ETHANOL MARKET POTENTIAL AND PRICE SENSITIVITY WITHIN CANE RESOURCE PORTFOLIOS

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1 ABSTRACT

This paper assesses the potential for ethanol within the context of a financially and environmentally sustainable sugarcane resource portfolio. As the world's most economically significant bio-energy crop, the sugarcane plant is appropriately viewed as a global resource for sustainable development and climate protection. The most commercially significant bio-energy co-products at present are ethanol and co-generated electricity. The cane-based ethanol potential is shown to be roughly equal to the estimated potential fuel blending market in the year 2020, with an accompanying significant potential for carbon emission reductions. A global strategy emphasizing cane ethanol and complementary bioenergy resources has significant implications for trade, technology transfer and other aspects of international cooperation since cane ethanol has a far superior energy balance compared to other feedstocks and is based predominantly in the developing world, while demand for motor fuels is based in OECD countries.

Turning from the macro-perspective to a micro-perspective, it is useful to consider the joint economics of ethanol alongside sugar and cogenerated electricity, so that the three products can be seen in the context of a cane resource portfolio. A comparison of different alternative scenarios from a recent case study illustrates some key features of the joint economic performance of this portfolio. The economic optimisation is mainly dependent on the relationship between ethanol and sugar prices, but is also impacted by the potential valued-added provided through surplus electricity sales. Given price fluctuations in sugar and oil, there is also an element of risk reduction provided through product diversification across the portfolio. This paper argues that ethanol produced from cane is appropriately viewed in the long term within the context of the overall cane resource portfolio, for both economic and environmental reasons. A modelling structure is proposed to explore the issues in more detail in future research.

2 THE CANE RESOURCE BASE

The sugarcane plant is one of the world's most cost-effective and diversified renewable resources, offering many alternatives for production of food, feed, fibre, and energy. Owing to climatic factors, sugarcane is found predominantly in the developing world and as such represents a valuable tool in the simultaneous search for sustainable energy sources and new development alternatives. Co-generated electricity and ethanol are the most important cane co-products in commercial terms. As sugar companies look to diversify into bio-energy, new markets can emerge through international cooperation in modernising the cane resource base.

Due to the fact that sustained growth is limited to tropical and sub-tropical regions, the cane resource base is overwhelmingly concentrated in the developing world. As shown in Figure 1, India and Brazil together today account for half of global production. However, there are over 130 countries that produce sugarcane, making it a potentially more evenly distributed energy resource than fossil fuels in many respects. Africa and the ASEAN countries are among those regions that could increase their shares of world cane production through co-product strategies.

Even without expanded irrigation, there exist significant opportunities for expanding cane yields in many parts of the world, using new varieties, pest management, and other options. Assuming annual improvements varying between 0.5% and 1.5% depending on the region, a 25% increase in cane yield is achieved by 2020, as given in Table 1.

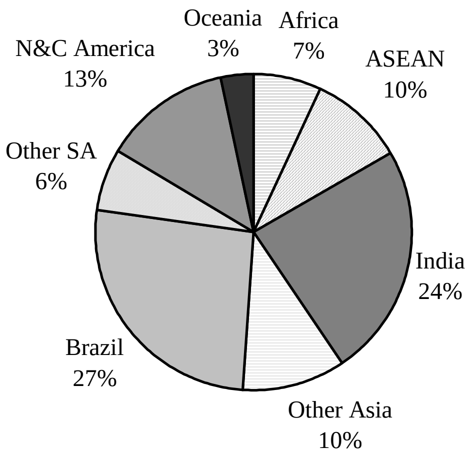

Figure 1: Shares of cane production in 2000. *Source:* [3]

In some parts of the world, there are also good opportunities for expanding the land devoted to sugarcane, assuming that concerted bio-energy strategies and the need for GHG reductions will help to open up new market opportunities. Expansion of up to 2% annually is feasible in underdeveloped and/or less densely populated areas, particularly in southern Africa. Expansion of 1% to 1.5% is feasible in parts of South America and Asia. Other regions are likely to be constrained by land pressures (India), limited markets (Australia), or limited opportunities for expansion (North America, including Central America and Caribbean). For these regions, small growth rates (0.25% to 0.5%) were assumed. These expansions in combination with the improvements in yield would increase world production by 46% by 2020 (see Table 1).

Table 1: Cane Production and Yields, Actual (2000) and Projected (2020). *Source, 2000:* [3]

	Cane Production (million tc)		*Cane Yields (tc/ha)*	
Region	***2000***	***2020***	***2000***	***2020***
Africa	86	173	63	84
ASEAN Countries	125	227	61	82
India	299	384	71	87
Other Asia	132	178	58	71
Brazil	328	442	68	83
Other South America	81	133	71	87
North and Central America	165	246	59	80
Oceania	42	54	81	95
WORLD	*1259*	*1836*	*66*	*82*

3 ETHANOL SCENARIOS

Using these regional projections for the cane resource base, some scenarios can be designed to show the bio-energy potential. It is assumed that the feedstock for ethanol production will be either molasses or cane juice. Yields were assumed to reach the levels given in Table 2 by 2020.

Table 2: Assumed ethanol yields in 2020 (litres/tc)

		Molasses		
Location	Juice	A	B	C
Brazil	93	27	15	10
Rest-of-World	87	26	14	9

There are essentially four different economic views taken by producers on cane ethanol. The first is simply that in which ethanol is perceived as having no market value. The second view is that of ethanol as strictly a by-product with much lower market potential than sugar and therefore the feedstock in this case would be C (final) molasses. A third (intermediate) view is that in which ethanol is potentially more valuable and the opportunity to be flexible in production choices between sugar and ethanol calls for the use of A or B molasses as feedstock. A fourth view is that in which ethanol is the primary or only product, and cane juice is used as feedstock. Since there are many regional differences and preferences in markets, is more appropriate to define scenarios by assuming different combinations of these perspectives. In the case of maximum ethanol production (from cane juice), it is assumed that the distillery will operate using other feedstocks 80% of the time in the off-season, so as to utilize the production capacity. Four scenarios along with the reference scenario were defined:

[1] Ref: 90% from C-molasses; 10% from B-molasses; Brazil continues its production trend.

[2] E1: 50% from C-molasses; 30% from B-molasses; 10% each from A-molasses and juice.

[3] E2: equal proportion from all feedstocks

[4] E3: 50% from juice; 10% from A-molasses; 20% each from B- and C-molasses.

[5] E4: 80% from juice; 20% from C-molasses

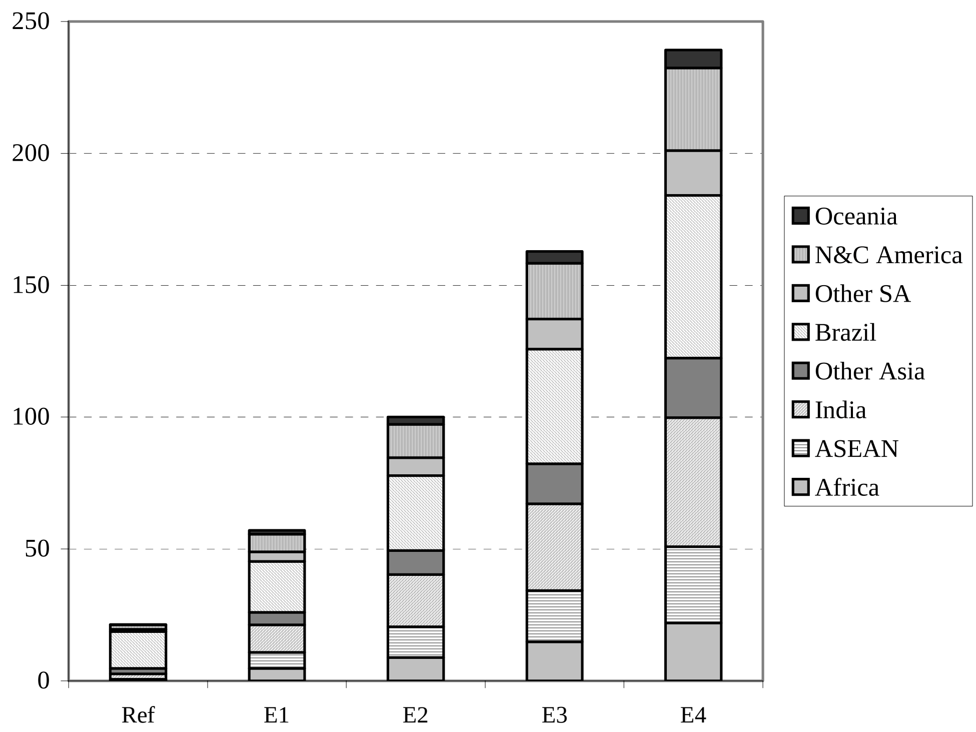

Figure 2: Ethanol production in 2020 under different scenarios (Billion litres).

The results indicate the potential for a ten-fold increase in cane-based ethanol production, under fairly modest assumptions about improvements in yields. The results also suggest the potential for a geographical redistribution in the production of ethanol (see Table 3). Regions where very little cane ethanol is currently produced could see substantial gains in market share. India, ASEAN, and Africa could potentially gain major increases in market share. India's market share would roughly double, to 20%. Brazil, which currently produces about two-thirds of the cane-based ethanol (i.e. excluding grain and other sources), would drop to 26%.

Table 3: Production and shares of cane ethanol in 2000 and projections for 2020

	Ethanol Production (billion litres)			***Share of total***		
Region/ Scenario:	**2000**	**2020 Reference Case**	**2020 E4 Scenario**	**2000**	**2020 Reference Case**	**2020 E4 Scenario**
Africa	0.1	0.2	22	1%	1%	9%
ASEAN Countries	0.3	0.4	29	2%	2%	12%
India	1.7	2.1	49	10%	10%	20%
Other Asia	1.7	2.1	23	10%	10%	9%
Brazil	11.4	13.9	62	66%	65%	26%
Other South America	0.7	0.8	17	4%	4%	7%
North and Central America	1.3	1.7	31	7%	8%	13%
Oceania	0.1	0.1	7	1%	1%	3%
TOTAL	*17.3*	*21.4*	*239*	*100%*	*100%*	*100%*

The current ethanol market is one in which Brazil exerts extreme market power, as the world's only major swing producer between sugar and ethanol. The expansion of the ethanol market could help to create many medium-size players and make the industry more competitive in the long-term. The geographical diversification will contribute to a transition towards ethanol as a global bio-energy resource rather than a regional one.

The scenarios considered here do not consider impacts on the sugar market itself. In scenarios E3 and E4, the cane-based sugar supply would all but disappear. However, the scenarios are only intended to represent the range of options available. Furthermore, by 2020 there will certainly be major changes in the sugar market that impact the sources and origins for the relevant products, especially after expected agricultural reforms are introduced and subsidies removed. At the same time, although not analysed in detail here, other crops such as sweet sorghum are expanding and will offer new feedstocks, so that the overall sugar supply will not necessarily be as linked to cane as it has been in the past.

4 FUEL SUBSTITUTION

Fuel ethanol can be blended with gasoline at levels varying from 10% to 25% with little or no effect on fuel economy and with relatively minor adjustments, if any (depending on the share) to the engine. It can also be blended with diesel in shares from 3% to 5% although some experience suggests that higher percentages can be used. A conservative assumption is made here, with a blend of 10% for gasoline and 3% for diesel. Table 4 gives current and projected gasoline and diesel consumption and Table 5 provides a comparison of the projected gasoline and diesel markets with the E3 and E4 scenarios defined above, including the trade balance under the assumption that cane ethanol is traded freely and captures the international market, given that cane is essentially the lowest cost feedstock.

Table 4: Gasoline & diesel consumption. *Sources:* [6] – 1998 data; [2] – 2020 forecast

	Gasoline Consumption (billion litres)			Diesel Consumption (billion litres)		
Region/Year	***1998***	***2020***	***2020, 10%***	***1998***	***2020***	***2020, 3%***
Africa	30	65	6.5	34	65	2.0
ASEAN	30	63	6.3	60	111	3.3
India	8	22	2.2	43	100	3.0
Other Asia	186	397	39.7	253	469	14.1
Brazil	24	50	5.0	34	61	1.8
Other South America	30	56	5.6	34	56	1.7
North and Central America	561	778	77.8	242	293	8.8
Oceania	22	32	3.2	16	21	0.6
Europe (incl. Russia)	242	366	36.6	333	439	13.2
WORLD	*1132*	*1829*	183	*1050*	*1614*	48

Table 5: Comparison of 2020 blending scenario with ethanol scenarios E3 and E4 (billion litres)

Region	*10% gasoline + 3% diesel*	*Ethanol (E3 scenario)*	*Balance*	*Ethanol (E4 scenario)*	*Balance*
Africa	9	15	6	22	13
ASEAN	10	19	9	29	19
India	6	33	27	49	43
Other Asia	56	15	-41	23	-33
Brazil	7	44	36	62	55
Other South America	8	11	4	17	9
North and Central America	88	21	-67	31	-57
Oceania	4	5	1	7	3
Europe (incl. Russia)	52		-52		-52
WORLD	*239*	163	-76	*239*	*1*

The comparisons are interesting in several respects. First, the total potential for cane ethanol in the E4 scenario is roughly equal to the projected blending demand. Second, the disparity between current centres of demand and supply suggests a need for addressing the transportation difficulties associated with ethanol, if it is to become an international product. Third and finally, the export/import implications offer a strategy for north-south cooperation in ethanol, providing Africa and other regions with new export options while achieving environmental goals. Given that the energy balance of cane ethanol is several times better than that of grain ethanol and other sources, environmental costs of transport are easily outweighed by higher renewable energy content. There are major political barriers in the form of protectionism, but as more prominence is given to global free trade, these issues will have to be addressed long before 2020.

The E3 scenario might be considered the more likely scenario from a global market perspective, given the trade distortions that persist. In particular, the high deficit for North America might be expected even in the long run, given the subsidies provided to the domestic ethanol industry in the U.S., which is based almost exclusively on corn (and therefore having a poor energy balance). On the other hand, it is interesting to note that total production and consumption could balance in scenarios similar to E3 and E4 if a NAFTA structure emerged fully across the Americas.

Of course it is important to note than this is not an ethanol market analysis, because it is focused only on cane ethanol, due in part to the low cost and high productivity of cane ethanol in energy and economic terms. In a market-oriented analysis, competing sources of ethanol would have to be assessed in a comparable manner. Ethanol from corn will continue to be important in the U.S. and elsewhere if subsidies continue to be provided. Other feedstocks such as municipal solid waste and sweet sorghum are likely to increase their share as scale economies are achieved and costs come down. In terms of the longer-term options, cellulosic biomass as a feedstock for ethanol production could become an important contributor to world ethanol production by 2020. However, the economic and environmental implications of cane ethanol widely available on the international market has special meaning in a North-South context and with respect to climate mitigation through the Clean Development Mechanism and other areas of climate cooperation.

Ethanol substituted for gasoline saves approximately 2.2 kg Carbon per litre, and an estimate is made for each region in Figure 3. Total estimated potential reductions for 2020 range from 125 to 526 million tonnes Carbon across the four scenarios. These totals are significant in comparison to the first commitment period Kyoto targets. For example, EU carbon emissions in the energy sector were 3150 million tonnes in 1990. The cane ethanol potential is equivalent to 4% to 17% of this total, which compares favourably with the EU Kyoto reduction commitment of 8%.

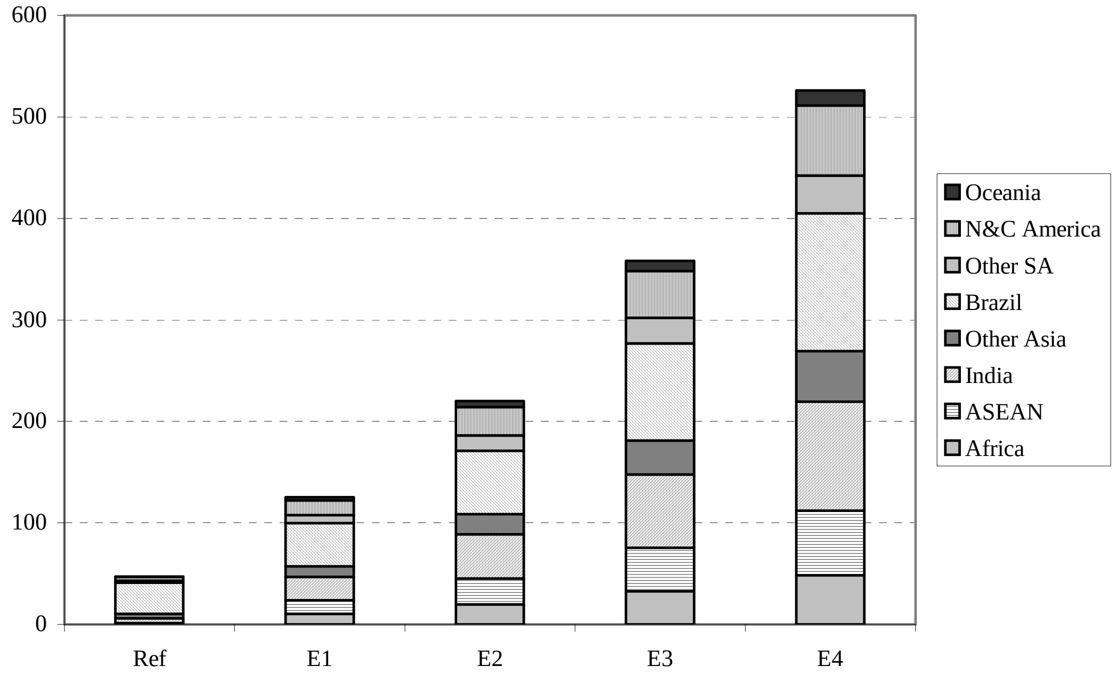

Figure 3: Carbon reductions in 2020 under different scenarios (Million tonnes C).

5 ETHANOL MARKET SENSITIVITY IN CO-PRODUCT SCENARIOS

Turning now from the global potential to some micro-level aspects of the cane ethanol market, it is useful to look at the different feedstock options in more detail. In particular, it is instructive to compare the choices faced by producers (and investors) with respect to the feedstock options and their implications for choices between sugar and ethanol production. Table 6 provides production parameters for different strategies from a recent case study in Zambia [1]. In this study, there were slightly over a million tonnes of cane to be harvested annually and the factory was to be configured for 250-300 tonnes of cane (tc) per hour.

Table 6: Alternative strategies for sugar and ethanol production. *Source: [1]*

		Sugar Production (tonnes)		Ethanol Production (1000 litres)		Ethanol Feedstock
Strategy	**Strategy Description**	*Design capacity*	*Realizable capacity*	*Design capacity*	*Realizable capacity*	

Label			(90%)		(90%)	
REF1	Sugar only	133,096	119,786	none		none
REF2	Ethanol only	none		87,360	78,624	Cane juice
REF3	Sugar & ethanol, fixed quantities	133,096	119,786	10,168	9,151	C molasses
REF4A	Sugar & ethanol, flexible quantities	105,160	94,644	26,378	23,740	A molasses
REF4B	Sugar & ethanol, flexible quantities	125,360	112,824	14,661	13,195	B molasses

The main issue with respect to market feasibility is the determination of the opportunity cost of diverting production from sugar to ethanol, which is determined from the cost structure in combination with the sugar and ethanol prices. Using a sugar price of 370 USD/tonne, an ethanol price of 0.45 USD/litre and a discount rate of 10%, a profitability analysis was conducted using the UNIDO COMFAR model, and some of the results are summarised in Table 7.

Table 7: Investment profitability analysis for alternative strategies. *Source: [1]*

Strategy Label	Initial Investment (million USD)	Net Present Value (million USD)	Internal Rate of Return (%)	Payback (Years)
REF1	132	32.7	13.9%	6
REF2	120	-25.2	-24.5%	N/A
REF3	133	26.9	13.2%	6
REF4A	130	-21.5	7.3%	N/A
REF4B	130	-15.4	-11.9%	N/A

Scenarios are financially viable if they have positive NPV and therefore IRR of 10% or higher. The results indicate that the sugar-only case and the “sugar in fixed quantities” case (C-molasses) are financially viable, due to the high fixed costs of sugarcane production and the rather high market price assumed for sugar. A further sensitivity analysis showed that increasing the ethanol price to 0.5 USD/tonne would make the other three scenarios financially viable [1, p. 64]. Although this ethanol price is high in comparison to established markets in Brazil, it could be feasible if carbon credits and other financing mechanisms were available. Furthermore, the calculation should take account of ancillary benefits, such as a simultaneous phase-out of lead additives, an important health issue in African countries, most of which still use leaded fuel.

The next step in the analysis is to include consideration for surplus electricity from bagasse cogeneration. The back-pressure turbines installed at most factories today provide only a small surplus of electricity after accounting for the factory needs. A Condensing Extraction Steam Turbine (CEST) could potentially provide a ten-fold increase in surplus electricity for sale to the grid or to other industries, assuming adoption of steam conservation measures so as to optimise overall efficiency and the use of cane trash in addition to bagasse. Using standard assumptions, the scenarios from Table 7 were assessed with the addition of CEST systems operating year-round and using an electricity price of 35 USD/MWh, and the results are given in Table 8.

Table 7: Investment profitability analysis for strategies with CEST cogeneration. *Source: [1]*

Strategy Label	Initial Investment (million USD)	Net Present Value (million USD)	Internal Rate of Return (%)	Payback (Years)
CEST1	167	38.1	13.7%	6
CEST2	156	-24.0	-18.6%	N/A
CEST3	169	34.2	13.3%	6
CEST4A	166	26.6	11.9%	6
CEST4B	166	23.1	12.3%	6

All but the ethanol-only scenarios are financially viable when CEST cogeneration is added. In other words, the addition of cogeneration improved the profitability of the ethanol scenarios, making scenarios 3, 4A, and 4B financially viable. The ethanol-only scenario remains unviable, as it depends only on the relative sugar/ethanol prices. The improvements in the other three scenarios are due mainly to the profitability of cogeneration, but also because internal electricity demand is lower when less sugar is produced since sugar production is more energy-intensive than ethanol production. Consequently more electricity can be sold as ethanol production increases. These results are quite interesting, because they suggest some of the opportunities for cross-subsidisation within a cane product portfolio. One might accept lower profitability on a given product if the whole portfolio is viable. The addition of cogeneration leads to the conceptualisation of the three products within the overall cane portfolio and calls for joint economic analysis that emphasises economies-of-scope.

A first-order analysis of the above or similar cases might suggest that ethanol should be dropped since cogeneration is more profitable. A more detailed analysis would include considerations for risk and product diversification, given fluctuations in prices over time. Leaving the purely financial analysis and applying environmental considerations might also change the way these products are viewed together. Carbon crediting and other environmental add-ons could be institutionalised in a way that takes advantage of the value-added provided through multiple products. The marginal investments in an existing resource base will generally be less expensive than new investments with respect to their cost of achieving environmental benefits. It is also important to note that the price assumptions for sugar and ethanol were somewhat arbitrary given the distortions in these markets and a great deal more price sensitivity analysis is needed.

6 CO-PRODUCT MODEL FOR FURTHER RESEARCH AND ANALYSIS

The case study from which the above examples were drawn does have some parameters that are specific to the country and region, particularly in labour costs and some operating costs. The high sugar price was based on some assumptions about preferential supports that are likely to change in the future. However, some of the costs and prices are similar around the world, or are at least comparable to a reasonable extent. As a result, the analysis could be generalised and parametised on variations in key output prices and input costs. In this section, a general modelling framework is presented, to be used in future research to analyse the cane co-product tradeoffs.

In this model, the firm(s) chooses production levels for a set of *4n* final products, as given in the matrix $\mathbf{q} = \{q_{ij}\}$. Markets for these final products are assumed to be competitive and firms are price-takers. These products are associated with the resource streams and the feedstock options. This set of final products is therefore characterized as a 4 x n matrix.

$q_{11} \ldots q_{4n}$ = product quantities

$p_{11} \ldots p_{4n}$ = market prices

$C_{ij}(q_{ij})$ = cost functions for each product

Π = profit function for the firm

α_{ij} = policy parameter = 1 where market is feasible; 0 if not

If mass balance is applied (with proper conversion of units), these quantities can be related to the quantities for intermediate products (ethanol feedstocks) x_i via a set of equality constraints:

$$(1) \quad x_i = \Sigma_j q_{ij} ; i = 1, \ldots 4$$

The profit function is then to be maximized subject to the above constraints:

$$(2) \quad \text{Max } \Pi = \{\Sigma_i \Sigma_j p_{ij} q_{ij} \alpha_{ij} - \Sigma_i \Sigma_j C_{ij}(q_{ij})\} ; \alpha_{ij} \in (0,1)$$

The binary parameter α_{ij} is used here to allow for cases where a market is not feasible due to spatial constraints or the absence of an enabling policy. Note that this formulation assumes that cost functions are separable for the various final products, which will not always be the case. A joint cost function could be specified where appropriate, although the solution and its interpretation would generally be more complicated. The form of the cost functions must necessarily be determined from empirical analysis.

Extension of the model to include uncertainty in prices is fairly straightforward, and firms in this formulation consider market risk. The firm(s) chooses a sugarcane co-product strategy, which is defined as a set of production choices **q**. The model is based on the same definitions as above, but the following additions or changes:

$p_{11....}p_{4n}$ = market prices (italics = random variables)

Π_{mean} = Expected Value of profit function for the firm

It is useful to consider how production choices influence the overall profit based on the covariance between prices, i.e. using the criterion of mean-variance efficiency. Such an approach implicitly assumes that the utility of wealth depends only on the first two moments of the probability distributions. A similar assumption is made in the celebrated Capital Asset Pricing Model (CAPM) although it should be noted that there are few other similarities between this model and CAPM. This model is concerned with a few empirically observable parameters whereas the CAPM is a theoretical construction dealing with the portfolio of *all* risky assets. [8].

It is desirable that any co-product strategy be mean-variance efficient, i.e. the strategy should minimize variance in profits for a given expected level of profits. This strategy can be formulated as follows:

$$(3)\quad \text{Min VAR}\ \{\Sigma_i\Sigma_j\, p_{ij}\, q_{ij}\alpha_{ij} - \Sigma_i\Sigma_j\, C_{ij}(q_{ij})\}\ ;\ \alpha_{ij} \in (0,1)$$

$$\text{such that:}\quad E\{\Sigma_i\Sigma_j\, p_{ij}\, q_{ij}\alpha_{ij} - \Sigma_i\Sigma_j\, C_{ij}(q_{ij})\} = \Pi_{mean}\ ;\ \alpha_{ij} \in (0,1)$$

In this formulation, a co-product strategy is analogous to an investment portfolio in the sense that other things being equal (i.e. for a specified return) an investor prefers less risky strategies. Let σ_{ij} represent the covariance between p_i and p_j. The cost functions contain no random variables and thus their Variance = 0. The minimization problem can then be expressed as a function of the covariance between prices:

$$(4)\quad \text{Min}\ \{\Sigma_i\Sigma_j\, q_{ij}\alpha_{ij}\sigma_{ij}\}\ ;$$

such that:

$$E\{\Sigma_i\Sigma_j\, p_{ij}\, q_{ij}\alpha_{ij} - \Sigma_i\Sigma_j\, C_{ij}(q_{ij})\} = \Pi_{mean}\ ;\ \alpha_{ij} \in (0,1)$$

The above model will serve the purpose of quantifying the value of adopting risk reduction strategies based on co-product portfolios. The strategies are only aimed at the risks associated with price fluctuations and not at other sources of uncertainty. There is no consideration for the technological risk that might be associated with the performance, cost, or availability of certain technologies, i.e. technology is known and static. Consequently technical advances are not considered endogenously in a model of this kind. There are also major differences in the cost structure across different regions of the world due to equipment, supplies, infrastructure, and the foreign exchange implications. Consequently, implementation of the model is likely to be regionally specific or even country-specific, particularly where equipment is imported and must be paid in non-local currency.

7 CONCLUSIONS

This paper presents a macro- and micro-perspective on the scenarios for expanded production and markets for ethanol from sugarcane. The global cane ethanol potential for 2020 is estimated as ranging between 57 and 239 billion litres per year in the four scenarios defined. At the high end, the total potential is roughly equal to projected demand based on a worldwide blend of 10% with gasoline and 3% with diesel. The carbon benefits range from 125 to 526 million tonnes, which compares favourably with Kyoto reduction targets for the EU, for example.

Turning to the micro-perspective at the level of individual firms or producers, it is useful to analyse ethanol in more detail as part of the cane portfolio that includes, at a minimum, surplus electricity in addition to sugar and ethanol. A recent case study illustrated some of the relevant features of such analysis. Consideration for cogeneration and other co-products can improve overall financial viability. Although the ethanol-sugar trade-off is fairly clear at the margin, once additional co-products are added, the overall equation for a cane portfolio has to be adjusted. Furthermore, due consideration must be given for price fluctuations and the value of product diversification away from sugar. A generalised modelling framework is presented through which product diversification, price sensitivity and risk reduction strategies can be analysed in more detail in future research.

In spite of its tremendous bioenergy potential, cane is still largely seen as a source of sucrose. The transition to cane as a bio-energy resource requires much more international cooperation if it is to help in meeting GHG reduction targets while also defining new paths for sustainable development and returning the sugar industry to competitiveness. Because of its high efficiency and its concentration in the developing world, the cane resource should be viewed as a global resource for sustainable development and should command much greater focus and concerted policy action through north-south and south-south cooperation.

8 DISCLAIMER AND ACKNOWLEDGEMENTS

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