Mathematical combination problem pertaining to bio-refineries

Industry: Renewal energy

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Rising oil prices and climate change are increasing the viability and necessity to produce plant based, as opposed to fossil based products, such as bio-plastics, bio-polymers, bio-fuels and other renewable energies. When it comes to converting radiation and water into biomass, sugarcane is one of the two most productive plants known to man. Also, sugarcane is already a commercially cultivated crop and is therefore a good bio refinery feedstock candidate. Worldwide there has been a significant drive within the sugar industries to research and develop bio refinery technologies. There are now more bio refinery technologies available than what we can install at any single sugarcane factory. Sugarcane comprise of various compounds, such as fibre, sucrose, glucose, fructose and starch. These compounds make up the feedstock for different bio products and it is therefore most viable that more than one bioprocess will be installed at a single sugarcane factory. A suitable combination of processes hence needs to be selected for a specific sugarcane producing area. This selection should ideally be based on economics, the typical composition of cane in the region, exposure to risk and the existing infrastructure on the ground. The purpose of this project will be to demonstrate how mathematical optimisation methods (and perhaps other approaches) could assist the sugar industry with this combinatorial problem.

The following description may help to conceive this research project:

Assume there are *n* known bio refinery processes available, such as

- a raw sugar crystallising plant,
- a sugar refinery,
- a bio ethanol distillery,
- a cogeneration electricity plant, etc….

Each of these processes demands a number of input feed stocks and will produce a set of output products and by-products. Table 1 provides a simple example of inputs and outputs associated with different processes (note that this table is just an example and needs significant refining). Typical input and output products are fibre, water, steam, sucrose, glucose, molasses, sugar, etc… The inputs for a cogeneration electricity plant, for example, would be water and dry cane fibres (either in the form of bagasse or trash). Outputs would typically include steam, water, ash and electricity. In return, the outputs of one process could easily make up some of the inputs for a subsequent process.

In addition to indicating whether or not an input / output is associated with a bio refinery process, the amount of input / output could also be expressed in relative terms. A cogeneration process, for example, may require 3 units of fibre and 4 of units of water in order to produce 1 unit of electricity, 2 units of steam and 0.75 units of ash.

Table 1. An example of different bio refinery processes and their respective input feed stocks and subsequent output products.

	INPUTS											OUTPUTS													
PROCESS	sugarcane	dry fibre	sucrose	fructose	glucose	sugar	reduced sugars	bagasse	water	steam	electricity	dry fibre	ash	sucrose	fructose	glucose	water	reduced sugars	bagasse	raw sugar	ethanol	venasse	steam	white sugar	electricity
Cane preparation	X										X						X		X						
Electricity plant		X							X				X										X		X
Raw sugar plant			X						X	X	X									X					
Ethanol plant				X	X		X			X	X										X	X			
Sugar refinery						X				X	X				X	X								X	
etc…																									

The first objective of this study is to select the most suitable combination of bio refinery processes for a site based on:

1. A given amount of sugarcane (and perhaps other crops, like soybean) containing a certain quantity of compounds (like fibre, sucrose, starch, etc...)
2. A market price for each product that can be produced.
3. A cost of production for each product (based on capital and running cost) and a minimum economies of scale for each process (e.g. you cannot justify a bio ethanol plant that will only produce 10 litres of bio ethanol per annum).

The optimisation procedure must attempt to find the most suitable combination of processes by concurrently maximising profits AND minimising wastage.

The second objective builds onto the first one and is primarily based on sensitivity analyses. In this case we can assume that there are already some processes on the ground, in which case the cost and capacity of production (point 3 above) may be altered. It will be interesting to examine to what extend these changes will influence the solution. As a risk indicator, it will also be interesting to examine how robust the solution is if some of the market prices (point 2 above) had to be changed, or if the quality of the feedstock (point 1 above) changes.

The third objective will be identify possible synergetic new opportunities that are not currently in the solution space. Certain compounds, like starch, fibre, molasses or even coal could be imported into the bio refinery from another site. In this case it will be interesting to examine the optimal combination of processes in the absence of some local feedstock constraints. This may open opportunities that are significantly more profitable and may encourage different sugarcane mills to share (or trade) feedstock compounds among each other. Some factories, for example, may purchase surplus fibre from other nearby factories or from framers' trash residues in order to justify a sizable cogeneration plant.