SCALING-UP A RESOURCE EFFICIENT ECONOMY: EMBEDDING BIOREFINERIES IN THE INDUSTRY OF THE FUTURE THROUGH AGILE SUPPLY CHAINS

An introduction to decentralized biomass supply chain superstructures

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1 Introduction

1.1 Problem definition

During recent years the design of industry supply chain has experimented significant changes through the establishment of collaborative networks. Nowadays, there is a strong necessity for reducing costs and offering the maximum agility in terms of product availability and rapid respond in front of unanticipated changes, facts that are being achieved by implementing decentralized supply chain structures.

Making reference to the article field of study, the biorefineries supply chain, some of their inefficiencies may be solved by adapting them to decentralised superstructures. Nevertheless, regarding the chemical and energy industry, these new guidelines in supply chain design are not yet full established due to the complications that may appear in terms of storage and transportation of intermediate products. There is a large amount of literature working on the objective to manage uncertainty in the biomass supply chain (Yue et al., 2014). As a concise summary, the main problems to face along the biomass supply chain consist on feedstock uncertainty, quality variability, demand variability, time dependence, storage, transportation and flexibility (Miret et al., 2016).

The aim of this document is to evaluate different feasible decentralized supply chain scenarios for the particular case of biorefineries, focusing on bio-ethanol production. The new scenarios are defined to struggle against the mentioned problems and provide more agility to the biomass supply chain.

The article will continue by introducing the current biorefinery concept, in order to define a starting point for the development of new scenarios. Next, a research on the state of the art of decentralised biorefineries will be presented. Right after, the KPIs selected to evaluate the advantages and disadvantages of the different scenarios will be introduced. Finally, a discussion of each scenario will be conducted for taking out the conclusions.

1.2 Current concept

Before introducing the scenarios it is important to define the current biorefinery concept:

First of all, a definition of the raw materials and the ethanol production steps has to be clarified as the article will consist on evaluating the feasibility of decoupling it. Regarding raw materials, the most common are sugarcane and corn, obtaining from them 1st generation bioethanol, and lignocellulosic, for the obtaining of 2nd generation bioethanol. The main difference between them reside in the competition of first generation bioethanol with the food industry, contrary to second generation bioethanol which, in addition, reduces water consumption and presents advantages in economical sustainability (Miret et al., 2016). Furthermore, more innovating raw material consists on microalgae, which, despite its still few development, is becoming an important source to take into account due to its valuable advantages, for instance in energy/volume rate (Mussatto et al., 2010).

In reference to the bioethanol production process, it is usually performed in three steps: (1) obtainment of a solution of fermentable sugars, (2) fermentation of sugars into ethanol and (3) ethanol separation and purification, usually by distillation–rectification–dehydration (Mussatto et al., 2010). The step before fermentation, to obtain fermentable sugars, is the main difference between the ethanol production processes from simple sugar, starch, lignocellulosic material or microalgae.

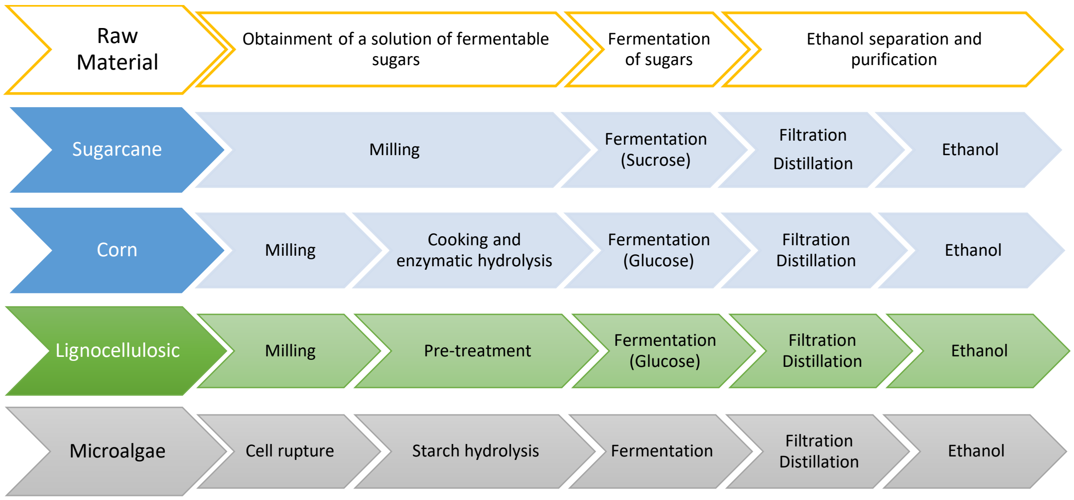

Figure 1 Flowchart with the main raw materials and processes used for ethanol production. Adapted from (Mussatto et al., 2010)

As a general view of the superstructure of the biomass supply chain, the stages considered in Miret (2016) have been defined as the standard starting point for this paper. In this way, the superstructure will consist on harvesting, intermediate transport to collecting facilities or biorefineries, storage, transformation process and final transportation.

From the definition of the supply chain superstructure, the stakeholders in charge of each stage of the superstructure for bioethanol production may be determined. Firstly, farmers carry out harvesting functions; secondly, collecting points storage the biomass harvested; thirdly, biorefineries are in charge of transforming biomass into bioethanol; and finally, the final market, either blending facilities or chemical plants. In addition, transportation functions may be taken either by one of the agents previously introduced or by a subcontracted transportation company.

2 State of the art

A research on existing literature considering the decentralisation of the biomass supply chain has been conducted in order to determine the current development of such innovation.

Yue et al. (Yue et al., 2014) made a summary of some recent publications on the modelling and optimization of biofuel supply chains. Despite there is a large body of literature regarding the modelling and optimization of biorefinery supply chains, analysing different feedstocks, products, processes, system properties and modelling viewpoints, there is few research covering the decentralization of the production. To describe the state of the art, this paper will mainly focus in documents from different authors, regarding both bioethanol production and bio-oil.

On the one hand, in the field of bioethanol production, the first paper studying this possibility was developed in Dunnett et al., 2008. His research was based on assessing the potential for spatial decoupling of processes within the processing chain, resulting in distributed processing and centralised purification systems. The drivers for such behaviour were characterised by two parameters: (1) the logistics ratio and (2) the economies of scale ratio, which were used to determine the benefit that would provide the introduction of the concept of a decentralized processing model for the lignocellulosic bioethanol supply chain. The production process was split into two phases: front-end processing (that is, pre-treatment and fermentation) and downstream separation technologies.

Regarding transportation, solid road transport was assumed for feedstock biomass and both wet and dry residual fuels. Liquid road transport was assumed for dilute ethanol solutions and pure ethanol. Rail logistics were not considered to be competitive owing to their high costs compared with road logistics over the relevant range of transport distances. Furthermore, Dunnett (2008) introduced an innovative mean of transport: pipeline transport was considered a feasible transport mode for all ethanol intermediate fractions, pure ethanol and wastewater. Has to be remarked that pipeline transport was studied in more detail by Braimakis (Braimakis et al., 2014) in his economic evaluation of decentralised pyrolysis for the production of bio-oil. In their article, a comparison between truck and pipeline transportation was made, considering the amount of bio-oil to be delivered and therefore the capacity as the key factor of the analysis. As a conclusion, pipeline transportation was determined to be increasingly advantageous for capacities over 23 dry t/h. This paper has no focus on selecting the most suitable mean of transport, but this literature proves the possibility to transport intermediate products. Furthermore, pipeline transportation is an interesting mean to be analysed in future works.

Likewise Dunnett's studies on the decentralisation of biorefineries, Eranki (Eranki et al., 2011) and Kudakasseril (Kudakasseril Kurian et al., 2013) introduced the concept of Regional Biomass Processing Depots (RBPDs). RBPDs were considered as factories to carry out the processes of grinding, densifying, mixing, and storing the biomass to be then transported to biorefineries. In the next points of this article RBPD concept will be analysed in depth.

On the other hand, in the field of biofuel production via fast pyrolysis there is some literature introducing decentralised production. Kim (Kim et al., 2011) proposed a distributed network system. Two conversion processes were described (conversion1 and conversion2) considering three intermediate products after the conversion1 (bio-oil, char, and fuel gas). Only bio-oil was transported to and converted into two final products (gasoline and biodiesel) at conversion2 plant locations. Char and fuel gas were to be consumed locally as utility energy sources at both conversion1 and conversion2 plants locations.

The objective was to determine the number, location, and size of the two types of processing facilities and the amount of materials to be transported between the various nodes of the designed network in order to maximise the overall profit while respecting product demands. Regarding the optimization of the transportation of intermediate products only transportation cost was considered as a parameter.

Finally, Bowling (Bowling et al., 2011) in the paper *Facility Location and Supply Chain Optimization for a Biorefinery* considered the possibility of sending the feedstocks to pre-processing hubs. After the pre-processing hubs process, an intermediate product was sent to the central facilities for further processing and subproducts that may be sold at that location.

Bowling's study concluded that distributed configurations usually represent better solutions than the centralized solutions.

There are some other researchers evaluating the implementation of decentralized production in the chemical industry, for instance You and Grossman (You and Grossmann, 2008) analysing the case for polystyrene supply chain, but only papers covering biorefinery supply chains have been considered.

3 Definition of the study

Taking into account the research made on the subject of decentralizing the production process in a biorefinery it is found that a decoupling into two production phases considering different plant locations has been studied by some researchers. Economic, environmental and social parameters have been considered for evaluating the convenience of having intermediate products to be stored and/or transported for posterior treatment in other plant locations.

Nevertheless, there is still further research that can be done on this subject. The possibility of splitting the production process into more than two steps has to be analysed; as the conversion of biomass into bioethanol consist on four main stages: milling, pre-treatment, fermentation and purification.

Moreover, the assessment of the performance and efficiency of an innovative supply chain structure has to take into account additional parameters to economic, environmental and social impact. A set of indicators to analyse the agility provided by the introduction of the decentralised perspective has to be defined. Parameters such as flexibility, responsiveness and effectiveness are crucial for evaluating agile supply chains (Charles, 2010). Agility indicators, had to take into account further interesting factors due to the particularities and the continuous developments that undergoes the biomass and biorefinery industries; some examples are adaptability to different raw materials, plant adaptability to future improvements in biorefinery subprocesses and the capability to deliver different byproducts available along the production process. A part from those, was interesting to consider local factors as degradation of byproducts.

In the current paper, the assessment of each scenario has been developed by considering economic, environmental and social criteria, as well as flexibility parameters and an evaluation of the risk assumed by each stakeholder.

	KPIs	Definition	
Economic impact	Investment cost	Amount of money needed for acquiring the equipment and building the plants	(Eranki et al., 2011; Miret et al., 2016)
	Transportation cost	Amount of money needed as a sum of fix and variable costs	(Miret et al., 2016)
Environmental impact	Transportation emissions	Amount of emissions due to transportation of byproducts and products	(Miret et al., 2016)
	Storage footprint	Surface needed to storage the biomass	(Eranki et al., 2011)
Social impact	Employment	Job opportunities that could be created	(Eranki et al., 2011; Kudakasseril Kurian et al., 2013; Miret et al., 2016)
	Local opportunities	Economic opportunities that could appear in regional areas	(Eranki et al., 2011)
Flexibility	Volume flexibility	Ability to change the level of aggregated output	(Charles, 2010)
	Manufacturing flexibility	Ability to change the current production method in terms of new developments	(Charles, 2010)
	Delivery flexibility	Ability to change planned or assumed dates	(Charles, 2010)
	Mix flexibility	Ability to change the range of products made or delivered within a given time period	(Charles, 2010)
	Product flexibility	Ability to introduce novel products, or to modify existing ones	(Charles, 2010)
Risk	Risk shared	Range of responsibilities balanced among all the partners participating in the supply chain	Contribution of this work

Table 1: KPIs for the assessment of biorefinery supply chains

As it was proposed in Charles (2011), parameters as responsiveness and effectiveness are, as flexibility, very important in the assessment of agile supply chains. Those parameters should be taken into account in a future development on the framework of the current paper.

Responsiveness	Reactivity	Ability to evaluate and take needs into account quickly	(Charles, 2010)
	Velocity	Ability to cover needs quickly	(Charles, 2010)
	Visibility	Ability to know the identity, location and status of entities transiting the supply chain, captured in timely messages about events, along with the planned and actual dates/time for these events	(Charles, 2010)
Effectiveness	Reliability	Ability to deliver the correct product, to the correct place, at the correct time, in the correct condition and packaging, in the correct quantity, with the correct documentation, to the correct user	(Charles, 2010)
	Completeness	Ability to realize the goals	(Charles, 2010)

Table 2: Extra parameters for further assessments

Regarding the last KPI defined for this work, the decentralised Supply Chain concept requires to determine the responsibilities of each stakeholder along the different stages of the process. That means, stablishing, by commercial contracts between the stakeholders, who takes the risk in case of having a problem. In this way, the International Commercial Terms (Incoterms) have been taken as a base for creating a new concept applied to biomass supply chains, which are generally based in a regional frame.

From a general perspective, Biomass Commercial Terms, as Incoterms, are classified in four categories depending on the transferring point of the risk in the commercial contract between the seller and the buyer: (“Incoterms® rules 2010,” n.d.)

E: the seller delivers when it places the goods at the disposal of the buyer at the seller’s premises or at another named place (i.e. works, factory, warehouse, etc.).

F: the seller delivers the goods to the carrier or another person nominated by the buyer at the seller’s premises or another named place.

C: the seller delivers the goods to the carrier or another person nominated by the seller at an agreed place (if any such place is agreed between parties) and that the seller must contract for and pay the costs of carriage necessary to bring the goods to the named place of destination.

D: the seller delivers when the goods are placed at the disposal of the buyer on the arriving means of transport ready for unloading at the named place of destination. The seller bears all risks involved in bringing the goods to the named place.

They are intended to reduce or remove altogether uncertainties arising from different interpretation of the rules, primarily to clearly communicate the tasks, costs and risks associated with the transportation and delivery of products (“Incoterms® rules 2010,” n.d.). The implementation of these rules would be significantly valuable for farmers as they are not familiarized with complex commercial contracts. In this way they could follow them and stablish commercial relations reducing or even deleting the necessity of lawyers.

4 Scenarios

The aim of this article is to introduce different scenarios towards a decentralization of the transformation process. Introducing new agents for developing specific stages of the production process and transferring responsibilities from an existing agent to another one. Basically, the objective is to manage the current problems and obstacles of the biomass supply chain by developing more agile and flexible models. As it has been described, the aforementioned KPIs have been used to assess the benefits or disadvantages of the implementation of each scenario.

Based on Miret's biomass Supply Chain superstructure, mentioned previously in the Current Concept point, four different scenarios have been defined:

1. Centralised transformation process: the whole production process from biomass to bio-ethanol takes place at the biorefinery.
2. Pre-treatment facilities in collecting points: the pre-treatment previously carried out by the biorefineries, now is developed in the collecting points.
3. Pre-treatment facilities in rural areas: the pre-treatment is in charge of the farmers.
4. Distillation at the final market: the product is fermented and filtered in the biorefineries but the distillation process, if needed, is carried out by chemical plants, blending facilities or other any users.

Note that each of the scenarios presented are based on the previous one, by adding a singularity. In the following points, the different scenarios are described in further detail: the stakeholders participating and the definition of the supply chain stages. After each scenario definition, a discussion on the requirements, responsibilities, consequences and the resulting advantages and disadvantages of its implementation is conducted.

4.1 1st scenario: Centralised transformation process

The first scenario considered was typified by encompassing the whole transformation process in the biorefinery. That meant, to carry out the aforementioned three main steps for the production of ethanol in one specific place: the biorefinery. In this way, as it is shown in Figure 2, farmers carry out the harvesting, collecting points are in charge of the intermediate storage and, finally, biorefineries transform the biomass into ethanol to be transported to the final market. Collecting points would be strategically located in order to provide storage facilities to nearby farmers (Eranki et al., 2011).

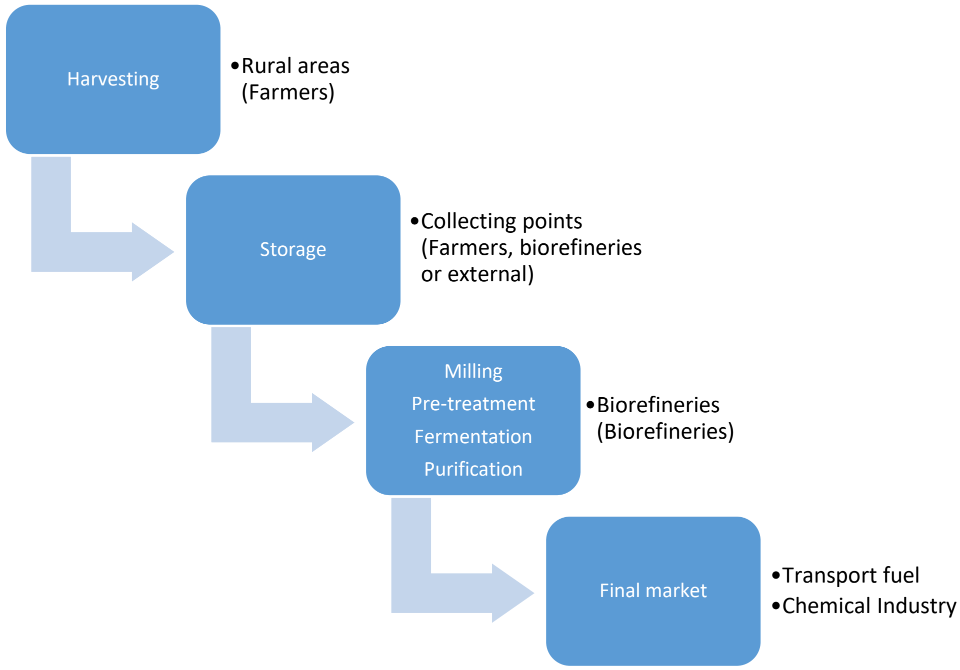

Figure 2: 1st scenario: Superstructure of the biomass supply chain

Therefore, from a first view, this scenario considered four stakeholders: farmers, collecting points, biorefineries and final market. Nevertheless, collecting points could be either an external service or owned by the farmers' community or by the biorefineries, which would end up considering only three stakeholders.

It is important to determine the owner of the product during each of the transportations that take place along the Supply Chain superstructure by defining the Biomass Commercial Terms.

4.1.1 Discussion

This scenario had some limitations in terms of flexibility (regarding mix and product flexibility) since the biorefinery could only treat one type of biomass (raw material) unless it is provided with different pre-treatment facilities; which would increase the investment and maintenance costs. The last consideration also implies possible idle time in some pre-treatment facilities due to insufficient amount of raw material arriving to the biorefinery.

Regarding the economic field, the investment cost conducted to build a large centralised biorefinery and, afterwards, to maintain it, is considerable.

Other economic issues concerning this scenario are related to logistics operations. It was estimated that in the price of the second generation ethanol, 17% is due to transportation cost, being the rest distributed as follows: 49% due to investment cost, 21% due to operational cost, 10% corresponding to feedstock collection cost and 3% for inventory (Kudakasseril Kurian et al., 2013). By transporting the raw material directly from rural areas to collecting points and then to biorefineries, without any densifying operation, higher logistic costs and, therefore, higher emissions may be entailed due to its low energy/volume rate. Has to be noticed that this comes from the fact that harvesting points are usually distributed in a broad area, therefore biomass provided by their farmers should be transported long distances until the centralised biorefinery.

As an environmental advantage, establishing strategic collecting points would reduce the need for large storage locations in the biorefineries, minimizing in this way the storage footprint. Collecting points would be strategically located in order to provide storage facilities to nearby farmers.

From a social perspective, regarding the interests and objectives of each stakeholder, it was remarkable that 1st scenario was the most unfavourable for farmers due to the poor value of their selling product. Considering the definition of value as:

$$Value = \frac{Quality * Service}{Time * Cost} \quad (1)$$

(Henry J Johansson et al., 1993)

From the equation, quality of the biomass is supposed to be low due to its low energy/volume rate. Also the service that they give, the harvesting, is basic and low-skilled. Furthermore, the low relevance of farmers along the supply chain, may also be negative to generate local opportunities and will not be stimulating to create new jobs.

In reference to the risk shared KPI, the hypothesis that collecting points are not owned by the farmers has been taken. It could be analysed by considering the Biomass Commercial Terms. For instance, between farmers and collecting points, might be either farmers assuming the responsibility of transportation (that means: risk, cost, insurance) and therefore ensuring the quality of the biomass arriving to collecting points; or collecting points assuming that responsibility so farmers only have to ensure the quality of the biomass harvested and place the material at the disposal of the collecting points.

The first option implies higher responsibility for the farmers and, as it has been said previously, their selling product is lowly valued. The sum of both facts becomes determining to evaluate the shared risk among the stakeholders. It is remarkable that farmers would assume a disproportionate risk if they are in charge of the transportation. Therefore, the second option, which gives collecting points the responsibility of transporting the products seems to be more reasonable.

4.2 2nd scenario: Introducing pre-treatment facilities

To address the issue of the high transportation cost, pre-treatment facilities concept was introduced by Eranki (2011) and Kudakasseril (2013) as Regional Biomass Processing Depots (RBPDs). Those depots were defined as a factory to produce value added materials which is located strategically in the middle of a farming community (Eranki et al., 2011; Kudakasseril Kurian et al., 2013). Likewise, different farms were sharing the same RBPD, following a Distributed-Centralized network.

In Figure 3, the Supply Chain for this scenario is decoupled into its different stages, determining Collecting Points as the RBPD described by Eranki, agent in charge of the pre-treatment processes, in addition of the subsequent storage.

The rest of the Supply Chain superstructure remains as in the first scenario, to be considered, as well, the responsibilities and risks of each stakeholder.

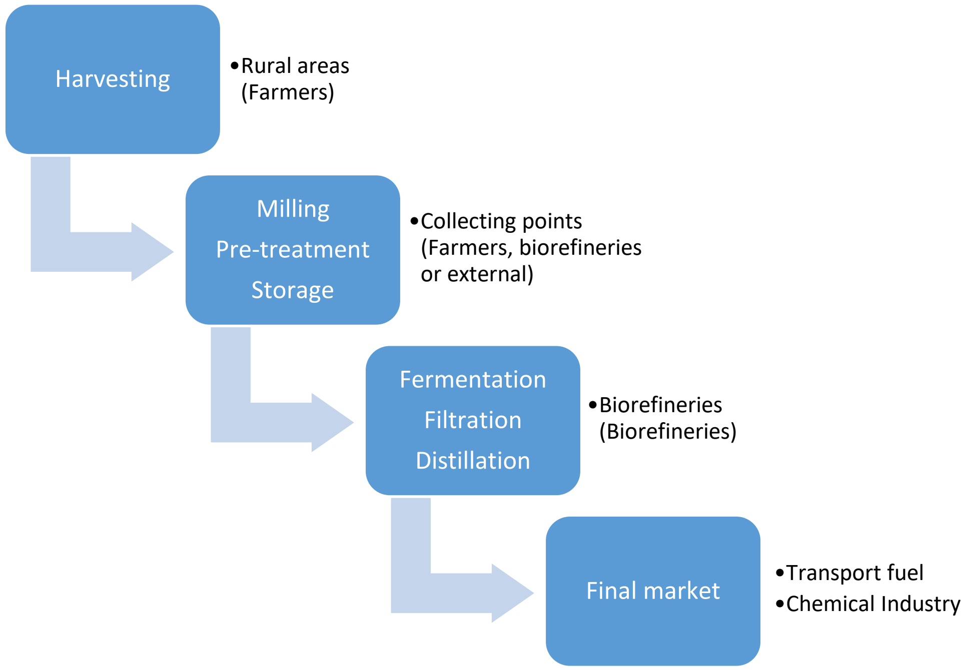

Figure 3: 2nd scenario: Superstructure of the biomass supply chain

4.2.1 Discussion

The described scenario has its main issue at the storage and transportation conditions after pre-treatment, so local parameters as temperature, time, degradation and product stability have to be considered. The design proposes to locate specialized depots in regions to collect biomass with similar characteristics which is subsequently treated to create a homogenized, consistent, and stable commodity. A major objective of the RBPD network is to process and pre-treat low-density and often unstable biomass into stable, dense intermediate products compatible with current logistics systems, allowing the densified biomass to be transported economically over much longer distances (Eranki et al., 2011).

Another concept affecting this scenario is flexibility. Grinding, densifying, mixing, and storing the biomass produces a consistent product that can be supplied to biorefineries or other markets while standardizing the supply system schedule and logistics.

In addition, densification of the feedstock will significantly reduce the traffic congestion resulting from the additional biomass supply process and, in this way, the transportation emissions, satisfying local and global environmental criteria. Likewise, from an economic perspective, will represent a reduction in transportation costs due to the increase in the energy/volume rate for the products shipped. Companies like Archer Daniels Midland (ADM), Deere, and Monsanto has already been looking into the potential of dispersed pre-treatment plants to reduce the transportation cost (Kudakasseril Kurian et al., 2013).

In this scenario, Collecting Points may be either owned by the farmers or by an external company. The first hypothesis, seems to be the most interesting from a social point of view due to the aim to provide rural employment and wealth through establishing low capital biomass processing facilities owned by the community to process the feedstock produced by the regional farmers. It also aimed to process the feedstock into intermediate products for the production of animal feeds and other biomaterials. The pre-treatment process for a Collecting Point should be of low cost and simple that can be used to produce stable intermediate products and valuable co-products. The biorefinery operations will provide additional income to the farmers and would also create rural employment opportunities (Kudakasseril Kurian et al., 2013). In this way, and differently from the previous scenarios, farmers will increase the value of their selling product and, therefore, their power in the biorefinery supply chain.

Has to be noticed that, despite the community is the owner of collecting points, this facility has to operate as an autonomous agent in order to negotiate individually with each farmer according to the product provided. This fact applies for all the scenarios.

Taking the hypothesis of farmers' community owning collecting points, the responsibilities of the farmers along the supply chain change from the first scenario. Now, they are responsible for the transportation between farms and collecting points, as they are the owners of both. The transportation may be carried out by the farmers or subcontracted to an external company. In comparison to the first scenario, it is important to remark that the risk the farmers assume by being in charge of the transportation is reduced due to the increase of the value of the product they sell.

For an appropriate shared risk, biorefineries will assume the responsibility of transportation between collecting point and biorefineries

4.3 3rd scenario: Transferring pre-treatment facilities to farmers

Third scenario introduce a little difference from the previous one: the aforementioned Collecting Points for pre-treatment processes are now located in the farms. Therefore, the farmers are the agents in charge of carrying out the pre-treatment of the biomass and the subsequent storage.

In fact, this scenario may be split into two sub-scenarios: on the one hand, a shared pre-treatment equipment formula could be introduced (pre-treatment units moving among the farms) in order to share investment costs; on the other hand, considering natural pre-treatment leaving the biomass in the field, no equipment would be necessary. The second possibility would have to take into account higher degradation of the biomass due to the instability of the weather conditions.

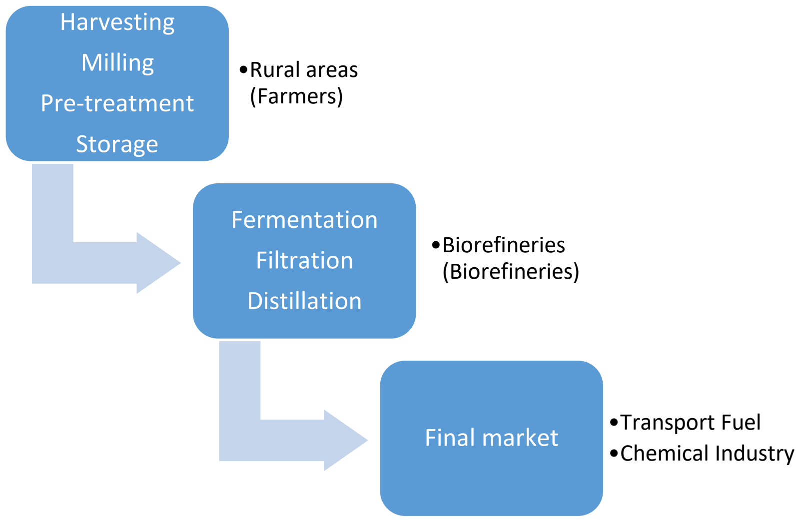

Figure 4: 3rd scenario: Superstructure of the biomass supply chain

4.3.1 Discussion

This scenario shares most of the advantages discussed for the previous one. To be remarked, as it was said in second scenario for the particularity of Collecting Points owned by the communities, the introduction of third scenario would ensure the value of farmers along the supply chain. In third scenario farmers would increase the value of their selling products and therefore their negotiation power along the superstructure. This fact, represents not only an important social advantage for the communities but also economic, as it will provide local economic opportunities.

Transportation issues will be affected by deleting the collecting points. On the one hand, the rate energy/volume will be reduced along the whole transportation distances. On the other hand, each trip will be contracted by an individual farmer so fix transportation costs could increase due to the lower quantity transported per trip. Stablishing transportation agreements among the farmers' community could be interesting for achieving better conditions.

In reference to environmental issues, storage footprint will be even more reduced from 2nd scenario, as biomass will be stored at the farms without the necessity of creating collecting points.

Regarding the difficulties to implement this scenario, as it was determined for the previous one, issues regarding pre-products storage and transportation. As it was said for second scenario, a consistent and stable product will be achieved after the pre-treatment processes, so it will facilitate the tasks.

Flexibility is also affected, from the perspective of biorefineries, due to the fact of having such a large amount of farms to deal with instead of negotiating with collecting points (which encompass several farms); and from the perspective of the farmers, in reference to the need to share pre-treatment equipment among different farms.

Responsibilities and risks also change from the previous scenario. Now farmers are in charge of transporting the products all the way from farms until biorefineries, which represents a higher distance in comparison to the previous scenario. Therefore, the cost and the risk they assume increase and could be disproportionate in front of the value of the product they sell. Transportation responsibilities may be otherwise taken by biorefineries but, in any case, the risk will not be appropriately shared among the participating stakeholders.

4.4 4th scenario: Transferring distillation process to final market

The last scenario consist on reducing even more the activity in the traditionally called biorefinery, by transferring the distillation process to the final stakeholders of the supply chain. That means, chemical plants, transport fuel distributors and manufacturing industry carrying out the distillation processes to obtain the final product, bio-ethanol, or just take the post-fermented product to be used for other applications.

Furthermore, some studies have evaluated the convenience and feasibility of totally decentralised small-sized biorefineries (Eranki et al., 2011). Likewise, it could be analysed even including the Fermentation process in the farmers set of operations, deleting the centralised biorefinery concept. For this situation, has to be taken into account the cost of the fermentation equipment for small quantities (or full plant encompassing Milling, Pre-treatment and Fermentation) which could be disproportionate and unaffordable for the farmers in front of the cost of the scenario described as 4th. Logistic issues would regard the demand of post-fermentation products in relation to the demand of pre-fermentation products not directed to fermentation plants. If there is null demand of pre-fermented, might be a profitable scenario as long as the investment costs for the equipment are worthwhile.

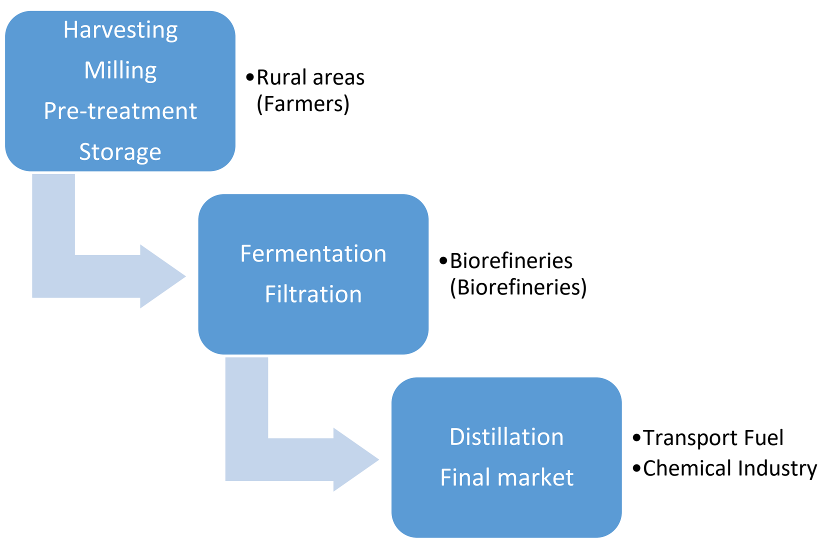

Figure 5: 4th scenario: Superstructure of the biomass supply chain

4.4.1 Discussion

The transformation process that was initially conducted in a centralised biorefinery now is decoupled by its main subprocesses: fermentation and distillation, which provides to intermediate and final users a certain level of customization of the desired product. In this way, by stablishing plants exclusively dedicated to fermentation operations, total flexibility is added to the supply chain due to the increase in product flexibility, allowing the availability of post-fermented product to be distilled or not. Some chemical plants and the manufacture industry often demand this by-product to be used in other ways. In this way, it is important to define a win-win situation between all the stakeholders selling or buying intermediate or final products.

The elimination of the distillation process from the biorefinery operation implies as well a reduction in the investment cost in conventional biorefineries, cost that is transferred to chemical plants and manufacture industries.

In terms of logistic issues, conditions for transportation of fermented biomass (before distillation) have to be analysed focusing on temperature conditions, degradation rate and product stability.

4.5 Suggestions

It is important to remark that the stages of each scenario may mixed and adapted with the stages of another one. In this way, advantages of each of them could be applied to the new design. For instance, the first two stages of second scenario could be adapted as follows, and joined to the final stages of fourth scenario.

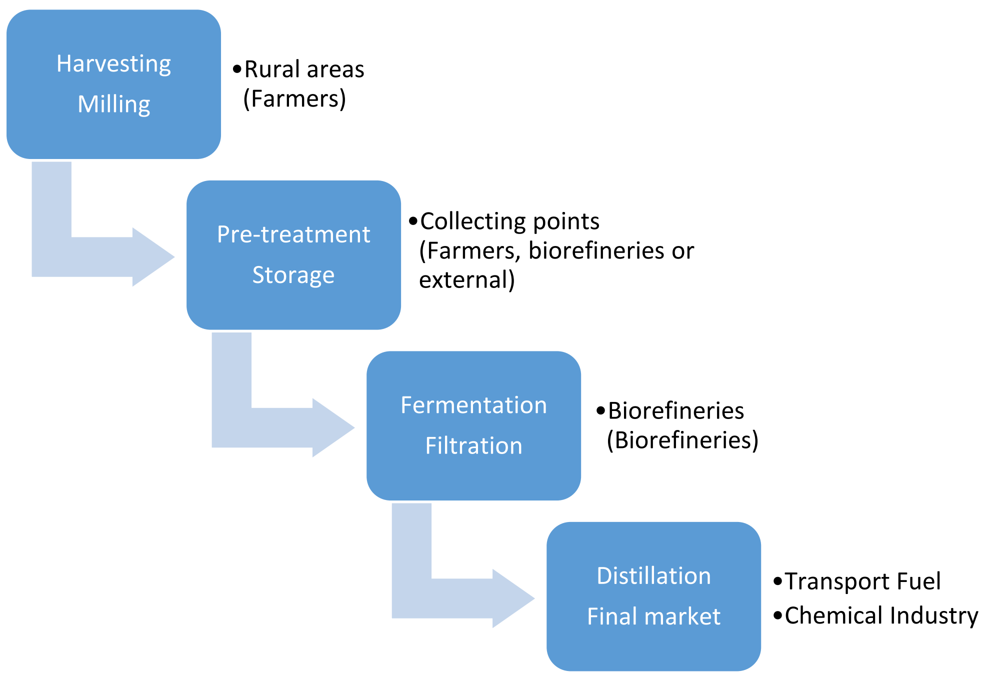

Figure 6: suggested scenario resulted from merging 2nd and 4th scenarios

This configuration gives the main advantages explained for scenario 2 and 4, which is notably interesting.

5 Conclusions

First of all, along the state of the art the feasibility of decentralising the biomass supply chain has been proved, by referencing to several articles (Braimakis et al., 2014; Dunnett et al., 2008; Kudakasseril Kurian et al., 2013). Moreover, the different scenarios proposed in the current article introduced advantages to the traditional centralised supply chain.

It has been noticed the importance of sharing risk among the different stakeholders that take party along the biomass supply chain. The definition of the Biomass Commercial Terms, which standardize the commercial contracts between stakeholders, should be valuable for determining the agent in charge of the risk in each step.

As the article has not covered consequences of decentralization in terms of responsiveness and effectiveness, further studies have to be taken in this direction. Furthermore, the advantages and disadvantages analysed in this article have been determined under a qualitative perspective, therefore a quantitative assessment is yet to be conducted.

Lastly, once the area of implementation is decided, explore the possibility to readapt existing centralized biorefineries to the development of one or some stages of the whole production process should be analysed. Or in other words, transforming existing plants by specializing them in a specific subprocess.

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