil refinery and basic chemical production capacity in Mton/(ha.yr).

All calculations and assumptions are described in more detail in Appendix C.

3.4.2 Establishment factor weighing method

The possible establishment of new biorefineries in a certain region will depend on numerous establisment factors such as:

- Land use in surrounding area (availability of feed stocks)
- Presence of animal husbandry (presence of side market for protein rich products)
- Presence of oil refineries and chemical industry
- Transport possibilities

The land use in the surrounding area of the new biorefinery will determine the quantity of available feed stocks, the presence of animal husbandry will indicate the possibilities to sell the by-products of biorefinery (e.g. DDGS, press cake) and the presence of oil refineries and chemical industry will indicate the possibilities to integrate biorefineries with existing industry and to sell other by-products (lignin, heat, tail gas). The presence of harbours indicates an opportunity to secure the supply of raw materials from elsewhere, or to send (by-) products to other locations.
The likeliness of biorefinery establishment will be a function of the preprocessed data (presented in section 3.4.1). This function uses a weight matrix that contains the (relative) impact of each individual establishment factor on the likeliness of establishment each type of biorefinery. Both a weight matrix for the development of current biofuel production and pulp and paper production (as a first test case of the method) and a weight matrix for future advanced biorefineries establishment were made. The values in these weight matrices (Table 12 and Table 15) are based on expert knowledge and common sense. Therefore, the results are indicative only.

A. Establisment estimate of current biofuel production and pulp and paper production
As a first test case, the weight matrix method was applied to the establishment of current biofuel production and current pulp and paper production. The weight matrix was based on the following assumptions:
Currrent biofuel production

- Biofuels are produced from wheat and rape
- Maize, potato, wood and grass volumes are not relevant for current biofuel production.
- The impact of milk and meat production was estimated to be 3 times lower than the impact of agricultural production, since the meat and milk industry is to a considerable extent fed by locally grown fodders and therefore already included in the agricultural production.
- The production volume of basic chemicals is not relevant for current biofuel production.
- The impact of the capacity of oil refineries was estimated to be 50 times lower than the impact of agricultural production. Not all oil will be replaced by biofuels (current target is 5.75% for 2010) and biofuels can also be blended into gasoline and diesel after transport from the refinery to the country of destination.
- Only the largest harbours were found in the statistic resources that were consulted in work package 4. No harbours were found in Sweden and Finland, but still it is known that Sweden and Finland export 23 Mton of pulp via these harbours. So it is clear that also small harbours can contribute significantly to the transport of biomass. The lack of reliable information on these small harbours has led to the consequence that the influence of harbours could not be taken into account in the analysis. Therefore the

weight factor in the matrix was set to zero. In fact, the presence of oil refineries has a very high correlation with the presence of harbours, this way the presence of harbours is implicitly taken into account.

Pulp and paper production

- Only wood is a relevant substrate for paper and pulp production
- Terpenes and lignin are used for production of chemicals. Terpenes are only a small part of the total wood biomass and most of the lignin is burnt for heat generation, therefore the weight factor was set to 0.05.

Table 12. Weighing factors for the establishment of current production processes.

Industry type	Sugar Beet	Wheat	Maize	Potato	Rapeseed	Roundwood	Grass production	Feed for milk production	Feed for meat production	Basic chemicals	Oil refineries	Harbours
Biofuel	1	1	0	0	1	0	0	0.33	0.33	0	0.02	0
Pulp and paper	0	0	0	0	0	1	0	0	0	0.1	0	0

The test results of current biofuel production and current pulp and paper production establishment are shown in Table 13. The results of the likeliness of current biofuel production and current paper and pulp production based on absolute etablishment figures show that Germany and France have very good establishment factors for biofuel production, which is actually confirmed by the high number of plants in these countries at the moment. The method however seems to miss the opportunities in smaller countries. This is mainly caused by the fact that these countries have lower absolute agricultural production volumes. Therefore, the per hectare values of the establishment factors were taken as described in Appendix C. The results of the likeliness of current biofuel production and current paper and pulp production per Mha are shown in the Table 14, where smaller countries show better opportunities. Here Belgium, Denmark and the Netherlands have very high scores because they have a very productive agricultural area and they also have large side product markets. Again the results comply with the fact that large biofuel production capacities are present or being built in these countries today.

Pulp and paper has very high establisment factors in Finland, Germany and Sweden. Especially Finland and Sweden indeed already have very large pulp and paper factories. The per Mha analysis shows that also considerable opportunities are present in Austria, Czech Republic, Estonia and Latvia. Austria, Czech Republic and Estonia indeed have a considerable pulp industry.

Table 13. Likeliness of current biofuel and pulp and paper production establishment in European countries (using absolute establishment factors values).

Country	Country code	Biofuel	Pulp and paper
Austria	AT	1.2	2.0
Belgium	BE	1.3	1.4
Bulgaria	BG	1.2	1.3
Cyprus	CY	1.0	1.0
Czech Republic	CZ	1.5	1.9
Denmark	DK	1.5	1.1
Estonia	EE	1.0	1.6
Finland	FI	1.1	4.2
France	FR	5.0	3.2
Germany	DE	4.1	4.5
Greece	EL	1.2	1.1
Hungary	HU	1.4	1.3
Iceland	IC	1.0	1.0
Ireland	IE	1.1	1.3
Italy	IT	2.0	1.6
Latvia	LV	1.1	1.8
Lithuania	LT	1.2	1.4
Luxembourg	LU	1.0	1.0
Malta	MT	1.0	1.0
The Netherlands	NL	1.4	1.2
Norway	NO	1.0	1.5
Poland	PL	2.2	3.0
Portugal	PT	1.1	1.7
Romania	RO	1.3	1.9
Slovak Republic	SK	1.2	1.4
Slovenia	SL	1.0	1.2
Spain	ES	1.8	2.0
Sweden	SE	1.3	5.0
Switzerland	CH	1.1	1.3
United Kingdom	UK	2.6	1.6

Legenda

Value	**Establishment**
4.0 till 5.0	Very likely
3.0 till 4.0	Likely

Table 14. Likeliness of current biofuel and pulp and paper production establishment in European countries (using /Mha values of the establisment factors).

Country	Country code	Biofuel	Pulp and paper
Austria	AT	1.9	4.5
Belgium	BE	4.8	4.6
Bulgaria	BG	1.7	1.8
Cyprus	CY	1.1	1.0
Czech Republic	CZ	3.1	4.5
Denmark	DK	5.0	1.7
Estonia	EE	1.3	5.0
Finland	FI	1.1	3.8
France	FR	3.5	2.2
Germany	DE	4.0	3.9
Greece	EL	1.5	1.2
Hungary	HU	2.6	2.1
Iceland	IC	1.0	1.0
Ireland	IE	1.6	2.1
Italy	IT	2.1	1.6
Latvia	LV	1.5	4.5
Lithuania	LT	1.9	2.7
Luxembourg	LU	2.9	2.9
Malta	MT	3.1	1.0
The Netherlands	NL	4.5	2.5
Norway	NO	1.0	1.4
Poland	PL	2.3	2.9
Portugal	PT	1.2	3.2
Romania	RO	1.4	2.2
Slovak Republic	SK	2.2	3.6
Slovenia	SL	1.4	3.2
Spain	ES	1.5	1.6
Sweden	SE	1.2	3.6
Switzerland	CH	1.7	3.0
United Kingdom	UK	3.3	1.7

Legenda

Value	**Establishment**
4.0 till 5.0	Very likely
3.0 till 4.0	Likely

The mehod is well able to ‘predict’ the establishment of current biorefinery concepts. Therefore, the model was also used to predict the establihsment of future, more advanced biorefinery schemes.

B. Establishment estimate of biorefineries
The weighing factors for biorefinery establishment were based on the following assumptions (Table 15):

- Whole crop biorefineries will have the same establishment factors as current biofuel production facilities, but also potatoes, wheat straw and maize straw will be used as feedstock. Therefore, the availability of dry matter from wheat and maize will double. The use of lignocellulosic feedstocks will cause the production of lignin that can be used to produce basic chemicals or to be fed into oil refineries. Biochemicals can also be made from sugars, amino acids, glycerol or other components that are present in the crops.
- Lignocellulosic biorefineries will be established in regions where wood is abundant, but also straw from wheat and maize will be used. Not only the roundwood, but also tops, branches and stubs will be used. The side products from lignocellulosic biorefinery (lignin) will be used to produce basic chemicals or will be fed into oil refineries.
- Green biorefineries will be fed with grass. Side products will be sold to the feed industry, and to a lesser extent to the basic chemistry and oil refineries.
- Syngas will have more or less the same profile as lignocellulosic biorefinery. The gaseous intermediate products will cause a higher need to be close to basic chemistry or oil refineries, since transport of gases is expensive.
- Zero weight factor for harbours due to inadequate data.

Table 15. Weighing factors for biorefinery establishment factors for 4 types of future advanced biorefineries.

Biorefinery type	Sugar Beet	Wheat	Maize	Potato	Rapeseed	Roundwood	Grass production	Feed for milk production	Feed for meat production	Basic chemicals	Oil refineries	Harbours
Whole Crop	1	2	2	1	1	0	0	0.33	0.33	0.1	0.02	0
Lignocellulosic	0	1	1	0	0	2	0	0	0	0.1	0.02	0
Green	0	0	0	0	0	0	1	0.33	0.33	0.05	0.01	0
Syngas	0	1	1	0	0	2	0	0	0	0.2	0.04	0

3.4.3 Results per country

The preprocessed data of work package 4 for the absolute values of the establishment factors were multiplied with the weight matrix (Table 15) and normalized to a 1 to 5 scale. This generated the likeliness of biorefinery establishment in the different countries for the four biorefinery types as shown in Table 16.

Table 16. Likeliness of biorefinery establishment in different countries for 4 different biorefinery types – using absolute values of the establisment factors.

Country	EU code	WCBR	LCBR	GreenBR	SyngasBR
Austria	AT	1.3	1.9	1.6	1.9
Belgium	BE	1.3	1.4	1.5	1.5
Bulgaria	BG	1.2	1.4	1.5	1.3
Cyprus	CY	1.0	1.0	1.0	1.0
Czech Republic	CZ	1.4	1.9	1.3	1.9
Denmark	DK	1.4	1.3	1.2	1.3
Estonia	EE	1.0	1.5	1.0	1.4
Finland	FI	1.1	3.4	1.1	3.3
France	FR	5.0	5.0	5.0	5.0
Germany	DE	3.6	4.9	3.7	5.0
Greece	EL	1.3	1.3	1.7	1.3
Hungary	HU	1.9	1.9	1.2	1.8
Iceland	IC	1.0	1.0	1.0	1.0
Ireland	IE	1.1	1.2	2.6	1.3
Italy	IT	2.4	2.4	2.4	2.5
Latvia	LV	1.1	1.6	1.1	1.6
Lithuania	LT	1.1	1.3	1.1	1.3
Luxembourg	LU	1.0	1.0	1.0	1.0
Malta	MT	1.0	1.0	1.0	1.0
The Netherlands	NL	1.4	1.3	1.8	1.4
Norway	NO	1.0	1.4	1.1	1.4
Poland	PL	2.0	3.0	2.2	2.9
Portugal	PT	1.1	1.6	1.3	1.6
Romania	RO	1.5	2.0	2.4	2.0
Slovak Republic	SK	1.2	1.4	1.3	1.4
Slovenia	SL	1.0	1.1	1.1	1.1
Spain	ES	1.9	2.3	2.6	2.4
Sweden	SE	1.2	4.1	1.2	4.0
Switzerland	CH	1.1	1.2	1.3	1.2
United Kingdom	UK	2.3	2.2	4.5	2.3

Legenda

Value	**Establishment**
4.0 till 5.0	Very likely
3.0 till 4.0	Likely
2.0 till 3.0	Possible if proper measures are taken

France and Germany have good opportunities for all types of biorefineries. Sweden and Finland have good opportunities for wood based biorefeneries. The UK shows good prospects for green biorefineries and Poland could create opportunities for the lignocellulosic and syngas biorefinery. It is clear that using the absolute production volumes per country as establishment factors leads to an over-representation of biorefinery likeliness for large countries (France and Germany for all biorefinery types, and the UK for the green biorefinery). This overrepresentation of large countries was corrected by using the establishment factor values per Mha before weighing, as described in Appendix C. The result is given in Table 17. This table shows a more nuanced view on the likeliness of biorefinery establishment, where also smaller countries have (very) good opportunities for biorefinery establishment. Good opportunities for whole crop biorefineries are present in Belgium, Czech Republic, Denmark, France, Germany, Hungary, The Netherlands and the UK. Good opportunities for lignocellulosic biorefineries in Austria, Belgium, Czeck Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Latvia, The Netherlands, Slovak republic, Luxembourg, Poland, Slovenia. Good opportunities for green biorefineries exist in Belgium, Ireland, The Netherlands and The UK. Good opportunities for syngas biorefineries are present in Austria, Belgium, Czeck Republic, Estonia, Germany, Hungary, Latvia, The Netherlands and Slovak republic.

Table 17. Likeliness of biorefinery establishment for 4 different biorefinery types – using per Mha establishment factors.

Country	EU code	WCBR	LCBR	GreenBR	SynBR
Austria	AT	2.3	4.2	2.3	3.6
Belgium	BE	5.0	5.0	3.7	5.0
Bulgaria	BG	1.7	2.0	1.8	1.8
Cyprus	CY	1.1	1.0	1.0	1.0
Czech Republic	CZ	3.0	4.5	1.7	3.9
Denmark	DK	4.7	3.1	1.9	2.8
Estonia	EE	1.3	4.1	1.2	3.5
Finland	FI	1.1	3.2	1.0	2.8
France	FR	3.9	3.2	2.3	2.9
Germany	DE	3.9	4.3	2.3	3.9
Greece	EL	1.8	1.6	1.9	1.5
Hungary	HU	4.9	3.8	1.4	3.3
Iceland	IC	1.0	1.0	1.0	1.0
Ireland	IE	1.7	1.9	5.0	1.9
Italy	IT	2.9	2.4	1.8	2.3
Latvia	LV	1.4	3.8	1.4	3.3
Lithuania	LT	1.8	2.6	1.4	2.3
Luxembourg	LU	2.4	2.9	1.9	2.6
Malta	MT	2.8	1.4	2.2	1.3
The Netherlands	NL	4.6	3.1	4.6	3.8
Norway	NO	1.0	1.3	1.0	1.3
Poland	PL	2.3	2.9	1.7	2.6
Portugal	PT	1.4	2.9	1.6	2.6
Romania	RO	1.9	2.3	2.1	2.1
Slovak Republic	SK	2.5	3.6	2.0	3.2
Slovenia	SL	1.7	3.0	1.9	2.6
Spain	ES	1.7	1.8	1.6	1.7
Sweden	SE	1.2	3.1	1.1	2.7
Switzerland	CH	1.7	2.8	2.2	2.4
United Kingdom	UK	3.1	2.5	3.6	2.3

Legenda

Value	Establishment
4.0 till 5.0	Very likely
3.0 till 4.0	Likely
2.0 till 3.0	Possible if proper measures are taken

The results of both types of analysis are summarized in Table 18, where the highest score of both tables is shown.

Table 18. Summary of countries with high establishment factors.

Country	EU code	WCBR	LCBR	GreenBR	SynBR
Austria	AT				
Belgium	BE				
Bulgaria	BG				
Cyprus	CY				
Czech Republic	CZ				
Denmark	DK				
Estonia	EE				
Finland	FI				
France	FR				
Germany	DE				
Greece	EL				
Hungary	HU				
Iceland	IC				
Ireland	IE				
Italy	IT				
Latvia	LV				
Lithuania	LT				
Luxembourg	LU				
Malta	MT				
The Netherlands	NL				
Norway	NO				
Poland	PL				
Portugal	PT				
Romania	RO				
Slovak Republic	SK				
Slovenia	SL				
Spain	ES				
Sweden	SE				
Switzerland	CH				
United Kingdom	UK				

Legenda

Color	Establishment
	Very likely
	Likely
	Possible if proper measures are taken

3.4.4 Results per region

The results can also be calculated per region (see Appendix C). First, the establishment factors were calculated per region (Figure 15 and Figure 16). From these establishment factors, the likeliness of biorefinery establishment was calculated (Table 19).

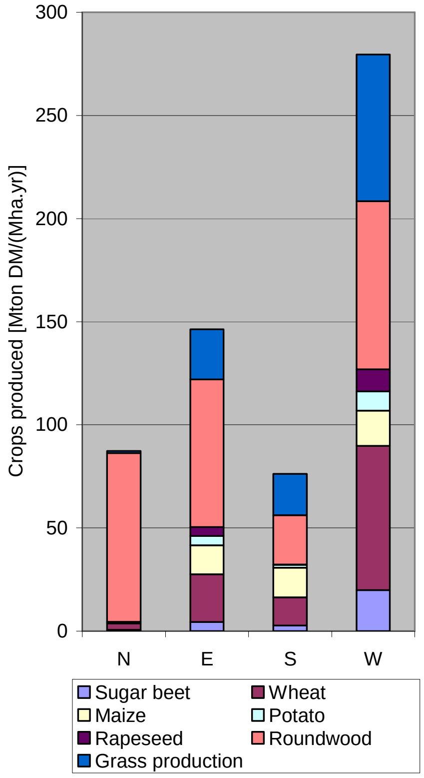

Figure 15. Crop production in EU regions

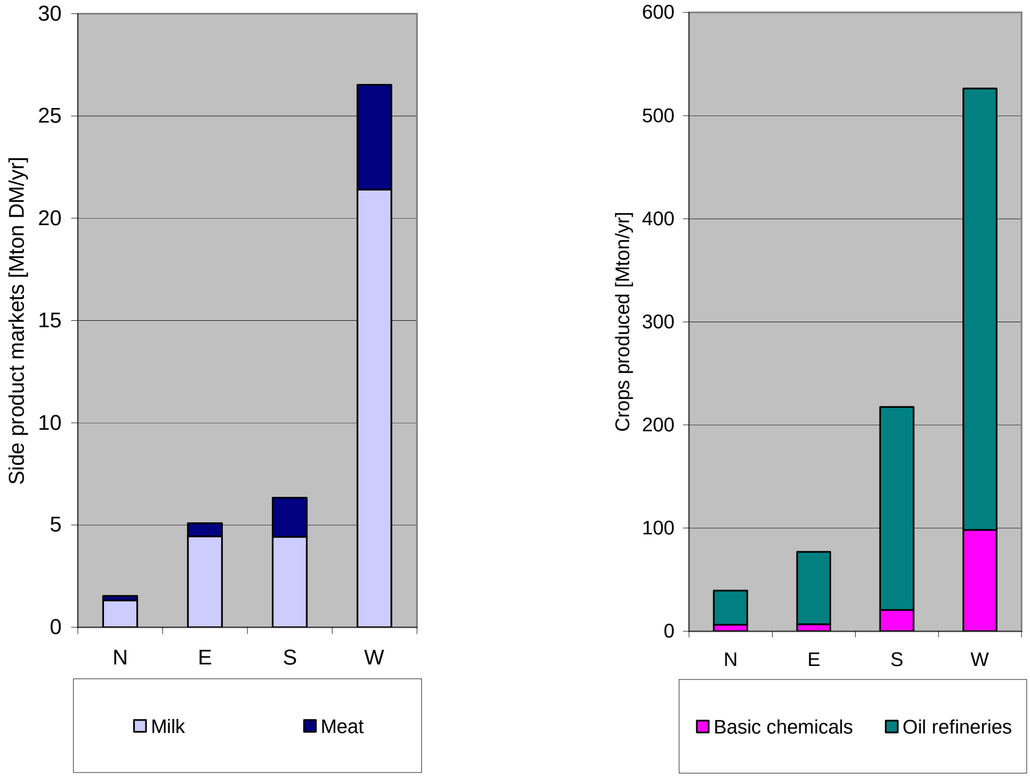

Figure 16. Side product market potential for biorefineries in regions of EU.

Table 19. Likeliness of biorefinery establishment per region (using absolute values of the establishment factors).

Region	WCBR	LCBR	GreenBR	SyngasBR
North	1.0	2.2	1.0	2.0
East	2.4	2.8	2.1	2.6
South	2.0	1.0	2.1	1.0
West	5.0	5.0	5.0	5.0

Legenda

Value	Establishment
4.0 till 5.0	Very likely
3.0 till 4.0	Likely
2.0 till 3.0	Possible if proper measures are taken

Clearly, Western Europe has a very promising outlook for all biorefinery types. In the East a lot of potential is present because these countries still have good opportunities to improve their agricultural yields. The Northern part of Europe seems to mainly have opportunities for syngas biorefineries.

3.4.5 Discussion and conclusions based on the mapping data

The establisment factor model
The use of absolute establishment factors (based on absolute values) can easily lead to an overrepresentation of large countries (such as France and Germany). By taking per Mha values of the establishment factors, a more subtle impression was obtained. The model indication of biofuel and pulp and paper production establishment opportunities was in accordance with the mapping results of work package 4. The current biorefineries that were mapped by work package 4, are mainly situated in France, Germany, Belgium and The Netherlands (see Figure 3.2 of deliverable 4.2 of work package 4). Many pulp and paper plants are present in Sweden and Finland.

Results using absolute establishment factor values
France and Germany show very high potentials for all biorefinery types (Table 16) when only looking at the absolute values of the establishment factors.

Results using per Mha values of establishment factors
The predominance of France and Germany (as seen with absolute establisment factor evaluation) is largely caused by the fact that these countries have the largest amount of arable land. This overrepresentation is not always justified. Even though the production volumes of some crops can be very high in large counties, the production can still be very dispersed and therefore biorefineries will still not always develop. When a per Mha approach is used (Table 17), good opportunities for whole crop biorefineries are present in Belgium, Czeck Republic, Denmark, France, Germany, Hungary, The Netherlands and The United Kingdom. Good opportunities for lignocellulosic biorefineries are present in Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Latvia, The Netherlands, Slovak Republic Slovenia and Sweden. Good opportunities for green biorefineries exist in Belgium, Ireland, The Netherlands and The UK. Good opportunities for syngas biorefineries

are present in Austria, Belgium, Czeck Republic, Estonia, Germany, Hungary, Latvia, The Netherlands and Slovak Republic. The high ratings for Belgium and The Netherlands are caused by a combination of high agricultural yields, high densities of animals to eat side products and large oil processing industries to process other side products such as lignin.

By region

Based on the absolute establishment factors Western Europe has very good prospects for all types of biorefinery (Table 19). One might have expected that lignocellulosic and syngas biorefineries would have good opportunities mainly in the North, but he development of straw based biorefineries could cause a huge shift to countries with high straw availability (France and Germany).

Eastern Europe could increase its agricultural yields and therewith increase the development potential of biorefineries. Such an increase of agricultural productivity is less likely in the South of Europe, where shortage of water for irrigation is a main reason for the lower agricultural yields.

Some potential for development of lignocellulosic and syngas biorefineries is present in the North of Europe. The potential for the whole crop biorefinery is very low in the North of Europe. This is to a large extent caused by the far lower agricultural biomass yield in the North of Europe (see Figure 16). This is mainly a consequence of the (very) short growth season of agricultural crops in a large part of Northern Europe. Also, it is assumed that the chemical industry is an establishment factor for biorefineries, but in the North, the large availability of biorefinery side products has already become an establishment factor for some chemical industry. This effect was not taken into account in this analysis.

By biorefinery type

The analysis indicates that whole crop biorefineries will develop in traditional areas of wheat, potato or sugar beet production (France and Germany) and near harbours and where feed is needed (Belgium and The Netherlands). Wheat is more easily transported over large distances than potatoes and sugar beets (which have far larger water content). Therefore, wheat is more likely to be processed in harbour areas such as Rotterdam and Antwerp and potatoes and sugar beets are more likely to be processed in the area where they are grown. Development of whole crop biorefineries is currently seen in countries with large areas of cereals or oil seed crops. The analysis shows opportunities for whole crop biorefinery in Belgium, Czeck Republic, Denmark, France, Germany, Hungary, The Netherlands and the United Kingdom.

Lignocellulosic biorefineries will mainly develop in straw (e.g. France and Germany) and in wood regions (like Sweden and Finland). However, the production of straw in Western Europe is much larger than the production of wood in the North of Europe. Lignocellulosic biorefineries might also develop in countries with large harbours that can import lignocellulosic feedstocks and countries with well developed oil refineries and base chemical production sites (like The Netherlands and Belgium). In practice the development of lignocellulosic biorefinery does not occur on a large scale yet. A considerable amount of research is currently committed in the USA, where large investment subsidies for pilot and demonstration scale research are given by the DOE. The likeliness of lignocellulosic biorefinery in the analysis is high in Austria, Belgium, Czeck Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Latvia, The Netherlands, Slovak Republic, Slovenia and Sweden.

Green biorefinery will most probably develop in regions where grass and clover are produced (wet agricultural land) and where feed for animals is needed. These areas are mainly situated in Western Europe. Countries that show high opportunities for green biorefinery in the analysis are Belgium, France, Germany, Ireland, The Netherlands and the United Kingdom.

Syngas biorefinery will preferentially develop in an area with large availability of lignocellulosic raw materials (wood or straw), harbours (supply of feedstocks) and traditional oil refineries and base chemical production (to further process the synthesis gas). The transport of lignocellulosic raw material is relatively easy (at proper dry matter content no decay will take place) and therefore, syngas biorefinery might also develop in regions with less lignocellulosic biomass, but better facilities. Syngas biorefineries have high chances of development according to the analysis in the countries Austria, Belgium, Czech Republic, Estonia, Finland, France, Germany, Hungary, Latvia, The Netherlands, Slovak Republic and Sweden.

4 Combining the results of individual Work packages

In this chapter, the results of the individual work packages discussed in chapter 3 will be integrated and presented in spider plots. The results from work package 2 and work package 3 are not region or biorefinery type specific and will be presented in paragraph 4.1. The results from work package 1 are biorefinery type specific and the results from workpackage 4 are both region and biorefinery type specific. These results will be presented in paragraph 4.2.

4.1 Results from industry and consumer survey and political opinion (WP2 & WP3)

Figure 17 shows the data from work packages 2 and 3. The data are not region or biorefinery type specific.

Label	Issue
1	Promising concept
2	Economical potential
3	Implementable
4	Interesting markets
5	Fits into regulations
6	Economical barriers
7	Political/legal barriers
8	Technological barriers
9	Other barriers
10	Feedstock/raw material problems
11	Plant/mill/manufacturing problems
12	Problems with market conditions
13	General attitude
14	Biorefineries are eco-friendly
15	Technical materials
16	Birefineries are odourless
17	Willingness to pay
18	Stakeholder opinion
19	CO_2 reduction
20	Security of supply
21	Food and feed competition
22	(Rural) economy

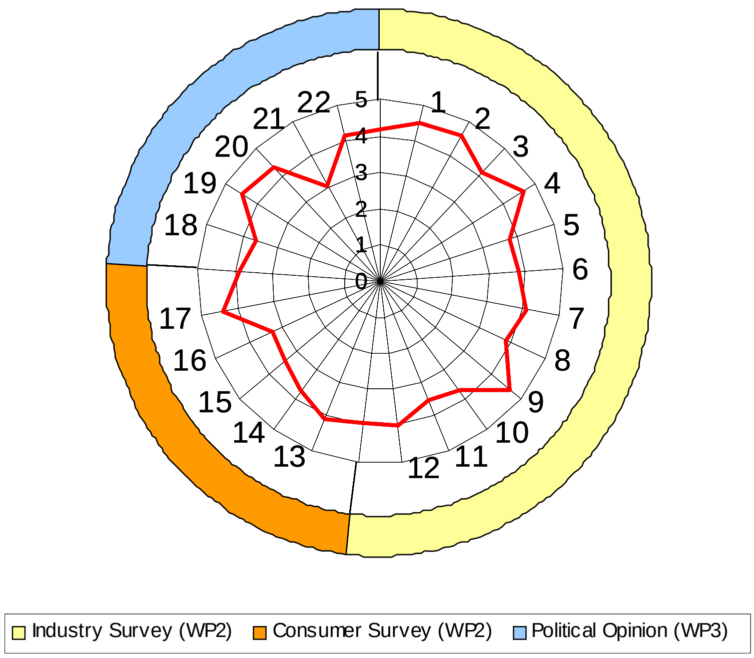

Figure 17. Likeliness score biorefinery establishment based on selected WP2 and WP3 parameters.

In general the establishment of biorefineries is considered to be likely by respondents from industry, consumers and policy makers (all scores are larger than 3). The issues with a relatively weak score are:

- Plant/mill/manufacturing problems (Technical Survey);
- (Presumed) air polution (Consumer Survey);
- Food and feed competition (Politicians Opinion).

4.2 Results from technical and economic evaluation and mapping (WP1 & WP4)

Figure 18 - Figure 21 show the data from work packages 1 and 4. The data from work package 1 were not specified for different regions, therefore the technical evaluation issues (1 – 4) in the spider diagram are labelled as indifferent for regions. However, differences per region do occur for the raw material evaluation issues and the side product market issues. These are indicated by region specific lines in the spider diagram.

4.2.1 Whole Crop Biorefinery (WCBR)

Label	Issue
1	Technical feasiblity
2	Captial costs not a problem
3	Feedstock costs not a problem
4	Technological improvement potential
5	Agricultural crops
6	Roundwood
7	Husbandry
8	Basic chemicals
9	Oil refineries

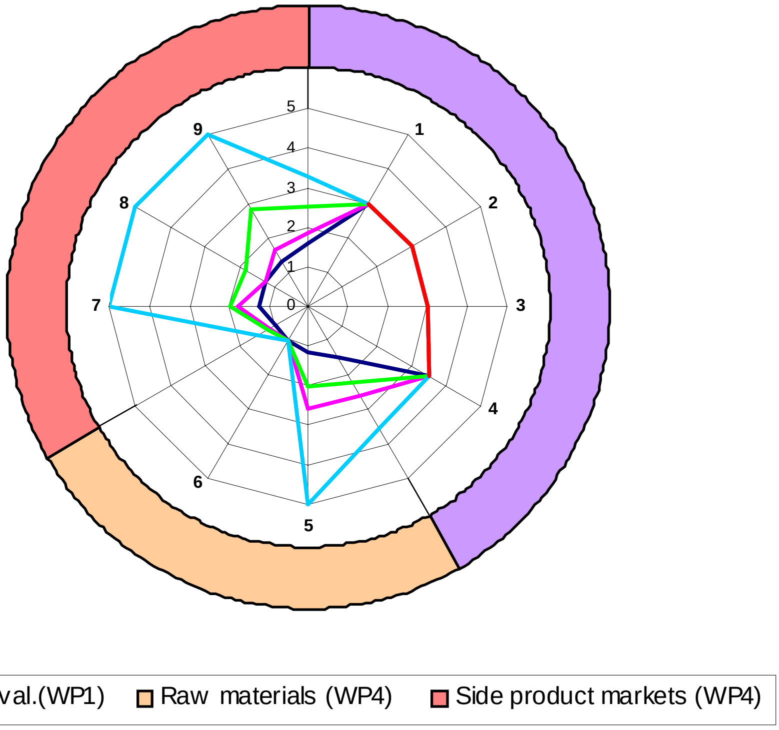

Figure 18. Likeliness score of whole crop biorefinery on selected WP1 and WP4 parameters.

Whole crop biorefineries are (in all aspects) most likely to develop in Western Europe (Figure 18). Eastern Europe has considerable potential to increase its agricultural output. After an increase of the agricultural yields, this region could probably provide sufficient raw materials for biorefinery establishment. The technical evaluation parameters are not optimal for the whole crop biorefinery. The technical feasibilty at the moment is insufficient (value=3) to allow immediate full scale establishment. Capital costs and feedstock costs are not expected to consititute a significant problem (value=3). Some potential for technical improvement can be seen (value=3.5)

4.2.2 Ligno Cellulosic Feedstock Biorefinery (LCBR)

Label	Issue
1	Technical feasiblity
2	Captial costs not a problem
3	Feedstock costs not a problem
4	Technological improvement potential
5	Agricultural crop residues
6	Roundwood
7	Husbandry
8	Basic chemicals
9	Oil refineries

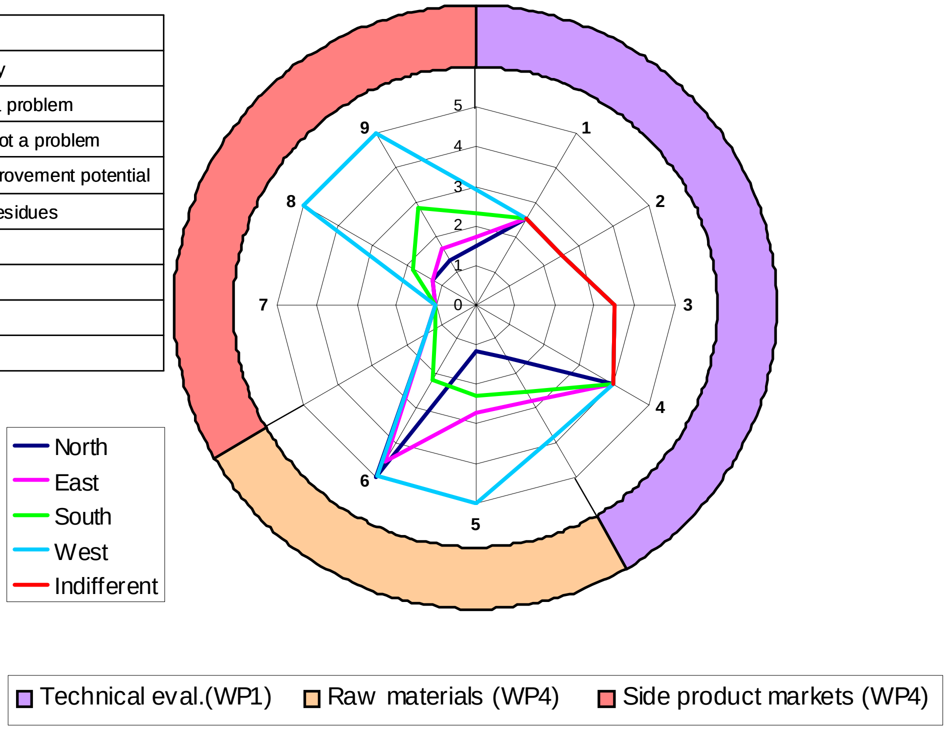

Figure 19. Likeliness score of lignocellulosic biorefinery on selected WP1 and WP4 parameters.

The establisment of lignocellulosic biorefineries is most likely in the West of Europe (Figure 19). The North of Europe has large amounts of wood, but little chemical industries and oil refineries to sell side products such as lignin and bark. The South and East have some amounts of raw materials (wood and straw) and also usefull side product markets. Especially in the East of Europe a considerable increase of agricultural yield (increasing the production of straw) is possible. Thus, this could become an increasingly important region of establishment of lignocelullosic biorefineries in the future. The relatively low technical feasibilty (value=2.5) prevents immediate lignocellulosic biorefinery establishment. The capital costs could be a problem (value=2.5), but the feedstock costs do not seem to be a problem (value=3.5). Also the technical improvement potential is high (value 4) and therefore, future establishment of lignocellulosic biorefineries is likely.

4.2.3 Green Biorefinery (GreenBR)

Label	Issue
1	Technical feasiblity
2	Captial costs not a problem
3	Feedstock costs not a problem
4	Technological improvement potential
5	Agricultural crops
6	Roundwood
7	Husbandry
8	Basic chemicals
9	Oil refineries

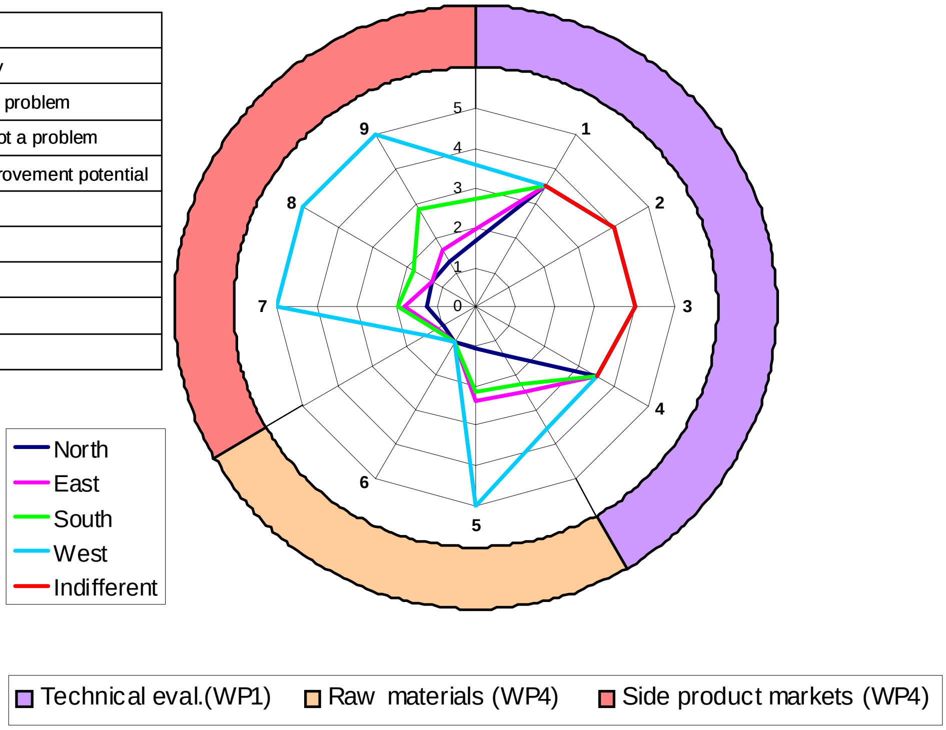

Figure 20. Likeliness score of Green biorefinery on selected WP1 and WP4 parameters.

Western Europe has large amounts of grass and large side product markets in the form of animal husbandry (possibly needing feed from side streams) (Figure 20). Western Europe also has high values for the presence of basic chemicals industry and oil refineries. The other regions are quite behind. The technical feasibility at the moment is rather high (value=3.5). Also the capital costs (value=4) and the feedstock costs (value=4) should not be a problem. Finally still some technical improvement potential appears (value=3.5).

4.2.4 Syngas Platform Biorefinery (SyngasBR)

Label	Issue
1	Technical feasiblity
2	Captial costs not a problem
3	Feedstock costs not a problem
4	Technological improvement potential
5	Agricultural crop residues
6	Roundwood
7	Husbandry
8	Basic chemicals
9	Oil refineries

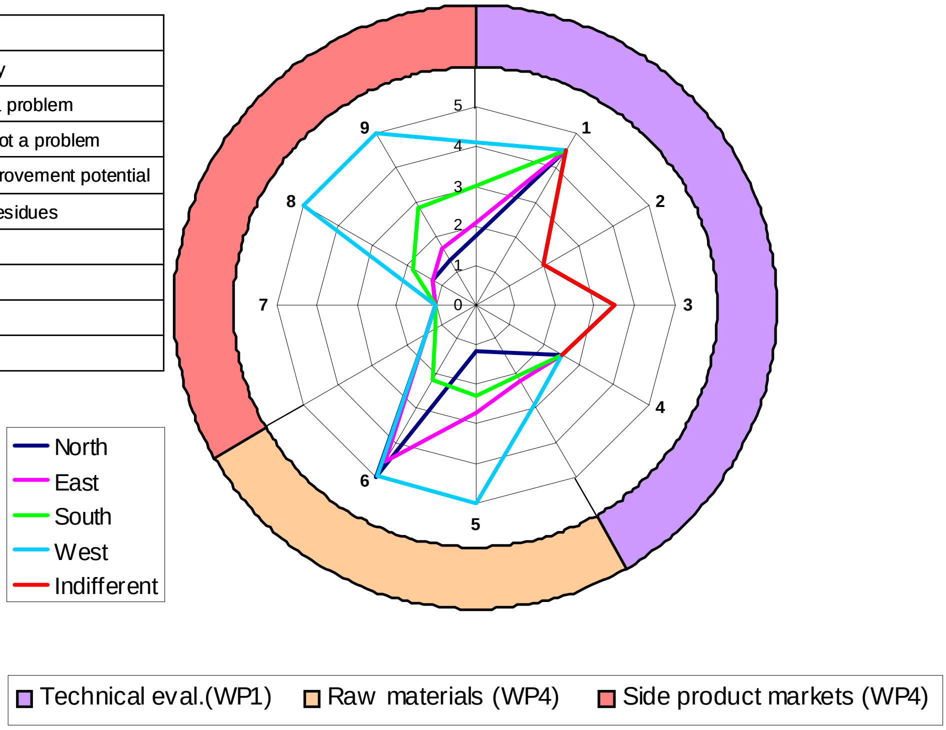

Figure 21. Likeliness score of Syngas biorefinery on selected WP1 and WP4 parameters.

The establisment of syngas biorefineries is most likely in the West of Europe (Figure 21). The North of Europe has large amounts of wood, but little chemical industries and oil refineries to sell side products such as lignin and bark. The South and Easth have considerable amounts of raw materials (wood straw) and also usefull side product markets. Especially in the East of Europe a considerable increase of agricultural yield (increasing the production of straw) is possible. If this region could also attract some chemical industries, it could become an increasingly important region of establishment of syngas biorefineries in the future. The technical feasibility of the syngas process is more or less proven (value=4.5). However, capital costs present a problem (value=2), the more because a very large scale facility will probably be required. In general feedstock costs should not be a problem (value=3.5), although the logistics should be taken care off. The technological improvement possibilities are not particularly high (value=2.5).

5 Revenues and costs of pilot and demo scale biorefineries

The concept of biorefineries is rather new and therefore there are no standard methods for cost calculation yet. Cost calculations for chemical processes are far better developed and biorefineries are more or less plants where chemical processes are executed. Therefore a cost calculation method from the chemical industry (Douglas, 1988) was used to estimate the costs of pilot, demonstration and full scale biorefineries. The costs were calculated for expansions of existing factories (alongside) and for building of new plants in a developed area (water, natural gas, and electricity connections are already available at the new site) (stand alone) (paragraph 5.1). The costs of pilot scale plants was also estimated from a research approach (paragraph 5.2). For numerous plants, information on the costs of biorefineries was found (paragraph 5.3). Conclusions are given in paragraph 5.4.

5.1 Cost calculation of demonstration and pilot scale plants

The fixed capital investment (FCI) of biorefineries is higher for new plants than for plants alongside existing plants because new plants cannot share facilities with the existing plant. The fixed capital investment is also depending on the scale of the new plant. The risk to exceed the budget is included in the FCI estimate as contingencies. This factor is higher for pilot scale plants (where start up trouble is part of the game) than for full scale plants (where the whole process is known and well understood).
In equation (1) the Fixed Capital Investment (FCI) is given as a function of inside battery limits costs (ISBL). The inside battery limit costs are the costs of the installed equipment of the new plant. The fixed capital investment also includes working capital, outside battery limits costs and utilities. The derivation of the numbers in this figure can be found in Appendix D.

$$\begin{array}{cc} \text{new} & \text{exp.} \end{array}$$
$$\text{FCI} = \begin{pmatrix} 2.25 & 2.03 \\ 1.95 & 1.76 \\ 1.88 & 1.69 \end{pmatrix} \text{ISBL} \quad \begin{array}{l} \text{pilot scale} \\ \text{demonstration scale} \\ \text{full scale} \end{array} \qquad (1)$$

Workpackage 5 should yield a method to calculate the costs of pilot and demonstration biorefineries. The costs of biorefineries will be the same as the negative income. The income is the revenues minus the costs. The costs are a function of fixed capital investment, raw material costs and utility costs. If the biorefinery is producing a reasonable amount of useful products, revenues could be generated. Below, the income of full scale, demonstration scale and pilot scale biorefineries will be elaborated. More detailed information can be found in Appendix D. If the interest rate is assumed to be 6%, the income can be calculated.

For full scale plants it is assumed that the plant life time is 10 years (dr=1/10). This yields the following income:

$$\text{Income} = 0.97\ \text{Rev} - 0.37\ \text{FCI} - 1.26\ \text{RMC} - 1.26\ \text{UC} \quad (2)$$

Where: Rev = Revenues
FCI = Fixed capital investment
RMC = Raw material costs
UC = Utility costs

For demonstration plants it can be assumed that the plant life time is 3 years (dr=1/3) and that the revenues are equal to the raw material costs (Rev = RMC + UC). This yields the following (negative) income:

$$\text{Income} = -0.67\ \text{FCI} - 0.29\ \text{RMC} - 0.29\ \text{UC} \quad (3)$$

For pilot plants, it can be assumed that the plant life time is 1 year (dr=1/1) and that the revenues are equal to zero (Rev = 0). This yields the following (negative) income:

$$\text{Income} = -1.5\ \text{FCI} - 1.26\ \text{RMC} - 1.26\ \text{UC} \quad (4)$$

To get some feeling for the above given equations, some typical values were filled in. A very large scale facility will process around 1 Mton of raw materials per year. A small full scale facility will process 100 kton/yr. A demonstration scale plant will process 10 kton/yr and a pilot plant might have a capacity of 1 kton/yr, but could also be much smaller. The raw materials will cost around 100 €/ton. The utility costs will be around 10% of the raw material costs. The investment will be around 100 M€ for a very large scale facility (60 M€ ISBL). The investment costs are assumed to depend on scale according to Equation 5 (paragraph 5.3) with M=0.8. Based on these results, the following tables were generated.

Table 20. Capacity and FCI of typical biorefinery.

Scale	Capacity (kton/year)	FCI (M€)
Pilot	1	0.48
Demo	10	2.6
Large Scale	100	16
Very large scale	1000	100

Table 21. Costs and revenues of typical biorefinery.

Scale	Cap depr (M€/yr)	RMC (M€/yr)	Other (M€/yr)	Total costs (M€/yr)	Reve nues (M€/yr)	Income (M€/yr)	Years (yr)	Total (M€)
Pilot	0.48	0.1	0.28	0.86	0.00	-0.86	1	-0.86
Demo	0.87	1	1.3	3.2	1.1	-2.1	3	-6.2
Large Scale	1.6	10	9	21	30	9.4	10	94
Very large scale	10	100	75	185	300	115	10	1154

The last column in Table 21 gives the expected revenues or costs (negative numbers) of pilot, demo and full scale biorefineries.

5.2 Alternative approach to estimate pilot plants costs

The economics of pilot plants are very different from the economics of full scale plants. Therefore the approach followed in paragraph 5.1 will be less suitable for cost calculation of pilot plants. A pilot plant might also be seen as a research project with ditto cost calculations. A research project has usually 0.5 till 5 full time researchers and 0.25 till 2.5 full time assistants. The full costs of a researcher is around 1680 hr/yr times 120 €/hr = 202 k€/yr. The full cost of an assistant is around 1680 hr/yr times 90 €/hr = 151 k€/yr. The costs to build a pilot plant can range from 100 to 1000 k€. Materials will range from 10 to 100 k€. From this reasoning the total cost of pilot scale research are given in Table 22.

Table 22. Range of pilot plant costs (research project approach) in k€.

	From:	To:
Researcher	101	1010
Assistant	38	380
Pilot plant	100	1000
Materials	10	100
Total	249	2490

The costs calculated with this approach are much higher than with the approach followed in paragraph 5.1: the total costs is 2.5 times FCI instead of 1.5 times FCI. This can be explained from the different points of view: method 1 has a focus on running a chemical plant (research costs are not included), method 2 has a focus on research activities (plant design included with research labor; not with FCI).
The indicated problems for pilot plants will also (to a lesser extent) apply to demonstration plant cost calculations. These problems can be overcome by a good estimation of labor costs (instead of 10% of total costs as was assumed in Appendix D) and adaptation of some of the factors in the calculation (more and higher educated staff will be needed to run a demonstration plant than to run a full scale plant).

5.3 Real world pilots and demos

As an alternative approach it was tried to find investment costs of pilot and demo biorefineries that have been or are planned to be built in the near future. Nearly all the cellulosic ethanol plants are built in the USA. The whole crop and green biorefineries are mostly built in Europe. The investment data were largely taken from press releases. Therefore it is often unclear which costs are included in these figures (plant costs, outside battery limits costs, research costs). Even operational costs of a pilot or demo scale biorefinery could be seen as investment costs (the plant is usually not built to make any profit). Especially in the USA the investments tend to be very large. Partially this is due to the fact that lignocellulosic plants need large capital investments. Another factor might be the very high subsidy grants that were recently given by the DOE. Table 23 gives an overview of the pilot and demonstration plants including locations, type, estimated costs, and capacity.

Table 23 shows that the investment costs of pilot and demo scale biorefineries reach up to over 200 M€. The largest demo plant is even larger than some full scale plants. The investment costs of whole crop biorefineries seem to be comparable to cellulosic plants (Figure 22). This is not the case however: cellulosic ethanol plants have only one valuable product, whereas whole crop biorefineries have several valuable products. Therefore the capital costs of the whole crop biorefinery should be attributed to all the products and not only ethanol.

The investment costs of green biorefineries and their specific investment is given per volume of input capacity (Plants 1 to 5). That is why they are grouped in the lower part of the diagram.

The scale of the plants is not related to the previously given classification, but it is taken as such from the source of information.

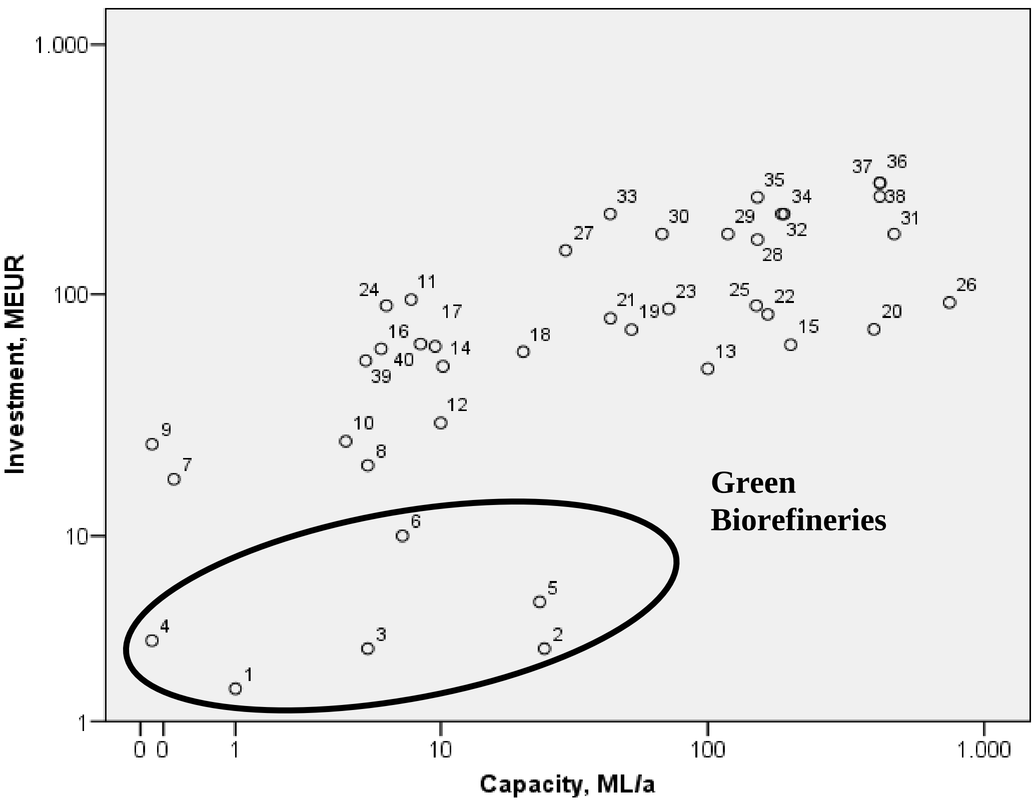

Figure 22. Investment costs as function of production capacity for given biorefineries. Numbers on the figure correspond to the numbers in Table 17.

Table 23. Worldwide biorefineries overview.

Nr.	Owner	Capacity [Mliter/yr]	Investment [MEUR]	Spec. Inv. [EUR.yr/L]	Scale	Setup	Process	Feed	Location
1	Energie AG	1.0	1.7	1.7	demo			grass	Aus
2	Biowert Industrie	25	2.9	0.1	demo		products	green	Ge
3	Biowert Industrie	5.0	2.9	0.6	demo		products	green	Ge
4	Leibniz institut	0.01	3.2	320	pilot		lactic acid	rye	Ge
5	Biopos	24	5.0	0.2	demo		products	green	Ge
6	Icelandic biomass company	7.0	10	1.4	pilot		bioethanol	cellulosic	Ic
7	Coskata	0.15	17.5	116	demo		ethanol	cellulosic	USA
8	BioAmber	5.0	20	4	demo				Fr
9	Abengoa	0.0011	24.5	21377	pilot	alongside	ethanol		USA
10	Marathon/ Syntroleum	4.0	25.2	6.3	demo		GTL		USA
11	Mascoma	7.6	95.2	12.6	demo		ethanol	cellulosic	USA
12	BornBioFuel	10	30	3	pilot		ethanol	cellulosic	De
13	Greenmills	100	50	0.5	full scale		bioethanol		NL
14	Pacific Ethanol	10	51.1	5	demo	alongside	ethanol	lignocellulosic	USA
15	Rotie	200	62.5	0.3	full scale		bioethanol	waste	NL
16	ICM	5.7	60.2	10.6	pilot	alongside	ethanol	residues	USA
17	Lignol Innovations	9.5	61.6	6.5	pilot				USA
18	Stora Enso	21	58.6	2.8	demo		GTL		USA
19	Alico	53	72	1.4	pilot		ethanol	waste	USA
20	WHEB	400	72.2	0.2	full scale		biodiesel		NL
21	IBUS	44	80	1.8	pilot		ethanol	cellulosic	De
22	Bioro	165	83	0.5	full scale		biodiesel	rapeseed	Be
23	Bluefire	72	87.3	1.2	demo		ethanol		USA
24	Roquette	6.0	90	15	demo		products	wheat/green	Fr
25	Greenmills	150	90	0.6	full scale		biodiesel		
26	Cargill	750	92.6	0.1	full scale		products	wheat	UK
27	Nedalco	30	150	5.0	demo		bioethanol	cellulosic	NL
28	Range Fuels	151	166	5.9	full scale		ethanol		USA
29	Broin	118	175	1.5	full scale	alongside	ethanol		USA
30	Iogen	68	175	2.6	demo		ethanol	cellulosic	USA
31	Poet	473	175	0.4	full scale		ethanol	lignocellulosic	USA
32	Abengoa	185	210	1.1	full scale		ethanol		USA
33	Abengoa	44	210	4.8	pilot	alongside	ethanol	cellulosic	USA
34	SotA cellulosic	189	210	6	full scale		ethanol		
35	Iogen	151	245	1.6	full scale		ethanol		USA/Can
36	BF, BP and Dupont	420	247	0.6	full scale		bioethanol		UK
37	BP	420	280	0.7	full scale	alongside	ethanol	wheat	UK
38	UK	420	280	0.7	full scale		ethanol		
39	Ecofin LLC	4.9	53.9	11	pilot		ethanol	lignocellulosic	USA
40	RSE Pulp	8.3	63	7.6	pilot		ethanol	cellulosic	USA

* Scale as indicated by literature sources (Abengoa 2007, BP 2008, Cellulosic head quarters 2008, DOE 2007, E-wire 2008, Fehrenbacher 2008, Green car congress 2008, Hasan 2008, KnowledgeNow 2007, Vicenzo 2008, Michigan Economic Development Corporation, WP4 BioPol 2009, Mapping EuroView 2009).

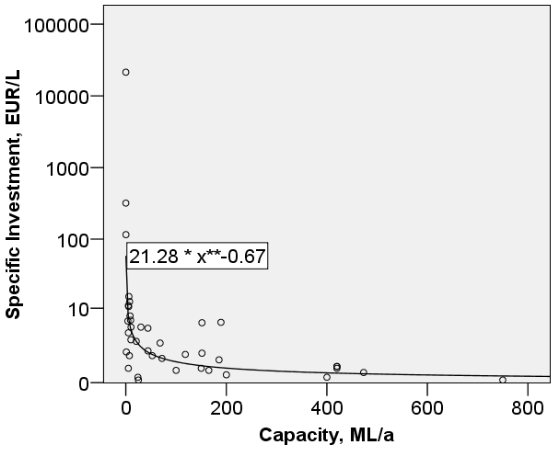

Figure 19. **Specific investment as a function of design capacity for worldwide biorefineries (X). R^2=0.712**

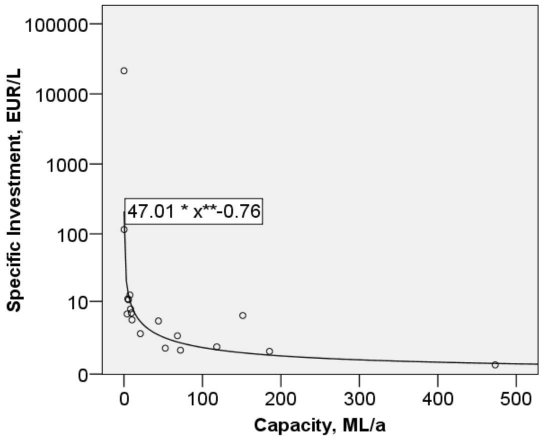

Figure 20. **Specific investment as a function of design capacity for US-based biorefineries (X). R^2=0.927**

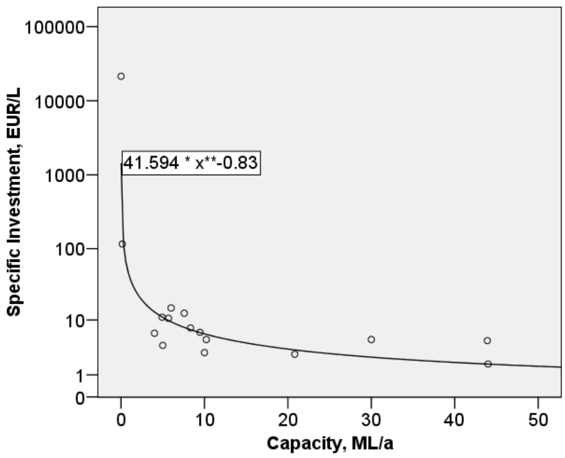

Figure 21. **Specific investment as a function of design capacity for worldwide small-scale* biorefineries (X). R^2=0.936**

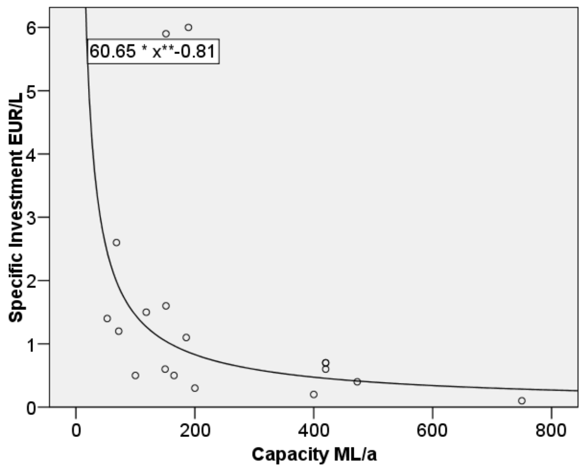

Figure 22. **Specific investment as a function of design capacity for demonstration and large-scale* biorefineries (X). R^2=0.332**

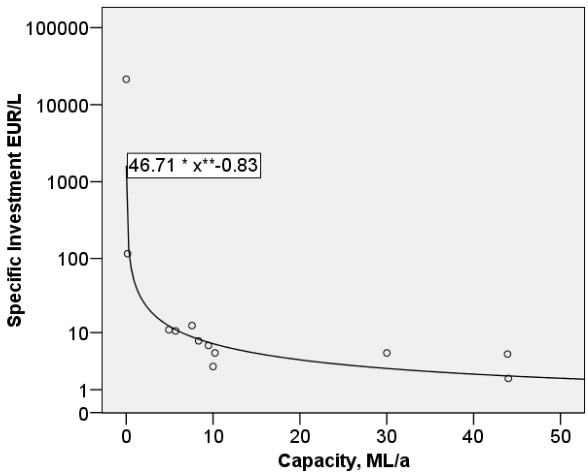

Figure 23. **Specific investment as a function of design capacity for ethanol producing small-scale* biorefineries (X). R^2=0.961**

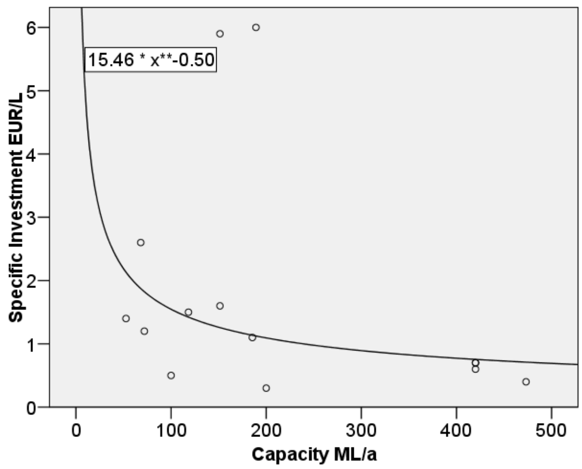

Figure 24. **Specific investment as a function of design capacity for ethanol-producing large-scale* biorefineries (X). R^2=0.360**

*** Plants producing less than 50ML/a were considered to be small-scale, all others were considered to be large-scale.**

Figure 19 – 24 show the specific investment (per liter of design capacity) for worldwide biorefineries as a function of the corresponding design capacity. A fit with a power function was found to give the best correlations. It is seen that the quality of the fit varies considerably (from $r^2 = 0.33$ in Figure 22 till 0.961 in Figure 23). US-based facilities show good correlation (Figure 20), much better than outside of US facilities. This is expected due to diverse financial systems in countries analyzed and different special systems of subsidies in different countries. Small-scale biorefineries (Figure 21) correlate much better than large-scale biorefineries (Figure 22), which might at the first sight look rather unusual. As a matter of fact large-scale (demonstration and full-scale) biorefineries show hardly any correlation at all. This can be explained by the fact that the very different types are present in the group of large scale plants: beside ethanol-based plants also biodiesel, BTL, or biochemical oriented plants are considered, with significantly different investments. On the other hand the costs of the pilot facilities are more influenced by the type of analytic equipment and the labor cost, which is irrespective of the type of technology.
A very good correlation is found if all other technologies are excluded and only ethanol producing pilot plants are analyzed (Figure 23). The correlation is still bad for large scale ethanol facilities (Figure 24).

One of the widely used methods for rough estimation of the plant investment is the so called “six-tenth rule” (Williams, 1947). This is a very easy way for fast calculation of the plant investment, based on the costs of earlier projects using the same (similar) manufacturing process. Equation (5) shows this relation:

$$PlantInvestment = BaseInvestment \cdot \left(\frac{PlantCapacity}{BaseCapacity} \right)^M \qquad (5)$$

Where, for (petro)chemical plants, M usually is in the range from 0.4 to 0.8.

The error of this equation is probably larger than ±30%, but since nothing better is available, this method is often used in the early stage of design. The power curve fit that gave the best fitting results in Figure 19 – 24 can be rewritten to yield this same equation:

$$PI = BI \cdot \left(\frac{PC}{BC} \right)^M \text{ (Six-tenth rule equation)} \qquad (6)$$

Where: PI is Plant investment (to be estimated),
BI is Base investment (known investment),
PC is Plant capacity (to be estimated),
BC is base capacity (known capacity) and
M is the scale coefficient.

This equation could be transformed into:

$$\frac{PI}{PC} = \frac{BI}{BC^M} \cdot PC^{M-1}, \text{ which is equivalent to } SI = K \cdot PC^N \qquad (7)$$

Where SI is Specific investment per volume of capacity,
K is BI/BC^M and
N is M-1.

The best fits (Figures 19, 20, 21 and 23) have a value of N ranging from -0.83 till -0.67. Thus, M (N+1) ranges from 0.17 to 0.33. This range is much lower than usually found for (petro)chemical plants. This implies that the increase in the design capacity doesn't increase investment in the biorefinery as much as in the (petro)chemical plant. Doubling the capacity of the biorefinery increases the investment for a factor 1.2 (for M=0.25) in contrast with the increase of 1.5 for (petro)chemical plants. In other words investment per liter of design capacity is decreasing faster with increasing the capacity of the plant in case of biorefineries, than in case of (petro)chemical plants.
The very low value of M could be explained by one very important difference between petrochemical and biorefinery industry: petrochemical plants use continuous processes, whereas biorefineries also have batch processes (fermentation, pretreatment) etc. During scale up by a factor of 2, the number of fermentors will simply double (M = 1), but if the fermentors are running successively, the volume of the buffer tanks would not need to increase at all (M = 0). This will also hold for all the solids handling at the beginning of the plant: it is far more efficient to load several fermentation tanks successively with one operator in one shovel, than to load only one fermentation per day and then change jobs to fulfill other tasks.
It is difficult to assess validity of this statement especially because of the level of development in the biorefinery area and the fact that emerging biobased economy is heavily subsidized. Most of all, accuracy of the gathered data is doubtful, since none of the plants is finished and therefore the investments in the table are only predictions.

5.4 Conclusions cost calculations

The income of full scale plants can be estimated from the revenues, the fixed capital investment, the costs of raw materials and the costs of utilities.
The costs of pilot plant can be estimated from a chemical plant point of view and from a research point of view. Most probably the research point of view is better.
The costs of demonstration plants can be estimated from the fixed capital investment, the costs of raw materials and the costs of utilities. Adaptation will be needed to account for higher labor costs.
The real world pilots and demos show a huge spread of investment costs ranging from 3 to 200 M€. The investment costs increase within increasing scale, but the scale factor (M) is far lower than usually observed in the petrochemical industry (0.25 instead of 0.6).
This difference might be explained by the fact that large scale processes (with several fermentaters in consecutive configurations) will resemble a continuous process, allowing a more or less continuous upstream and down stream processing without large buffer vessels.
Especially in the USA, facilities that are indicated (by the owner) as pilot or demo scale can be very large (in fact equally large as normal full scale plants).

6 Conclusions and recommendations

6.1 Conclusions

Technical and economical evaluation

- The lignocellulosic biorefinery has a relatively low technical feasibility at the moment: there is proof of principle, but further development of the technology still has to take place. The syngas biorefinery is ready for full scale implementation. Both the green biorefinery and the whole crop biorefinery are ready for demonstrations.
- The syngas biorefinery has high capital costs due to a required large scale of implementation. The green biorefinery on the other hand requires relatively simple equipment, so capital costs are much lower. The lignocellulosic biorefinery and the whole crop biorefinery have intermediate capital costs compared to the other two types.
- The syngas biorefinery and lignocellulosic biorefinery that use wood residues and straw have relatively cheap feedstocks. However, specially grown wood will be far more expensive. The feedstock will usually be a mix of these two. The feedstocks for the whole crop biorefineries are slightly less expensive because residues, that were previously underutilized, are now used. Finally, grass for the green biorefinery is easily grown and has a very high yield. Therefore this feedstock can be relatively cheap.
- Not much technological improvement is expected for the syngas biorefinery since the yield is already very high, the residence time is very short and FT-technology is well developed: little improvement expected. The lignocellulosic biorefinery has plenty of room still for improvement of the technology. The technology of the green biorefinery is still new, and improvements are still to be expected. In the whole crop biorefinery half of the crop (e.g. wheat) is already processed very efficiently (so hardly any improvement is expected), but half of the crop (straw) goes through lignocellulosic biorefinery with high improvement opportunities.

Evaluation by industry and consumers

- The market acceptance of biorefinery concepts in industry is of crucial importance to the establishment of biorefineries. Without investments from the industry, no establishment will occur.
- The market acceptance of biorefineries by industry is generally very good. However, industry experiences some problems with existing regulations.
- Generally, no large barriers are seen by the majority of respondents from industry. The respondents see slightly larger barriers from economic and technological issues, but still these are only minor.
- Little disadvantages or problems were indicated by the respondents from industry. The issues feedstock/raw material and plant/mill/manufacturing are indicated as only slightly more negative than market conditions. However, none of the issues are considered to be a real problem.
- Consumers have to be willing to pay for the products from biorefineries. They should acknowledge the benefits of the new technology. This will at least mean that they do not see threats from the technology.

- The general consumer attitude and acceptance of biorefineries was positive.
- The consumers are also positive on the issues ‘biorefineries are eco-friendly’, ‘it is positive that agricultural products are also used for technical raw materials’ and ‘biorefineries are odourless (do not smell and poison the air)’
- Some 85% of the consumers is willing to pay equal or more to get renewable products. This clearly shows that most people do not feel any objections to buy renewable products.

Political evaluation

- The opinion of policy makers on advanced biorefineries is better than on current biofuel production facilities on all aspects. In general, their opinion on biofuel production facilities is positive with respect to CO_2 reduction and security of supply issues. The food/feed competition is seen as a mildly negative aspect of current biofuel production facilities, but it is seen as a neutral aspect with advanced biofuel and bioproduct facilities.
- Some reputational and general acceptance issues, such as ‘GMO’, ‘competition with food’, ‘competition with forestry’ and ‘deforestation in the rest of the world’ showed relatively low scores. This indicates that all these issues could be potential barriers to the development and implementation of biorefineries according to the respondents from policy. Especially the competition for food could form a potential barrier.

Mapping of existing biorefineries and establishment factors

- The possible establishment of new biorefineries in a certain region will depend on numerous establishment factors such as land use in surrounding area, presence of animal husbandry, presence of oil refineries and chemical industry and transport possibilities.
- Based on the absolute establishment factors Western Europe has very good prospects for all types of biorefinery. One might have expected that lignocellulosic and syngas biorefineries would have good opportunities mainly in Northern Europe, but he development of straw based biorefineries might cause a huge shift to countries with high straw availability (France and Germany). Eastern Europe could increase its agricultural yields and therewith increase the development potential of biorefineries. Such an increase of agricultural productivity is less likely in the South of Europe, where shortage of water for irrigation is a main reason for the lower agricultural yields. Some potential for development of lignocellulosic and syngas biorefineries is present in the North of Europe.
- The use of establishment factors per Mha yields a more nuanced view on the likeliness of biorefinery establishment, where also smaller countries have (very) good opportunities for biorefinery establishment. Besides the large countries like France and Germany, also smaller countries have opportunities for biorefinery establishment, such as Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, Hungary, Ireland, Latvia, The Netherlands, Slovak Republic, Slovenia, Sweden and the United Kingdom. Of course differences can be seen between the likeliness of the four biorefinery types per country, depending on the specific regional circumstances.
- Whole crop biorefinery will develop in traditional areas of wheat, potato or sugar beet production (France and Germany) and near harbours and where feed is needed (Belgium and The Netherlands). Wheat is more easily transported over large distances than potatoes and sugar beets (which have far larger water content). Therefore, wheat is more likely to be processed in harbour areas such as Rotterdam and Antwerp and potatoes and sugar beets are more likely to be processed in the area where they are

grown. The analysis shows opportunities for whole crop biorefinery in Belgium, Czech Republic, Denmark, France, Germany, Hungary, The Netherlands and the United Kingdom.

- Lignocellulosic biorefinery will mainly develop in straw regions (e.g. France and Germany) and in wood regions (like Sweden and Finland). Lignocellulosic biorefineries might also develop in countries with large harbours that can import lignocellulosic feedstocks and countries with well developed oil refineries and base chemical production sites (like The Netherlands and Belgium). The likeliness of lignocellulosic biorefinery in the analysis is high in Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Latvia, The Netherlands, Slovak Republic, Slovenia and Sweden.
- Green biorefinery will develop in regions where grass and clover are produced (wet agricultural land) and where feed for animals is needed. These areas can be found in the whole of Europe, but mostly in Western Europe. Countries that show high opportunities for green biorefinery in the analysis are Belgium, France, Germany, Ireland, The Netherlands and the United Kingdom.
- Syngas biorefinery will preferentially develop in an area with large availability of lignocellulosic raw materials (wood or straw), harbours (supply of feedstocks) and traditional oil refineries and base chemical production (to further process the synthesis gas). The transport of lignocellulosic raw material is relatively easy (no decay) and therefore, syngas biorefinery might also develop in regions with less lignocellulosic biomass, but better harbour facilities. Syngas biorefineries have high chances of development according to the analysis in the countries Austria, Belgium, Czech Republic, Estonia, Finland, France, Germany, Hungary, The Netherlands, Slovak Republic, Sweden and the United Kingdom.

Combining the results

- Some improvement is possible on the following issues ($3 \leq$ score < 4): Fits well into regulations; Economic issues; Technological issues; Feedstock/raw material problems; Plant/mill/manufacturing problems; Biorefineries are eco-friendly; It is positive that agricultural products are also used for technical raw materials; Biorefineries are odourless; Political stakeholder opinion; Food and feed competition.
- Western Europe has the best prospects for biorefinery development. It has: high agricultural yields, vast amounts of ligno-cellulosic agricultural side streams and good possibilities to sell biorefinery side products
- The countries in the East of Europe have opportunities to improve agricultural yields.
- Northern Europe is currently a natural market leader of lignocellulosic biorefinery due to the presence of large forests.

Cost calculations

- The income of full scale plants can be estimated from the revenues, the fixed capital investment, the costs of raw materials and the costs of utilities.
- The costs of pilot plant can be estimated from a chemical plant point of view and from a research point of view. Most probably the research point of view is better.
- The costs of demonstration plants can be estimated from the fixed capital investment, the costs of raw materials and the costs of utilities. Adaptation will be needed to account for higher labor costs.
- The real world pilots and demos show a huge spread of investment costs ranging from 3 to 200 M€. The investment costs increase within increasing scale, but the scale factor (M) is far lower than usually observed in the petrochemical industry (0.25

instead of 0.6). This difference might be explained by the fact that large scale processes (with several fermentaters in consecutive configurations) will resemble a continuous process, allowing a more or less continuous upstream and down stream processing without large buffer vessels.
- Especially in the USA, pilot and demo plants can be very large (in fact equally large as normal full scale plants).
- The costs of pilot and demo scale biorefineries can vary tremendously. It seems that the size of subsidies dictates the size of the costs for pilot and demo scale projects.

6.2 Recommendations

The analysis in this report was of a general nature due to the available data. Therefore, country specific conclusions are only an indication of possible opportunities. Per country these conclusions should be further validated, based on more detailed specific data.

Some general recommendations can be made:
- Improve regulations
- Improve profitability (cut costs, increase revenues)
- Solve technological issues
- Improve image of biorefineries
- Tackle food and feed issue

It the last two issues are tackled, it is expected that the negative opinion of some political stakeholders will also change.

The North of Europe could attract more chemical industry to increase the efficiency of their lignocellulosic biorefineries. This way, the presence of lignocellulosic biorefineries could become an establishment factor for the chemical industry instead of the other way around.

Denmark is traditionally seen as a part of Northern Europe. From a climatological perspective however, it is much more similar to the countries of Western Europe than to the other Northern countries.

The size of harbours was mapped, but the data that were found were not adequate as establishment factors. The largest harbours (Rotterdam, Antwerp) are far larger than the pulp harbours in Sweden and Finland. Therefore, these harbours were not found in the statistics that were consulted. So harbour size should be made suitable as an establishment factor for biorefineries in the current methodology. Therefore, at least the location and size of smaller harbours should also be added to the available data list. It is also recommended to only account for biomass related cargo, instead of the total tranported volume. Only biomass streams will influence the attractiveness of harbours for biorefinery establishment.

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Appendix A Processing of data from WP 2

Data processing of paragraph 3.2.1

Propositions
The following propositions from the questionnaire were assumed relevant to the future prospects of biorefineries:

Biorefinery

- is a promising concept
- makes good economic sense
- is implementable
- offers interesting markets
- fits well in existing regulations

The respondents were asked to rate these statements with “I fully agree”, “I agree”, “I don’t agree”, “I fully disagree”, “I don’t know”. The respondents answering “I fully agree” or “I agree” were seen as positive respondents. The percentage of positive respondents was calculated from the data provided from work package 2 as seen in Table 24 column 2 using Equation 1. In column 3 this percentage is scaled to a 1 to 5 scale, where 1 corresponds to 0% and 5 corresponds to 100%.

Equation 1

$$Score = \frac{\%\_I\_agree + \%\_I\_fully\_agree}{100\%} \cdot 4 + 1$$

Table 24, positive scores of respondents on statements as inquired by work package 2

	0-100 scale	1 to 5 scale
Is promising concept	86	4.5
Makes good economic sense	90	4.6
Is implementable	77	4.1
Offers interesting markets	91	4.6
Fits well in existing regulations	69	3.7

Barriers
The respondents were asked to indicate 11 issues where they foresee barriers. In order to cut down the number of issues, the barriers were grouped in economic issues (economic barriers, market conditions and negative opinion of stakeholders), political/legal issues (political framework, legal framework, environmental regulations), technological issues (technological barriers) and other issues (behaviour of clients, qualification /knowledge of staff, co-operations of the actors/knowledge transfer).

The scores were calculated by adding the number of respondents that indicated the issue as important (number of tics) divided by the total number of respondents (Equation 2). These scores were averaged if more than one item was evaluated into one parameter. Thereafter the score was calculated to a 1 to 5 range. The result is shown in Paragraph 3.2.1, Table 5.

Equation 2

$$Score = \frac{\sum_{i=1}^{n} \frac{Number\_of\_tics_i}{Number\_of\_respondents_i}}{n} \cdot 4 + 1$$

Where n is the number of items averaged into one parameter.

Appendix B Processing of data from WP 3

In this appendix, the derivation of Table 10 and Table 11 presented in paragraph 3.3 will be shown.

Political opinion on current biofuel and advanced biofuel and bioproduct facilities (Paragraph 3.3, Table 10)
The political opinion on current and future biorefineries was derived from data that were collected in workpackage 3. From the percieved opinion of stakeholders and the credibility of these stakeholders the rated stakeholder opinion was calculated. Several other issues were simply grouped and scaled. The Swedish, Dutch and UK surveys were weight averaged to generate
Only the data from the Swedish survey are shown here; the Dutch and UK surveys were treated analogously.

Influence of stakeholder opinion
The calculations start from the opinion of stakeholders on first generation biorefineries as perceived by Swedish politicians (Table 25) and the credibility of these stakeholders according to the Swedish politicians (Table 26). The influence of opinion on the Swedish politicians (Table 27) was then calculated from these data by weighing the perceived opinions of stakeholders (Table 25), with the credibility of the respective stakeholders (Table 26) according to Equation 3. In this equation, the data of Table 25 are first. ISO is the rated opinion of politicians (Table 27), C is the credibility of stakeholders (Table 25 scaled to a -2 to +2 scale) and OS is the perceived opinion of stakeholders (Table 26).

Equation 3

$$ISO_{i,j} = \left(C_{i,j} - 3\right) \cdot OS_{i,j}$$

The results were then averaged (Table 27, column 13) and rescaled from a -10 to + 10 scale to a 1 to 5 scale (last column). The final result is then averaged to the figure in the lower right corner (marked in *italics*), which is seen in the second row and second collumn of Table 32.

Table 25, Opinion of several stakeholders on current biofuel production facilities as perceived by the Swedish politicians

Respondent	Multi-national Agencies (e.g. UN)	EU Agencies	Your National Government Agencies	Regional Development Agencies	Local Government	Private Industry	Industry Associations	Mass Media	Educational Institutions	NGOs	Research Institutes/Networks
1	2		3			4		2		4	
2											
3											
4	2	4	5	4	4	4	4	4	4	2	4
5	4	4	5	5		3	2	3	4	4	3
6	1	5	3	5	5	5				1	5
7			4	3	4			2	3	1	3
8											
9											
10	2	4	3			4	4	2	3	2	3
11											
12	1	1	1			4	2	2	3		
13	1	4	4	4	4	4	4	4	3	4	3
14											
15	4	5	3			5	4	4			4
16											
17	4	4	4		4	4	2	3	3	2	3
18											
19											
20	4	4	4	4	4	3	3	2	3	2	3
21											
22	5		5	5	4	3	3	5	4	4	4

Table 26, Credibility of several stakeholders according to Swedish politicians

Respondent	Multi-national Agencies (e.g. UN)	EU Agencies	Your National Government Agencies	Regional Development Agencies	Local Government	Private Industry	Trade/Industry Associations	Mass Media	Educational Institutions	NGOs	Research Institutes/Networks
1						3	4	4		3	
2											
3											
4	3	4	5	3	3	4	3	4	3	2	4
5	3	4	5	3		3	3	4	4	4	5
6	4	4		4	2	4		4	3	5	3
7	5	5	5	3	2	1	1	5	5	4	5
8											
9											
10	4	3	4			1	2	2	3	2	3
11											
12	5	5	4	4		5	5	4	2		2
13	5	3	3	3	3	3	3	4	2	2	3
14											
15	4	5	5			5		4		2	4
16											
17	4	4	4		3	3	3	3	2	2	2
18											
19											
20											
21											
22	3	4	4	5	5	3	3	2	3	3	3

Table 27, Influence of stakeholder opinion on current biofuel production facilities (Swedish politicians)

Respondent	Multi-national Agencies (e.g. UN)	EU Agencies	Your National Government Agencies	Regional Development Agencies	Local Government	Private Industry	Industry Associations	Mass Media	Educational Institutions	NGOs	Research Institutes/Networks	Averaged	Scaled
1						3		-4		3		0.7	3.1
2													
3													
4	-3	4	10	3	3	4	3	4	3	-2	4	3.0	3.6
5	3	4	10	6		0	-3	0	4	4	0	2.8	3.6
6	-8	8		8	4	8				-10	6	2.3	3.5
7			5	0	2			-5	0	-8	0	-0.9	2.8
8													
9													
10	-4	3	0			1	2	-2	0	-2	0	-0.2	3.0
11													
12	-10	-10	-8			5	-5	-4	0			-4.6	2.1
13	-10	3	3	3	3	3	3	4	0	2	0	1.3	3.3
14													
15	4	10	0			10		4			4	5.3	4.1
16													
17	4	4	4		3	3	-3	0	0	-2	0	1.3	3.3
18													
19													
20													
21													
22	6		8	10	5	0	0	4	3	3	3	4.2	3.8
count													6.0
average													*3.3*

The same was done for second advanced biofuel and bioproduct facilities by weighing Table 28 with Table 26 (Table 29).

Table 28, Opinion of several stakeholders on advanced biofuel and bioproduct facilities as perceived by the Swedish politicians

Respondent	Multi-national Agencies (e.g. UN)	EU Agencies	Your National Government Agencies	Regional Development Agencies	Local Government	Private Industry	Industry Associations	Mass Media	Educational Institutions	NGOs	Research Institutes/Networks
1		4	4	3	3	4	3	3			5
2											
3											
4	2	4	4	3	4	4	4	4	4	2	5
5	4	5	5	5		3	2	3	4	4	4
6	5	5	5		5	5	3	3			5
7	3	3	4					2	3	1	3
8											
9											
10	4	4	3			4	4	4	4	4	4
11											
12	5	5	5	5		4	5	4			4
13	3	4	4	4	4	4	4	4		2	3
14											
15	4	5	5			5		4			5
16											
17	4	4	4		4	4	2	3	3	4	3
18											
19											
20											
21											
22	2		3					3	4	4	4

Table 29, Influence of stakholder opinion on advanced biorefineries (Swedish politicians)

Respondent	Multi-national Agencies (e.g. UN)	EU Agencies	Your National Government Agencies	Regional Development Agencies	Local Government	Private Industry	Industry Associations	Mass Media	Educational Institutions	NGOs	Research Institutes/Networks	Averaged	Scaled
1						3	0	0				1.0	3.2
2													
3													
4	-3	4	5	0	3	4	3	4	3	-2	8	2.6	3.5
5	3	8	10	6		0	-3	0	4	4	5	3.7	3.7
6	8	8			4	8		0			6	5.7	4.1
7	0	0	5					-5	0	-8	0	-1.1	2.8
8													
9													
10	4	3	0			1	2	2	3	2	3	2.2	3.4
11													
12	10	10	8	8		5	10	4			2	7.1	4.4
13	0	3	3	3	3	3	3	4		-2	0	2.0	3.4
14													
15	4	10	10			10		4			8	7.7	4.5
16													
17	4	4	4		3	3	-3	0	0	2	0	1.7	3.3
18													
19													
20													
21													
22	-3		0					0	3	3	3	1.0	3.2
count													11
average													3.6

Other issues

In Table 30 and Table 31 the opinion of Swedish politicians on the other issues are given. The last rows show the results of the averaging process. At the bottom row the scores are calculated through weighted average of food and feed and rural development, farm income increase and employment.

Table 30, Opinion of Swedish politicians on impact of current biofuel production facilities on some key aspects

Respondent	CO2 Emission Reduction	Energy Security	Food Production	Feed Production	Rural Development	Increasing farm incomes	Employment
1	4	4	3	4	3	4	3
2	4						
3							
4	4	4	3	4	5	5	5
5	5	5	3	3	4	4	4
6	4	4	2	3	3		3
7	4	3	2	2	5	5	5
8							
9	4	3	2	2	2	4	4
10	2	4	4	2	4	5	3
11							
12	3	4	2	2	4	4	4
13	4	4	1	1	2	4	4
14							
15	3	4	1		3	3	3
16							
17	5	4	3	1	4	4	4
18							
19							
20	4	3	3	3	3	3	2
21							
22	5	4	2	1	5	5	5
count	14	13	13	12	13	12	13
average	3.9	3.8	2.4	2.3	3.6	4.2	3.8
score	3.9	3.8		2.4			3.8

Table 31, Opinion of Swedish politicians on impact of advanced bifuel and bioproduct facilities on some key aspects

Respondent	CO2 Emission Reduction	Energy Security	Food Production	Feed Production	Rural Development	Increasing farm incomes	Employment
1	5	5		3		4	
2							
3							
4	5	5	3	3	5	4	5
5	5	5	3	3	4	4	4
6	5	5	3	3	3	3	3
7	4	2	3	2	5	5	5
8							
9	4	4	2	2	4	4	4
10	5	4	4	4	4	3	3
11							
12	4	4	3	3	4	3	4
13	3	2	1	2	2	4	4
14							
15	5	5	2		4	3	2
16							
17	5	5	3	1	5	5	5
18							
19							
20	4	5	2	3	3	3	4
21							
22	5	5	3	1	5	5	5
count	13	13	12	12	12	13	12
average	4.5	4.3	2.7	2.5	4.0	3.8	4.0
score	4.5	4.3		2.6			3.9

Averaging

Finally the results from the Swedish, Dutch and UK survey are weight averaged as shown in Table 32, Averaging of Swedish, Dutch and UK surveys on current biofuel production facilities (weighted by number of respondents)Table 32 and Table 33. Data marked in **bold** end up in row 2 till 6 of Table 10.

Table 32, Averaging of Swedish, Dutch and UK surveys on current biofuel production facilities (weighted by number of respondents)

	Stakeholder opinion	Number of respondents	CO2 Emission Reduction	Number of respondents	Energy Security	Number of respondents	Food Production	Number of respondents	Feed Production	Number of respondents	Rural Development	Number of respondents	Increasing farm incomes	Number of respondents	Employment	Number of respondents
Se	*3.3*	6	3.9	14	3.8	13	2.4	13	2.3	12	3.6	13	4.2	12	3.8	13
NL	3.0	7	3.4	8	3.1	8	2.5	8	2.5	8	3.6	8	4.3	7	3.9	8
UK	3.2	12	3.4	13	3.9	14	2.6	14	2.5	14	3.9	14	4.2	13	4.1	13
Average	**3.1**	25	**3.6**	35	**3.7**	35	2.5	35	2.4	34	3.7	35	4.2	32	3.9	34
							Food/Feed				Rural economy					
Average							**2.5**				**3.9**					

Table 33, Averaging of Swedish, Dutch and UK surveys on advanced biofuel and bioproduct facilities (weighted by number of respondents)

	Stakeholder opinion	Number of respondents	CO2 Emission Reduction	Number of respondents	Energy Security	Number of respondents	Food Production	Number of respondents	Feed Production	Number of respondents	Rural Development	Number of respondents	Increasing farm incomes	Number of respondents	Employment	Number of respondents
Se	3.6	11	4.5	13	4.3	13	2.7	12	2.5	12	4.0	12	3.8	13	4.0	12
NL	3.3	7	4.4	8	4.3	8	3.4	8	3.5	8	4.1	8	4.3	8	4.1	8
UK	3.7	12	4.5	14	4.4	14	3.1	13	3.2	13	4.2	13	4.3	13	4.2	13
Average	**3.6**	30	**4.5**	35	**4.3**	35	3.0	33	3.0	33	4.1	33	4.1	34	4.1	33
							Food/Feed				Rural economy					
Average							**3.0**				**4.1**					

Political significance of reputation and acceptance issues (Paragraph 3.3, Table 11)
The respondents were asked whether they would consider some aspects of biorefineries a ‘Strong Barrier’, ‘Weak Barrier’, ‘Neutral’, ‘Weak driver’ or ‘Strong driver’. The results from the Swedish, Dutch and UK survey were added as shown in Table 34.

Table 34, Swedish, Dutch and UK opinion on issues regarding biorefinery

	GMO	compete for food	compete for forestry	deforestation
Strong barrier	19	20	6	16
Weak barrier	5	8	16	10
Neutral	4	0	5	1
Weak driver	0	2	4	1
Strong driver	4	2	1	3
Total ticks	32	32	32	31

These numbers were converted to fractions using Equation 4 and then a 1 to 5 score was assigned with Equation 5 as shown in Table 35.

Equation 4

$$F_{i,j} = \frac{Ticks_{i,j}}{Total\_ticks_i}$$

Equation 5

$$Score = \frac{F\_strong\_barrier \cdot 1 + F\_weak\_barrier \cdot 2 + F\_neutral \cdot 3 + F\_weak\_driver \cdot 4 + F\_strong\_driver \cdot 5}{F\_strong\_barrier + F\_weak\_barrier \cdot + F\_neutral + F\_weak\_driver + F\_strong\_driver}$$

Table 35, Calculation of 1 to 5 score based on Table 34

	Score	GMO	compete for food	compete for forestry	deforestation
Strong barrier	1	0.6	0.6	0.2	0.5
Weak barrier	2	0.3	0.5	1.0	0.6
Neutral	3	0.4	0.0	0.5	0.1
Weak driver	4	0.0	0.3	0.5	0.1
Strong driver	5	0.6	0.3	0.2	0.5
Score		**1.9**	**1.7**	**2.3**	**1.9**

Appendix C Processing of data from WP 4

Firstly, all data were converted to have allt the establishment factors in the same unit (ton DM/yr). Then the establisment factors were used to calculate the biorefinery likeliness (BL).

Establishment factors (EF)
The flow of the basic chemistry was recalculated to a mass flow assuming a product price of 2 €/kg. The crop data were recalculated to dry matter flow using the dry matter contents as shown in Table 36.

Table 36, Dry matter content of crops

Crop	Sugar beet	Wheat	Maize	Potato	Rapeseed	Roundwood
Dry matter	24%	90%	90%	25%	90%	58%

Milk and meat flows were recalculated to a feed dry matter consumption using the assumptions shown in Table 37.

Table 37, Milk and meat dry matter content and feed conversion factor

	Milk	Meat	Unit
DM content	12%	32%	
Feed conversion	0.5	0.33	ton product/ton feed

The calculated establishment factors (EF) are presented in Table 38 and Table 39.

Table 38, Agricultural crop production or crop demand from milk and meat production (Mton DM/yr)

	Sugar beet	Wheat	Maize	Potato	Rapeseed	Roundwood	Grass production	Feed for milk production	Feed for Meat production
AT	0.53	1.26	1.40	0.12	0.13	6.69	9.59	0.57	0.21
BE	1.15	1.33	0.54	0.58	0.03	1.93	4.88	0.68	0.26
BG	0.00	2.15	0.28	0.06	0.08	1.96	8.08	0.19	0.03
CY	0.00	0.01	0.00	0.03	0.00	0.00	0.01	0.03	0.00
CZ	0.52	3.56	0.55	0.16	0.93	6.33	4.33	0.57	0.08
DK	0.45	4.07	0.00	0.33	0.54	0.66	2.69	1.08	0.12
EE	0.00	0.29	0.00	0.03	0.12	4.18	0.52	0.15	0.01
FI	0.13	0.72	0.00	0.14	0.10	21.84	0.40	0.56	0.85
FR	6.47	29.90	11.80	1.25	4.10	14.19	60.52	5.48	1.45
DE	5.22	19.23	3.13	2.32	4.79	22.13	32.81	6.44	1.15
EL	0.17	1.26	1.59	0.17	0.01	0.62	11.69	0.18	0.06
HU	0.40	3.59	7.56	0.11	0.45	2.30	3.15	0.35	0.03
IC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IE	0.01	0.62	0.00	0.09	0.02	1.04	25.00	1.26	0.55
IT	0.93	6.53	8.90	0.37	0.01	3.53	17.41	2.38	1.07
LV	0.00	0.73	0.00	0.13	0.19	5.18	2.44	0.14	0.02
LT	0.16	1.25	0.02	0.12	0.28	2.48	1.97	0.31	0.05
LU	0.00	0.06	0.00	0.00	0.02	0.11	0.00	0.00	0.24
MT	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.04
NL	1.08	0.89	0.20	1.44	0.01	0.42	7.67	2.56	0.34
NO	0.00	0.34	0.00	0.08	0.01	3.56	0.63	0.00	0.00
PL	2.21	7.54	1.48	2.24	1.90	13.29	18.34	2.12	0.34
PT	0.06	0.12	0.58	0.13	0.00	4.69	4.49	0.44	0.10
RO	0.14	2.58	3.32	0.70	0.31	6.41	24.75	0.27	0.02
SK	0.17	1.30	0.61	0.08	0.30	2.94	4.33	0.23	0.02
SL	0.05	0.12	0.28	0.03	0.01	1.04	1.69	0.12	0.04
ES	1.03	5.74	3.28	0.50	0.03	6.61	23.49	1.38	0.64
SE	0.40	2.03	0.00	0.16	0.20	27.32	1.79	0.75	0.13
CH	0.32	0.51	0.17	0.10	0.06	1.91	5.20	0.00	0.00
UK	1.30	12.03	0.00	1.13	1.90	3.36	55.09	3.34	0.81

Table 39, Basic chemical production, oil refinery capacity and harbour capacity (Mton/yr)

	Basic chemicals	Oil refineries	Harbour
AT	1.48	9.40	0.00
BE	9.36	39.00	167.00
BG	0.18	7.10	0.00
CY	0.01	0.00	0.00
CZ	1.78	7.60	0.00
DK	0.53	7.80	0.00
EE	0.06	0.00	0.00
FI	2.05	14.00	0.00
FR	16.08	86.00	260.00
DE	31.00	119.00	218.00
EL	0.41	23.00	0.00
HU	1.13	8.70	0.00
IC	0.00	0.00	0.00
IE	11.03	2.80	0.00
IT	11.62	101.00	110.00
LV	0.01	0.00	0.00
LT	0.26	5.70	0.00
LU	0.07	0.00	0.00
MT	0.00	0.00	0.00
NL	16.41	84.00	462.00
NO	2.15	0.00	70.00
PL	2.11	21.00	0.00
PT	0.86	13.00	0.00
RO	0.71	14.00	0.00
SK	0.30	6.30	0.00
SL	0.16	0.00	0.00
ES	7.61	60.00	70.00
SE	2.20	19.00	0.00
CH	0.00	0.00	0.00
UK	12.27	80.00	155.00

Biorefinery Likeliness (BL)

The establishment factors (EF) (Table 38 augmented with Table 39) were multiplied with the weight matrices (W) Table 12 for current establishment and Table 15 for future establishment) as shown in Equation 6.

Equation 6

$$M_{i,j} = W_{i,k} \cdot EF_{k,j}$$

The results (M) were scaled to a 1 to 5 scale to calculate the current (Table 13) and future (Table 16**Error! Reference source not found.**) biorefinery likeliness (BL) using Equation 7.

Equation 7

$$BL_{i,j} = \frac{M_{i,j}}{\max(M_j)} \cdot 4 + 1$$

The method leads to an overrepresentation of biorefinery likeliness for large countries (France, Germany, UK) and countries with exceptional large values of some establishment factors (Netherlands).
The overrepresentation of large countries can be prevented by using establishment factor density instead of establishment factors. The establishment factor density is the value of each estblishment factor divided by the surface area of each country. The establishment factor densities (EFD) were calculated via Equation 8, where EF is Table 38 augmented with Table 39 and Area is a list of the areas of all EU countries.

Equation 8

$$EFD_{i.j} = \frac{EF_{i,j}}{Area_j}$$

After multiplication of the establishment factor densities with the weight factors and scaling (Equation 6 and Equation 7), Table 14 and Table 17 (Paragraph 3.4.3) were generated.

The likeliness of biorefineries (BL) was also determined for four regions of Europe (North, West, East and South). The establishment factors (EF) and a matrix where each country is allocated to a region (CA) were used to calculate the regional establishment factors (REF) for the 4 regions in Europe (using Equation 9). The results are shown in paragraph 3.4.4, Figure 15 and Figure 16

Equation 9

$$REF_{i,j} = EF_{i,k} \cdot CA_{k,j}$$

After multiplication with the weight matrix and scaling (as in Equation 6 and Equation 7), Table 19 (paragraph **Error! Reference source not found.**).

Appendix D Costs of pilot and demo plants

Investment costs (all equations in €)

The total costs to run a plant depend to a large extent on the fixed and total capital investment. The total capital investment (TCI) is calculated from the fixed capital investment (FCI), the working capital (WC) and the start up costs (SUC).

$$TCI = FCI + WC + SUC$$

The working capital (WC) is usually around 15% of the total capital investment. The working capital is needed because the costs (raw materials, wages) have to be paid before the product is ready and can be sold.

$$WC = 15\% \cdot TCI$$

Substitution and rewriting yields:

$$TCI = 1.18 \cdot FCI + 1.18 \cdot SUC$$

The start up costs (SUC) are usually around 10% of the fixed invested capital.

$$SUC = 10\% \cdot FCI$$

Resulting in the following relation:

$$TCI = 1.29 \cdot FCI$$

The fixed capital investment (FCI) is calculated from the direct (DI) and indirect (IDI) investment costs.

$$FCI = DI + IDI$$

The direct investment costs are estimated from the inside battery limits costs (ISBL) and outside battery limits costs (OSBL).

$$DI = ISBL + OSBL$$

The indirect investment costs include the owner's costs plus contingencies and is usually around 25% of the direct costs. For more experimental plants such as pilot and demonstration plants, the uncertainty is higher. Therefore, the indirect costs are estimated to be 30% for demonstration and 50% for pilot plants.

$IDI = 25\% \cdot DI$ for full scale plants
$IDI = 30\% \cdot DI$ for demonstration scale plants
$IDI = 50\% \cdot DI$ for pilot scale plants

The outside battery limit costs (OSBL) are estimated from the inside battery limit costs (ISBL). The outside battery limit costs include the adaptation of utilities, and facilities (canteen) that are not situated on the site of the process itself. With expansions the OSBL will be 35% of the ISBL costs and with new plants, the costs will be 50% of the ISBL costs.

$OSBL = 35\% \cdot ISBL$ for expansions of existing plants

$OSBL = 50\% \cdot ISBL$ for new plants at developed site

Substitution yields the following relation for pilot and demonstration plants as expansion and as new plant.

$$FCI = \begin{pmatrix} 2.25 & 2.03 \\ 1.95 & 1.76 \\ 1.88 & 1.69 \end{pmatrix} ISBL$$

	new	exp.	
	2.25	2.03	pilot scale
	1.95	1.76	demonstration scale
	1.88	1.69	full scale

The inside battery limit costs are usually estimated from the sum of the equipment costs (EC) multiplied by a factor to include installation costs (f_L). The value of this factor is around 4.

$$ISBL = f_L \cdot \sum EC$$

The income of a full scale biorefinery can be calculated from the total costs (TC) and the revenues (Rev).

$$Income = Rev - TC$$

With full scale plants the revenues are the sum of product volumes (Q_p) times product prices (P_p).

$$Revenues = \sum Q_p \cdot P_p$$

The total costs (TC) of the process can be calculated from the total manufacturing costs (TMFC), the depreciation (Depr) and the interest (I).

$$TC = TMFC + Depr + I$$

The total manufacturing costs are calculated from the product costs (PC) and the general costs (GC).

$$TMFC = PC + GC$$

The product costs are directly depending on the process. The general costs (GC) are the costs of sales (usually 2.5% of the revenue costs). The pilot plant will have no sales and therefore the costs of sales will be zero.

$$GC = 2.5\% \cdot Rev$$

The product costs are made up of direct costs (DC), fixed costs (FC) and overhead costs (Ov).

$$PC = DC + FC + Ov$$

The direct costs (DC) are the raw material costs (RMC), utility costs (UC), maintenance costs (MC), operating labor costs (OL), staff costs (Staff), laboratory costs (LC) and other costs (Other).

$$DC = RMC + UC + MC + OL + Staff + LC + Other$$

The maintenance costs (MC) are estimated from the fixed capital invested.

$$MC = 6\% \cdot FCI$$

The costs of staff and laboratory costs are estimated from the operating labor.

$$Staff = 50\% \cdot OL$$
$$LC = 15\% \cdot OL$$

The other costs (Other) are neglected.

The fixed costs (FC) are made up of taxes and insurance costs and rent (for the land and buildings). Taxes and insurances are usually 1% of the fixed capital investment and the rent is usually around 1% of the total capital investment.

$$FC = 1\% \cdot FCI + 1\% \cdot TCI$$

The overhead costs are usually around 60% of labor costs, staff costs and maintenance costs.

$$Ov = 60\% \cdot (LC + Staff + MC)$$

Substitution yields the following equations:

$$PC = RMC + UC + 2.04 \cdot OL + 0.106 \cdot FCI + 0.01 \cdot TCI$$

and:

$$TMFC = RMC + UC + 2.04 \cdot OL + 0.106 \cdot FCI + 0.01 \cdot TCI + 0.025 \cdot Rev$$

The depreciation is depending on the fixed capital investment (FCI) and the expected plant life time (τ). The plant life time of full scale plants is usually 10 years.

$$Depr = \frac{FCI}{\tau}$$

For a convenient mathematical representation, the following equation was used instead:

$$Depr = dr \cdot FCI$$

Where the depreciation rate (dr) is the reciprocal of the plant life time.

$$dr = \frac{1}{\tau}$$

The interest costs are dependent on the total capital investment and the interest rate (ir).

$$I = ir \cdot TCI$$

Substitution of all equations above yields:

$$TC = (ir + 0.01) \cdot TCI + (dr + 0.106) \cdot FCI + 2.04 \cdot OL + RMC + 0.025 \cdot Rev + UC$$

If the operating costs are unknown, it can be assumed that the operating costs are 10% of the total costs.

$$OL = 10\% \cdot TC$$

Of course it is far better to estimate the operating labor costs from the amount of operators that are needed to run the plant. This number multiplied by the yearly wage costs per operator will give the operating costs. This is especially the case if this method (that is developed to evaluate full scale processes) is used to evaluate pilot and demonstration plants, where the labor costs will be higher than in normal chemical plants.

Substitution and solving for TC yields the next equation:

$$TC = (1.256 \cdot dr + 0.133) \cdot FCI + (1.256 \cdot ir + 0.013) \cdot TCI + 1.256 \cdot RMC + 0.031 \cdot Rev + 1.256 \cdot UC$$

Substitution of:

$$TCI = 1.29 \cdot FCI$$

Yields:

$$TC = (1.256 \cdot dr + 1.621 \cdot ir + 0.149) \cdot FCI + 1.256 \cdot RMC + 0.031 \cdot Rev + 1.256 \cdot UC$$

If the interest rate is assumed to be 6%, the income can be calculated. For full scale plants it is assumed that the plant life time is 10 years (dr=1/10). This yields the following income:

$$Income = 0.97 \cdot Rev - 0.37 \cdot FCI - 1.26RMC - 1.26 \cdot UC$$

Economic evaluation of biorefineries

The potential of biorefineries can be assessed from the Return on Investment (RoI) and pay out time (PoT). These criteria are only sensible if the plant has a positive income. The income of pilot and demonstration scale plants is usually negative and therefore these criteria are irrelevant for pilot and demonstration plants.

The Return on Investment (RoI) is calculated from the income and the total capital investment. This number should be high enough to convince investors that the plant is far more profitable than a savings account (usually this value ranges from 15% till 50%). Depending on the risks involved, this percentage is high or low. New products and processes should generally have an ROI above 30%. Existing products with established technology can have lower ROI rates (for example power plants).

$$\mathrm{ROI} = \frac{\mathrm{Income}}{\mathrm{TCI}}$$

Substitution yields:

$$\mathrm{RoI} = \frac{0.75\cdot \mathrm{Rev} - 0.97\cdot \mathrm{RMC} - 0.97\cdot \mathrm{UC}}{\mathrm{FCI}} - 0.29$$

The pay out time (PoT) is calculated from the income before depreciation (=cash flow) and the fixed capital investment. The pay out time is the moment that the plant has paid back its investment. From this moment the plant will make a profit. Usually this moment is in the range of 3 to 5 or more years. Since the income of pilot and demonstration scale plants is usually negative, the pay out time of such plants is infinite. Again, the risk involved in the process and product will determine the value of an acceptable pay out time.

$$\mathrm{PoT} = \frac{\mathrm{FCI}}{\mathrm{Income} + \mathrm{Depr}}$$

Substitution yields:

$$\mathrm{PoT} = \frac{\mathrm{FCI}}{0.97\cdot \mathrm{Rev} - 1.26\cdot \mathrm{RMC} - 0.24\cdot \mathrm{FCI} - 1.26\cdot \mathrm{UC}}$$

Contrary to full scale plants, pilot and demonstration scale biorefineries will generally not be profitable. The purpose of pilot and demonstration scale facilities is primarily to show the technical feasibility of a new process. The bad process economy of these processes is caused by several reasons. (1) Through the small scale and the experimental character of these facilities, the costs of capital and operating labor will be high (bad economy of scale). (2) At the same time it is difficult to generate any income from the products. The product volume is usually low and therefore unattractive to customers. The experimental character of the facility will lead to varying product qualities and process failures. (3) Process failures will lead to unsaleable products (=waste). Process lines will start up and close down more often than in normal plants, further increasing start up, off spec and cleaning losses.
In this study it is assumed that pilot plants will have no revenues at all (product sales are fully cancelled by waste disposal costs) and that demonstration plants will have sufficient revenues to pay for the raw material and utility costs.
Another factor that will influence the profitability of pilot and demonstration plants negatively, is their short expected lifetime. Usually these plants are closed down as soon as larger scale plants are running. The life time of a pilot plant is estimated to be 1 year, the life time of a demonstration plant is expected to be 3 years. This short lifetime increases depreciation costs considerably, therewith further decreasing profitability.
Due to the small scale and experimental character of pilot and demonstration plants, it is often difficult to sell the products at normal market prices. In this study it is assumed that pilot plants will have no revenues at all (product sales are fully cancelled by waste disposal costs) and that demonstration plants will have sufficient revenues to pay for the raw material and utility costs.

For demonstration plants it is assumed that the plant life time is 3 years (dr=1/3) and that the revenues are equal to the raw material costs (Rev = RMC + UC). This yields the following (negative) income:

$$\text{Income} = -0.67 \cdot \text{FCI} - 0.29 \cdot \text{RMC} - 0.29 \cdot \text{UC}$$

For pilot plants, it is assumed that the plant life time is 1 year (dr=1/1) and that the revenues are equal to zero (Rev = 0). This yields the following (negative) income:

$$\text{Income} = -1.5 \cdot \text{FCI} - 1.26 \cdot \text{RMC} - 1.26 \cdot \text{UC}$$

Appendix E Valid combinations of crop and biorefinery

For each case (each combination of region, crop type and biorefinery type), the above mentioned key parameters should be evaluated. There are x regions, y crop types and z biorefinery types, so in principle there are x·y·z cases. Some combinations of crop and biorefinery type however, are never applied. This already limits the amount of cases as shown in Table 40.

Table 40, Combinations of crop and biorefinery type (cases)

		wheat/maize/rape	grass/clover	wood/straw	sugar beets/potato
		C1	C2	C3	C4
whole crop	BR1	+			+
green biorefinery	BR2		+		+
lignocellulosic biorefinery	BR3	½		+	
syngas	BR4	½	½	+	

The amount of cases is further limited because of crop growth limitations. Crop growth is a strong function of region. Both climatological (large scale) and local (regional scale) conditions exert a strong influence on crop growth. The short growth season in the very North of Europe does not allow the production of wheat, sugar beets etc. Wetlands and peat soils cannot be cultivated with heavy machinery and therefore will produce only grass or wood. Below all crops are discussed for their culture possibilities.