Systemic Challenges for Innovative and Sustainable Energy Supply Chains

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Abstract

The development of sustainable energy supply chains represents one of the most relevant challenges to our contemporary society. The dynamics of this evolution are conditioned by a broad array of positive and negative feedbacks. In this context, the present paper aims to approach systemic challenges for innovative and sustainable energy supply chains. Initially, a conceptual model of the innovation process in energy supply chains will be described. Then, using a scenario planning methodology, systemic challenges and potential overcoming strategies for the Brazilian bioethanol supply chain will be systematised. Finally, policies and guidelines for decision-makers of this energy supply chain will be proposed. Innovation tackling sustainable energy supply chains in a complex world will come to life along networks that properly deal with diversity and complementarity of knowledge, resources and assets. Today and in the decades to come, sustainable energy supply chains will represent a huge challenge for the integration of production and logistic networks.

Keywords: energy supply chains; innovation; sustainability; scenario planning; integration of production and logistic networks.

1 Introduction

Innovation occurs through a complex interaction between agents and stakeholders involved in the production, diffusion and use of new and economically-useful knowledge. Innovation can be interpreted as an iterative matching of technical possibilities to market opportunities. The fitting occurs through both market and non-market interactions and feedbacks along research and development (R&D), production and logistic networks. Innovative and sustainable energy supply chains represent one of the most relevant challenges to our contemporary society. Nevertheless there are broad arrays of positive and negative feedbacks that bound the evolution of these energy supply chains.

In this context, the present paper aims to approach systemic challenges for innovative and sustainable energy supply chains, focusing specifically in the Brazilian bioethanol supply chain. The paper is structured as follows: first, a conceptual model of the innovation process in energy supply chains is described. Then, using a scenario planning methodology, systemic challenges and potential overcoming strategies for the Brazilian bioethanol supply chain are systematised. Finally, policies and guidelines for decision-makers of this energy supply chain are discussed and further research guidelines are proposed.

2 Conceptual model of the innovation process in energy supply chains

Innovation can be defined as the economically-useful combination of capabilities (Nelson and Winter, 1992), based on an evolutionary routine both path- and context-dependent. The connection and further integration of demand and supply must be congruent with strategic choices that determine which activities and processes an organisation will perform and how they will be design and coordinated. In fact, business strategy is about how to combine and fit activities and processes to obtain and sustain

competitive advantage (Porter, 1996). Furthermore to preserve this advantage the organisation has to be unique; and, to generate and sustain uniqueness, its resources must be (Barney, 1991): (i) valuable, in the sense that it exploits opportunities and/or neutralises threats in firm's environment; (ii) rare among a firm's current and potential competitors; (iii) imperfectly imitable, either through unique historical conditions, causal ambiguity, or social complexity; and (iv) singular, without strategically equivalent substitutes.

The adoption of business strategies that meet the needs of the enterprise and its stakeholders today while sustaining the resources that will be needed in the future (IISD, 1992) is a well-recalled requirement nowadays. In a broader sense sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs (UN, 1987). Social, political, environmental and economic perspectives should be taken into account throughout the evolution for a sustainable world.

Systems thinking can uncover the systems complexity by revealing what underlying structures exist, how complex problems are generated and which/how factors influence them over time (Senge, 1990). Absorptive capacity management construct will be adopted as basis for the conceptualisation of the innovation process in energy supply chains. Absorptive capacity is the firm's ability to value, assimilate and apply new knowledge to create value through innovation (Cohen and Levinthal, 1990). Its cognitive basis is derived from individual's absorptive capacity including, for instance, prior related knowledge. At the most elemental level, this heritage would include basic skills and even shared language, but might also comprise market, scientific or technological knowledge, obtained by educational formation and/or practical experience. Thus prior related knowledge confers a potential ability to recognize the value of new information, assimilate and apply it to commercial ends.

In a recent reconceptualization, absorptive capacity is defined as a dynamic capability (Barney, 1991) pertaining to knowledge creation and utilization that enhances a firm's ability to gain and sustain competitive advantage (Zahra and George, 2002). The absorptive capacity concept (Cohen and Levinthal 1990) emphasises that successful knowledge identification and acquisition require the receiver to possess a suitable knowledge base and skills to assimilate new information. Potential absorptive capacity represents the organisational capability of (i) identifying and obtaining external knowledge and experience, and (ii) integrating it in order to attain and/or enhance competitive advantage. Potential absorptive capacity is directly influenced by the awareness of contextual information and knowledge. Promoting wide organisational awareness is important for organisations aiming to recognise a fuller set of opportunities to leverage its assets (Frazzon, 2009).

On this basis, the absorptive capacity of an organisation in a networked environment would be a realistic starting point for the analysis of strategic interactions (Frazzon, 2009). Absorptive capacity within logistic systems refers to the organisational ability to recognize the value of new information, assimilate and integrate it in order to be applied to a competitive advantage creation. This organisation acts in a multi-level logistic system where the sources of information are positioned in different layers. The descriptive model represents a strategic overview and aspires to connect in a suitable fashion the constructive elements, enhancing the understanding of this specific socio-technical system. In fact, innovation activity results from interactive relationships between institutional and organisational elements of science, technology and business, which together could be called systems of innovation (Sundbo, 1998). Expected benefits derived from a collaborative network approach normally include: acquisition of institutional relevance, access to new/wider markets and knowledge, share of risks and resources, and optimisation of complementary skills and capacities, which would allow each entity to focus on its core competencies while keeping a high level of agility (Camarinha-Matos and Afsarmanesh, 2006).

The following section approach the systemic challenges and potential overcoming strategies for Brazilian bioethanol supply chains, like: existing and forthcoming complex environment, technologies, logistic systems, sources and markets.

3 Brazilian bioethanol supply chain

Increasing renewable share in world energy matrix would help to (i) prolong the existence of fossil fuel reserves, (ii) address some threats posed by climate change, and also (iii) improve security of energy supply on a global scale (Goldenberg, 2007). Nevertheless energy supply and climate change are not just economic and environmental issues, being connected to fundamental social geopolitical challenging topics. Many decisions of critical importance for both global climate and transition to a low-carbon economy will take place outside the climate policy community, in the fields of energy, security, trade, investment and development cooperation (IISD, 2007).

Most of the new renewable energy sources (e.g. modern biomass) are still undergoing large-scale commercial development with small market-share. On this grouping, biofuels are referred to liquid or gaseous fuels for the transport sector that are predominantly produced from biomass. Biofuels are generally considered as offering many advantages, including aspects of sustainability, reduction of net greenhouse gas emissions, regional development and supply security (Reijnders, 2006). One of them, ethanol or bioethanol is a petrol substitute/additive derived from alcoholic fermentation of sucrose or simple sugars, which are produced from biomass by hydrolysis process (Demirbas, 2007).

3.1 Overview

As an important part of this scene, Brazilian sugarcane bioethanol is: (i) a well-established program (30 years in production), (ii) an energetic commodity fully competitive (Figure 1), without subventions, in global market against gasoline and, (iii) suitable to be replicated in other developing countries (Goldenberg, 2007).

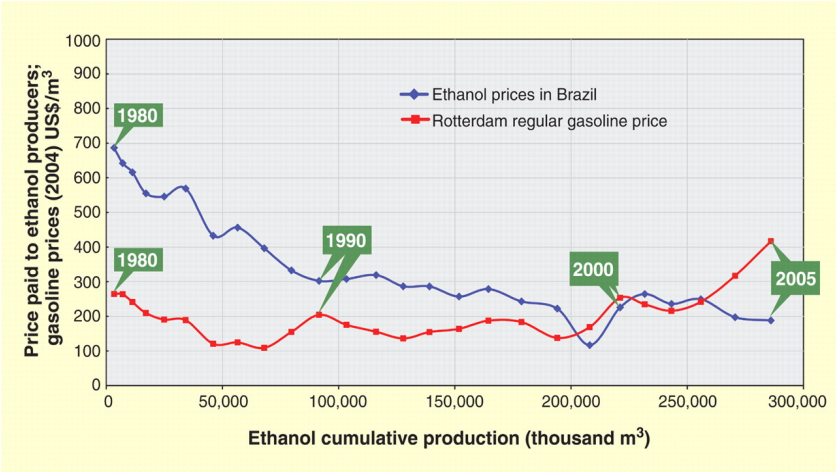

Figure 1: Ethanol Learning Curve (Goldemberg et al. 2004)

Today, bioethanol production from sugarcane in Brazil is 27 billion litres per year, requiring around 6 million hectares of land (Dias et al, 2011). The competition for land use between food and fuel has not been substantial, i.e. sugarcane covers 10% of total cultivated land and only 1% of total land available for agriculture in the country (Goldenberg, 2007). Nevertheless the enormous scale of the automobile industry creates a wide range of feedback processes that confer substantial disadvantage to new technologies, like: lack of field experience, doubts about vehicle performance and lack of drive-experience. The successful introduction and diffusion of alternative fuel vehicles is more difficult and complex than that for many products (Struben and Sterman, 2006).

As for The Economist (2007) 'transport is trickier, because car ownership is rocketing and the demand for fuel is fairly inelastic. If people want to drive they are going to drive, unless governments jack up petrol prices to levels that are politically unacceptable. So for emissions to fall in the transport sector, new technologies, such as more efficient biofuels or electric cars, are needed'. And, 'given a big research and development (R&D) effort in this sector, there is a good chance that those will be forthcoming'. Of course,

this implies that barriers to development, acquisition, deployment and diffusion of technologies and to market access are effectively addressed (IPCC, 2007).

Considering that, an effective market-driven innovation should be pursued by: (i) introducing and continuous adopting of flex-fuel vehicles (FFV, vehicles that could run using both gasoline and/or ethanol) and (ii) increasing ethanol blends. Then, the growing demand for pure/blended ethanol would draw automotive industry and oil sector along with the initiative (Mathews, 2006). It is probable, based on Brazil's experience, that these two measures would have the desired effect of underpinning bioethanol diffusion trajectory, progressively diminishing the dependence on fossil fuels.

In Brazil, one of the pillars of the success of ethanol is due to creation of the motor vehicle flex-fuel. These have significant participation in the Brazilian vehicle fleet, with successive increases in the sales (Gurgel, 2011). Since 2003, participating with only 4% of all licensed vehicles, the trend was significant in sales, closing the year 2011 with 83.1% of all licensed vehicles (ANFAVEA, 2012). FFV's allow for a conscious decision of consumers for renewable fuels and also increase the visibility of biofuels in the market (BMVEL, 2005). They would give motorists a choice – fill up with ethanol or petrol, depending on the price and personal preference. This choice engenders confidence, and overcomes any lingering doubts about ethanol, building consumer demand, bringing competition to the petrol forecourt and finally creating a real bioethanol market. Then, the previously planned and implemented policies for supplying ethanol – either through imports or through local production – would get a relevant impulse based on popular demand (Mathews, 2006).

There is already substantial momentum behind the enactment of subsidies to encourage production of ethanol in northern temperate climates – from corn in the United States and from sugar beet in Northern Europe. Considering future demand, complementary bioethanol supplies might be imported from developing countries in tropical regions. Nevertheless, issues regarding feedstock's cost and energy balance have to be necessarily taken into account (Table 1).

Table 1: Ethanol cost and energy balance

Feedstock	**Cost** (US$ per gallon)	**Energy balance** (renewable output to fossil input)
Sugarcane, Brazil		
2006, without import tax	0.81	10.2
2006, with U.S. import tax	1.35	
Sugar beet, Europe, 2003	2.89	2.1
Corn, U.S., 2006	1.03	1.4
Cellulose ethanol, U.S.		
Achieved in 2006	2.25	10.0
Target for 2012	1.07	

Source: Goldemberg (2007)

Brazilian impulse could be transfused to others developing countries in tropical regions. It should comprise primarily an indispensable and consistent long-term political commitment and also transparent strategic choices, regarding mechanisms to balance and ensure supply for both internal and external markets. Furthermore, the existence of long-term commercial agreements (including import tariffs and/or quotas) as well as clear and stable regulatory model could drive both national and international investments.

3.2 Production of bioethanol

The crescent energy demand spurred the need to develop more efficient systems and technologies, particularly clean and renewable energy (Masiero & Lopes, 2008). Biofuels are a viable alternative in the global context. Global biofuel production had a notable expansion, from 20 billion litres in 2001 to 50 billion litres in 2007 (Gurgel, 2011). Accordingly, this tremendous growth creates opportunities to countries that hold the production technology to attend the requirement of global demand.

Brazil has proved a strong contender in this stage. A number of factors influenced the country to achieve this level. In Brazil, areas planted with sugarcane had a significant increase over the years, observing an increase of 67% in volume produced, considering the crops from 2004/05 to 2008/09 (UNICA, 2012a).. Most areas are in South-Central region of the country, where the State of São Paulo stands holding 60,1% of sugarcane production produced in Brazil. Worldwide, the production of sugarcane, raw material to bioethanol production, is 1,5 billion tons and is found in the tropical zone of the planet, particularly in developing countries of Latin America, Africa and Southeast Asia (UNICA, 2012b). In this context, Brazil stands as the largest sugarcane producer, followed by India, China, Thailand, Pakistan and Mexico (Rudorff et al, 2010). Factors such as productivity developments of sugarcane, involving constant researches, whose results show growth indicators around 18,63% over the last six crops harvested, contributed to reinforce this prominent position.

Over three decades Brazil led fuel bioethanol production, losing its position to the United States after the commitment to its use required by *Energy Policy Act* of 2005 (Masiero & Lopes, 2008). The growth of sugarcane sector in Brazil can be noted by the expansion of producing mills, ending 2011 with 406 producing bioethanol mills (ANP, 2011). The Brazilian bioethanol production showed significant growth over the years. Considering the crops from 2006/2007 to 2010/2011, an increment happened in 53,87% of bioethanol production, increasing from 17.939.428 m^3 to 27.604.120 m^3, severally (Figure 2).

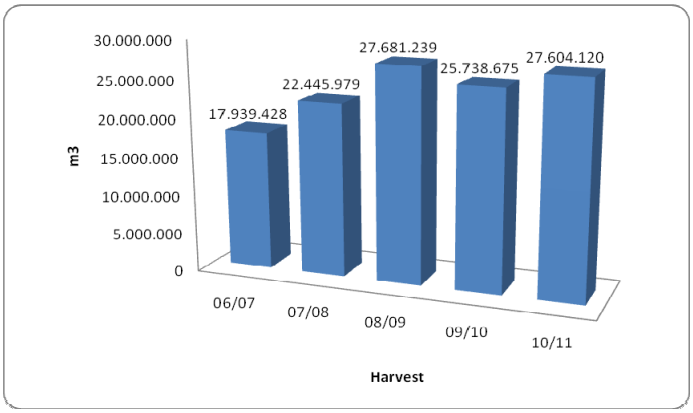

Figure 2: Brazilian ethanol production (UDOP, 2012a)

The majority of bioethanol produced in Brazil is consumed in domestic market. In the international market 2008 was the year which presented the most expressive results with exported volume of 5,12 million of m^3. In 2011, the bioethanol exportations reached 1,96 million of m^3. Most part of it was directed to the United States of America (33,8%), followed by South Korea (15,3%) and Japan (14,3%). (UDOP, 2012b)

3.3 Logistics

Logistics has primordial importance in the sugarcane sector in view of the requirement to supply the producing sugarcane mills and distribute bioethanol to the dealers' network reaching the consumer. The process to turn the raw materials, semi-finished products and stocks of finished products available in the right place and with the lowest possible cost is the logistic responsibility (Bowersox & Closs, 2001). The implementation of these processes requires a set of involved companies, direct or indirectly, that belong to a supply chain. The supply chain of Brazilian fuels is fairly comprehensive, including a number of interrelated agents during the process to turn the product available to the consumer.

The cane transport until the mills is done in bulk in open trunks (Caixeta-Filho et al, 2001). From the mill to the distribution bases road transportation is the most widely used, followed by railroad and in small proportion the pipeline (Milanez et al, 2010). In the distribution to retail tankers are used because they are suitable for this purpose and type of product. In the export flow, the predominance of road transportation to the ports as only choice is related to short routes, high costs of intermodal transfers and deficiencies in the structure of other modalities in the access to ports (Milanez et al, 2010). An overview of the supply chain of Brazilian fuels can be seen in Figure 3.

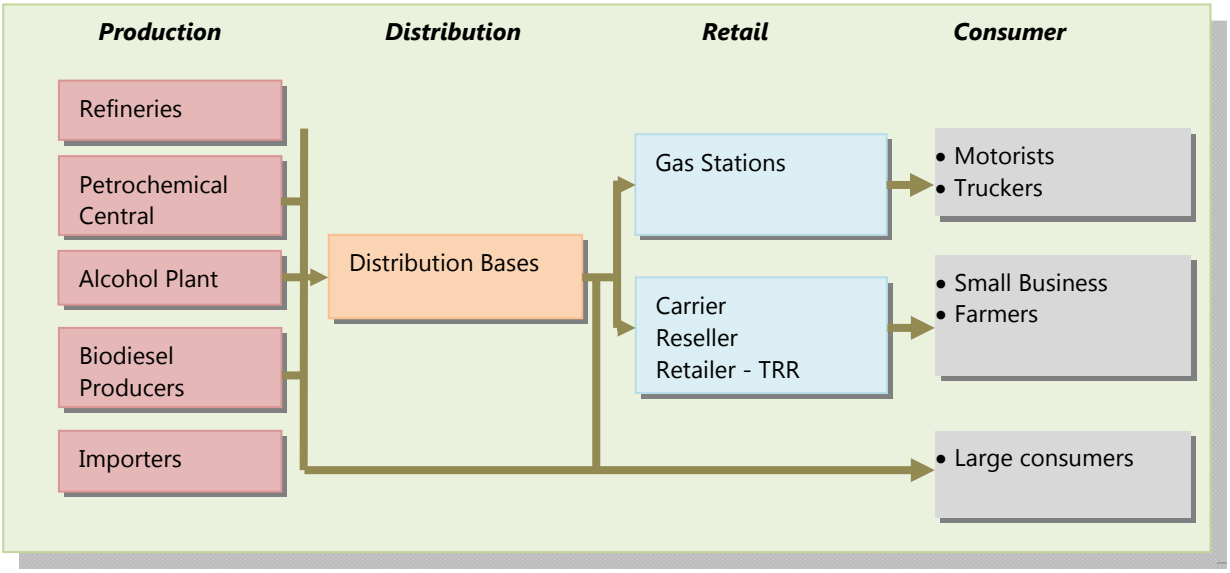

Figure 3: Brazilian matrix of Brazilian fuel logistics (SINDICOM, 2012)

According to Caixeta-Filho et al (2001), the cost of cutting, loading and transport represents 30% of sugarcane production cost, and transport cost represents 12%. Accordingly, logistic costs are directly affected by the distance to be travelled. The distribution of the plants to produce fuels refers to the grassroots distributors that perform the delivery to service stations and other stakeholders serving the end consumer. The choice of transport mode influences the levels of stock. Normally, the transport modes that are more present lower freight costs are also slower, what create the need to maintain higher inventory levels.

These are crucial questions that need to be analysed, because the complex production process and the fuel distribution requires a wide infrastructure, e.g. railways, waterways, roads and polyducts, that allow the fuels distribution via bases distribution established in the country.

4 Systemic challenges and potential overcoming strategies

Planning the future is a challenge to the strategist. Stage planning constitutes an important tool that aims to visualize certain future plausible situation. Therefore, good stages are devices of thought and perception that have the function of making a new and restructured perspective visible (van de Heijden, 2009).

A scenario is an internally consistent view of what the future could become (Porter, 1989). It is not a prediction exercise, but an effort to describe future situations in plausible and consistent form (Wright & Spers, 2006). It is a continuous process of iterance, in which the analysis result of the environment surrounding the business, identifying a small number of fundamental uncertainties, whose construction stage is given by the combination of this uncertainties with the predetermined elements: the events already known that are underway (van der Heijden, 2009). These interpretations substantiated with the predetermined events refer to the stages constructions. The starting point is the survey of the sector landscape, previously interpreted considering what really makes difference.

In this article, the applied methodology to stages construction uses the SRI International method, classified as intuitive logics (Ringland, 1998 apud Boaventura et al, 2004). The method includes specific steps that direct the planner's actions: (i) strategic decisions; (ii) decision key factors; (iii) analysis of environmental forces; (iv) logical stages development; (v) stages description and, (vi) strategic implications (Boaventura et al, 2004). The authors describe that, in the current version, the method suffered slight changes such as the junction of steps 1 and 2 and steps 4 and 5, but the creation of the monitoring phase seems to have been the main change.

Based on the investigation of the Brazilian bioethanol panorama, key factors related to "supply" and "demand" sides where proposed. From these factors, an interpretation of the environmental forces that impact the sector was created. In the sequence, plausible scenarios for a horizon of 10 years are presented.

The analysis is based on the following questions to (i) how to turn Brazil into a real *player* in bioethanol global market; (ii) how to make Brazilian bioethanol competitive in global market. These questions are related to key factors of "supply" and "demand". Regarding to the supply, Brazil has consolidated itself as a strong sugarcane and bioethanol producer. The demand from the domestic market is already consolidated and from the global market has a huge potential. The supply and demand of bioethanol are affected by environment forces, domestic and foreign, and they are related to: (i) predominant weather; (ii) charged price; (iii) competition; (iv) governments regulatory processes; (v) geopolitical and economic conditions of countries; (vi) innovation capacity of companies.

In Brazil, the challenges of bioethanol supply chains are the complexity of the operations performed between the various actors involved and the unpredictability of demand. This unpredictability is influenced by (i) lack of information on real demand down the supply chain, (ii) fluctuations in the selling price of bioethanol, (iii) fluctuations in sugar prices, and causes an increase in costs related to inventory, imbalance in production and transportation difficulties in programming.

Considering that a supply chain is a set of companies that aims to provide products to final consumers, it is noteworthy to say that the unpredictability of demand affects all elements of this chain. The factor is called the bullwhip effect, refers to the distortion of demand information throughout the various companies, generating cost overruns by the mismatch between production and demand. To partly solve this mismatch, it creates the safety stocks to meet these oscillations, reflecting the costs that become representative.

In the process of production and distribution of bioethanol, the rebuilding of inventories in distribution bases occurs when their levels are reducing and are established through deterministic rules. The existence of unpredictability requires safety stock, which have to consider variations of supply and demand. The frequency and amount of resupply are the main factors that determine the level of inventory to be maintained.

The unpredictability affects the production plants and is related to the production process of both raw material and finished product. The lead-time of sugar cane production is usually 12-18 months, which requires a more refined plan in relation to demand forecasts. Thus, variations in demand cannot be supported, quickly, by the transformation industry. Considering this situation, three scenarios were systematized for the Brazilian supply chain of bioethanol in the following section. Policies and guidelines for dealing with these systemic challenges for innovative and sustainable energy supply chains of were also proposed.

4.1 Stage 1 – Optimistic

In the next decade, bioethanol is a certified and standardized fuel, widely spread in the international market, with growing demand in recent years, particularly in the United States of America (EUA). In Europe, the use of renewable is 10%, 6% of first generation biofuels and 4% from alternative sources. Estimates indicate a global demand of about 73 billion liters / year. According to estimates, Brazilian exports should reach 6.8 billion liters by the end of the decade. Other countries, such as China and India, increased their participation in the American and European markets that present strong demand due to the requirements imposed by programs to reduce greenhouse effect. Ethanol production in the U.S. and European countries is significant, but almost uncompetitive in regard to costs. In Brazil, it is anticipated a demand for fuel ethanol from 63.1 million liters / year. The second generation of Brazilian ethanol is a consolidated reality, but the volumes produced are still lower than the first generation. Cooperation agreements between countries help in the diffusion of technology.

Global manufacturers of vehicle have incorporated, broadly speaking, the flex-fuel engine in its production, and other means of transport such as bus, airplanes and motorcycles also use bioethanol intensively. On the other hand, electrically powered vehicles have become known and accessible.

Strengthening the ecological awareness of consumers of ethanol enhances its image by projecting it as a fuel with low levels of pollution. The choice of renewable and low emission of pollutants is the difference that motivates consumers to choose this fuel.

In Brazil, the investments in the logistics structure offer advantages in terms of costs and production flow with the use and integration of various transportation modes.

4.2 Stage 2 – Realistic

In the next decade, ethanol is a fuel widely used in the international market, but there are still tariff barriers, especially in European and Asian markets. The European and Asian countries reinforce their position as global competitors in bioethanol supply, but the division between the production of food and fuel generates instability in the countries.

Global vehicle producers maintain global production of vehicles with flex-fuel engines, but the efforts are focused on engines powered by other energy sources, such as electricity. The 2008 crisis in Europe still has its lingering effects in the medium term generating some shrinkage of markets.

The environmental awareness of consumers is large, but the actions taken by these people do not take into account the type of fuel with the level of pollution exhaled. The actions are restricted to other consumption habits and the price is a determinant factor in the demand for ethanol.

In Brazilian logistic matrix, investments in smaller proportion and regions result in the development of certain producing regions over others.

4.3 Stage 3 - Pessimistic

In the next decade, Brazilian bioethanol has difficulties to establish itself in the international market. Only a few countries import Brazilian products. Agreements signed between the European Union (EU) and Asian countries ensure the supply of fuel to these regions. The U.S. sign agreements with smaller countries and propitious for ethanol production, but also reduces the imports from Brazil.

Global vehicle producers are not interested in continuing the flex-fuel vehicle and direct their investments in powered engine researches, mainly electricity and solar energies. Sales are regionalized, and the market resists accepting this vehicle. Consumers do not incorporate earth-friendly habits. Demand for Brazilian ethanol remains essentially in the domestic market. The logistic problems in Brazil will continue to exist and investments will be directed to other fronts. It implies bottlenecks in the logistic process.

The stages visualization assists in setting policies and strategic guidelines, which will be discussed in the next session.

5 Discussion

The consolidation of bioethanol in the world market goes through the promotion of some initiatives, beyond the need to establish policies and guidelines that support strategic decision makers of renewable energy supply chains. Production and distribution of biofuels imply important challenges for supply chain design, planning and integration. The following aspects have to be properly considered: production, processing, and logistic technical and economic characteristics; taxes, monetary policies and fiscal incentives in different regions/countries. Clear commitment to existing or forthcoming public-private frameworks would also ensure fair partnering in strategic logistic projects. These projects would include the necessary infrastructure for transportation, intermediary and regulatory stocks, intermodal terminals and further interfaces that support stable and reliable supply of biofuel.

The balance between production and demand implies the control of variables that impact the flow of information and products. Sharing information about the actual demand between companies in the network, enables a mitigation of effects that influence the unpredictability and the consequent imbalance between production and demand. The real market information represents the most significant portion of the process. As the vast majority of the gas station has a unique supply company, the insertion of check devices, in real time, for measuring the consumption would allow a more effective control, allowing a greater degree of assertiveness for production volumes as well as inventory to be maintained. This information should be shared among all other members along the chain. Concomitantly, other actions would be important to minimize the effects of the imbalance between production and demand. Equilibrium is achieved when prices remain constant, without abrupt changes. Also, clear rules for the government would provide stability, reliability and consistency in the supply of bioethanol.

The interaction between different members must be coordinated for a common goal, with the purpose of optimizing the supply chain. For this a systemic view that offers a complete analysis of all functions, activities, relationships and processes would be need. The alignment should focus on the timing, seeking to simplify tasks, eliminate delays, expedite flows and scale processes for allowing greater dynamism among the elements of supply chain.

Regarding to environmental issues and the integration within existing natural systems, it is obligatory and critical to ensure and enhance bioethanol holistic sustainability, from feedstock till final consumption. Clear foundations for the cited holistic sustainability are: establishment of stable and optimal production zoning, ensuring minimal impact on the environment (e.g. reuse of degenerated areas like pasturage); studies related to production expansion; development of human capital; as well as macro and micro-logistic integration.

Intensification of researches related to advanced biofuels and new applications, besides, stimulating the exchange of experiences and technologies searching for standardization and product certification are important to consolidate bioethanol in global market.

Prospective research, considering the multitude of direct and indirect effects as well as private and public actors/stakeholders that should be involved in order to deal with existing complexity, is definitively a huge challenge. This applied research could follow a 4-phase structure: (i) identification of potential partners and collaboration frameworks; (ii) identification of main focus considering business interests; (iii) development of customised descriptive model and evaluation framework, and (iv) proposition of strategic implementation roadmap, including feasible actions toward increasing competitive advantage.

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