A market driven algorithm for the assessment of promising biobased chemicals

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Abstract

Actors willing to participate in biomass-based value chains need to screen through a vast number of product options to identify the most promising ones. This is challenging as (i) processes for biomass-based chemicals/materials are still in development stage, thus do not perform well in techno-economic evaluations, (ii) factors as which and how many links of the value chain should be uptaken, are not fully addressed by techno-economic analysis. Inspired by the Five Forces framework for industry analysis, this work presents an algorithm-like approach for assessing the attractiveness of biomass-based products. The algorithm relies on market data to classify the different sources as posing a low, medium or high threat to the profit of a company that is considering production of a certain chemical/material. The approach is exemplified by analyzing the attractiveness of the biomass-lactic acid-PLA route in the context of defining pathways for development of a biomass-based industry in Uruguay.

Keywords: Bio-refineries, Product portfolio, Five forces (Porter) analysis, PLA

1 Introduction

Replacement of the traditional fossil based chemicals by biomass based chemicals has been in the spotlight since the early 2000s. As of today a vast number of chemicals and processing routes have been proposed [1], [2], [3], [4], many other are under development, and frame-

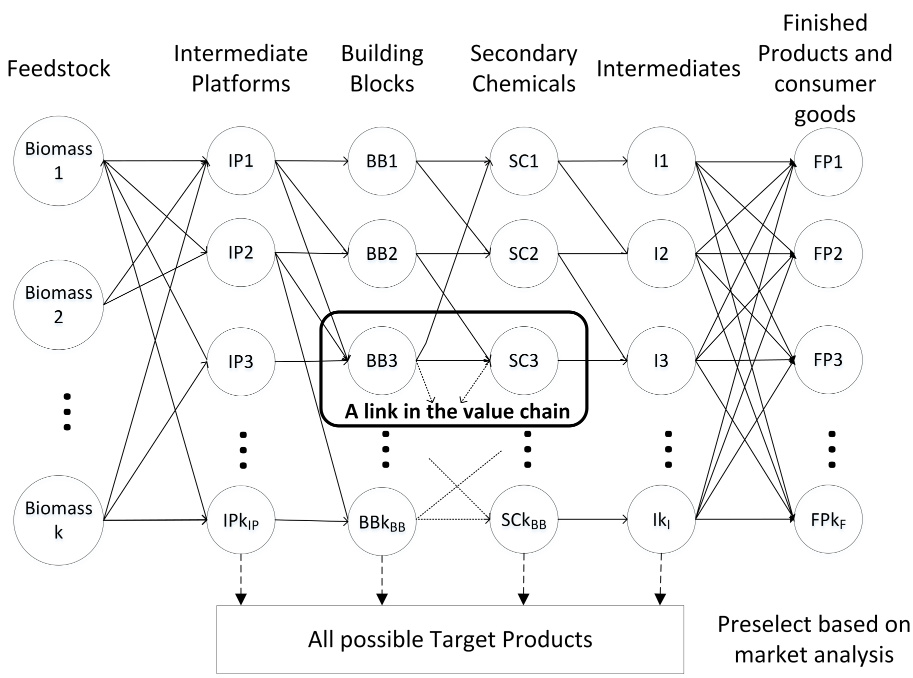

Figure 1: Scheme of the biomass to consumer products value chain: biomass is upgraded through a series of chemical compounds: Intermediate Platforms, Building Blocks, Secondary Chemicals and Intermediates. Classification coincides with the diagram in DOE "top ten" report [1]. In the most general case all these chemicals are possible target products. Preselection of the product portfolio should be done based on a systematic market analysis and taking into account the place the actor occupies in the value chain, then economic indicators combined with superestructure optimization may be considered for final selection (see Fig.S1).

works for the identification of molecular characteristics that make a chemical a promising "replacement chemical" have just been recently been proposed [5].

Still, screening through these options and identifying the ones that will make it to the market is a challenging task. Techno-economic analysis (TEA) is for Chemical Engineers the first choice for screening. However, it is of limited use in the bio-refinery context, in which most technologies are still in development or non-optimal stage and thus perform poorly when compared to the highly optimized fossil-based technologies. In addition, TEAs alone do not take into account factors that move the needle towards commercialization of biomass based products. For example, the willingness of the general public to pay more for more sustainable goods (see [6]).

An aspect that is important to the screening process, and usually overseen, is the fact that many actors seek the development of a biomass based industry, each have a different perspective, pursue a different interest, and thus have a different answer to the "what product should we make out of biomass?" question. Looking at the bio-refinery development problem from a holistic perspective, we have identified five classes of actors that have (potentially different) interests in the definition of a bio-refinery product portfolio. Before discussing each, it is pertinent to introduce the biomass to chemicals value chain and some considerations that are important to this work. Fig. 1 schematizes this value chain which starts with biomass based feedstocks that are processed through different pre-treatment steps into intermediate platforms (eg. sugars), these into building blocks, which in turn are converted in secondary and intermediate chemicals before production of consumer products. In principle, any of these building blocks, intermediates or secondary chemicals is a possible target product for a future bio-refinery. TEAs that analyze the overall conversion process from biomass to a specific compound, do not take into account that the chemicals' value chain is usually distributed among different companies (actors). Thus, implicitly assume the position of either (i) a single actor bio-refinery in which the actor dominates all the processing steps up to the target product, or (ii) that of an overarching entity that ignores internal interactions/restrictions among the different actors [7]. On the other hand TEAs that focus on a single conversion step, for example fructose to HMF [8] which is placed in the middle of the value chain, implicitly assume a distributed position in which the actor takes for granted the access to a certain chemical at a certain quality and price (without caring about the original biomass feedstock itself), and sells the upgraded chemical to other actors for further processing. Analyzing the biomass to chemicals value chain as distributed and understanding where each actor "plays" in it and how it connects with downstream and upstream actors, is in our opinion a key point to address for advancing on the definition of a future biomass based industry.

Below, we provide a brief discussion on the actors that we have identified as having an interest in the definition of a bio-refinery product portfolio and hypothesize on their interests within the value chain:

Chemical processing industries (CPI's) These are the companies that will upgrade the biomass and/or biomass derived chemicals. Their interests lie in producing green products, that might be similar to the ones they already produce from fossil sources, or completely new ones. These companies may already be installed in the market or have a particular set of clients to whom they supply. Their decision will probably be more related in how to satisfy the needs of their clients, and how to fit in already existing chemical products value chains. Deciding how many links to capture is part of their decision. Techno-economic analysis as well as expertise and current position in the market are required inputs. They may also exploit the "greener" or "more sustainable" characteristic of their product/process to sell the product at a price above the non-green options available in the market.

Biomass based feedstocks owners In general, these actors already participate in the market, occupying a place at the very beginning of the processing value chain. They may produce the biomass as their main product (e.g. energy crops) or as a residue of another process (i.e. other crops, forest related activities, food processing industry). In case of owners of residual biomass, development of a bio-refinery is not usually the core of their business, but see in its development a venue for getting additional profit. This additional profit may come either from selling the biomass itself or by overcoming disposal and treatment costs. Forward integration to produce chemicals, might be a possibility in cases where they already know the market, already consume a product that could be obtained from biomass and/or the target chemical is just a step away in the processing value chain.

Researchers Researchers are actors interested in solving problems. Depending on their particular expertise they may focus on developing new chemicals/materials, overcome technological bottlenecks or develop new technologies, etc. Specific to the academic sector, there is an expectation of novelty and impact, which results in a publication. Researchers from non-academic sectors may focus more on further developing academic based findings and scaling-up the technologies. Altogether researchers span the overall value chain, some specializing in certain parts, some having a wide overview, some analyzing the effects of a bio-refinery beyond the processes themselves, eg. their interaction with the environment, resources and society. Their interest in market analysis and TEAs lies in the fact that if positive, they provide stronger arguments for applying to grants.

Capital investors These actors are the ones who have the resources to materialize the bio-refinery. They will take into account returns and risks, and most probably invest in one or a few (not necessarily connected) links at a time, if it is more advantageous than other investment alternatives. Market attractiveness as well as TEAs of the different options are inputs that they take into account for decision making.

Politicians or government based entities These entities are the ones that have a wide overview of the biomass to products value chain, and for strategic reasons might pursue a design as if it were a single actor. Their objectives generally include generation of jobs, long term development strategies such as expansion of the already existing value chains or establishment of new connections between the links, substitution of imports, promotion of a particular economic sector, etc. Placing funds for directed R&D is also at the core of their decisions. For them, TEAs play an important but secondary role as these entities have the power of placing subsidies to pursue a particular goal. Understanding the market, and in particular how to fit in worldwide value chains and attract investors, is a key aspect for policy makers. In order to do so, they may want to identify actors, their connections, the obstacles that they face, and the opportunities to improve the "link-ability" among them.

Definition of a bio-refinery product portfolio using market-driven approaches is uncommon but not unheard of in the Chemical Engineering community. The most relevant examples come from the Stuart group, who has studied Canada-based biorefineries: [9] summarizes the work related to the Forest bio-refinery; while [10], [11] and [12] present different analysis related to the triticale biorefinery. These contributions have focused on the metrics that should be calculated to assess the different options and how to weigh them in order to represent the point of view of the decision maker.

In here, we have taken a complementary approach and base our decision-making strategies on the "Five forces" framework proposed by Porter [13]. Porter analysis is a tool that is commonly used by managers and decision-makers for the development of business strategies. The main concept behind the framework is that besides businesses that sell the same products (i.e. direct competitors), suppliers, customers, potential entrants to the market, and products that might substitute the ones sold by the company, will also affect the level of profits. The tool fits perfectly in our value-chain vision of the bio-refinery as once decided how many links are we interested in capturing, downstream links become suppliers, and upstream consumers. Then depending on the results of the analysis the links to be captured might be changed. Apart from suppliers and consumers, the tool also analyzes the potential of attracting new entrants, product substitutes and the rivalry with existing companies. The intensity with which each force is expressed depends on sources that are commented in Section 2.2. If the forces are intense then, the company will not have high profits, or if entering the market will face low IRRs.

Contributions that have applied Porter's Five Forces analysis to bio-refinery problems include the work from Stern [14] who evaluated the attractiveness of producing dietary fiber products (cellulose-based products, gum arabic and arabino-galactan) from wood for companies operating in Germany, Switzerland and Austria; the MSc. thesis from Borgman [15] who utilized Porter's model to analyze the structure of the bio-ethanol market with the aim of formulating strategic options for large scale European producers; and the MEng. thesis from Bruce [16] who also analyzed the structure of the bio-ethanol market in order to assess advantages and disadvantages of bio-ethanol fuel in the U.S.

The usual way to assess the strength of the each source considered in the Five Forces analysis, is a qualitative description of what the source involves and an also qualitative argument stating how much this source affects or not the particular case that is under study. In some cases (see [15]), market data is used to backup the argument. However, the overall qualitative nature of the analysis and the multiplicity of actors (i.e. government, multinational corporation, already in the market, trying to enter in the market) whose point of view could be taken to perform the analysis, makes it difficult for an engineer working on the assessment of priorities for bio-based products to (i) understand the rationale and follow the line of thought behind each assessment, (ii) systematically compare the options and (iii) propose "what if" scenarios to analyze solutions that mitigate or enhance a particular source.

The objective of this work is to present an algorithm-like methodology for screening/assessment of promising bio-based products using a Porter's Five Forces approach. The rationale is that Porter's descriptions can be translated into questions and parameters that are pertinent to the development of a biomass based chemical industry. Then, these questions can be put into decision making trees to categorize and infer on the strength of the sources. We envision our methodology to be used by decision makers to understand their own or other actor's positions.

We exemplify the systematic through the study of the biomass-lactic acid-PLA route in Uruguay: a country with no proven fossil feedstocks reserves but plenty of biomass and biomass-based residues, that sees in the expansion of the biomass based value chains a promising pathway for development.

2 Methodology

This section is divided in two parts: the algorithm itself and its connection with Porter's original work [13] is presented in the second part; in the first part we provide an organized list of the data that needs to be collected for conducting the algorithm.

2.1 Data needs

As the result of the analysis is highly dependent on the perspective of the analyst, the first need is to clearly define whose perspective is the decision maker taking. This is a key definition, as the decision maker might really want to know if her/his business will be competitive, or a decision maker, for example a governmental entity, might be trying to understand which forces will another actor face and take actions to mitigate/intensify them. In this second case we will distinguish between the *Decision Maker*, this would be the real actor, and the *Target Decision Maker (TDM)*, this would be the actor whose perspective is considered.

A summary and roadmap of the data required for the analysis is presented in Fig. 2. To start the analysis the *TDM* selects (1) a Target Product, (2) a Geographic Target Market, this is the market where the product will be sold, i.e. the location of the customers, and (3) a Geographic Location, this is where the processing plant is or will be located.

Once the Target Product is selected, its possible uses needs to be listed (P1) and data from global market reports (P2) and techno-economic analysis (TEA) (P3) be gathered. From these last two the most important information is that of market growth (CAGR values) and an estimation of capital requirements for at least one scale of production. From the list of target uses, two things need to be done. The first one is to classify each product/use combination (P6); we propose (and have used throughout the text) the following categories: For the *Target Product*: (i) New: refers to a product that is not yet commercialized in the Geographic Target Market (ii) Existing from fossil feedstock sources: refers to a product that already exists in the market and the target product intends to act as a bio-based replacement of it (iii) Existing from biomass based sources: refers to a product that is already obtained through a biomass based pathway, and has attracted renewed interest in the context of a future biomass based industry. For the *Target Use* the categories are New and Conventional and are both self-explanatory.

The second one is to identify current products that might be substituted by the Target Product (P7), and the differences between them from a customer perspective (P8). The goal of this exercise is to be able to infer about the cost incurred by our customer for switching from the product the customer currently uses to our proposed Target Product and if this extra cost will in the end result in a benefit for the customer (P9).

The choice of a Geographic Target Market allows the *TDM* to look for specific information for that market. The search should be done for both the Target Product (1) and the possible substitutes (P7). Relevant data in this case are import/export and production data (M1). Import/export data is collected by customs. Potential sources of production data are government departments and agencies, although some may only be available if physically in the territory. The data collected allows for the estimation of a market potential and the price of the product in the market (M2), and also for the identification of the companies involved (M3). All the companies involved should be further classified as *Competitors* or *Consumers*. Competitors (aka incumbents) (M4) are the companies that produce or import the Target Product to the Geographic Target Market for distribution to other companies; Consumers (M5) are the companies that currently purchase from the Competitors or directly import for their own needs. Data needs required to analyze the competitors is listed in (M6), while that required for the consumers is listed in (M7).

Given the choice of Geographic Location a list of policies (G1) that might favor or disfavor the venture in that region should be gathered. We have included here the access to banking loans (G2), assuming that the *TDM* will need to borrow money and the first choice is locally. Despite if the borrowing location coincides or not with the location of the facility, the important point in here is if the *TDM* will require a loan from a banking syndicate or international funds.

The choice of Geographic Location also affects the availability of feedstocks. In here it is important to list the types of biomass (S1) and for each the total availability and whether they are residues from other industry or purposely grown (e.g. energy crops). In addition, for each raw material a list of the suppliers (S2) and the characteristics listed in (S3) should be prepared. As will become clear later, the importance of this step is to be able to infer about the concentration of the suppliers, the importance of our feedstock (their product) for their profitability and whether or not the supplier possess the technological knowledge to forward integrate and start producing the Target Product. This information is compiled in (S4).

Finally, given consumption and feedstock availability data (in M1 and S1 respectively), the *TDM* can infer lower and upper limits for its production scale (C1), and roughly estimate capital cost requirements (C2) by combining these limits with already available TEAs, prior updating using the six-tenth rule and the Chemical Engineering Plant Cost Index [17].

2.2 Systematic assessment of the competitive forces

The systematic in here proposed "translates" the generic statements in the Five Forces framework [13] into decision making trees that categorize each source as low threat (L), medium threat (M), or high threat (H). We do so by postulating questions that are relevant to the production of biomass based chemicals, and can be answered/inferred using the data gathered before. It is important to remark the *threat* characteristic, as this implies that if a large amount of sources are classified as H production of the Target Product will *not* be attractive. The decision-making diagrams are presented in Figs. 3-7. A source by source explanation of the rationale is provided next.

2.2.1 Force 1: Entry barriers

S1: Supply side economies of scale " *arise when firms that produce at larger volumes enjoy lower costs"*[13] " *deter entry by forcing the aspiring entrant either to come into the industry on a large scale, (...), or to accept a cost disadvantage."*[13]. The rationale behind the diagram is that if incumbents' production scale is larger than ours or their technology is up-to-date, then they will have an advantage.

S2: Demand side economies of scale *"network effects, arise in industries where a buyer's willingness to pay for a company's product increases with the number of other buyers who also patronize the company"*[13]. We do not envision network effects in CPIs as quality and price are the most important features. This effect is a priori not considered.

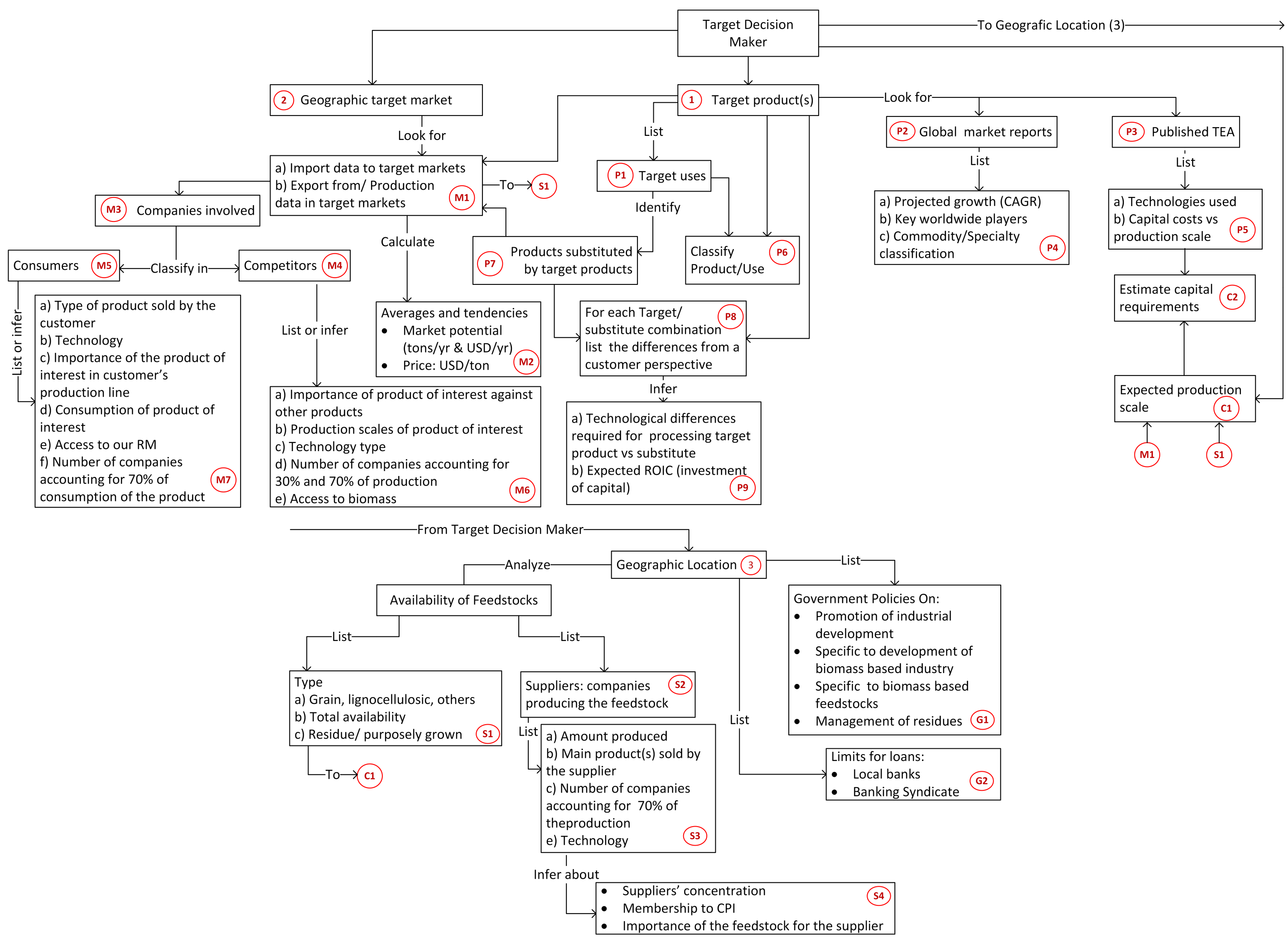

Figure 2: Roadmap of data needed for the analysis

S3: Customer switching costs *"Switching costs are fixed costs that buyers face when they change suppliers"*[13]. In the context of CPI possible causes are the need of updating product specifications or modification of processes. We infer about this source by considering the differences between the Target Product and the product the customer is currently using. We assume that if the product is the same, being the only difference the bio-based source of the Target Product, then the switching cost is low and so the entry barrier. If this is not the case, then only a better performing product might mitigate the barrier.

S4: Capital requirements To infer about this source we looked at the amount of money that the company will need to borrow, and divided the barrier in three categories. If no loan or a loan from a local bank is needed, then the barrier is low; a loan that requires a banking syndicate is classified as medium; a loan that requires borrowing from an international bank is classified as high.

S5: Incumbency advantages independent of size *" ... stem from such sources as proprietary technology, preferential access to the best raw material sources, preemption of the most favorable geographic locations, established brand identities, or cumulative experience..."*[13]. From these, we assume that proprietary technology, preferential access to biomass and experience with processing biomass to produce their product are the most important factors. If the incumbent's answer to any of these is yes, then it has an advantage. The more yes, the higher the entry barrier will be.

S6: Unequal access to distribution channels In here, the rationale is that if the product is a commodity then incumbents already have established distribution channels, which pose a barrier to the new entrant. We also consider that this barrier is mitigated if geographic location is an advantage for the entrant. In addition, we consider that if the target product is new then, the distribution channels are not yet developed, thus there is not a barrier yet.

S7: Government policy *" Policy can hinder or aid new entry directly, as well as amplify (or nullify) the other entry barriers"*[13]. Government policy affects not only Entry Barriers, they can also be targeted to mitigate/enhance sources of the other forces. Some examples include: laws for promotion of industrial/sector development, environmental and safety regulations, restriction/promotion of foreign investment; laws for protection of proprietary technology; subsidies, provision of funds for R&D [13].

S8: Retaliation This is the reaction of the incumbents to the new entrants. From the factors mentioned in Porter's original work we consider *"Incumbents seem likely to cut prices because they are committed to retaining market share at all costs ..."*[13], and *"Industry growth is slow so newcomers can gain volume only by taking it from incumbents...."*[13], to be the most important. We associate the need of retaining market share with the Incumbents' concentration. If the market is split among many companies, then we assume that each company is small and the effect that a newcomer has, is larger than if just a few larger companies dominate the market. We consider market growth as the second most important effect, and set the benchmark limits shown in Fig. 3.

A note must be made at this point with respect to the benchmark limits; throughout the manuscript we have used the *m-firm concentration ratio* as defined in Belleflamme and Peitz [18] $I_m = \sum_{i=1}^{m} \alpha_i$, in which the firms are ordered according to their market share α_i and the m top firms added up. We have assumed $m = 3$ and considered the market concentrated if $I_3 \geq 70\%$ and distributed if $I_3 \leq 30\%$.

Force 2: Bargaining power of suppliers

S1: Supplier's concentration *"A supplier group is powerful if: It is more concentrated than the industry it sells to."*[13] We have again used the I_3 criteria and assigned a high power to suppliers if they are concentrated and low if distributed. Anything else is classified as medium.

S2: Supplier's dependence on revenue from feedstock *" A supplier group is powerful if: does not depend heavily on the industry for its revenues."*[13] In here we infer that a supplier that offers our feedstock as its main product, depends heavily on it for revenues. Thus its bargaining power is low, unless no other supplier nearby can satisfy the demand for

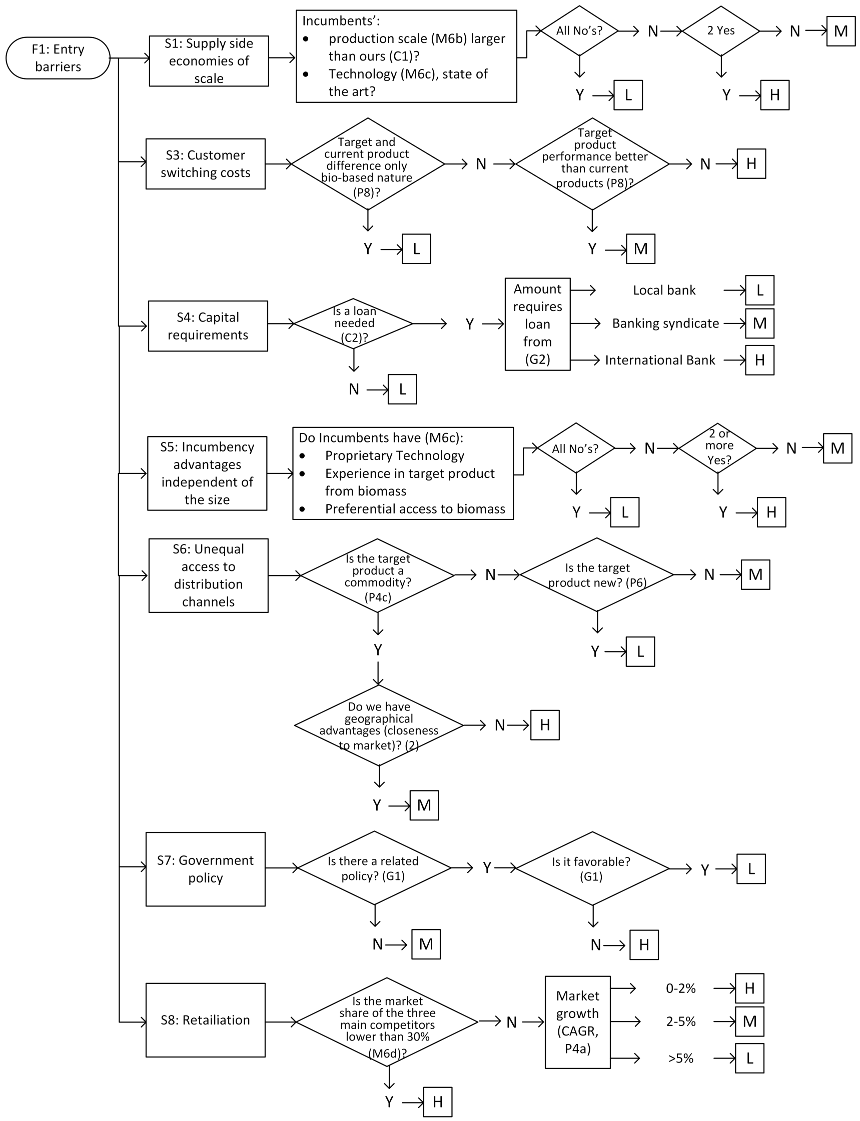

Figure 3: Decision-making Diagram for Force 1: Entry Barriers

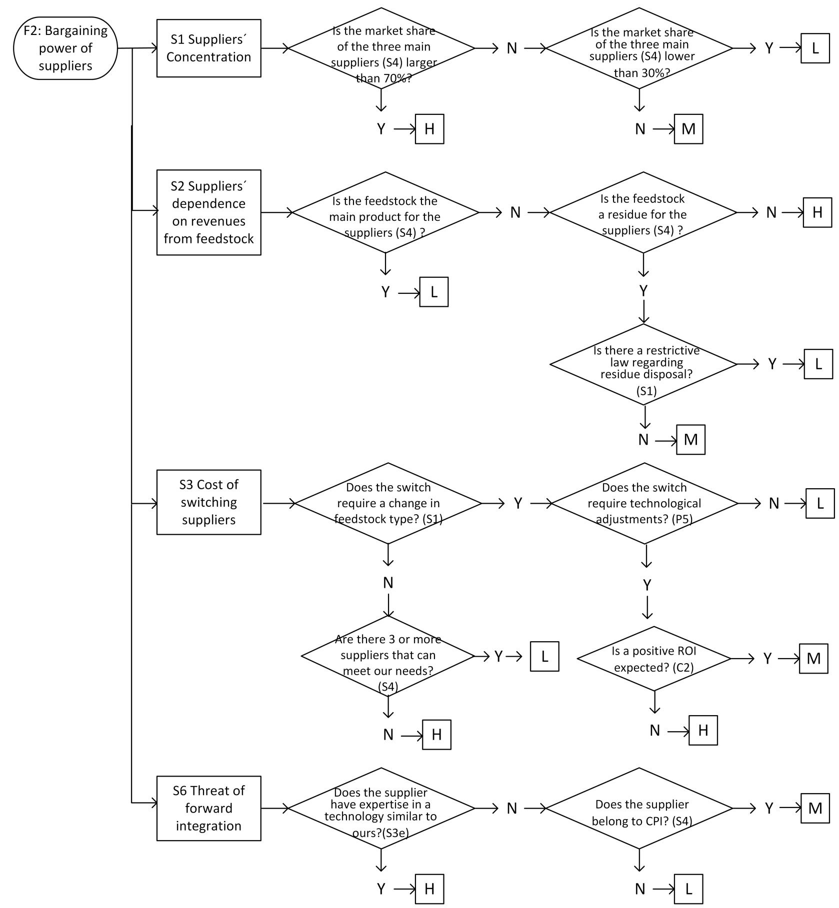

Figure 4: Decision-making Diagram for Force 2: Bargaining Power of Suppliers

the feedstock. If the feedstock is not the main product, the supplier may also have low bargaining power if it is a residue and local laws require specialized disposal for it. On the other hand, if the feedstock is a residue, and there are not laws restricting its disposal, then, there is no incentive for the supplier to sell the feedstock posing a threat classified as high.

S3: Cost of switching suppliers The rationale is that if the same feedstock is sold by different suppliers or using a different feedstock does not require technological adjustments, then there is little cost of switching suppliers, thus their bargaining power is low. If changing suppliers requires a technological adjustment, then the supplier has bargaining power, which could be mitigated if a positive ROI is expected after investing in the adjustment.

S4 & S5: Feedstock differentiation and uniqueness We do not foresee that in the setting of a chemical biomass based industry, a feedstock could be differentiated in the sense that is implied in the original reference [13], much less a feedstock be completely unique. Therefore, these two sources are not considered.

S6: Threat of forward integration Suppliers threat of start producing the product themselves is high if they already possess technological knowledge similar to ours. If the supplier is a CPI, then forward integration is possible but as it requires possibly large adjustments, the threat in this case is classified as medium.

Force 3: Bargaining power of consumers

S1: Consumers' concentration *"A customer group has negotiating leverage if: There are few buyers, or each one purchases in volumes that are large relative to the size of a single vendor"*[13]. To infer about the concentration of the consumers, we have considered the $I_3 \geq 70\%$ criterion. We have not used the $I_3 \leq 30\%$, criterion for inferring about distribution as, even if this is the case, customers may associate to purchase together and act as concentrated. To classify the customers as distributed we request that the product may be used for at least three different uses, a situation that has a much lower probability of association.

S2: Threat of switching the product *"A customer group has negotiating leverage if: The industry's products are standardized or undifferentiated"*[13]. In here we use the Product/Use classification in Section 2.1. The rationale is that if the use is new, then the product is targeting a new market, therefore the risk of being undifferentiated from other possible chemicals that might also target this market is higher. However, if the use is conventional, then the product is replacing other products that already exist in the market. In here we look if the *bio* feature may be used as a positive differential characteristic for differentiation. This is the case when the product is new, and to a lesser extent if the same product already exists from fossil-based sources. If the product already exists from bio sources for conventional use, then the classification has to be done case by case. We have marked these as (neutral, M).

S3: Threat of switching supplier The rationale is: if the product already exists in the market, there is a considerable threat of buying the product from some other company. The only case in which we consider the threat as low is when both product and use are new as there might not be many suppliers, yet. Any other case is treated as a (neutral, M) threat.

S4: Threat of backward integration As with the suppliers, if the consumers' expertise is not similar to ours or they can not be classified as CPIs, then the threat is low. The threat of backward integration may be considered high if one of those is true, and the consumers have access to feedstocks similar than the ones used by us.

S5: Price Sensitiveness *"A buyer group is price sensitive if: The product it purchases from the industry represents, a significant fraction of its cost structure"* or *"earns low profits"* or *" the quality of buyers' products or services is little affected by the industry's product"* or *"The industry's product has little effect on the buyer's other costs"*[13]. In here, we considered that the essence of price sensitiveness can be captured by two factors: (1) if the product is an important feedstock to the customer, then the customer will be sensitive to price changes; (2) if the product is used by a company in the pharma or cosmetic sectors, then they will most probably have large profits and prefer quality over price, then be less sensitive to price changes.

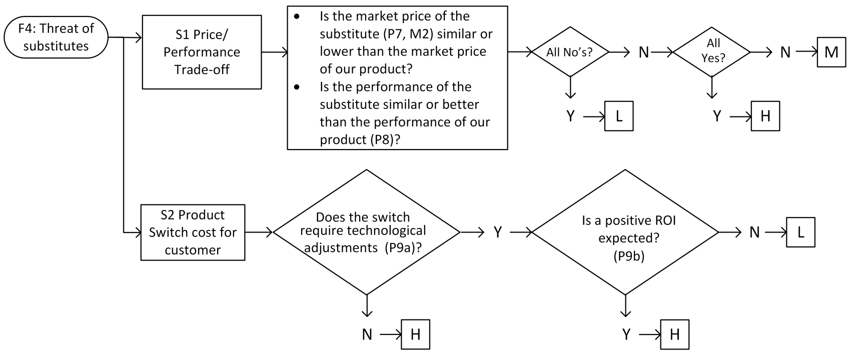

Figure 5: Decision-making Diagram for Force 4: Threat of Substitutes

Force 4: Threat of substitutes

S1: Price/performance trade-off A product that combines similar o better performance with similar or better price is easily substituted by another one. We inferred about this source looking at the list of differences from the customer's point of view.

S2: Product switch cost for the customer This source is somehow complementary to Sources S2 and S3 from Force 3, but is focused on the cost that a change will cause. We infer about its strength in a way similar to the one used when analyzing our possibility of changing suppliers: if the switch does not imply a technological adjustment or if it does, a positive ROI is expected, then the threat is high. Otherwise we will consider it to be low.

Force 5: Rivalry with competitors

S1: Competitor's size *" The intensity of rivalry is greatest if: Competitors are numerous or are roughly equal in size and power. In such situations, rivals find it hard to avoid poaching business. Without an industry leader, practices desirable for the industry as a whole go unenforced."*[13]. Our reasoning in here is that if after entering the market the largest three other main producers still have a large market share then our company will not be considered a rival. On the other hand if the market share is low, and assuming we are not entering as the market leader, then we will be perceived as a rival and the source should be classified as high.

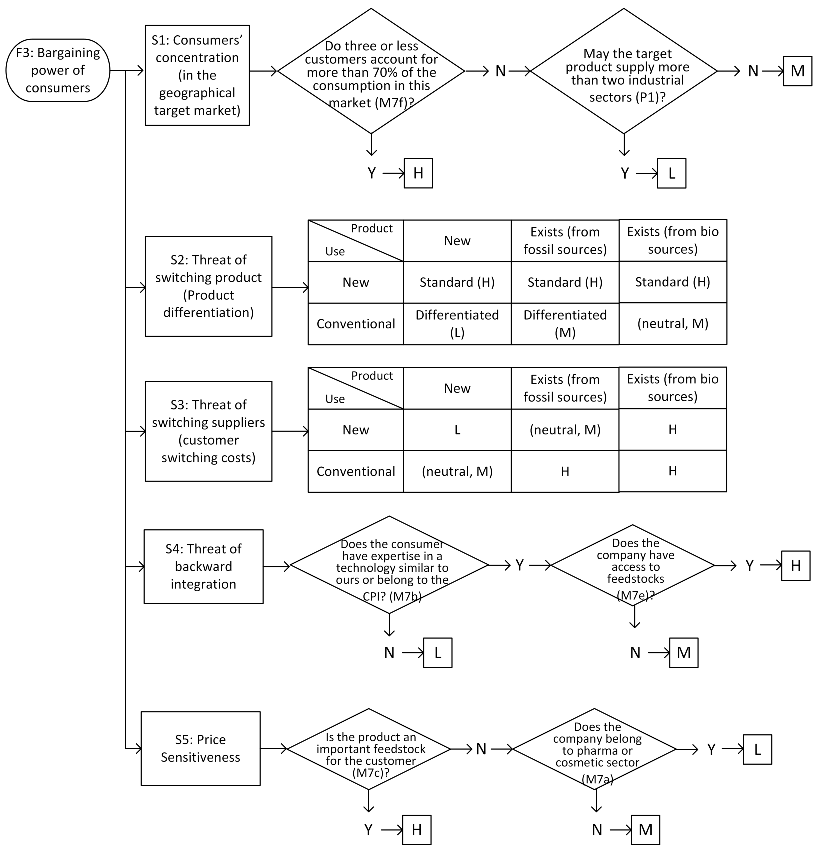

Figure 6: Decision-making Diagram for Force 3: Bargaining Power of Consumers

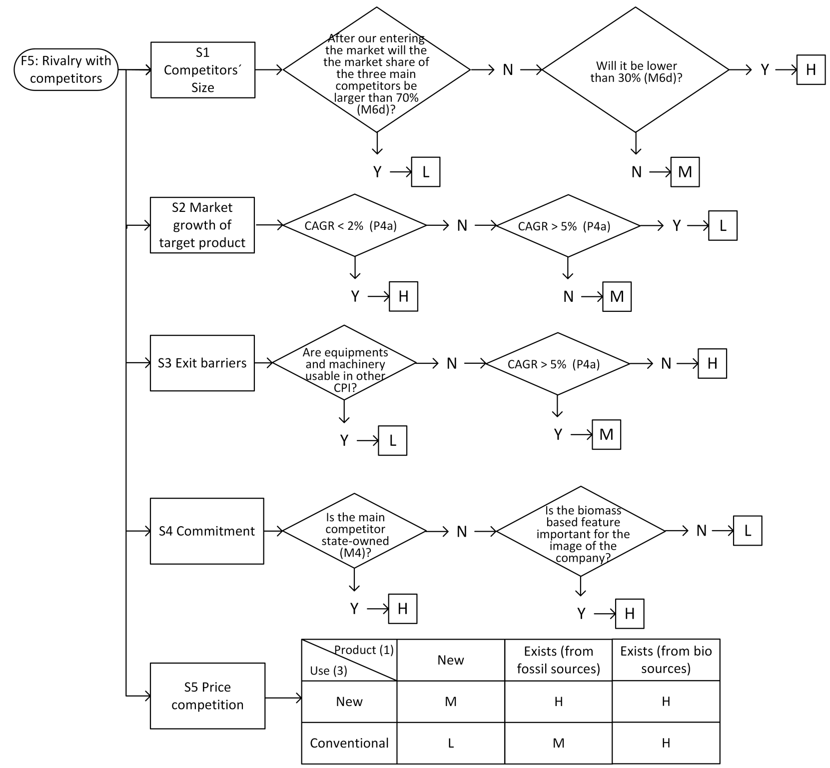

Figure 7: Decision-making Diagram for Force 5: Rivalry with Competitors

S2: Market growth This source is self-explanatory: if the market is not growing fast then competition is fiercer.

S3: Exit barriers *"These barriers keep companies in the market even though they may be earning low or negative returns."*[13]. We inferred about this source by considering the easiness of selling the equipments and machinery to other companies. Thus if the chosen technology uses equipments that can be sold to other CPIs then the barrier is low. Otherwise, if it is specialized, but the market of the product is growing then, equipment and machinery might still be used by a company in a similar business.

S4: Commitment *" (Rivals) have goals that go beyond economic performance in the particular industry ..."*[13]. In here we consider two types of companies that will result in a categorization of high in this source: competitors that are state-owned and companies for which the biomass based feature is an important part of their image. In any other case the source will be classified as low.

S5: Price Competition For classifying this source we again resort to the Product/Use classification in Section 2.1. Our reasoning is that if the same product could be obtained from alternative biomass-based sources then there will always be price competition. If the product might be obtained by fossil sources, if the use is new customers might place a lower value to the bio-based feature of our product, then forcing to lower the price; if on the other hand the use is conventional the bio-based feature might be exploited. A new product that replaces an older one in a conventional use might charge more for it thus facing a lower pressure for its price.

3 Case study: Residual biomass to Lactic acid to Polylactic acid route in Uruguay

3.1 Context

Uruguay is a country in South America which occupies an area of 176.215 km^2 and has a population of 3.5 million people. It has the second largest GDP per capita in Latin America and an economy characterized by an export-oriented agricultural sector. Agricultural land itself (arable, crops and pastures) occupies 87% of the total land, while forests occupy 10.5%. Exports represent 22% of the GDP; roughly 70% come from the Agricultural and Forestry sectors or Milk and Meat Industries (values based on a Datamyne [19]search, see Fig. S2). Imports represent 22.5% of the GDP; $\sim$ 45% of those correspond to oil, vehicles and parts and machinery; and $\sim$10% to chemicals (polymers, fertilizers and pharma (see Fig. S2).

Natural resources include arable land, hydropower, minor minerals and fish; the country does not have proven reserves of petroleum, coal, or natural gas [20]. Due to the lack of these conventional feedstocks, the country has not developed a sizeable chemical industry, and local chemical companies' traditional focus has been the production of finished products and consumer goods for which the required chemicals are imported. On the other hand, the country has promoted the growth of the agricultural and forestry sectors and current production levels largely surpass the needs of the country, are exported without much added value, and generate a significant amount of residues [21]. In addition, bio-fuels, ethanol from sugar cane and sweet sorghum and bio-diesel from soy/canola oils and beef tallow, are produced by state owned companies [22], and as in other countries, subsidized.

A growing new market for biomass-based chemicals, ample availability of feedstocks, and government incentives towards valorization of the natural resources that the country posses and transformation of the productive matrix [23], sets the stage for development of a biomass-based chemical industry. The question now is what to produce and where to focus the first efforts.

3.2 Preliminary definitions

Target decision maker: Following the discussion in the above paragraph, we will carry the analysis as an Uruguayan governmental entity that would like to assess on the competitiveness of producing biochemicals, and evaluate how to attract private investors to establish their businesses in the country. Thus the Target Decision Maker for this analysis is a private investor that will be placed in Uruguay and entering the market. A priori, we do not assume any connection with existing value chains.

Geographic location of business and feedstock availability: As mentioned above, the facility will be located in Uruguay, and the interest is that it consumes Uruguayan feedstocks. In here, it is worth mentioning that this work belongs to a wider effort aimed at proposing solutions for the residues that are generated in the country. Thus, only relevant agricultural and industrial residues were considered as possible feedstocks. A more complete analysis of the residues produced in the country was previously published by our group and can be found in and Torres et. al. [24]. Figure S4 and Table S1 partially reproduce these results. From the available options we have considered:

Whey: Can be used as a precursor of chemicals in biotechnological (fermentation) processes with or without previous recovery of proteins; currently it is produced in very large amounts and has disposal costs. There is a clear market leader in terms of production of milk and milk derived products in the country, thus its production is concentrated both geographically and in ownership.

Lignocellulosics: This type of biomass is produced from different sources, which combined result in $\sim$ 4500 kTon/yr just considering available amounts. Some of the residues are generated in an amount that may justify a bio-refinery for themselves (e.g. residues for soy harvest); another option that should be considered is a more flexible bio-refinery that can process several LG-residues. The residues are in this case distributed, both geographically and in ownership.

Target Product Selection: Lactic acid (AL) and polylactic acid (PLA) were chosen as the first candidates for a potential biorefinery as a result of a pre-screening in which after brainstorming 50-60 possibilities, a short list of 11 options was obtained by considering: (1) Imports or substitutes of those products that are imported into the country in large quantities (2) Local expertise in processing the product in which we made the distinction between academic knowledge and industrial knowledge (3) World reports, such as DOE "Top ten" [1], "Top ten revisited" [25], NREL 2016 Market Assessment [4], The BREW Report [2], and (4) the possibility of linking to already existing value chains.

LA met three of these criteria: we found evidence of expertise in the production of lactic acid in local academia (personal communications and public data from funding agencies), is cited as a "top" potential product in the "Top ten revisited" [25], NREL 2016 Market Assessment [4], and the BREW [2] reports, and as can be easily obtained by fermentation of either whey, lactose or lignocellulosic biomass, links with milk, agricultural and forest industries.

PLA could in principle be used to substitute some of the polymers that the country currently imports in very large amounts and, although there is not evidence of previous expertise in production of this (or any) polymer neither in academia nor in industry, we decided to include it in the study as it could link the previous lactic acid-including chain with the local polymer processing industries.

Geographic target market: The geographic target market refers to the physical location of the consumers. As a starting point, we will consider satisfying the internal market, and as Uruguay belongs to the Southern Common Market MERCOSUR, we would also aim to partially satisfy imports to MERCOSUR countries. Due to geographic closeness, we have considered Argentina and Brazil. In addition, as China is currently Uruguay's largest trading partner, we have also gathered import/export data of this country.

Government related regulations: Uruguay has specific laws for promotion and protection of investment in the country, promotion of the biotechnological sector, and environmental protection. A recent law also prevents the use of non-biodegradable plastic bags. Individual law numbers are provided in Section S4.

3.3 Five forces analysis

For the sake of space, data collected to satisfy the Data Needs (Section 2.1) is provided in the supporting information (Tables S2). A brief summary of the data as well as the results of the applying the algorithm is provided here.

3.3.1 Lactic acid

LA is used as a feedstock in the production of biomass-based biodegradable polymers (PLA), and in the food and beverage industry (F&B) as an acidity regulator, other uses include personal care and pharmaceutical products. We will focus on the first two. For F&B, the product/use classification is "Exists from bio-sources" and the product use is "conventional"; for the PLA industry, the product/use classification is "Exists from bio-sources" and the product use is "new". Acetic acid (AA) and citric acid (CA) can be considered as substitute products for F&B; there is no replacement for LA in the PLA industry. However, in a future with multiple biomass-based biodegradable polymers available, monomeric precursors of those polymers could also be considered possible substitutes.

Data regarding import/exports indicate that Uruguay imports 313 tons/yr of LA, while Argentina and Brazil together 5800 tons/yr; its price ranges from 1400 to 2250 USD/ton. Both substitutes for F&B (AA, CA) account for $\simeq$ 189 kton/yr of imports to the three countries; of these roughly 70% corresponds to acetic acid, which is also cheaper than citric acid (half the price).

In accordance to the defined Geographic Target Market, companies that currently import to Uruguay for distribution, as well as those that export to Argentina and Brazil qualify as competitors or incumbents. [1]. For the Uruguayan case, through custom records, we have obtained the complete list of companies that import these chemicals into the country, and found that they also import several other compounds in similar amounts. With this information we inferred that these were not their main products. As several companies participate in the market with roughly equal amounts of share, competitors are classified as distributed. In addition, these importers do not possess technological knowledge or experience in processing or access to biomass.

Companies that currently import to Uruguay for consumption, as well as those that import into Argentina and Brazil qualify as consumers. Again, through custom records, we have found complete data of companies that import to Uruguay. We also accessed import data to Argentina and Brazil, however, no details of the companies could be found for these countries. As we did not find evidence of production of PLA in Uruguay, Argentina or Brazil, we did not further consider the option of producing LA for PLA producers. In addition, knowing that both countries possess large F&B industries, we assumed that LA imports were aimed for these. As LA is mainly used in companies that produce processed food (bread, bakery products, chips, etc.), preserves and beverages, it is not expected for these companies to have the technological knowledge to start producing LA on their own. Also, as LA is not their main feedstock, backward integration is not expected. Regarding substitution LA for AA or CA or the other way around, from a F&B customer perspective the need of technology adjustment is not expected, but there might be important differences as a change may: result in a different final product pH, introduce off-flavors, change texture (e.g. yoghurt) and not provide an antioxidant function. Then performace upon switch may actually be worse.

Global market reports [26] [27] indicate that lactic acid is a commodity, and key worldwide players are NatureWorks LLC, BASF SE, CSM N.V, Netherlands, The Dow Chemical

[1] The analysis could be expanded to include companies that produce the products both in Argentina and Brazil. However, we have not done that yet as production data internal to these countries is not reasonably easy to find.

Company, Teijin Ltd., and project a CAGR of 18.6%, mainly due to PLA. In terms of technology, LA is produced mostly by fermentation using lactic acid bacteria, and purification involves a series of steps that include precipitation by $CaCO_3$, esterification with methanol or ethanol, distillation and hidrolysis. Both lignocellulosic residues and whey could be used as a starting material.

According to data presented in Section 3.2 there are several suppliers of lignocellulosic residues in the country, producing the residue is definitely not the goal of these suppliers, but in addition there is no penalty for them for just leaving them on-site. Lignocellulosic biomass needs a pretreatment step to extract the sugars before they can be fed to the fermentation reactor. Switching suppliers may require minor technological adjustments in these steps, if a different type of lignocellulosic biomass is used, and the expense of this adjustment will most probably not result in a positive ROI (i.e. the adjustment will not result in a product that could be sold as superior). This group of suppliers are knowledgeable in growing biomass or processing wood into manufactured goods, thus can be considered not knowledgeable in the production of chemicals.

The case of whey is completely different as most whey in the country is produced as a residue of the Milk processing industry, in which there is a single clear market leader. These suppliers face a penalty for these residues as their disposal is regulated by law. Switching suppliers would mean finding another supplier of whey, in which case there will not be a change in raw material. Although being classified as food industry, these suppliers dominate many of the traditional Chemical Engineering operations, thus their technological expertise can be considered similar.

TEAs for these two types of feedstocks using the fermentation pathway described above have been performed by our group [28]. We We have estimated the following capital requirements: 38 MUSD for LA from LG (assuming a consumption of 200 kton LG/yr with $\simeq$ 60 kton/yr carbohydrates [2]); 12.2 MUSD for LA from whey (assumes consumption of 340

[2]The scales correspond to possible target consumptions provided by personal communications. Further studies should be conducted to analyze the effect of other scales.

kton/yr whey residues: with 15.6 kton/yr of fermentable carbohydrates), the large difference accounts both for a difference in scale and, mainly, a costlier pre-treatment step required in the LG case [28]. Even if better/cheaper technologies could be found, these amounts can be borrowed from local banks which is the most favorable case. In terms of possible re-use of the machinery and equipments, those included in our designs are common to several CPIs, so we assume they might be sold to other companies in case of exit.

In terms of regulations, those for establishing a biomass based industry are as discussed in Section 3.2. Additional regulations is the US-FDA GRAS (Generally Regarded As Safe) requirement for using LA in F&B which is commonly regarded as a worldwide standard. According to the specific legislation, LA obtained from the feedstocks we considered is classified as GRAS [29].

3.3.2 Polylactic acid

PLA is a biomass-based and bio-degradable polymer used mainly as replacements of fossil based polymers in the fabrication of textiles, food packaging and containers, and generic packaging ("green" plastic bags). It has also found new uses, for example it is the base polymer used in the filaments for 3D printers, and as it is bio-compatible with human tissues, its use for biomedical implants is also expected to grow. Data regarding import/exports indicate that Uruguay imports 0.5 ton/yr of PLA, while Argentina and Brazil together 220 tons/yr; price ranges from 1900 to 4600 USD/ton. In order to identify the current trade of potential replaceable polymers (PET, PS and PE), we identified the harmonized MERCOSUR custom codes (NCM) under which they could be imported (in total 19 codes) and collected data for all of them. Through this search we estimate that Uruguay imports $\simeq$ 82 kton/yr (139 MUSD); Argentina $\simeq$ 405 kton/yr (618 MUSD); and Brazil $\simeq$ 1321 kton/yr (1952 MUSD) of polymers that could potentially be substituted by PLA. Note that the amounts of PLA that can be produced considering the previous LA productions (9.4 kton/yr from whey, $\simeq$ 15 kton/yr from Lignocellulosic) are considerably lower than the local (uruguayan) consumption of these polymers. Thus, from now on we will focus on producing PLA for the local market.

As in LA, companies that currently import to Uruguay for distribution, qualify as competitors or incumbents. Again, through custom records, we have obtained the complete list of companies that import these polymers into the country. Opposite to the LA case, importing these polymers is the main business of the competitors. The three largest companies import 12.1 kton/yr (16.6 MUSD). With this information we inferred that competitors are distributed. In addition, as competitors are just importers, they do not possess technological knowledge or experience in processing biomass or chemicals.

Companies that currently import to Uruguay for consumption qualify as consumers. Custom records contain complete data of companies that import these products to Uruguay. Most of these companies import polymers for molding, extrusion, injection or thermoforming into packaging products. Then, the polymer is their main feedstock, and the technology they dominate is not similar to the one required for producing the polymers. Thus, it is not expected that they will backward integrate. The three largest companies import 6.9 kton/yr (10.6 MUSD), thus can be considered as distributed. Regarding substitution of PET, PS or PE for PLA from a customer perspective, PLA advantages for packaging are: better aesthetics and printability, good resistance to grease and oils, reduced issues in taste and odor, and disadvantages include: brittleness, inferior long term food storage when compared to PET, and unsuitability for packaging that requires high temperatures.

Global market reports [26] [27] indicate that key worldwide players are NatureWorks LLC, BASF SE, CSM N.V, Netherlands, The Dow Chemical Company, Teijin Ltd.. The projected CAGR is 18.6%. In terms of technology, PLA is produced from LA through a route that requires a first direct polymerization step in which a low molecular weight PLA is obtained. This low-MW-PLA is then de-polymerized to produce lactide, a LA dimer. Then, high MW PLA is obtained by polymerizing lactide. Purification involves separation of PLA from lactide and consists of a series of steps that include neutralization, evaporation and distillation operations.

We have considered three possible feedstocks for PLA: whey and lignocellulosics as before, and lactic acid coming from a hypothetical company that could produce it in the country. The justification is that the pathway starting from whey or LG to PLA implies a single actor dominating several steps of the value chain, while only one company focusing on the LA to PLA upgrade seems a more reasonable configuration. The analysis for whey and lignocellulosics is similar to the one done for LA, with the exception that chances that whey suppliers (milk industry) forward integrate up to polymerization, are slim. Thus the threat of forward integration is low.

The analysis for LA as feedstock was performed by considering that there will be a single supplier, which is currently reasonable as there are not LA producers in the country. If this is the case, switching suppliers implies importing. The threat of forward integration is classified as medium as LA producers do not have expertise in polymerization but do have expertise in Chemical Engineering operations. From our previous TEA coupling the LA to PLA process to the that of the biomass to LA, we inferred that the extra capital costs did not change the decision of whether a local bank loan will suffice or not. No further regulations form the ones in Section 3.2 could be found.

3.3.3 Discussion

As seen in Table 1 the sources qualified as L roughly double those qualified as H then, from the market point of view, production of both products is favorable in Uruguay. In principle, there is not a clear difference between expanding the current value chain one or two links, i.e. stopping at LA or at PLA. However, from the analysis it could be inferred that: (i) if stopping at LA as there are not yet consumers of LA for PLA in the region, production should be targeted to the F&B industry, thus already available process designs and TEA should be modified to include operations that satisfy the requirements of these industries; (ii) if produced, PLA could be all consumed locally to partially substitute current polymer

Table 1: Five Forces Analysis. Nomenclature for feedstock: W=whey; LG=lignocellulosic; LA=lactic acid

Force	**Source**	**Lactic Acid**				**Polylactic Acid**					
		Pathway		**Result**		**Pathway**			**Result**		
		W	**LG**	**W**	**LG**	**W**	**LG**	**LA**	**W**	**LG**	**LA**
Entry Barriers	Supply side economies of scale	All No's		L		All No's			L		
	Customer switching costs	$N \rightarrow N$		H		$N \rightarrow Y$			M		
	Capital requirements	$Y \rightarrow$ Local		L		$Y \rightarrow$ Local			L		
	Incumbency advantages ...	All No's		L		All No's			L		
	Unequal access to ...	$Y \rightarrow Y$		M		$Y \rightarrow Y$			M		
	Government policy	$Y \rightarrow Y$		L		$Y \rightarrow Y$			L		
	Retaliation	$Y \rightarrow \geq 5$ %		L		$Y \rightarrow \geq 5$ %			L		
Bargaining Power of Suppliers	Concentration	Y	$N \rightarrow N$	H	L	Y	$N \rightarrow N$	Y	H	L	H
	Dependence on (...) feedstock	$N \rightarrow Y \rightarrow Y$	$N \rightarrow Y \rightarrow N$	L	M	$N \rightarrow Y \rightarrow Y$	$N \rightarrow Y \rightarrow N$	Y	L	M	L
	Cost of switching suppliers	$N \rightarrow N$	$Y \rightarrow Y \rightarrow N$	H	H	$N \rightarrow N$	$Y \rightarrow Y \rightarrow N$	$N \rightarrow N$	H	H	H
	Threat of forward integration	Y	$N \rightarrow N$	H	L	$N \rightarrow N$	$N \rightarrow N$	$N \rightarrow Y$	L	L	M

Table 1 (cont.): Five Forces Analysis. Nomenclature for feedstock: W=whey; LG=lignocellulosic; LA=lactic acid

Force	Source	Lactic Acid				Polylactic Acid					
		Pathway		Result		Pathway			Result		
		W	LG	W	LG	W	LG	LA	W	LG	LA
Bargaining Power of Consumers	Concentration	N → Y		L		N → Y			L		
	Threat of switching products	Exists, conventional		M		New, conventional			L		
	Threat of switching suppliers	Exists from biosources, conventional		H		New, conventional			M		
	Threat of backward integration	N		L		N → N			L		
	Price sensitiveness	N → N		M		Y			H		
Threat of substitutes	Price/Performance Trade Off	Y, N		M		Y, Y			H		
	Product Switch to customer	N		H		N			H		
Rivalry with competitors	Competitor's size	N → N		M		N → N			M		
	Market growth of Target Product	N → Y		L		N → Y			L		
	Exit Barriers	Y		L		N → Y			M		
	Commitment	N → N		L		N → N			L		
	Price/Competition	Exists from biosources, conventional		H		New, conventional			L		

imports. However, as the biomass-LA link has not yet been established, if the PLA producer wants to start operating soon, LA production steps must be included in the planning.

For both LA and PLA, the LG path seems slightly more attractive than the whey path from the market point of view. This is because whey production is too concentrated and represents a considerable threat. This will also be the case if establishment of a single large LA supplier is promoted with the aim of developing a stand alone LA to PLA facility. However, it has to be noticed that from the TEA whey is easier and much cheaper to process (both OPEX and CAPEX, roughly half if similar production scales are considered) as it does not require a pre-treatment step.

Another important comment is that so far the analysis was performed considering a neutral investor as the *Target Decision Maker*, and much of the data already gathered is useful in the analysis of other *TDM*. In particular, after this first study, we identified the major whey owner (as explained previously a large local dairy products company) as an actor that might be interested in forward integrating its operations to produce LA. We are currently working on gathering the data required for application of the algorithm under this perspective.

4 Summary and final remarks

This work, presents an algorithm for the assessment of the attractiveness of biomass based products using a market driven approach. The algorithm has its basis on the Five Forces framework[13], which is an analysis tool familiar to managers and business strategists. Our contributions lie in (i) "translation" of the qualitative description of the sources into questions that are pertinent to the development of a biomass to chemicals industry, (ii) creation of an ordered list of the data needed for the assessment and (iii) establishment of decision-making trees to classify the level of threat of the different sources that constitute the forces. The overall objective of proposing such an algorithm was to allow for a systematic analysis useful in the comparison of different products and situations in a language that both engineers and business strategists understand.

The use of the algorithm was exemplified by analyzing the production of lactic acid and polylactic acid in Uruguay, a country for which valorization of its biomass based resources represents a path for expansion of its current value chains. The conclusion of the case study is that both products are attractive from the market point of view. The analysis provided useful inputs for selection of feedstocks and also product uses that make sense in the current scenario, and impact technology selection and process design. The analysis was also useful in the identification of further analysis that need to be performed, in particular in terms of feedstock owners that might find attractive to forward integrate to produce LA.

We envision this tool to be used by engineers working in the screening of biomass based products as a complement to techno-economic criteria, who may take advantage of looking at the product portfolio problem from the perspective of different actors to make their own decisions. Although the tool works with current data, thus provides a static analysis, "what if" scenarios can be easily implemented to analyze the effect of other future possibilities.

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