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An economic assessment of potential ethanol production pathways in Ireland

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Abstract

An economic assessment was conducted on five biomass-to-ethanol production pathways utilising the feedstock: wheat, triticale, sugarbeet, miscanthus and straw. The analysis includes the costs and margins for all the stakeholders along the economic chain. This analysis reveals that under current market situations in Ireland the production of ethanol under the same tax regime as petrol makes it difficult to compete against that fuel, with tax breaks however it can compete against petrol. On the other hand, even under favourable tax breaks it will be difficult for indigenously produced ethanol to compete against cheaper sources of imported ethanol. Therefore, the current transport fuel market has no economic reason to consume indigenously produced ethanol made from the indigenously grown feedstock analysed at a price that reflects all the stakeholders costs. To deliver a significant penetration of indigenous ethanol into the market would require some form of compulsory inclusion or else considerable financial supports to feedstock and ethanol producers.

Keywords: Ethanol, economics, lignocellulose

1. Introduction

Bioethanol is a partly renewable fuel that is produced from the fermentation of organically derived monosaccharides using various strains of yeast. While ethanol produced from biomass does generally have a positive impact on reducing greenhouse gas (GHG) emissions, there are in

most cases unavoidable direct and indirect emissions of GHGs during the products life-cycle, such as through the use of synthetic fertilisers and transportation processes that generally rely on fossil based energy sources (Kim and Dale, 2008, Kendall and Chang, 2009). The source of these monosaccharides can come directly from sugar producing plants such as sugarbeet and sugarcane or through the hydrolysis of starch producing plants such as wheat and corn. Alternatively, the monosaccharides can be produced from cellulose and hemi-cellulose compounds derived from organic material such as grasses, crop residues and municipal waste using either acid/alkaline or enzymatic hydrolysis (Gray, 2006). The production and supply of bioethanol is of interest to governments, industry and the agricultural community as it has perceived benefits such as benefiting national energy security, reducing GHG emissions and rural economies. For these reasons ethanol has had fiscal support at the national and regional level around the world, in particular the EU, US, and Brazil have been proactive in this regard.

The global fuel ethanol industry has expanded considerably over the past decade mainly due to monetary incentives delivered to biofuel producers and blenders by various local and national governments which has made biofuel production economically attractive to ethanol producers, blenders and investors. From a policy perspective most countries, particularly OECD countries have at least some policies that try to promote the use of biofuels or other renewable energy sources. Examples would include Brazils PROALCOOL program (Goldemberg, 2004), the EU's biofuels directive (EC, 2003) and the United States energy independence and security act (USDOE, 2005). The US and Brazilian biofuel support polices have resulted in a notably rapid expansion of their respective ethanol industries. Total ethanol production internationally in 2007 was in the order of 50 billion litres, of which the US (24.6 billion litres) and Brazilian (19 billion litres) ethanol industries accounted for 43.6 billion litres or 87% of worldwide production. The European union countries produced around 1.77 billion litres or 3.5% of total worldwide production (e-bio, 2008, RFA, 2008) which, when compared to EU consumption of 2.7 billion

litres, accounts for 65% of internal consumption, the balance is generally made of imports from Brazil and countries with whom the EU have preferential trade agreements (Schnepf, 2006). High crude oil prices leading to higher petrol prices coupled with low feedstock and input costs initially made ethanol a very attractive fuel to produce and use. Fuel ethanol is becoming increasingly evident in mainstream commodities trading with the Brazilian mercantile and futures exchange (BM&F) and the Chicago board of trade (CBOT) adding ethanol to their respective lists of commodities traded on their futures exchanges. Europe has no such trading mechanism for ethanol as yet with all ethanol being traded privately between buyers and sellers.

From an EU and Irish policy perspective two directives in particular will impact on biofuel production into the future. The first is the EU directive 98/70/EC also known as the fuel quality directive which is being amended in order to allow wider blending limits and will allow the maximum blend of biofuels go from 5% to 10% by volume in both ethanol/petrol and diesel/biodiesel blends (EC, 2007). The other is a proposed new directive known as the renewable energy directive which will follow on from directive 2003/30/EC (the biofuels directive) and aims for a mandatory inclusion of biofuels in the transport fuel mix of 10% by energy by 2020 (EC, 2008).

Within Ireland, current monitory supports for biofuels are limited to a number of government administered tenders that grant full excise duty (tax) relief on biofuels including pure plant oil, biodiesel and ethanol (DCMNR, 2006). While the pure plant oil and biodiesel tenders were generally acted upon by industry, the tenders for ethanol from agricultural crops were not.

The main factor affecting the cost and therefore competitiveness of most biofuels is the cost of the feedstock, which generally constitutes some 60-85% of the total production cost (Kwiatkowski et. al, 2002, Shapouri and Gallagher, 2002). Gray (2006) describe the processes that use lignocellulose based feedstock as the source of plant sugars for fermentation and

describe it as a more favourable feedstock source due to its greater abundance, yield potential and potentially better economic and GHG efficiencies.

From an agricultural perspective the general rise in commodity prices, which have been to the detriment of the ethanol industries, has benefited farmers in particular crop producers. In Ireland in 2006, tillage crop production was the second most profitable farming activity to be involved in after dairy production with the average family farm income for crop producers being €28,536 (DAFF, 2007). In 2007 national and international grain prices reached record levels. In 2006 the average farm size was 31.4ha, with the average tillage farm size being 53.9ha (CSO, 2004). The average industrial wage in Ireland across all industries was €32,471 per annum (CSO, 2007).

1.1 Background to feedstock

Wheat is an annual cereal crop, the grains of which are traded both locally and internationally. Broad sub-groups include: Feed wheat (soft), milling wheat (hard), durum wheat and white wheat. The uses of wheat include food (bread, pasta, breakfast cereals, brewing), animal feeds and industrial (chemicals, ethanol). As an ethanol feedstock it is noted for its high carbohydrate content in the form of starch ranging from 60% to 68% (Matz, 1991).

Wheat is grown extensively around the world and is traded internationally through efficient and well-defined transport and handling infrastructure (Matz, 1991). Ireland is a deficit producer of wheat (CSO, 2006), therefore the value of wheat grown in Ireland is directly related to the cost of imported wheat. For this reason the price paid for wheat grown in Ireland is usually higher than in other net exporting regions. The monthly average price of feed wheat in Ireland over the period January 2007 to January 2008 was €197/t. Over the first two quarters the average was €160/t and over the last two quarters the average was €239/t. For this paper the market value was taken to be €239/t (15%mc) (IGFA, 2008). As highlighted in table 1 the expected yield would be 391.7 litres (l) per metric tonne (t) this represents a gross feedstock cost of €0.61/l. (see Table 1).

Sugarbeet is a root crop of the Brassica family and is therefore related to oilseed rape. While oilseed rape is known for its high oil content, sugarbeet is known for its high sugar content. For this reason it lends itself well to ethanol production due to its store of easily attainable and fermentable carbohydrates (Draycott, 2006) Sugarbeet amounting to approximately 1.5 million tonnes annually was grown extensively in Ireland up until 2006 (CSO, 2006) at which point the last sugar refinery, owned by Irish sugar, ceased production of sugar from this feedstock due in part to the EU reforms of the sugar common market organisation (CMO). (Busse and Jerosch, 2006) As a product in itself it is not traded internationally due to its high moisture content and poor storage characteristics. However, the various products of sugar extraction are readily transportable and tradeable, these include raw sugar, white sugar, molasses and dry beet pulp.

As sugarbeet is no longer grown for purposes other than as a forage crop in Ireland market analysis focused on the value of raw sugar, the nearest tradable product which would reflect closest its potential value. Raw sugar is traded internationally and is generally the precursor to white or brown sugar production. Over the same period as reviewed for wheat (2007) the raw sugar price imported to the UK was 29.76US c/lb (€468/t), this was used to calculate the potential value of sugarbeet (UNCTAD, 2008). As sugarbeet grown in Ireland contains approximately 16.5% sugar and allowing for processing costs the value of sugarbeet therefore was calculated to be €38.61/t. The expected ethanol yield is 100l/t representing a gross cost of €0.38/l. (see Table 1)

Triticale is a cross between wheat (**Trit**icum) and rye (Se**cale**). It yields similar to wheat and sometime times better in certain conditions such as water deficient or poor quality land (Matz, 1991). The size, quality and content of the seed are similar to that of wheat although certain agronomic features make it less desirable for crop growers such as its longer stem and subsequent susceptibility to lodging and also a greater susceptibility to certain diseases such as Ergot, though it does have a greater resistance to other diseases such as rust, smuts and mildew

and also a lower nutrient requirement, therefore the overall input are lower than that of wheat (Hackett, 2004). The primary factor leading to Triticales consideration for this study was its ability to be grown in poorer soils which may be required if the arable area is to expand to accommodate an ethanol industry in Ireland. According to Matz (2006), the starch content of Triticale is 53%, Jozefiak et al, (2007) measured a starch content of 63.4%.

There is currently no organised market for Triticale with most buying and selling done locally and privately. In Ireland the production of Triticale is negligible with any production being used for forage purposes (Hackett, 2004). For this reason the price of wheat minus 10% was used as the market value of Triticale given the lower level of inputs involved in its production. Therefore, the market value for Triticale was taken to be €224/t. The ethanol yield from triticale is expected to be 361.6 l/t and at expected markets prices it would therefore have a gross feedstock cost of €0.62/l (see Table 1).

Miscanthus, similar to other herbaceous plant species originating in dry arid regions such as sugarcane and corn, uses the C4 photosynthetic pathway. The C4 photosynthetic pathway uses a unique leaf anatomy to form a four carbon compound (oxaloacetate) as its first product as apposed to a three carbon compound (pyruvate) in the more common plant species found in the temperate climate of Ireland. This allows the plant to minimize respiration and enhance sugar production in even the most hot and dry conditions when the stomata are required to be partially closed (Campbell, 1996). Another important agronomic feature is its ability to store vital nutrients below ground during winter senescence which minimises nutrient export and costs during growth and harvest cycles. Clifton-Brown, (2000) modelled yields of 16-26 tonnes of dry matter per hectare for miscanthus under Irish conditions, with the highest yields achieved in the south of the country. The composition of miscanthus biomass was assessed by de Vrije (2002) and a cellulose content of 38.2% dry matter (dm) was calculated. The hemicellulose content was

measured to be 24.3%dm, therefore the total polysaccharide content amounts to 62.5%dm. Of the polysaccharides, glucose and xylose represented the greatest fractions (39.5% and 19% respectively). Like triticale and sugarbeet no formal market exists in Ireland or elsewhere, nor are there international movements of the crop due to its low bulk density. There are however fixed contracts for miscanthus between producers and consumers in Ireland (energy companies) and at present the prices being paid for miscanthus bales at 20% moisture content (mc) is €60/t. With an expected ethanol yield of 286l/t (dm basis) and a €60/t price this would generate a gross feedstock cost of €0.25/l of ethanol produced. (see table 2)

The primary source of straw in Ireland comes from wheat and barley. Wheat and barley are the two primary cereal crops grown in Ireland accounting for 94% of the arable area in 2006 and this situation has indicative of the past ten years (CSO, 2006). There is approximately 100, 000 hectares of wheat and 190, 000 hectares of barley grown annually. However, due to wheat generally being of winter varieties (70%) and barley being constituted of spring varieties (89%) and the subsequent yield differentials the production tends to be somewhat similar in mass terms with around 1million tonnes of wheat and 1.3million tonnes of barley being produced annually. The use of the residual straw after the grains have been removed is many and varied and statistics regarding their use are very difficult to source due to the highly unregulated market in which straw is traded. The uses however are: Animal bedding, mushroom compost, animal feed and re-incorporation into the soil. In terms of the relative amounts being used for each purpose they would likely follow that order although specific data is unavailable due to the unregulated nature of the market. The composition of straw as analysed by McKendry (2002) indicates a cellulose content of 33-40% and a hemi-cellulose content of 20-25%, therefore a total polysaccharide content of 53-65% is potentially available for fermentation by a suitable organism.

Due to the unregulated nature of the straw market in Ireland and also the inconsistency of bale type and quality definitive prices are difficult to ascertain. The only reference was through consultation with traders and reviewing agricultural media. Based on this analysis the price of straw is currently around €41/t (+/-€7/t), the main variants being straw quality, type of bale and location. The market price was taken to €41/t, an ethanol yield of 255l/t would therefore generate a gross feedstock costs of €0.19/l of ethanol produced (table 2)

1.2 Co-product values

During ethanol production, co-products are produced and in some cases the products can be numerous with varying monetary values. Some bio-refineries produce valuable chemicals such as furfurol, levulinic acid and formic acid (LU). Currently, ethanol plants generally produce a small range of co-products such as beet pulp in the case of sugarbeet and distillers grains in the case of wheat and corn. The importance of co-products to the overall economics of both an ethanol industry and individual ethanol plants cannot be understated (Kwiatkowski, 2006). For the economic analysis conducted in this paper it was assumed that wheat and triticale produced distillers grains and solubles (DDGS) at a rate of $0.31kg_{DDGS}/kg_{feedstock,}$ sugarbeet produced dry sugarbeet pulp at a rate of $0.37kg_{dsbp}/kg_{feedstock}$ and that both straw and miscanthus produced lignin based biomass pellets at a rate of $0.34kg_{pellets}/kg_{feedstock.}$ Work conducted by White (1986) indicates that the calorific value of lignin based biomass pellets would be in the order of 19.7MJ/kg which is a similar energy content to woodpellets, therefore the value of woodpellets would be a good basis for determine the potential value of lignin based pellets. It was taken that the current market prices of the by-products DDGS, sugarbeet pulp and biomass pellets are €220, €220, and €100 per tonne respectively.

1.3 Ethanol price

As no part of the European ethanol market operates in a futures or commodities exchange and is therefore conducted on a privately negotiated price basis a definitive price or time series of prices is difficult to determine. For this study the market price for fuel ethanol was taken to be €0.56/l. This is derived from: The near month Brazilian futures (BM&F, 2008) price of €0.30/l + shipping and handling (€0.04/l) + Import tariffs (€0.19) + Margin (€0.03/l) = €0.56/l, this resembles closely values quoted in media at the time (Kingsman, 2008).

2. Procedure

2.1 Scenario development

An economic model was developed that mapped in economic terms all the costs along the supply chain from feedstock production through to fuel ethanol distribution and sale at the pumps. The model was broken down to three cost centres, namely: Feedstock producer, ethanol producer and finally the ethanol distributor/blender.

In order to compare the economics of the various chains three economic comparisons were made: the first is a purely market based analysis whereby all current market values are inputted to the system to assess the individual and overall economics under current conditions. This scenario is the market scenario. The next two scenario look at each stakeholders associated costs and determines firstly the minimum pump price required to cover each stakeholders costs and then secondly to cover each stakeholders costs and also derive a reasonable income. These scenarios are called cost only scenario and costs + income scenario respectively.

2.2 Model description:

The model was developed using the Excel™ spreadsheet software and has three distinct input sections, namely, the farm level economics, the processing level economics and the distribution level economics. The farm level economics assesses all the costs associated with producing the various feedstock analysed. These are then compared with crop yields to determine the various prices required to cover costs and return various margins on a mass basis (per tonne). The ethanol processing economics determines the costs associated with converting the feedstock to an-hydrous ethanol and other by-products. The final distribution level economics deals with the costs associated with distributing ethanol it could include excise which in Ireland is currently charged at €0.44/l and value added tax (VAT) which is 21% and is calculated after the excise has

been paid. For this study it is assumed however that initially excise is not charged on the ethanol fuel.

Feedstock production economics C_f:

Production costs were based on annual working capital costs such as fertiliser, sprays and contractor charges, and fixed costs such as insurance, interest and loan repayments for the 2007-2008 growing season. The model was populated with data from fertiliser distributors, contractors, fuel and chemical distributors. The model estimates the overall production costs of each of the feedstock considered on an area (hectare) and a mass (tonne) basis using yield estimates. In the unique case of miscanthus which is a perennial crop the establishment costs were amortized over life of the crop. The life of the crop was taken to be 16 years. In the case of straw it was treated as a by-product of winter wheat production therefore its costs are those associated only with baling, collection and transport. Transport costs are also determined and it is assumed that the feedstock producer incurs those costs. All costs are based upon 2008 input prices.

Ethanol processing costs Cp:

This section is concerned with how much it costs to convert a particular biomass source to fuel ethanol ready for blending. A total ethanol processing cost was taken to be the sum of annualised fixed costs and variable costs spread over the annual fuel ethanol output from the plant. The cost of capital is estimated by inputting economic data such as an initial capital cost estimate which can be serviced by differing proportions of loans, grants and equity the expected interest rate, loan period and investor equity and expected return on equity are also inputted to determine the overall cost of capital. For this study the capital cost of the process battery limits were primarily derived from previous work conducted by Murphy and McCarthy, (2004) and Gallagher et al, (2005) and using the CHE and M & S cost indexes where appropriate to update estimates. Other capital costs such as auxiliary investment, working capital, land costs and start up costs were

derived using data from Tedder, (2005) and land price statistics CSO, 2005. Running cost data was derived from various sources such as Kiatkowski, (2006), Galbe et al, (2007), McAloon et al, (2000) Dale and Tyner, (2006), Shapouris and Gallagher (2002),), Murphy and Power, (2007), Power et al, (2007). The capital cost structures vary from project to project, for this study a 40% equity to 60% debt ratio was used with an interest rate of 7% and a 12% return on equity. For the purposes of this study it was assumed in all cases that the output of ethanol was 100 million litres per annum.

The main variable processing costs consist of energy, labour, repairs, chemicals/enzymes, water, electricity, denaturant and waste management. Total annual costs are divided by total annual production to determine the total cost per litre of fuel ethanol produced.

Distribution economics Cb:

Distribution costs are those that are incurred once the ethanol leaves the processing facility. In Ireland there is no national pipeline distribution or history of significant rail based distribution system therefore the model assumes the costs associated with road haulage are employed and data on these costs were determined from an industry consultation process. The overall model chain is described in figure 1.

3 Results

Feedstock producer

At the farm level the lowest cost feedstock to supply both on a mass basis and a potential ethanol production basis is straw at €25.06/t and €0.09 /l although this is mainly due to allocating all the production costs of the crop to the grain fraction while straw incurs only its own handling, storage and transportation costs. Sugarbeet and miscanthus have a comparatively lower cost of production on a mass basis than any of the other specifically grown crops. However, they are also both lower value products, for this reason the margins are lower than wheat at only €149 per

hectare for miscanthus and -€361 for sugarbeet at expected prices (table 3). The most expensive crop to produce is triticale at €145/t or €0.51 per potential litre of ethanol (table 4).

Ethanol producer

Based on outputs from this analysis, an ethanol producer using the proposed feedstock in current market condition will not be able to sell the ethanol at wholesale prices and be profitable (table 3). In the case of wheat and triticale this is mainly attributable to the high cost of these feedstock at present while for miscanthus and straw it is mostly attributable to the high processing costs as indicated in figure 2. To cover the cost of the feedstock producer and plant owners, ethanol could be produced for a minimum of €0.35 per litre in the case of a straw-to-ethanol pathway increasing to €0.61 per litre production cost in the case of the sugarbeet-to-ethanol pathway (table 4). Only the sugarbeet-to-ethanol pathway produces ethanol that is above the current market value. For the plant owners and feedstock producers to cover their costs and minimum income thresholds the lowest ethanol value equates to €0.43 per litre for ethanol produced from straw supplied by tillage farmers. While the most expensive pathway €0.88 per litre when ethanol is produced from sugarbeet produced by average sized farmers. In all cases except the straw-to-ethanol pathway overall costs are above the market value of wholesale ethanol (table 5).

Blenders and consumers

Under current market conditions wholesale ethanol can be bought and distributed profitably both for the blender/distributor and consumer. On an energy basis a consumer would save €9.65 per GJ of petrol displaced by ethanol (table 3). At breakeven for all parties along the various production pathways ethanol could be supplied at its most inexpensive by using a straw-to-ethanol production pathway which could deliver ethanol at a cost of €21.97 per GJ which is 46% less expensive than petrol at the pumps On the other hand the most expensive pathway is the sugarbeet-to-ethanol pathway, although it still works out 12% less expensive than petrol at €35.78 per GJ (table 4). All pathways deliver ethanol that is cheaper than petrol both on a

volume and energy basis. In order to deliver anhydrous ethanol to the consumer that is representative of all the stakeholders costs and income expectations ethanol can be delivered less expensively than petrol via the wheat, triticale and straw to ethanol pathways assuming that tillage farmers are the producers of the feedstock. When average sized farmed farmers supply the feedstock only the wheat and straw to ethanol production pathways cover all the stakeholders costs and income expectations and still deliver ethanol at a cheaper price than petrol at the pumps (table 5).

4. Discussion/sensitivity analysis

The impact of feedstock cost and petrol prices

A sensitivity analysis was conducted to gauge the impact of feedstock and petrol price on the competitiveness of ethanol as a fuel. It was found that only at comparably high petrol prices and low feedstock prices is ethanol production competitive with petrol under parity of excise duties on the two fuels. With excise relief however, the range within which ethanol production is competitive against petrol is much greater. Within the price ranges assessed all the production processes return over 73% of the permutations as being competitive against petrol once excise relief is granted on the ethanol. However, this only proves that ethanol can be produced, in a lot of cases, competitively against petrol in Ireland, however, it remains that indigenously produced ethanol using the proposed pathways is uncompetitive against imported ethanol. This is followed by wheat (figure 3), triticale (figure 4) and miscanthus (figure 5) and all have an equal proportion of uncompetitive scenarios within the price ranges assessed. Sugarbeet has the greatest proportion of uncompetitive scenarios (figure 6). Straw (figure 7) appears to have the least likelihood of being uncompetitive against petrol.

The impact of processing costs

Processing costs for ethanol produced from all resources are higher than for other countries such as Brazil and the US and even other EU countries. This is due to higher energy, labour, feedstock and land costs. There is a potential to reduce these costs, examples include the production of hydrous as apposed to an-hydrous ethanol as modelled in this study. Also, by-products could be sold in their wet state, in particular DDGS if local markets for that material were available. Energy cost savings through the production of heat and electricity using plant by-products could be explored, although by-products such as DDGS and beet pulp have a high value in Ireland due to restriction of supplies from countries with extensive production of genetically modified plant varieties (IGFA, 2008). Also, in respect to the conversion of lignocellulose material technological advances such as the development of better enzymes and chemical processes to liberate greater quantities of fermentable sugars from lignocellulose material which should reduce processing costs further.

Observations

At current likely imported ethanol prices indigenously produced ethanol will not be able to compete imported ethanol, however, it has a good chance of competing successfully against petrol sold in Ireland. Excluding a complete inability to import ethanol or a significant increase import taxes, transport costs or ethanol values distributors of ethanol would be better served importing ethanol than buying indigenous ethanol at prices that reflect the cost of production and income expectations for the stakeholders in the pathways modelled in this study.

5. Conclusion

The results of this analysis show clearly the significant economic challenges that face a potential ethanol industry in Ireland in making indigenously produced ethanol a competitive source of ethanol to the Irish market. Indigenously produced ethanol does have the potential to compete

favourably against petrol at the pump in Ireland, but not against imported ethanol. This highlights the competitive advantage other producing countries such as Brazil and the US have in the production of ethanol. In order to proliferate the use of indigenous ethanol produced from the proposed pathways and costs associated with those pathways, will require significant internal market supports or protection from external markets. In the face of ongoing WTO negotiations that are endeavouring to open up rather close international markets this will be unlikely. Excise relief will be a pre-requisite for any indigenous ethanol from the proposed pathways based on likely feedstock, processing and distribution costs and converse petrol prices. While a straw-to-ethanol pathway looks to be the most promising there are still considerable obstacles to the proliferation of this method of production such as:

- It is as yet an unproven technology at a commercial scale
- The capital costs are probably prohibitive in the current financial climate
- Appropriation of straw may be difficult due to the conflicting uses in other sectors such as bedding for livestock and compost for mushroom growers
- The intensive removal of straw poses some risk to the quality of soil structure and subsequent loss of fertility as well as other environmental risks

Based on this study, the production of ethanol in Ireland using the selected indigenously produced feedstock is economical challenging in its current guise.

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	Input	Output
Sugarbeet	1000	
Sugar content	0.165	165.0 kg
Sugar extraction rate	0.96	158.4 kg
Ethanol stoichiometric yield	0.51	80.8 kg
Glucose fermentation efficiency	0.97	**78 kg**
Market value	**€ 39**	**100 l/t**
Feedstock cost	**€ 0.38**	**/l**
Wheat	1000	
Starch content	0.65	650.0 kg
Starch to Dextrin	0.98	637.0 kg
Dextrin to Glucose	0.99	630.6 kg
Ethanol stoichiometric yield	0.51	321.6 kg
Glucose fermentation efficiency	0.95	**306 kg**
Market value	**€ 239**	**392 l/t**
Feedstock cost	**€ 0.61**	**/l**
Triticale	1000	
Starch content	0.6	600.0 kg
Starch to Dextrin	0.98	588.0 kg
Dextrin to Glucose	0.99	582.1 kg
Ethanol stoichiometric yield	0.51	296.9 kg
Glucose fermentation efficiency	0.95	**282 kg**
Market value	**€ 224**	**362 l/t**
Feedstock cost	**€ 0.62**	**/l**

		Input	Output
Glucose	**Straw**	1000	
	Cellulose content	0.38	380.0 kg
	Cellulose conversion and recovery efficiency	0.76	288.8 kg
	Ethanol stoichiometric yield	0.51	147.3 kg
	Glucose fermentation efficiency	0.9	**132.6 kg**
			169.9 L
Xylose	Straw	1000	
	Hemicellulose content	0.29	290.0 kg
	Hemicellulose conversion and recovery efficiency	0.9	261.0 kg
	Ethanol stoichiometric yield	0.51	133.1 kg
	Xylose fermentation efficiency	0.5	**66.6 kg**
			85.3 L
	Total	***199***	**kg**
	Total	***255***	**L**
	Market value	***€ 41.00***	
	Moisture content	***20%***	
	Gross feedstock cost	***€ 0.19***	**/l**
Glucose	**Mischanthus**	1000	
	Cellulose content	0.43	430.0 kg
	Cellulose conversion and recovery efficiency	0.76	326.8 kg
	Ethanol stoichiometric yield	0.51	166.7 kg
	Glucose fermentation efficiency	0.9	**150.0 kg**
			192.3 L
Xylose	Mischanthus	1000	
	Hemicellulose content	0.32	320.0 kg
	Hemicellulose conversion and recovery efficiency	0.9	288.0 kg
	Ethanol stoichiometric yield	0.51	146.9 kg
	Xylose fermentation efficiency	0.5	**73.4 kg**
			94.2 L
	Total	***223***	**kg**
	Total	***286***	**L**
	Market value	***€ 60.00***	
	Moisture content	***20%***	
	Gross feedstock cost	***€ 0.25***	**/l**

Market scenario 1

	Wheat	Triticale	Sugarbeet	Miscanthus	Straw
Farm level costs (€/ha)					
Total costs	€1,354.01	€1,231.00	€2,098.62	€811.10	€112.33
Yield	9.8	8.5	45.0	16.0	4.5
Market price	***€239.00***	***€224.00***	***€38.61***	***€60.00***	***€41.00***
Margin	€988.19	€673.00	-€361.17	€148.90	€71.45
Ethanol processing costs: (€/l)					
Total processing cost*	€0.24	€0.23	€0.27	€0.46	€0.46
Gross feedstock cost	€0.61	€0.62	€0.38	€0.25	€0.19
Co-product credits	-€0.17	-€0.19	-€0.08	-€0.12	-€0.13
Total production costs	€0.68	€0.66	€0.57	€0.59	€0.52
Market value	***€0.56***	***€0.56***	***€0.56***	***€0.56***	***€0.56***
Estimated margin	***-€0.12***	***-€0.10***	***-€0.01***	***-€0.03***	***€0.04***
Distribution level costs (€/l)					
Distribution/retail costs	**€0.08**	€0.08	€0.08	€0.08	€0.08
Ethanol purchase price	€0.56				
Excise rate	0%				
Excise	€0.00				
VAT (21%)	€0.13				
Pump ethanol price	€0.77				
Pump gasoline price	€1.30				
Ethanol (€/GJ)	€30.98				
Gasoline (€/GJ)	€40.63				
Ethanol v gasoline (€/GJ)	-€9.65				

Stakeholder scenario 1

	Wheat	Triticale	Sugarbeet	Miscanthus	Straw
Feedstock costs (€/ha)					
Total costs	€ 1,354.01	€ 1,231.00	€ 2,098.62	€ 811.10	€ 112.33
Yield	9.8	8.5	45.0	16.0	4.5
Required margin	€ -	€ -	€ -	€ -	€ -
Required price	**€ 138.16**	**€ 144.82**	**€ 46.64**	**€ 50.69**	**€ 25.06**
Ethanol processing costs: (€/l)					
Total processing cost	€ 0.20	€ 0.20	€ 0.23	€ 0.39	€ 0.39
Total feedstock costs	€ 0.35	€ 0.40	€ 0.46	€ 0.18	€ 0.10
Co-product credits	-€ 0.17	-€ 0.19	-€ 0.08	-€ 0.12	-€ 0.13
Required market value	**€ 0.38**	**€ 0.41**	**€ 0.61**	**€ 0.45**	**€ 0.35**
Distribution costs (€/l)					
Distribution/retail costs	€ 0.08	€ 0.08	€ 0.08	€ 0.08	€ 0.08
Ethanol purchase	€ 0.38	€ 0.41	€ 0.61	€ 0.45	€ 0.35
Excise rate:	0%	0%	0%	0%	0%
Excise	€ -	€ -	€ -	€ -	€ -
VAT	€ 0.16	€ 0.18	€ 0.20	€ 0.18	€ 0.11
Total pump price	**€ 0.63**	**€ 0.67**	**€ 0.89**	**€ 0.70**	**€ 0.55**
Gasoline price:	€ 1.30	€ 1.30	€ 1.30	€ 1.30	€ 1.30
Ethanol (€/GJ)	**€ 25.03**	**€ 26.88**	**€ 35.78**	**€ 28.08**	**€ 21.97**
Gasoline (€/GJ)	**€ 40.63**	**€ 40.63**	**€ 40.63**	**€ 40.63**	**€ 40.63**
Competitiveness (gasoline =100)	62	66	88	69	54

Stakeholder scenario 2

	Wheat	Triticale	Sugarbeet	Miscanthus	Straw
Feedstock costs (€/ha)					
Total costs	€1,354.01	€1,231.00	€2,098.62	€811.10	€112.33
Yield	9.8	8.5	45.0	16.0	4.5
Required margin Average Farmer (AF)	€1,019.27	€1,019.27	€1,019.27	€1,019.27	€1,019.27
Required margin average Tillage Farmer (TF)	€605.13	€605.13	€605.13	€605.13	€605.13
Required price (AF)	***€242.17***	***€264.74***	***€69.29***	***€114.40***	***€31.99***
Required price (TF)	***€199.91***	***€216.02***	***€60.08***	***€88.51***	***€27.57***
Ethanol processing costs: (€/l)					
Total processing cost	€0.24	€0.23	€0.27	€0.46	€0.46
Total feedstock costs AF:	€0.62	€0.73	€0.69	€0.40	€0.13
Total feedstock costs TF:	€0.51	€0.60	€0.60	€0.31	€0.11
Co-product credits	-€0.17	-€0.19	-€0.08	-€0.12	-€0.13
Required market value AF	***€0.68***	***€0.77***	***€0.88***	***€0.74***	***€0.45***
Required market value TF	***€0.58***	***€0.64***	***€0.79***	***€0.65***	***€0.43***
Distribution costs (€/l)					
Distribution/retail costs	€0.08	€0.08	€0.08	€0.08	€0.08
Ethanol purchase AF	€0.68	€0.77	€0.88	€0.74	€0.45
Ethanol purchase TF	€0.58	€0.64	€0.79	€0.65	€0.43
Excise rate:	0%	0%	0%	0%	0%
Excise	€0.00	€0.00	€0.00	€0.00	€0.00
Required margin (€/l)	€0.02	€0.02	€0.02	€0.02	€0.02
Vat A/F	€0.16	€0.18	€0.20	€0.18	€0.11
Vat T/F	€0.14	€0.15	€0.18	€0.16	€0.11
Total pump price AF:	€0.96	€1.07	€1.19	€1.02	€0.68
Total pump price TF:	€0.81	€0.89	€1.07	€0.90	€0.64
gasoline price:	€1.30	€1.30	€1.30	€1.30	€1.30
Ethanol (€/GJ) AF	€38.26	€42.62	€47.65	€40.99	€27.08
Ethanol (€/GJ) TF	€32.44	€35.50	€42.62	€36.02	€25.64
Gasoline (€/GJ)	€40.63	€40.63	€40.63	€40.63	€40.63
Competitiveness AF (gasoline =100)	94	105	117	101	67
Competitiveness TF (gasoline =100)	80	87	105	89	63

Table 1: Ethanol conversion efficiency and feedstock costs for conventional tillage crops in Ireland

Table 2: Ethanol conversion efficiency and feedstock costs for lignocellulose crops in Ireland

Table 3: Results of the market scenario

Table 4: The results of the “stakeholder scenario 1” (breakeven) analysis

Table 5: The results of the “stakeholder scenario 2” (costs plus income) analysis for farms with a size equal to either the national Average for all farms (AF) or the national average for Tillage Farm (TF) only.

Figure 1: Model description and layout

Figure 2: Breakdown of the breakeven production pathways analysed

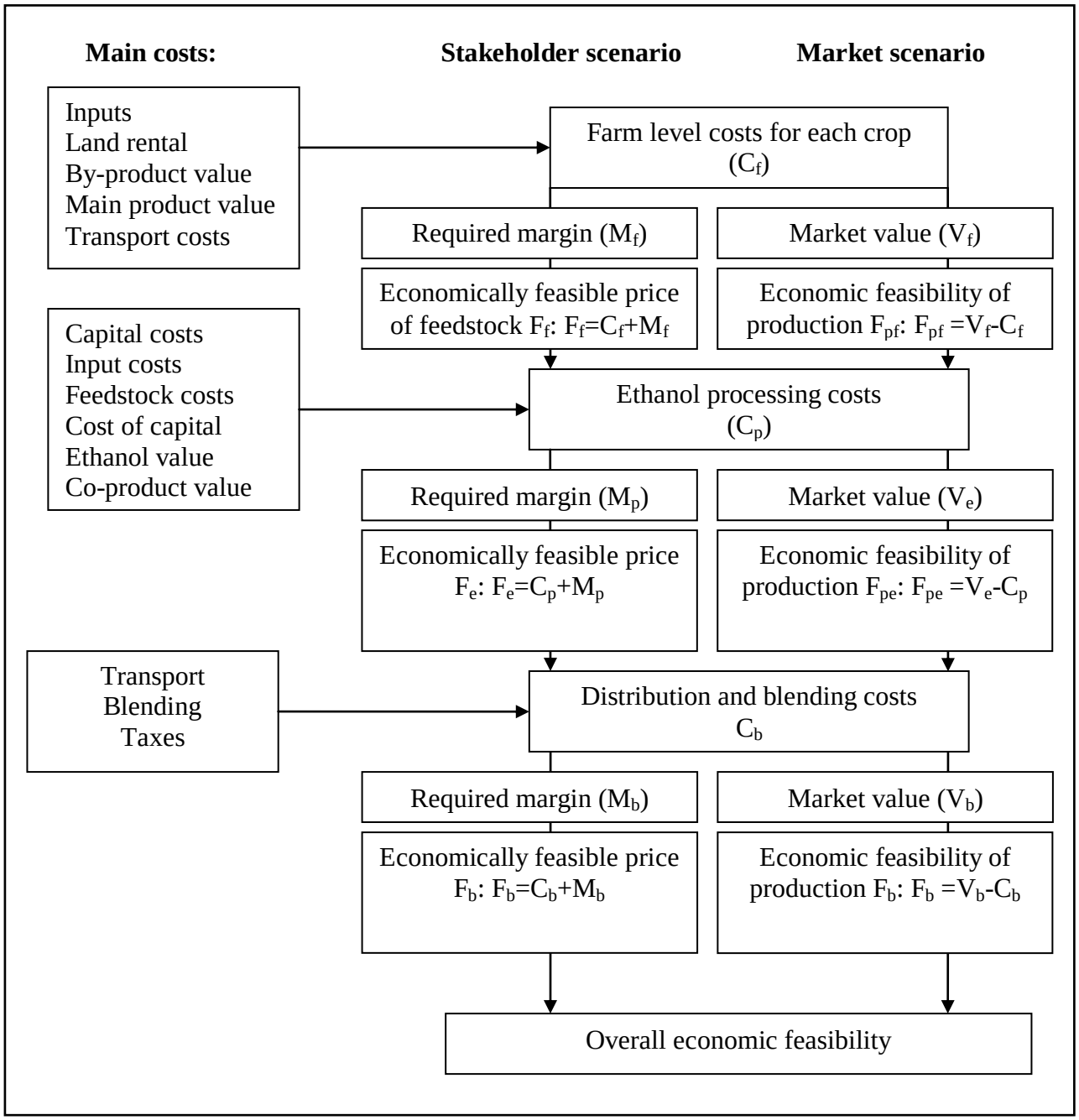
Figure 3: Ethanol production economics sensitivity analysis for wheat to ethanol conversion pathway

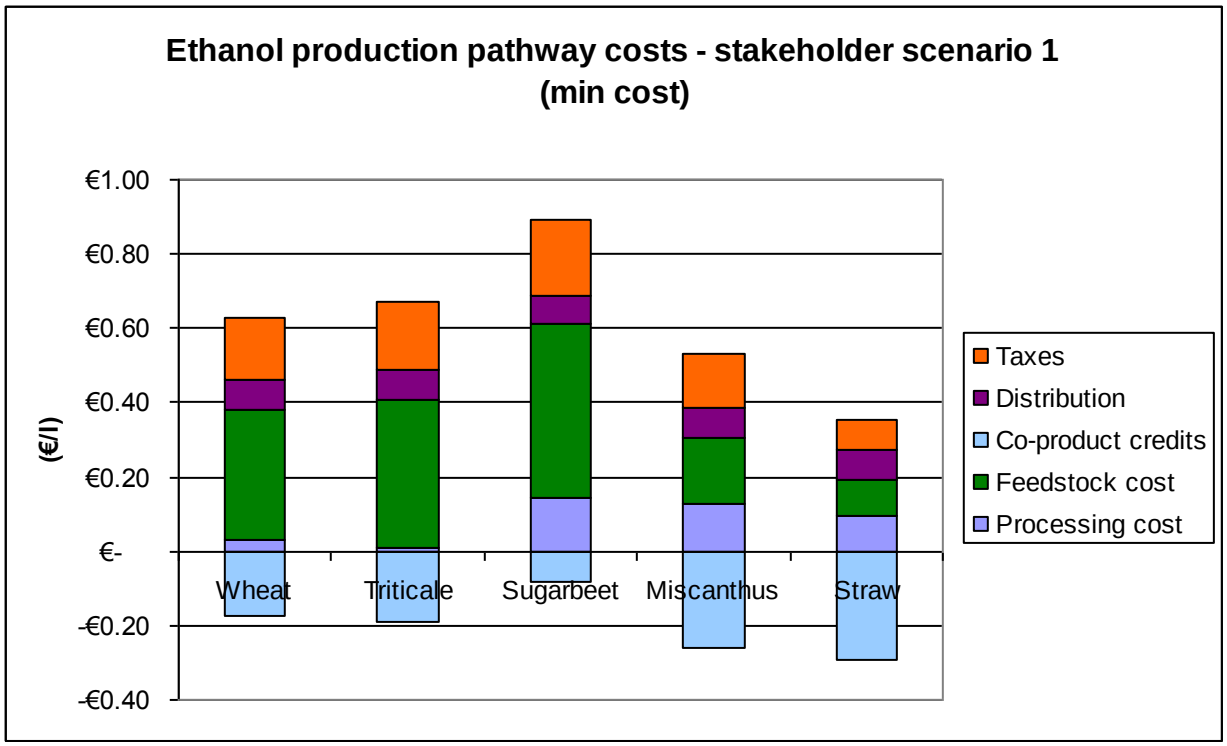
Figure 4: Ethanol production economics sensitivity analysis for Triticale to ethanol conversion pathway

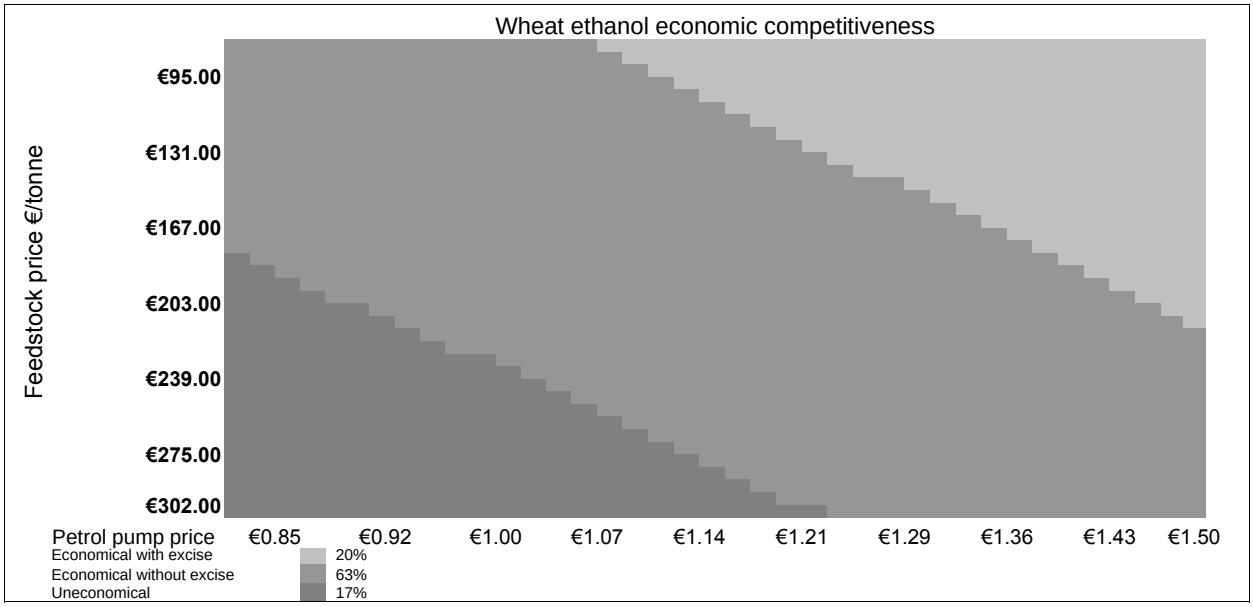
Figure 5: Ethanol production economics sensitivity analysis for miscanthus to ethanol conversion pathway

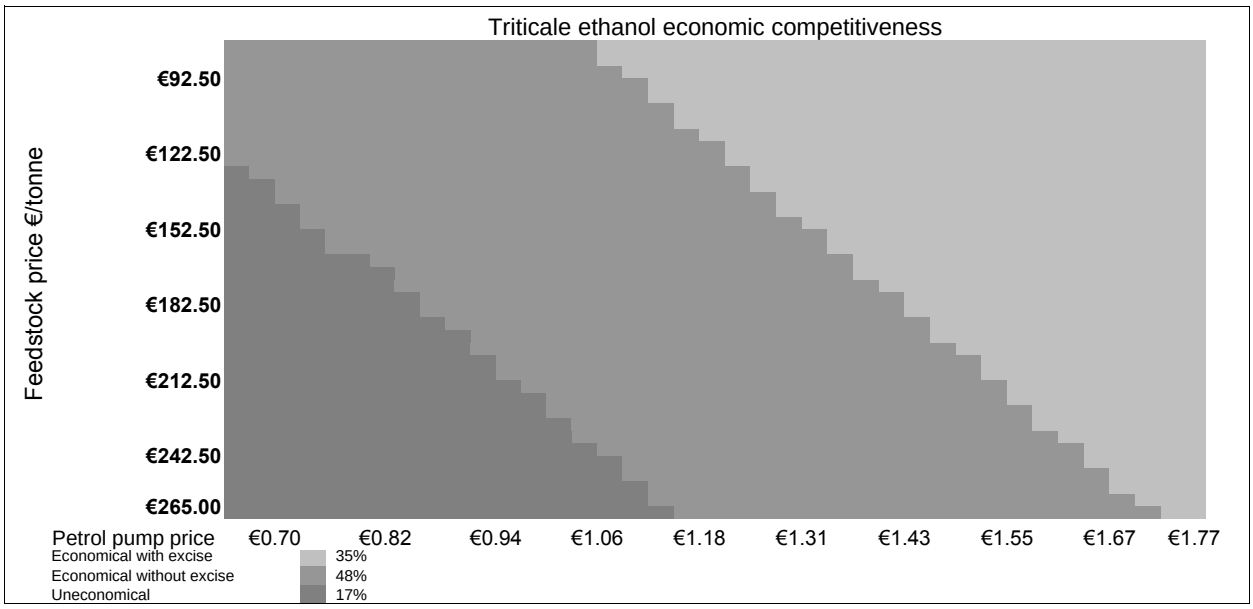
Figure 6: Ethanol production economics sensitivity analysis for sugarbeet to ethanol conversion pathway

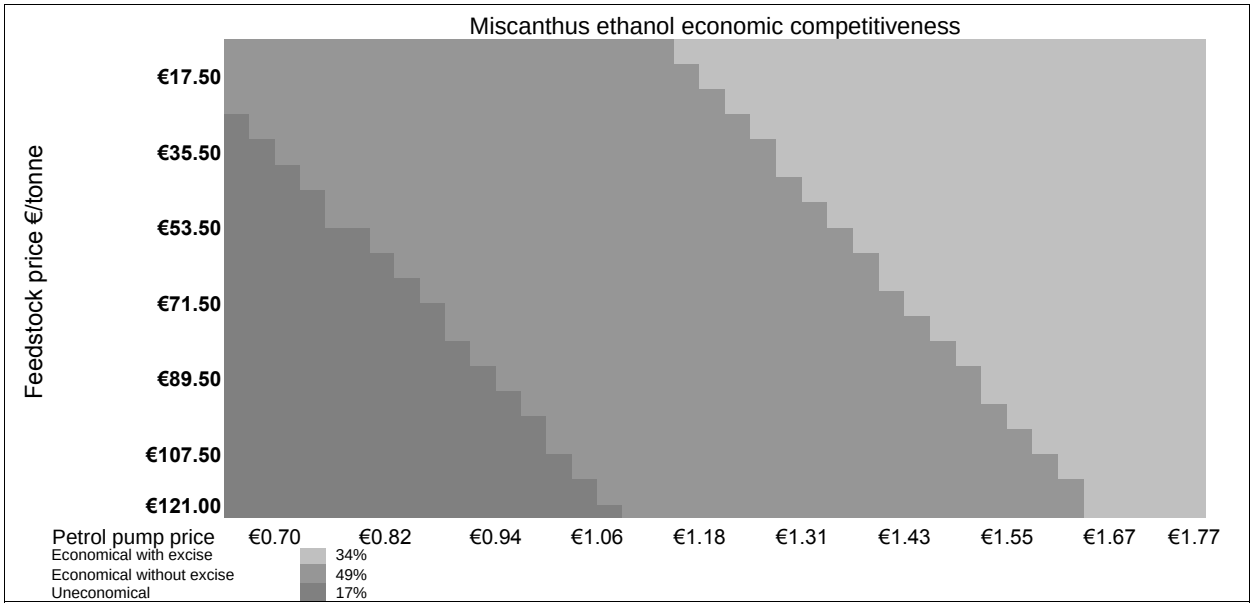
Figure 7: Ethanol production economics sensitivity analysis for straw to ethanol conversion pathway

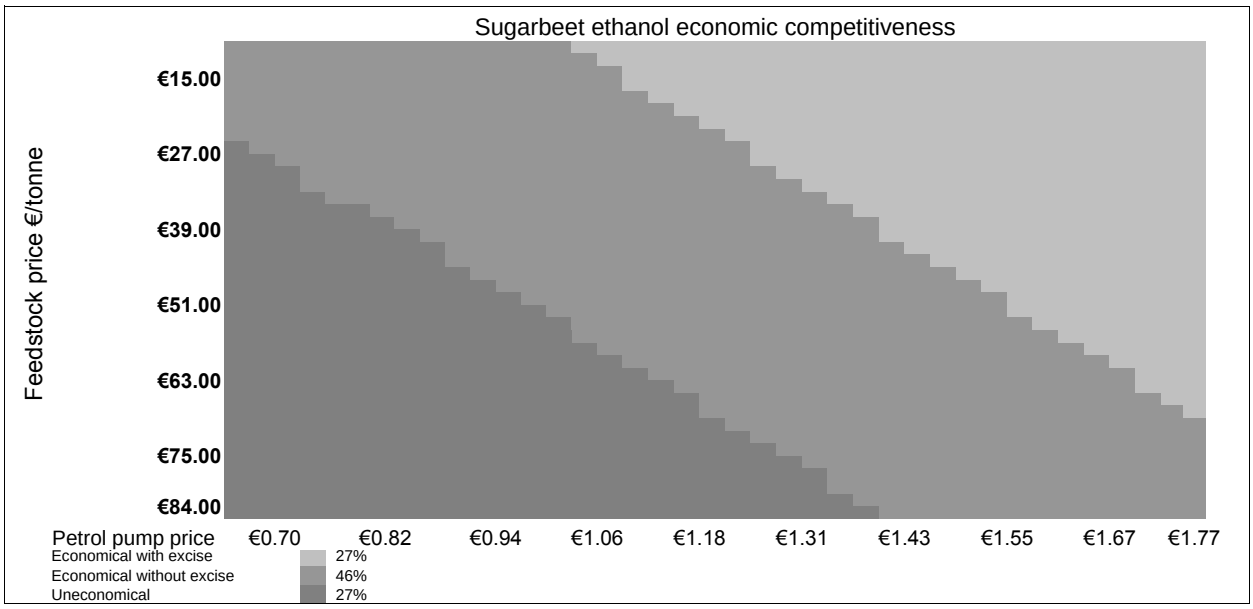

Main costs:
Stakeholder scenario
Market scenario
Inputs
Land rental
By-product value
Main product value
Transport costs
Farm level costs for each crop (C_f)
Required margin (M_f)
Market value (V_f)
Economically feasible price of feedstock F_f: $F_f=C_f+M_f$
Economic feasibility of production F_{pf}: $F_{pf}=V_f-C_f$
Capital costs
Input costs
Feedstock costs
Cost of capital
Ethanol value
Co-product value
Ethanol processing costs (C_p)
Required margin (M_p)
Market value (V_e)
Economically feasible price F_e: $F_e=C_p+M_p$
Economic feasibility of production F_{pe}: $F_{pe}=V_e-C_p$
Transport
Blending
Taxes
Distribution and blending costs C_b
Required margin (M_b)
Market value (V_b)
Economically feasible price F_b: $F_b=C_b+M_b$
Economic feasibility of production F_b: $F_b=V_b-C_b$
Overall economic feasibility

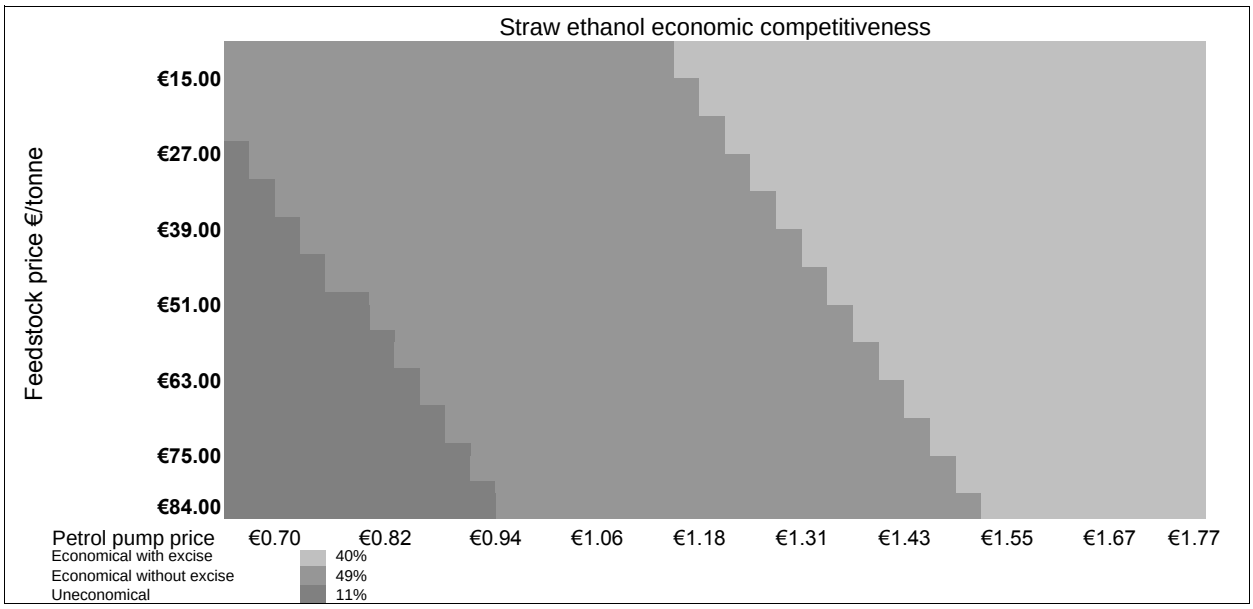

Ethanol production pathway costs - stakeholder scenario 1
(min cost)
€1.00
€0.80
€0.60
€0.40
€0.20
€-
-€0.20
-€0.40
(€/l)
Wheat
Triticale
Sugarbeet
Miscanthus
Straw
Taxes
Distribution
Co-product credits
Feedstock cost
Processing cost


Wheat ethanol economic competitiveness
Feedstock price €/tonne
€95.00
€131.00
€167.00
€203.00
€239.00
€275.00
€302.00
Petrol pump price
€0.85
€0.92
€1.00
€1.07
€1.14
€1.21
€1.29
€1.36
€1.43
€1.50
Economical with excise 20%
Economical without excise 63%
Uneconomical 17%


Triticale ethanol economic competitiveness
Feedstock price €/tonne
€92.50
€122.50
€152.50
€182.50
€212.50
€242.50
€265.00
Petrol pump price
€0.70
€0.82
€0.94
€1.06
€1.18
€1.31
€1.43
€1.55
€1.67
€1.77
Economical with excise 35%
Economical without excise 48%
Uneconomical 17%


Miscanthus ethanol economic competitiveness
Feedstock price €/tonne
€17.50
€35.50
€53.50
€71.50
€89.50
€107.50
€121.00
Petrol pump price
€0.70
€0.82
€0.94
€1.06
€1.18
€1.31
€1.43
€1.55
€1.67
€1.77
Economical with excise 34%
Economical without excise 49%
Uneconomical 17%


Sugarbeet ethanol economic competitiveness
Feedstock price €/tonne
€15.00
€27.00
€39.00
€51.00
€63.00
€75.00
€84.00
Petrol pump price
€0.70
€0.82
€0.94
€1.06
€1.18
€1.31
€1.43
€1.55
€1.67
€1.77
Economical with excise 27%
Economical without excise 46%
Uneconomical 27%


Straw ethanol economic competitiveness
Feedstock price €/tonne
€15.00
€27.00
€39.00
€51.00
€63.00
€75.00
€84.00
Petrol pump price
€0.70
€0.82
€0.94
€1.06
€1.18
€1.31
€1.43
€1.55
€1.67
€1.77
Economical with excise
40%
Economical without excise
49%
Uneconomical
11%