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ORIGINAL PAPER

Key issues of the upstream segment of biofuels supply chain: a qualitative analysis

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Abstract The role that liquid biofuels will play in future energy systems will depend on biomass-to-energy supply chain to overcome the barriers that may hinder the development and international trade, as well as a sustainable and efficient production of biomass resources. This research paper is based on an extensive literature review, and its purpose is to identify and to investigate the variables that, throughout the agricultural biomass-to-energy supply chain, give rise to the barriers that are common to most varieties of biomass. For achieving it and to assess the effects of referred barriers were used techniques of the Soft Systems methodology. Although biomass-to-energy supply chains are diverse in terms of pattern and operations, the characteristic of the barriers involved in the research provides a broad insight into the issues and challenges to define consistent strategies and interventions for overcoming them. So, this review might be useful for further research related to agricultural biomass-to-energy supply chain optimization that is needed.

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1 Introduction

The world energy system is currently dominated by fossil fuels being critical to the economic growth, especially in increasingly energy-consuming countries [7, 15, 23].

World oil production is reaching its development peak and a declining trend is expected to start in the next 5 up to 10 years, being unlikely that its demand will go along with referred trend [5].

As hydrocarbon-based fuel resources are not renewable, energy prices fluctuate and future energy security as well as climate change concerns grow, become more apparent the interest in energy efficiency and alternative competitive supply options, as a mean to reduce dependency on fossil fuels, such as bio-energy that is renewable and environmentally friendly. For transportation, liquid biofuels as ethanol and biodiesel are potential alternatives in the immediate future to petroleum-derived fuels [49], as they can be used in existing internal combustion engines and supported by the existing fuel supply infrastructure [54]. Biofuels are, however, just one part of the strategy to meet future energy demand. Another key energy supply option is the promotion of electricity produced from renewable energy sources.

Many countries have implemented programs to promote biofuels production and use as, for instance, political targets that have been set by the European Union. The Directive 2009/28/EC [11] amending the Directives 2001/77/EC and 2003/30/EC requires mandatorily all Member States to ensure the substitution of 20 % of fossil fuels consumption by renewable sources and a 10 % minimum target for the share of biofuels in transport by 2020.

The literature [3, 47, 55] emphasizes that, in the years to come, transport energy systems will tend to be shaped into flexible and reliable networks integrating a mix of fossil and biofuel technologies and systems. Despite the advantages of biofuels, from which the most significant are greenhouse gases (GHGs) reduction, energy supply security, promotion of rural development [23, 50] and resource potentials, their 'economic viability is still a critical issue to large-scale commercialization' [3, p. 3760]. Besides, critics argue that edible biomass for producing biofuels might threat food security and inflate food prices [52] and that in general with agriculture-derived biofuels are associated environmental damages [40]. Another criticism regarding biofuels is their inefficiency due to the fact that biomass has lower energy content than conventional petroleum products [35], and this results in a larger biofuels consumption [7].

Thus, the role that liquid biofuels will play in the future 'global mix of energy supply' will depend upon its upstream supply chain to overcome several barriers or constraining factors that may inhibit the development and international trade as well as a sustainable and efficient production of biomass resources, constraining in this way necessary investment [12, 15, 23–25, 44]. Associated with competitiveness, since biofuels and fossil fuel compete on direct price and production cost basis [21, 25], the referred role will also depend on the high valuable co-products processed together with the biofuels in the biomass refining conversion [9, 33], or midstream segment of biofuels supply chain.

This paper outlines the results of a literature review related to the upstream segment of liquid biofuels supply chain, which represents agriculture-related biomass-to-energy production and supply. The research is limited to the key issues of biomass-to-energy supply chain, focusing on the variables that give rise to the above-mentioned barriers that are common to most of the agriculture-related biomass types. Besides, as the cost of biofuels is closely related not only to biomass logistics but also to refining [3], the impact on biofuels competitiveness of the co-products resulting from biomass refining will be summarily considered.

On addressing those issues, the paper aims to contribute to further research focusing on biomass-to-energy supply chain optimization as there is scarcity of reviews in the field.

The frame of this paper is structured in four sections. After the introduction, Sect. 2 refers to the research method that has been used for the literature review. Section 3 addresses the barriers that may inhibit the development of biomass resources in a sustainable and production cost competitive way. In Sect. 4, the key findings are discussed, and Sect. 5 presents the conclusions.

As a description of the situation within which the problem occurs, Fig. 1 illustrates the context of the investigation as it incorporates the logic of the problem situation and captures conceptually the relationships between relevant elements of biomass supply chain. It shows the main structure of the

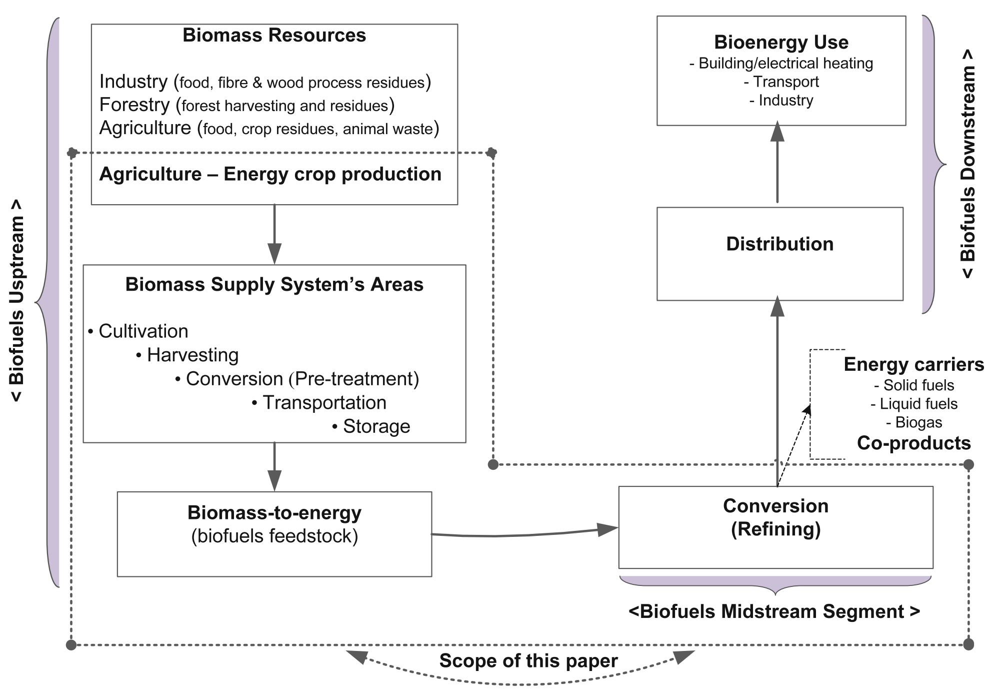

Fig. 1 Agriculture-derived biofuels production chain

logistics system, identifying the biomass supply areas that determine its performance.

2 Research method

For providing insight into the problem situation, we have defined the research delimitation, an essential condition for conducting a literature review or content analysis, described by Fink [14, p. 3] as a 'systematic, explicit, and reproducible design for identification, evaluating and interpreting the existing body of recorded documents'. It was guided by the following questions:

- Which barriers may hamper the sustainable development and international trade of agriculture-related biomass-to-energy?
- Which factors in the biomass-to-energy logistics system might have a harmful incidence on efficiency and cost-effectiveness of biomass-to-energy supply?
- To what extent might biofuels become more competitive?

For conducting the review on the basis of a structured literature search and to answer those questions, we used the procedure model delineated by Mayring [34]. The identified literature was classified into content analytical units through a deductive and inductive approach [34, 45] using criteria focusing on biomass-to-energy supply chain, biomass-to-energy sustainable international trade, biofuels competitiveness and biorefinery.

In the material analysis, aforementioned content analytical units have been assessed for capturing the structure and impact of the barriers and to appraise biomass-to-energy efficiency and cost-effectiveness, focusing on biomass-to-energy logistics system and associated biofuels competitiveness issues.

Taking into consideration the complexity of that analysis as it involves simultaneously issues of political, economic, social, environmental and logistical nature, the soft system methodology (SSM) was applied.

The SSM was developed in the 1970s by Checkland and Scholes [8] and is suitable to address the issues that are essential in the scope of the research. It has been essentially chosen as it is a problem-solving methodology suitable for addressing complex and poorly defined real problem situations. Its techniques serve well for evaluations as such addressed in this paper and to draw resulting key findings. For the characterization of the situational elements and parties involved in the issues, we used its essence or the root definition CATWOE, a mnemonic also developed by Checkland and Scholes [8] and represented in Table 1.

In the root definition, the customers (C) are the fuel consumers and the environment meaning the 'physical, chemical and biotic factors as climate, soil and living beings' [36].

The actors (A) involved in the process are governments, farmers, landowners, local community and market players (e.g. biomass sellers such as farmers and buyers, or food-, feed- and biofuels-producing industries).

Transformation (T) represents the need for overcoming the problem situation, that is to say, the barriers that may hamper not only biomass development and international trade, but also a biomass sustainable and competitive supply.

Weltanschauung (W) is typified by the drivers for biofuels development, from which the main ones are [23, 50]:

1. the promotion of a renewable energy source as a possibility to reduce greenhouse gas emission,
2. energy supply security,
3. the rising prices of fossil fuels, and
4. the promotion of rural development.

The importance of these drivers differs according to the political and economical concerns as well as the priorities or the resources of decision-makers. Mainly in the industrialized countries so far, energy supply security and concerns regarding climate change are reported as growing in their importance [15], building together the critical driving base of the development of bio-energy that is taking place [18].

The owners (O) are governments, farmers and biomass-producing industry. And the environment (E) or the circumstances surrounding the situation is the existing concern related to greenhouse gas emission increase,

Table 1 CATWOE definition

C	*C*lients/customers	Those who more or less directly benefit or suffer losses from T
A	*A*ctors	Those who are involved in T
T	*T*ransformations	The need to overcome the barriers to the biomass-to-energy sustainable development
W	*W*eltschauung	The relevant world-views that underlines the need to promote the development of biofuels
O	*O*wners	Those who are involved in the definition of essential policies and planning processes to enable *T*
E	*E*nvironment	Concerns of ecological, political, social and economical nature

Source: Checkland and Scholes [6]

pressure on biodiversity, ecosystems and food security, as well as the opinion that fossil fuels are depleting and their supply is vulnerable to uncertainties [6].

In our literature review–based research, Transformation and Weltanschauung underpin the analysis, as in exploring them we also address the other elements of the CATWOE.

3 Analysis of the problem

The research addresses the upstream of biofuels supply chain analysing the key barriers or constraining factors that may hamper biomass-to-energy development, international trade, and sustainable and competitive supply. Those barriers arise mainly from existing sustainability concerns and economic and political issues shown in Fig. 2, as well as from costs associated with the biomass supply system's or logistics areas referred to in Figs. 1 and 3. As a consequence of this differentiation on origin, the barriers were respectively categorized into macro and micro. Since their relevance is above all emphasized by the fact that they have a negative effect on biofuels competitiveness, midstream segment of biofuels supply chain will be briefly considered in the analysis of the biomass conversion.

3.1 Macro-level barriers

The macro-level barriers impacting biomass supply are presented in Fig. 2. Having been reproduced in the root definition by the 'Actors' and 'Environment' of the CATWOE in Table 1, they result essentially from economic factors, political decisions, as well as sustainability concerns that impact not only the price competitiveness but also the trade of biomass-to-energy.

The impact on price competitiveness results mainly from three factors. The first one is the absence of centralized marketplaces for biomass-to-energy that prompts a lack of commodity pricing [50]. The second factor is the fact that the development of international trade of biomass-to-energy is in its initial stages, being currently limited by the circumstance that mostly by reason of protectionism many countries tax biomass-to-energy with the same import duties as foodstuff [12, 44, 54]. And the third factor becomes relevant when there is an imbalance between biomass-to-energy supply and demand sides [12, 22, 25]. This imbalance might occur in the case of some critical biomass resources, especially those linked with heating purposes, where the supply capacity is frequently not able to meet high and unforeseen demand requirements and prices become volatile [12, 26].

The aforementioned market organization generates a lack of price transparency causing uncertainties that make difficult for potential investors to get a full overview of critical conditions to an investment [24]. Thus, they result on constraints on investments in more efficient biomass production systems and conversion technologies that are essential for improving biofuels competitiveness [24]. Furthermore, as biomass-to-energy markets are not sufficiently developed; they can be immature and unstable [13]. Hence, trade of biomass-to-energy is largely bilateral and as the literature highlights poorly documented [12, 24, 25].

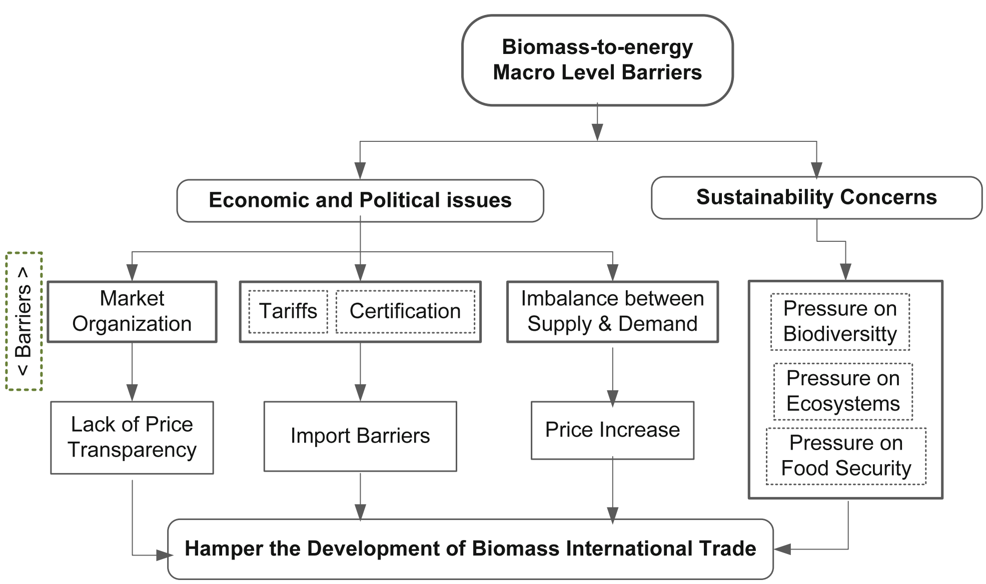

Fig. 2 Macro-level barriers

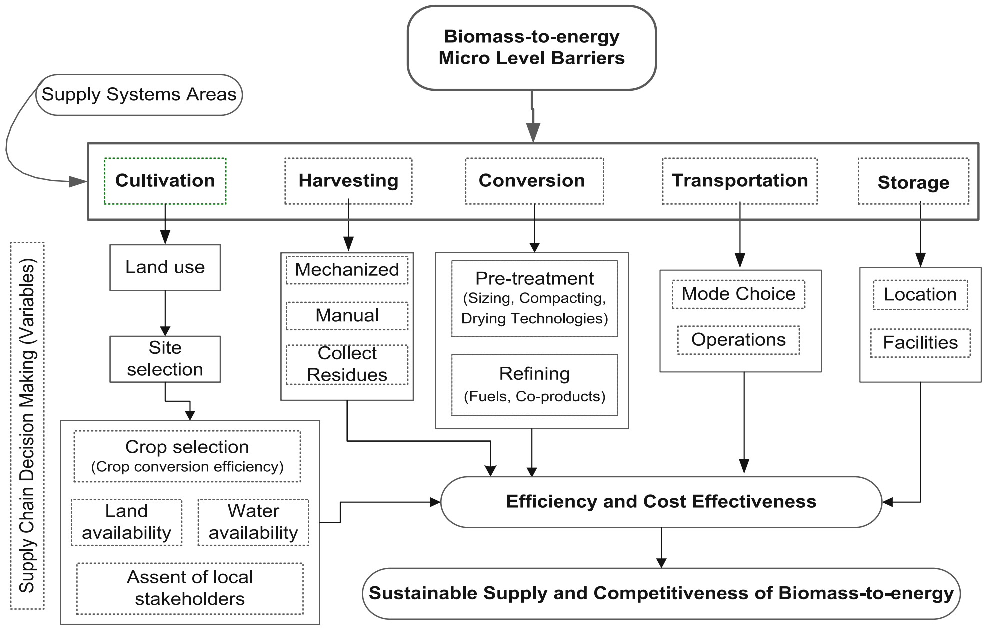

Fig. 3 Micro-level barriers

Regarding sustainability concerns, the use of land and water for the production of biomass resources, especially energy crops, is amongst the most relevant pressures on biodiversity and ecosystems [43]. This is mostly associated with deforestation, nutrients loss, dissemination of fertilizers, pesticide application with harmful environmental effects and above all groundwater depletion [29, 43, 49]. Besides, biomass-to-energy production may also generate relevant pressures on food security, especially when there is competition with food production in fertile land use [9, 18].

All these concerns strengthen the need of a sustainable production of biomass-to-energy, that is, to develop biomass-to-energy resources and exploit their potentials with economical, environmental and social benefits [12, 44, 45, 54] and to establish certification schemes for ensuring it [51].

Being essential for the sustainable exploitation of biomass potential, certification is a complex matter because of the diversity of views on sustainability that shows a very close interaction of economic, environmental as well as societal issues [46].

3.2 Micro-level barriers

The micro-level barriers are reflected in Fig. 3. They result from decisions, made by the 'Actors' referred to in the CATWOE, related to the variables that, by determining the performance of the logistics system, influence the efficiency and cost-effectiveness of the biomass supply chain, due to the causal linkage between its logistics areas [2] or supply system's areas.

3.2.1 *Cultivation*

Variables: land use, site selection, crop choice, land and water availability, assent of local community.

As benefits of biofuels become progressively evident, dedicated growing of energy crops is being increasingly used as biomass feedstock to provide vegetable oil for the production of biodiesel, or sugar molasses and maize corn for bioethanol.

When energy crops need to be grown, the decision-making process involves mainly issues regarding land use, crop choice and site selection.

Land use is linked with crop choice, as it refers to land availability and its quality that are associated with the expected yields per hectare and conversion efficiency into energy carrier of biomass feedstock to be cultivated [23, 38, 49]. While the yields per hectare and the conversion efficiency of biomass feedstock concern crop selection, land quality is mainly coupled with soil fertility, water requirements and availability [23]. Thus, site selection has an increased importance for the sustainable production of biomass-to-energy as it includes issues related to soil type, land requirement and competition for land use with food industries. Other issues such as those associated with the impact on biodiversity and ecosystems and water resources [23, 53] as well as proximity of the cultivation site to the processing plant or to the export port are likewise considered [20, 41]. The proximity is relevant due to the impact of the cost of local transport on biomass-to-energy supply cost and hence on biofuels competitiveness [20]. As a result of the confluence of all those issues, depending on site selection decisions, cultivation might become a barrier to biofuels development and economic viability [3].

At site selection decision-making process, besides above-referred considerations, the assent of local community to energy crop cultivation has to be addressed, due to the involved socio-economic and cultural issues. As a matter of fact, in traditional areas, agriculture is closely connected with the formation of local cultural roots and cells of ecosystems dependent on human activities [31].This issue becomes critical when energy crops are to replace food-assigned monocultures [18].

3.2.2 Harvesting

Variables: crop seasonality, weather variability, manual (labour), mechanized (investment on technologies).

For addressing harvesting, there is a need to take a supply chain perspective reflecting its close relationships with cultivation, storage, transportation and even conversion, rather than to consider the area isolated [2, 3].

The type and use of biomass feedstock depend on the characteristics of the biomass demanded by the conversion plant [3] and determine the harvesting, storage as well as the transport systems to be used. And, the harvesting productivity might set the storage capacity requirements and truck local transport operations [2].

Furthermore, biomass feedstock yields are highly depending upon three factors: (1) the harvesting season's length, (2) the moment selected within the season to carry out harvesting operations and (3) the harvesting system and weather conditions [3].

As a result that weather conditions might change over multiple time periods during harvest season, and harvesting operations are carried out weather permitting, harvesting represents an uncertainty factor in biomass cost-effectiveness [10] and might become a barrier to the sustainable supply and competitiveness of biomass-to-energy.

Hence, any decision-making process at harvesting has to address issues related to crop seasonality, weather variability and harvesting system, storage, as well as transportation to be applied [2, 23, 25].

Harvesting system can be manual and mechanized, with both benefits and disadvantages, and respective decision may be controversial due to social and economical reasons [2, 3, 18, 51].

3.2.3 Conversion

Variables: pre-treatment technologies and refining.

Conversion consists of two processes. Primary conversion, also named physical or pre-treatment, takes place in the biofuels upstream segment, and the secondary conversion occurs in the biofuels midstream segment or refining phase [5, 16].

The main purpose of pre-treatment is to reduce biomass supply cost by contributing to the optimization of storage capacity and reduction in local truck transport costs [2], as well as to increase biomass secondary conversion efficiency [5, 16, 27].

As storage, transport and handling costs are mainly based on the volume of the material to be transferred, there is an economic driver to reduce biomass volume early in the supply chain and prior to transport [19, 56].

Pre-treatment can be achieved by the application of a number of technologies such as drying, resizing, densification and fractionation [5], each one with specific requirements, advantages and disadvantages [2]. The choice of pre-treatment technologies is usually determined by the properties of the biomass source, storage capacity and requirements of conversion plant in terms of biomass volume, quality and supply's frequency [3].

Pre-treatment efficiency is a key issue regarding biofuels economic feasibility due to the relevant impact on biomass supply costs. When it is inefficient, pre-treatment may give rise to a barrier to an efficient biomass supply, as becoming a biomass supply cost-increasing factor [3].

The secondary conversion or refining process is the conversion of biomass into biofuels and high valuable co-products such as biobased products, biomaterials and biochemicals [9, 27, p. 1984].

Since investments in biorefineries are capital–intensive, they would become economically not attractive if depending only on biofuels, because biofuels are high-volume and low-value products [5, 30]. So, co-products gain an increased importance, as respective high margins not only compensate the low value of biofuels [5] but also make biofuels cost competitive [5, 9, 27].

This importance of the co-products for biofuels competitiveness results from the fact that biofuels and fossil fuels are competing on direct production cost basis, and fossil fuel externalities are not considered in cost accounting [9].

3.2.4 Storage

Variables: facilities location and capacity.

Storage is a major issue concerning the cost of biomass supply chain logistics. It is needed in the points of the supply chain in which biomass resources availability and subsequent transportation are not coincidental [20]. And it can be located in the cultivation area, in the conversion plant, in intermediate points between cultivation area and conversation plant, or even in the export harbour [2].

Decision-making related to storage has to take into account not only biomass organic nature that may restrict storage time [41, 42], but also its location and capacity that may determine the volume of inventory in each operation and/or planning period [1]. Several biomass feedstocks have seasonal harvesting, and when biomass secondary conversion occurs all year round, large quantities have to be stored [39]. In such cases, large gathering storage is required.

The location and capacity of storage as well as pre-treatment efficiency and the number of delivery trips impact the local transport cost of biomass supply [2]. This cost becomes very high and thereby increases biomass supply costs, harming biofuels competitiveness, when storage facility is of small capacity, located not close to conversion plant, and this one requires regular supply volumes exceeding referred capacity [2].

3.2.5 Transportation

Variables: mode choice, operational variables (distance, product weight, product volume, carrying capacity, fossil energy consumption)

Transportation establishes the physical link between all activities of the biomass supply chain. In general, after harvesting, biomass feedstock is transferred to a gathering storage facility where it is pre-treated and thereafter transferred again to conversion plant or harbour according to the demand requirements [20]. Local transport is usually performed by truck, and long distance runs by train and ship [20].

With transportation are associated relevant variables that may inhibit a cost-effective biomass development, mainly due to biomass physical and chemical properties that might harm biomass supply efficiencies [2, 23, 24]. Whether biomass is wet or dry, the low density and bulky nature by influencing the product weight and volume of biomass to be hauled in each trip make its transport costs high and, in general, all logistics operations expensive. This enforces the relevant importance of pre-treatment [5, 20, 56].

Other factors such as trip distance, truck carrying capacity and fossil fuel consumption may have the same negative impact on local transport cost and logistics operations making, together with the effect of aforementioned properties, biofuels less competitive than fossil fuels [2, 20].

Biomass local transport costs are, in general, high when biomass feedstock is dispersed over large areas requiring therefore significant road haulage, when there is lack of or no efficient biomass pre-treatment technologies and when biomass is produced and used in different sites, having large volumes to be collected and transferred [5, 20, 56].

3.3 Summary

The analysis shows that the micro-barriers are highly interconnected and extensively interdependent. Hence, when planning biomass supply chain management, those traits highlight the need of taking an integrated, holistic approach. And also the need to consider that biomass supply chain is particularly vulnerable to sustainability and competitiveness risks resulting, for instance, from the lack of support from governments, public and other stakeholders, based on economic and political issues as well as on environmental and food security concerns, associated with the macro-barriers.

4 Discussion

Table 2 shows the key findings that have been drawn and the conditions conceptualized that will enable the fulfilment of the Transformation's objective described in CATWOE definition.

Key findings related to economical and political issues as well as sustainability concerns are depicted in the item 1. Those regarding biomass-to-energy sustainable and competitive supply are reflected in the items 2 up to 6.

1. To overcome the economic, political and sustainability factors that affect the development and international trade of agricultural-related biomass-to-energy, there is a need for increasing regional and national supportive government policies, such as tax exemptions, tariff incentives, investment subsidies, obligatory blending of biofuels with fossil fuels and political decisions promoting a biofuels-sustainable production, trade and use. Germany [4, 35], USA [48] and Brazil [17] are examples of countries whose policies led to a relevant growth of biofuels production and use. For supporting those decisions, governments have to invest on research and development. Moreover, there is a need for the establishment of centralized or commodity markets for biomass-to-energy, to secure long-term and sustainable supply and demand of biomass-to-energy providing benefits to all parties involved. And also there is a need for the setting of worldwide-accepted sustainable biomass trade certification [32]. There are, for example, certification criteria for biomass-for-energy as EUGENE (European Green Electricity Network) and Green Gold Certificate, a track and trace system for biomass, developed in the Netherlands [32]. Nevertheless, for the control of biomass trade, there are so far neither sustainable criteria nor a certification system due to the fact that there is no consensus regarding the criteria that should be considered to ensure a sustainable biomass trade. [51]. Thus, for avoiding that, although essential, certification might become a barrier to biomass development and international trade, it is of utmost importance that the definition of sustainability

Table 2 Key findings

Key findings	Involved area	Involved actors	Factors in decision making
1. Need for biomass-to-energy supporting policies	Market development	Governments	Abolition of import barriers
Need to promote biomass sustainable production and use	Biomass certification	Researchers, farmers	Tax and tariff incentives
Need to Invest in research and development	Taxation and tariff policies, research and development		Development of biomass international trade
Need of setting of worldwide-accepted certification schemes	Biomass production, supply chain optimization		Definition of common sustainability criteria
Establishment of biomass central markets			Research and development
2. Importance of planning land selection and use to avoid competition between biomass-to-energy and food productions	Cultivation	Researchers	Land selection
		Farmers	Land use
		Local community	
Importance of the delimitation of cultivation areas for biomass-to-energy production		Governments	
3. Complexity of the decision making regarding harvesting system to be used	Harvesting	Researchers	Harvesting equipment versus labour manual
		Farmers	
		Governments	
4. Importance of conversion decision-making for biofuels competitiveness	Pre-treatment, refining	Researchers, farmers, storage owners, refineries	Technologies and location of pre-treatment and refining
5. Importance of transport planning in the framework of a supply chain strategy	Transportation	Researchers, farmers	Transport operations optimization
		Storage owners/operators	
		Transport providers	
		Refineries	
6. Importance of storage location and capacity for the supply chain cost-effectiveness	Storage	Researchers	Storage location and capacity optimization
		Storage owners/operators	
		Researchers	

criteria results from transparent discussions between biomass-producing and biomass-consuming countries [51].

2. In cultivation, decision-making process site selection and land use are of utmost importance, especially when biomass-to-energy production may lead to a competition with food agriculture. The importance becomes more critical whenever it implies a shift away from traditional production, mostly associated with well-adapted land use, towards new energy crops cultivation. This results from the fact that in addition to land use change, shifts constitute mainly a move from a single hierarchical decision-maker such as the farmer to an integrated and more complex production–distribution system [31]. In this context, the assent of the local community is therefore essential [31].
3. Harvesting-related decisions may sometimes become twofold controversial: firstly, manual harvesting, although benefitting employment and having low labour cost, may have harmful environmental effects [18, 51]; secondly, mechanized harvesting involves the financial risk of capital-intensive investments [51]. A most cost-effective and efficient harvesting system resulting from such investment may require an intensive storage systems, from which investment economic viability might not be assured by the biomass demand of the conversion plant [2, 3]. Besides, mechanized harvesting may generate an increase in unemployment in rural areas [51].
4. Conversion decision-making process is pivotal for biofuels competitiveness, as pre-treatment has a relevant impact on biomass supply costs and refining, which determine the economic profitability of biofuels production [9]. Thus, conversion-related decision-making has to jointly consider (a) investments in pre-treatment technologies, (b) pre-treatment location and performance and (c) investments in biorefineries that represent the key for biofuels competitiveness, due to the high margins of the processed co-products [5].

5. In transportation, decision-making processes have an increased importance in the pre-treatment technologies and cargo consolidation [20, 24]. Due to the diversity of the actors involved in the biomass supply chain, for enabling a reduction in transport costs, there is a need to develop a collaborative and information-sharing strategy to ensure a high level of supply co-ordination and information flow transfer. Hence, transport operations have to be linked to the supply chain strategy [37].
6. Both storage location and capacity are important for biomass supply chain cost-effectiveness, as they might be cost reduction factors and contribute to biomass supply efficiency, because any shortening of transport distance and any scaling effect, or increase in volume to be hauled, provide supply cost reductions [19, 28].

5 Conclusions

The research reveals that for overcoming the barriers that may inhibit the development of agriculture-related biomass-to-energy and biofuels in a sustainable and competitive way, apart from government incentives based on economic and environmental requirements, (1) biomass supply chain optimization is essential and (2) bio-processing technologies have to be efficient.

Supply chain optimization will enable the supply chain to obtain significant efficiency gains and effectiveness in the mitigation of environmental and social impacts. And efficiency of bio-processing technologies will enhance to keep high the value of the co-products resulting from biomass conversion.

The optimization of biofuel supply chains is closely related to the existing interrelationship and interdependence between all biomass supply areas, namely cultivation, harvesting, storage, conversion/pre-treatment and transportation. It refers to

(a) a choice of inedible crops with high yields;
(b) an operational co-ordination at tactical and strategic levels between transportation and pre-treatment as well as storage, that are associated with efficiency and scaling effects, for ensuring the best logistic system integration; and
(c) the use of advanced efficient process technologies,

to enable relevant reductions in environmental and biomass production costs, and an increase in biofuels competitiveness resulting from high-value biobased products, biomaterials and biochemicals processed together with biofuels in the biomass refining.

On identifying the close interdependencies that exist amongst all biomass system's areas, as well as the variables that influence biomass supply chain cost, the research gives evidence that biomass supply chain optimization deals with a wide set of complex strategic and operational decision choices not comprehensively enough analysed so far. The need for operation research analysing in depth the effects of the referred variables on the cost performance of the biomass logistics system is therefore critical.

That research should cover a widest possible range of agriculture-derived biomass, to become a consistent decision support on biomass supply chain optimization. Besides, considering the great move towards an expanded biofuels use, it should address large-scale biomass supply.

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References

1. Ahumada O, Villalobos RJ (2009) Application of planning models in the agri-food supply chain: a review. Eur J Oper Res 195:1–20
2. Allen J, Browne M, Hunter A, Boyd J, Palmer H (1998) Logistics management and costs of biomass fuel supply. Int J Phys Distrib Logistics Manag *28*(5/6):463–477
3. An H, Wilhelm WE, Searcy SW et al (2011) Biofuel and petroleum-based fuel supply chain research: a literature review. Biomass Bioenergy 35:3763–3774
4. Banse M, van Meijl H, Tabeau A, Woltjer G (2008) Impact of EU biofuels policies on world agricultural and food markets. In: Paper presented at 107th European Association of Agricultural Economists, EAAE, seminar "modelling of agricultural and rural development policies". Sevilla, Spain, 29 Jan–1 Feb 2008. pp 29, 107th seminar, Jan 30–Feb 1 2008, Sevilla, Spain. http://purl.umn.edu/6476
5. Bozell JJ (2008) Feedstocks for the future—biorefinery production of chemicals from renewable carbon. Clean 36(8):641–647. doi:10.1002/clen.200800100
6. Bravo ML, Naim MM, Potter AT (2010) Transportation issues in the upstream biofuels supply chain. In: Proceedings of the annual conference of the International Association of Maritime Economists (IAME), Lisbon, Portugal, 7–9 July
7. Charles MB, Ryan R, Ryan N, Oloruntoba R (2007) Public policy and biofuels: the way forward? Energy Policy 35:5737–5746
8. Checkland P (2000) Soft systems methodology: a thirty year retrospective. Syst Res Behav Sci 17:S11–S58
9. Cherubini F (2010) The biorefinery concept: using biomass instead of oil for producing energy and chemicals. Energy Convers Manag 51:1412–1421
10. Cundiff JS, Dias N, Sherali HD (1997) A linear programming approach for designing a herbaceous biomass delivery system. Bioresour Technol 59(1):47–55
11. Directive 2009/28/EC of the European Parliament and the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC

12. Faaij A (2008) Developments in international bio-energy markets and trade. Biomass Bioenergy 32(8):657–659
13. Faaij APC, Domac J (2006) Emerging international bio-energy markets and opportunities for socio-economic development. Energy Sustain Dev X(1):7–19
14. Fink A (2005) Conducting research literature reviews: from the internet to paper, 2nd edn. Sage, Thousand Oaks. Chap 1
15. GBEP—Global Bioenergy Partnership (2007) A review of the current state of bioenergy development in G8 + 5 countries, GBEP Secretariat, Food and Agriculture Organization of the United Nations (FAO), Rome 2007; Report Final http://www.fao.org/newsroom/common/ecg/1000702/en/GBEPReport.pdf. Last accessed 8 May 2011
16. Gheres MI, Ros V, Chira T, Fechete LV, Molnar A, Ranta O (2006) 'Technical and economical analysis of bioenergy production' Buletin USAMV-CN, 62/2006 (68–73) ISSN 1454-2382. http://journals.usamvcj.ro/agriculture/article/viewFile/1564/1535. Last accessed 19 July 2011
17. Goldemberg J, Coelho ST, Lucon O (2004) How adequate policies can push renewables. Energy Policy 32:1141–1146
18. Hall DO, Scrase JI (1998) Will biomass be the environmentally friendly fuel of the future? Biomass Bioenergy 15(4/5):357–367
19. Hamelinck C, Faaij A (2006) Outlook for advanced biofuels. Energy Policy 34:3268–3283
20. Hamelinck CN, Suurs RAA, Faaiji APC (2005) International bioenergy transport costs and energy balance. Biomass Bioenergy 29:114–134
21. Hanna MA, Isom L, Campbell J (2005) Biodiesel: current perspectives and future. J Sci Ind Res 64:854–857
22. Heinimo J, Pakarinen V, Ojanen V, Kässi T et al. (2007) International bioenergy trade—scenario study on international biomass market in 2020. Lappeenrannan University of Technology Department of Industrial Engineering and Management
23. IEA/OECD International Energy Agency (2007) Good practice guidelines, bioenergy project development & biomass supply. http://www.iea.org/textbase/nppdf/free/2007/biomass.pdf. Last accessed 3 Mar 2009
24. IEA, International Energy Agency (2006) *Bio-energy* task 40 opportunities and barriers for sustainable international bio-energy trade and strategies to overcome them. http://www.bio-energytrade.org/downloads/t40opportunitiesandbarriersforbio-energytradefi.pdf. Accessed at 18 Sept 2008
25. Junginger M et al (2008) Developments in international bioenergy trade. Biomass Bioenergy 32(8):717–729
26. Junginger M et al. (2006) IEA *Bioenergy* Task 40—Sustainable International Bioenergy Trade: Securing Supply and Demand Opportunities and barriers for sustainable international bioenergy trade and strategies to overcome them—Technology report. http://www.fao.org/uploads/media/0611_IEA_Task_40_-_Technology_report.pdf. Last accessed 3 Mar 2011
27. Kamm B, Kamm M (2007) International biorefinery systems. Pure Appl Chem 79(11):1983–1997. doi:10.1351/pac200779111983
28. Kema *Consulting* (2005) Bioenergy logistics cost structure and development potential. Report to Enova. Energidata, Institute of Transport Economics (TØI) and *KEMA Consulting*. www.bioenergytrade.org/downloads/bioenergylogisticschainfinalreport.pdf. Last accessed 2 Mar 2010
29. Koh LP, Ghazou J (2008) Biofuels, biodiversity, and people: understanding the conflicts and finding opportunities. Biol Conserv 141:2450–2460
30. Koo LY, Adhitya A, Srinivasan R, Karimi IA (2008) Decision support for integrated refining supply chains part 2. Design and operation. Comput Chem Eng 32:2787–2800
31. Krausmann F, Erb KH, Gingrich S, Lauk C, Haberl H (2008) Global patterns of socioeconomic biomass flows in the year 2000: a comprehensive assessment of supply, consumption and constraints. Ecol Econ 65:471–487
32. Lewandowski I, Faaij APC (2006) Steps towards the development of a certification system for sustainable bio-energy trade. Biomass Bioenergy 30:83–104
33. Lunnan A (1997) Agriculture-based biomass energy supply—a survey of economic issues. Energy Policy 25(6):573–582
34. Mayring P (2000, June) Qualitative content analysis. Forum-Qualitative Sozialforschung/Forum: Qualitative Social Research [On-line Journal] 1(2). Available at: http://www.utsc.utoronto.ca/~kmacd/IDSC10/Readings/text%20analysis/CA.pdf. Last accessed 1 June 2011
35. McCormick-Brennan K, Bomb C, Deurwaarder E, Käberger T (2007) Biofuels for transport in Europe: lessons from Germany and the UK. Energy Policy 35(4):256–2267
36. Merriam-Webster's Collegiate Dictionary (1993)
37. Naim MM, Potter AT, Mason RJ, Bateman N (2006) The role of transport flexibility in logistics provision. Int J Logistics Manag 17(3):297–311
38. Nonhebel S (2005) Renewable energy and food supply: will there be enough land? Renew Sustain Energy Rev 9:191–201
39. Pätz C, Seiffert M (2009) Optimised biomass logistics for conversion plants that produce heat, electricity and biofuels. In: Proceedings of the Chilean-German Biociclo workshop (Karlsruhe, 26.03.2009)—challenges for sustainable biomass utilisation, pp 45–55
40. Pimentel D (2003) Ethanol fuels: energy balance, economics, and environmental impacts are negative. Nat Resour Res 12(2):127–134
41. Ravula PP, Grisso RD, Cundiff JS (2008) Comparison between two policy strategies for scheduling trucks in a biomass logistic system. Bioresour Technol 99:5710–5721
42. Rentizelas AA, Tolis AJ, Tatsiopoulos IP et al (2009) Logistics issues of biomass: the storage problem and the multi-biomass supply chain. Renew Sustain Energy Rev 13:887–894
43. Robertson GP et al. (2008) Sustainable biofuels redux. Science 322:49–50. Downloaded from www.sciencemag.org on 22 Apr 2009
44. Smeets E, Junginger M, Faaij A, Walter A, Dolzan P, Turkenburg W (2008) The sustainability of Brazilian ethanol—an assessment of the possibilities of certified production. Biomass Bio-energy 32:781–813
45. Seuring S, Müller M (2008) From a literature review to a conceptual framework for sustainable supply chain management. J Clean Prod 16:1699–1710
46. Seuring S (2004) Integrated chain management and supply chain management comparative analysis and illustrative cases. J Cleaner Prod 12:1059–1071
47. Szklo A, Schaeffer R (2006) Alternative energy sources or integrated alternative energy systems? Oil as a modern lance of Peleus for the energy transition. Energy 31:2513–2522
48. Tyner W (2009) The integration of energy and agricultural markets. In: Presented at the 27th International Association of Agricultural Economists conference Beijing, China
49. UNEP, United Nations Environment Programme (2008) Convention on biological diversity. In: Conference of the parties to the convention on biological diversity; May 2008. UNEP/CBD/COP/9/26 www.cbd.int/doc/meetings/cop/cop-09/official/cop-09-26-en.pdf. Accessed at 2 Oct 2009
50. UNICAMP/IEA Bio-energy (2007) A report prepared by IEA *Bioenergy* Task 40 Sustainable Bio-energy Trade; securing Supply and Demand. Deliverable 8 lead by Brazil, Market Evaluation: Fuel Ethanol
51. van Dam J, Junginger M, Faaij A, Jürgens I, Best G, Fritsche U (2008) Overview of recent developments in sustainable biomass certification. Biomass Bio-energy 32:749–780

52. van der Laaka WWM, Raven RPJM, Verbong GPJ (2007) Strategic niche management for biofuels: analysing past experiments for developing new biofuels policies. Energy Policy 35:3213–3225 in Charles et al. 2007
53. Volk TA, Verwijst T, Tharakan PJ, Abrahamson LP, White EH (2004) Growing fuel: a sustainability assessment of willow biomass crops. Front Ecol Environ 2(8):411–418. doi:10.1890/1540-9295(2004)002[0411:GFASAO]2.0.CO;2
54. Walter A, Rosillo-Calle F, Dolzan P, Piacente E, da Cunha KB (2008) Perspectives on fuel ethanol consumption and trade. Biomass Bioenergy 32:730–748
55. Wilton P (2005) The energy revolution. *Engineering and Physical Sciences Research Council*, *Energy Special Edition*, Newsline 34 Autumn 205
56. Zwart RWR, Boerrigter H, van der Drift A (2006) 'The impact of biomass pretreatment on the feasibility of overseas biomass conversion to Fischer-Tropsch products. Energy Fuels 20(5): 2192–2197