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Abstract. The circular economy promotes the reuse of waste and recycling processes in agroindustry. Literature has focused on the development of frameworks related to the evaluation of environmental improvements brought by the biomass and biofuel supply chains. However, there is still a gap related to comprehensively understanding the costs of these supply chains. In this paper, the concept of Integrated Biomass Logistics Centers (IBLCs), developed in a European research project, is framed into a supply chain recycling wastes frm the agricultural sector and producing bio-commodities and/or intermediate bio-based feedstocks. In particular, this study, by using SCOR and Activity Based Costing, proposes an integrated framework to comprehensively evaluate costs of IBLCs' supply chains.

Keywords: biomass supply chain, circular economy, recycle business, Integrated Biomass Logistics Centers.

1 Introduction

Increasing concerns about the depletion of natural resources have boosted the commitment of governments towards a sustainable development in three dimensions: economic, social and environmental protection, as interdependent and mutually reinforcing pillars (UN, 2005). Sustainability is based on considering the entire lifecycle of a product during the planning stage, and is affected by several factors (Salonitis and Stavropoulos, 2013): raw materials, supply chain considerations, manufacturing operations, usage, service and decommissioning. In this regard, the European Commission has established an ambitious agenda to transform the economy of the European Union into a circular economy by 2030. In addition, by 2020, 20% of the energy production will stem from renewable sources such as wood pellets (Boukherroub et al., 2017). A circular economy starts at the very beginning of a product's life and the value of products and materials is maintained for as long as possible (EC, 2018). It is based on a recycling society to reduce waste generation and use waste as a resource, and the principle of "closing the life cycle" of goods, services, waste, materials, water and energy. In addition, waste and resource use are minimized, and products are used again at the end of its life to create further value. Circular economy is usually represented by means of four loops and represents four key principles (Urbinati et al., 2017): (i) product-life extension; (ii) redistribution/ reuse; (iii) remanufacturing; and (iv) recycling.
In the context of recycling and waste reuse in the agroindustry, many types of available biomass can be utilized as feedstock for the production of other products. Generally, two groups of biomass feedstock can be identified (Yue et al., 2014): (i) corn grain, sugar cane, soy bean, oil seed and so on, with direct implications in terms of world food prices and production; and (ii) cellulosic biomass, obtained from agricultural residues (e.g. plant parts left in the field after harvest), forest residues (e.g. leftover wood) and energy crops (i.e. fast-growing trees and perennial grasses specifically grown for energy uses). The use of agrifood waste and the associated by-product biomasses for energy recovery and nutrient recycling, help to mitigate climate change and eutrophication which are currently unexploited (Kahiluoto et al., 2011). However, second generation biofuels produced from agricultural residues present a scale limitation arising from the logistics of feedstock collection (Leboreiro and Hilaly, 2013).
While extensive studies have been performed to examine the environmental impacts of circular economies, some challenges remain in two main areas (Yue et al., 2014): (i) the development of an efficient feedstock supply chain for cost-effective and time-sensitive collection, preprocessing and transport; and (ii) to manage the seasonal nature and annual variability of biomass. To face these challenges, the concept of Integrated Biomass Logistics Center (IBLC) has been coined within a European research project, AgroInLog. An

IBLC is a center with a business strategy (Annevelink et al., 2017): *"a business strategy for agro-industries to take advantage of unexploited synergies in terms of facilities, equipment and staff capabilities, to diversify regular activity both on the input (food and biomass feedstock) and output side (food, biocommodities and intermediate bio based feedstocks) thereby enhancing the strength of agro-industries and increasing the added value delivered by those companies".* Four typical characteristics can be associated to an IBLC: (i) integrated value approach towards food and bio based markets; (ii) regional availability of biomass; (iii) logistics, storage operations and pretreatment; and (iv) exploiting the central position (Annevelink et al., 2017).

The running of the IBLC might imply new investments and costs, and its cost-effectiveness should be analyzed. Our review of previous research shows a fragmented area where several frameworks and Decision Support Systems (DSS) related to the assessment of biomass and biofuel supply chains have been developed, yet lacking an integrated and comprehensive view of the supply chain. For instance, some of the available models are applied to the upstream part of the supply chain (Sharma et al., 2013, De Meyer et al., 2016), computing costs for supplying materials or semi-finished products (Brechbill et al., 2011, Belbo and Talbot, 2014, Boukherroub et al., 2017). Others focus on the problem to optimally locate facilities in the bio-supply chains, see literature review provided by Atashbar et al. (2016), or simply examine and optimize transportation of bio-mass or bio-commodities (Gomes et al., 2012, Ebadian et al., 2014, Lautala et al., 2015). Belbo and Talbot (2014) simulate ten supply chains with a focus on the procurement of small tree biomass for energy production. The calculation of costs is made on the basis of production, handling, treatment and storage costs. Boukherroub et al. (2017) consider a wood pellet supply chain network design problema, i.e. the model selects the best feedstock locations and determines the optimal quantities to supply and the optimal production capacity (alternative biomass sources harvested in the forest and mill residues). Costs associated with the wood pellet supply chain relates exclusively to production factories, hence, raw material procurement costs, raw material transportation cost (from the forest to the pellet mill), investments, production and storage cost, wood pellet delivery cost (Boukherroub et al., 2017). Ebadian et al. (2014) develop an approach which includes both an optimization model to reduce biomass delivery costs in a bioethanol plant, and a simulation model which uses the optimization model to manage the biomass flow between farms, storage sites and the bioethanol plant. The objective function aims to minimize the total delivery cost defined by the collection costs, in-farm hauling costs, storage costs, loading costs and road transportation costs. Hence, our review of previous work shows that there is still a gap in research in terms of a comprehensive framework to identify main costs of activities in a supply chain, from raw materials to final customers.

More specifically, the following research question is considered: *how to perform a comprehensive and integrated cost analysis of agricultural waste supply chains?* The purpose consists of using SCOR and Activity Based Costing approaches and, thereby to propose an integrated framework to comprehensively evaluate costs of IBLCs' supply chains. Desk study research is used to identify main logistics costs and frame these into a biomass supply chains. The findings are expounded into an integrated model that will be further used for assessing costs in biomass supply chains.

The paper is structured as it follows: after the introduction extant literature to explain main supply chain activities is reviewed, important costs identified in these activities and also the Supply Chain Operations Reference (SCOR) model that could be used to categorize these activities. Thereafter, Activity Based Costing is expounded as a technique used for supply chain costing. Next, we develop and explain the integrated framework.

2 Supply Chain Activities

Knowing the costs of a supply chain is important to achieve maximum operational efficiency (Lin et al., 2001). A well known model that is typically used to refer to supply chain activities is the SCOR model, developed by the Supply Chain Council and currently used both in practical and academic instances (Huan et al., 2004, Huang et al., 2005, Lockamy III and McCormack, 2004). It is a tool that can be used by supply chain professionals, in order to identify and improve key supply chain processes. These processes can be linked to metrics, best practices and features associated with the execution of a supply chain (Huang et al., 2005, Stewart, 1997). The model follows the primary objective to satisfy customer demand through the implementation and fulfilment through the following processes: Plan, Source, Make, Deliver, Return and Enable (Huan et al., 2004). Lockamy III and McCormack (2004) perform an explorative study in order to link the SCOR model to supply chain performance. Huang et al. (2005) develop a computer-assisted tool to evaluate as-is versus to-be configurations of supply chains by following the SCOR model specifications. An ultimate goal of SCOR is to facilitate communication among departments but also supply chain companies, hence from suppliers to logistics service providers, manufacturers and distributors (Huang et al., 2005). This is accomplished by using the common terminologies and standards established by SCOR for the process elements.

3 Activity Based Costing in supply chains

Following the SCOR main processes and activities identified in a supply chain, it remains to determine which cost items will need to be considered and thereafter to understand how these costs ultimately affect performance. A relevant approach that should be considered in this context, is the Activity Based Costing. This is a system that emerged in1980s, aiming to measure business costs from a set of identified business activities (LaLonde and Pohlen, 1996). This process, related to the identification of activities and their relevant costs, is also mentioned as part of Value Chain Analysis tools. Costs can be diversified both in direct and indirect costs related to organization's resources and then traced back to costs for products (LaLonde and Pohlen, 1996). Activities are defined as supply chain processes or tasks happening over time in a supply chain.

Thereby, the identified costs are linked to performance measures and judged in terms of contribution of overall profitability (Kaplan and Cooper, 1998, Johnson and Kaplan, 1987). Hence, the main idea is that the system of interest can be split into a set of relevant activities, each of these driven by a specific set of cost items (Hilton and Platt, 2013). For instance, Tsai and Hung (2009) explain that costs related to activity cost pool machinery can be computed by using machine hour as a cost driver. Each of the cost drivers are considered to be made of a fixed and variable cost to be traced back to each of the logistics processes of the supply chain (Lin et al., 2001). Tsai and Hung (2009) applies activity based costing combined with fuzzy goal programming, in the context of green supplier selection.

In Value Chain Analysis the economic behavior of the supply chain can be framed by locating the cost drivers of each activity. To accomplish this, first of all, a thorough understanding of main logistics activities and their interrelated costs is necessary. Stock and Lambert (2001) identify the following main activities in supply chains:

- Order processing.
- Procurement.
- Inventory carrying.
- Transportation.
- Warehousing.

Obviously, logistics processes influence each of these costs, i.e. inventory carrying costs depends on activities like inventory management, packaging, reverse logistics, etc. (Lin et al., 2001). Order processing related to costs to issue and close orders (La Londe and Lambert, 1977). While procurement is the cost to purchase the necessary components/raw materials or services to ensure that the logistics activites will be correctly operating. Warehousing costs are different from inventory carrying costs and can change depending whether the warehouse is leased or owned. If owned, warehousing costs can be considered as a combination of throughput and storage costs (La Londe and Lambert, 1977). Storage costs should be part of inventory carrying costs. Other cost items have been identified within logistics activities, these include packaging and necessary administration to facilitate the movement of goods, while ensuring payments and regulatory compliance (Engblom et al., 2012). Another classification that has been widely used consists of costs of transportation, warehousing, inventory carrying and administration (Heskett et al., 1973). Other interesting indirect costs could be costs for lost sales (in case of stockouts), opportunity costs of capital used and storage, risk costs (Gunasekaran et al., 2004).

Other important costs to be considered are manufacturing and distribution costs. Concerning manufacturing, this activity includes costs like depreciation value of machines, labor, maintenance and rework costs (Beamon, 1999). Furthermore, other important costs to examine include set up and preparation of production lines (La Londe and Lambert, 1977). Finally, distribution costs can be assigned to individual functions that take place in distribution, hence warehousing, handling, storing and transportation (Beamon, 1999).

4 The Integrated costs framework

Based on the reviewed literature, a framework for integrated modelling is proposed, as a tool or set of guidelines to be used to configure and drive a cost-effective supply chain. In this framework several factors and costs indicators are reviewed and computed, in order to secure that the bio-commodities produced and marketed will be able to gain market shares and thereby justify a business case. Figure 1 shows the proposed framework for the evaluation of IBLCs' supply chains. In the framework, the following actors are distinguished:

- **Suppliers.** Farmers supplying/selling the focal companies with waste materials.
- **IBLC (Focal company).** Industrial plant transforming the waste materials into bio-commodities. Depending on the situation, and depending on the distribution strategy used, the focal company could also be a distributor of the bio-commodities produced. Otherwise, the company may sell the bio-commodities to a distributor.
- **Distributor.** Company acting as the distributor. It purchases the products from the focal company and sell to final consumers in specific geographic markets.

For each of the actors, following the SCOR approach, the following activities are distinguished: Source, Make and Deliver. Thereafter, main costs involved in the different parts of the framework are elaborated.

4.1 SUPPLIERS

SOURCE. In terms of sourcing, procurement activities will need to be tailored in order to ensure that factors as quality, supply and transport costs are well traded off. Some necessary equipment, materials, machines, and other terrain handling materials (e.g. seeds, fertilizers, pesticides etc.) will need to be purchased (Belbo and Talbot, 2014). Machine ownership and utilization in harvesting/waste collection concerns machines' fixed costs- depreciation, interest, insurance, garaging and licensing- and variable costs- fuel and lubricants, maintenance and repair (Ba et al., 2016). These are underlying purchasing costs for farmers that will need to be added to administrative costs related to ordering processes. Typically, these administrative costs can be quantified as it follows: processing Cost per Order = cost of operations/number of orders (Stock and Lambert, 2001).

MAKE. In relation to "MAKE" activities, the supply side of the supply chain, is characterized by costs related to the harvesting and collection of the waste materials. Tipically, the activities included in a biomass supply chain involve cultivation, harvesting, pre-processing, transportation, handling, and storage (Ba et al., 2016). Specifically, for farmers, costs related to the land use are relevant. Land is a cost derived from renting or other fiscal obligations in case of ownership. In addition to land costs, making activities include other costs related to seeding, harvesting and temporary storage of harvested material before outbound delivery (Belbo and Talbot, 2014):

- Seeding: this process is expected to include machining usage costs (renting costs or depreciation value of machines per distance travelled/hours of usage, fuel costs) and labor costs.
- Waste collection: fuel costs, renting or depreciation value of machines per distance travelled/hours of usage, fuel costs and labor costs.
- Bundling: personnel costs.

It is important to notice, that often farmers do not have production facilities, but simply lands to be seeded and harvested. In addition, due to the dynamic character of the farming production, soil regeneration activities are needed, therefore farmers must change cultivations at a certain pace. Land allocated to produce cereal straws will need to be switched after some years. Hence, in the long term, logistics activities and their related costs will need to adapt and dynamically change to these needs. To keep biomass exploitation sustainable, users need to determine which biomass and what quantities are feasible for collection, the collection points and, consequently, their geographical position (Ayoub et al., 2007). In addition, feedstock has to be cost competitive allowing supply chains to be feasible in the marketplace, and meeting quality requirements (Gautam et al., 2017).

DELIVER. In this case, activities include transport and storage that are needed at farmers' sites, both inbound and outbound. Typical decisions related to transport in biomass supply chains are transportation mode, schedule as well as transport routes and network (Hong et al., 2016). The selection of transport mode for minimizing delivering costs is influenced by the physical form, quality of feedstock and transport distance (Sokhansanj et al., 2009, Miao et al., 2012). The economic equilibrium of the whole system critically depends on logistic costs (Ba et al., 2016). In addition, a key factor in cost-effective supply chain

design is the trade-off between economies of scale and transport cost (Yue et al., 2014, de Jong et al., 2017). In a supply chain any raw materials, semi-finished or finished products will need to be packaged, moved, stored, processed from through a network of facilities in the supply chain. Hence, logistics include the management and related costs of activities like order processing, inventory, transportation, warehousing, materials handling and packaging (Bowersox et al., 2002).
On one side, transportation is key to add value and move inventory to the next stage of the business processes driven in the supply chain, providing benefits to the business. On the other side, it brings financial and environmental impacts. Transportation consumes time, financial and environmental resources. Hence costs can be modelled accordingly. The following equation proposes to calculate transportation costs between two points, an origin *o* and a destination *d* (Dunnett et al., 2008):

$$C_{o,d}^{T} = C_t \left(\frac{2 * L_{o,d}}{\overline{v_{o,d}}} + \sum_{i=o}^{d} mh_i \right) + C_l \ 2 * L_{o,d} \tag{1}$$

where $C^T_{o,d}$ is the cost for transporting from origin (*o*) to destination (*d*) (€); C_t is the cost of time unit (€/h); $L_{o,d}$ is the length (km) between origin *o* and destination *d*; $\bar{v}_{o,d}$ *i*s the average speed (km/h) measured on transport leg o→d; mh_i is the materials handling at i=o, origin and d, destination (h); c_l is the cost length unit (€/km), wear and tear of transport vessel, and fuel compsumtion. It is important to notice that sometimes transport could be outsourced to a logistics provider. In these cases, the computation of costs will be limited to the transport freight rates offered to farmers. The cost of the transport could be on the buyer or the seller, depending on the agreement stipulated.
A less visible aspect consists of in-transit costs in the supply chain. Products are actually stored during transport, i.e. in-transit inventory, hence, depending on when ownership is transferred, either the buyer or the seller will bear these costs. Typically, these costs are computed as the lot-sizing stock transported between inventories (Stadtler and Kilger, 2002). Hence, this is given by the following:

$$IIT = \frac{L}{O} * u * C_u \tag{2}$$

where *IIT* represents the Inventory In Transit (€), *L* is the lead time, *O* is the order cycle, *u* represents the number of units transport, e.g. as an annual average per order, and C_u is the cost per unit. In addition to inventory in transit, inventory carrying costs are also important to consider.

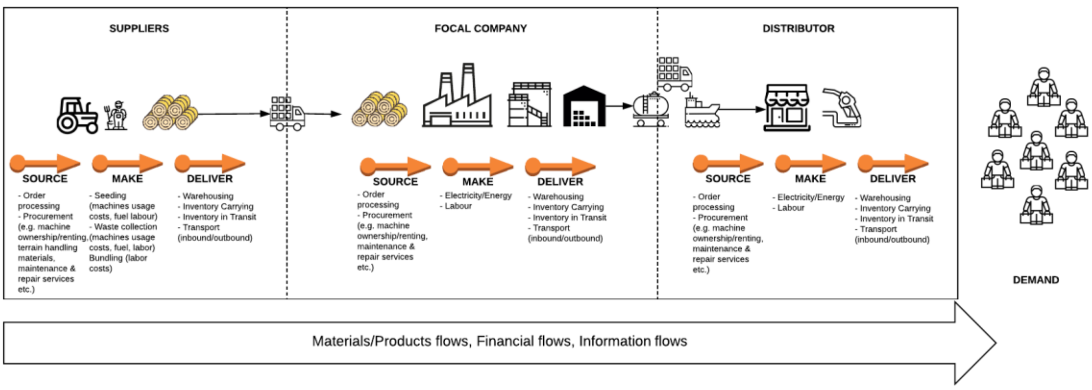

Figure 1: A framework for integrated modelling in the agro-food waste and recycle business.

Storage can be temporary and part of the transportation setup to ensure movement across longer distances and multiple transport modes. Storage could also be medium-long term if products are stored at the manufacturing plant/site, in a distribution warehouse or at the retailers' facilities. Storage costs are typically associated to holding costs, hence the following factors will need to be accounted (Chopra and Meindl, 2016):

- **Cost of money.** This item considers the cost of the capital that is tied up during storage time, i.e. the value of the cargo, or its opportunity cost.

- **Obsolescence.** This is a cost associated to the deterioration of the cargo during the period of storage. It is a financial loss estimated according to past experience.
- **Physical space and Handling costs.** Cost occupying a physical space in a warehouse and for handling the cargo (rent, utilities, insurances, taxes, wages of workers).

Storage costs, or inventory carrying costs, are calculated as an annual average value, in proportion to the cost of purchased inventory. Typically inventory carrying costs are in the ranges between 20-30%, however more in-depth computation could be done with available data. As a consequence, the inventory carrying costs can be calculated as a percentage of the costs of storing the items (Chopra and Meindl, 2016, Bowersox et al., 2002):

$$IC = HC * IV \quad (3)$$

where *IC* are the inventory carrying costs, *HC* are the holding costs, corresponding to costs in proportion to inventory value (%); and *IV* is the average inventory value (€).

4.2 IBLC (FOCAL COMPANY)

SOURCE. Also for the focal company, the IBLC that could be for instance a plant producing bio-oil or pellets from waste materials, procurement activities are very relevant. Hence, the company will need to put in place strategies and processes in order to aquire supplies (farmers' wastes) at reasonable price while keeping high quality. In addition, it is important that procurement activities are well synchronized and integrated with logistics. It is important to consider that purchased batches of raw materials or products cannot exceed the capacity of the transport vessels or other storing facilities of the upstream supply chain of the IBLCs. In addition, purchasing needs to be synchronized with farmers' production, transportation schedules and backhauls, production plants capacity and processes, and finally demand.
MAKE. It is during production that additional time and costs will raise. In this stage the production rate will be essential in order to determine at which speed inventory should be replenished, i.e. what replenishment policies should be adopted in order to regulate the amount and frequency of inbound shipments. The production rate needs also to be combined with processes and necessary costs to be internalized in the potential pricing offered to consumers. In production sites, typical costs to be considered include labour costs and utility (as for suppliers). The IBLCs will run more than one production lines in parallel. Conversion technology constrain the choice of biomass materials, type of pretreatment needed and capital and operational costs of the supply chain (Hong et al., 2016). In addition, it is important to consider electricity consumptions as part of production costs. In pariticular, size and quantities of ordered batches, inbound/outbound storage rooms and management of orders will need to be considered to synchronize production rates. Uncertainty in the quality of biomass affects the cost and amount of produced energy and must be considered in the modelling (Sowlati, 2016).
DELIVER. Exactly as for the suppliers, the focal company or IBLC, will need to take care of transport, inventory in transit, warehousing and storage costs. In general, also for this actor the costs equations showed in the previous section are applicable (see equations 1, 2 and 3). Transport will concern movemement of waste material from farmers to the IBLC and temporary storage at the plant's premises until injected into the production lines. As it was explained previously, inbound transport and in-transit costs will depend on how ownership has been agreed. Hence, it will be covered only if the IBLC is in charge of the transport costs. The same applies for the outbound logistics. Key considerations in storage planning are storage size, site selection, daily operations (Hosseini and Shah, 2011, Williams, 2016), and demand uncertainty (Hosseini and Shah, 2011). Production rates capabilities needs to be considered, the choice decision of a proper storage system according to holding costs and storage risks of different types of biomass is very complex (Hong et al., 2016).

4.3 DISTRIBUTOR

When it comes to distribution, there are four options that can be considered: the focal company/IBLC may decide to reach the market by 1) selling directly and using direct shipments to retailers, 2) developing and investing into a distribution network of facilities, vertical integration, 3) outsourcing distribution, or 4) selling to a distributor and shifting ownership from the IBLC's premises (Chopra and Meindl, 2016). Decisions related to how to distribute the bio-commodities downstream concern the identification of specific channels for penetrating a specific geographic market. In all cases costs will need to be traded off with speed of replenishment to retailers. For obvious reasons, distribution costs will add upon the total costs to be attributed to the IBLCs supply chains, shrinking the final marginal revenues. In this section we consider the alternative of selling the bio-commodities to a distributor, and therefore shifting ownership from the outbound warehouse of the IBLC. In the other cases, costs will need to be considered under the DELIVER activity of the IBLC.

SOURCE. Sourcing the bio-commodities is a main activity for the distributor actor. As for the other cases, procurement activities will trade off factors as pricing, quality, supply and transport costs. Administrative costs consisting of the processing costs per order will need to be added. In addition, a distributor will have purchasing costs related to necessary equipment for materials handling and transport.

MAKE. Typically, there is no real production taking place in the downstream distribution, but rather some small activities like simple assembly, adding accessories, mixing, kitting, sorting, sequencing, packing and labelling. These activities may need electricity consumptions, which needs to be considered as part of production/assembly costs. Hence, also in bio-supply chains some of these activities could take place in the supply chain under the supervision of the actor in charge of the distribution. In case of bio-fuel, depending on the quality obtained by the IBLC, refineries could be needed.

DELIVER. Finally, transport and storage costs will appear in the distribution as well, both inbound and outbound. The only different from the upstream part is that this time the level of complexity of the network can be higher, depending on the necessity of the distribution 1) to geographically cover the market, and 2) ensure a certain response time to customers. Another important factor to consider in costs is the quantities to be moved in the downstream network. Increased capillarity, corresponding to a higher number of intermediate facilities needed to allow temporary storage, cross-docking or merge in transit of the final products, reduces transport costs, while it increases inventory carrying and in-transit costs.

5 Conclusion

This paper develops a framework that could support stakeholders in estimating costs in bio-supply chains, specifically in supply chains aiming to collect wastes from farmers, transport to an IBLC and transform wastes into bio-commodities. For this, three types of actors in the supply chain have been identified: suppliers, IBLCs (focal company), and distributors; and following the SCOR approach three types of activities have been distinguished: Source, Make and Deliver (Lockamy III and McCormack, 2004, Huang et al., 2005, Huan et al., 2004).

The literature examined shows that there is quite consistent research driven to discover the costs of bio-supply chians, mostly focused on the upstream of the supply chain, yet there is a lack of comprehensive frameworks. The framework developed aims to overcome this lack by first identifying main actors, and then by using Activity Based Costing, exploring and determining prominent cost items. From a research viewpoint this study contributes by comprehensively summarizing and linking several studies related to the development of DSS for supply chain related decision making. Some of these have major focus on optimization or cost analysis upstream (Sharma et al., 2013, De Meyer et al., 2016), other merely on production or distribution (Ebadian et al., 2014, Gomes et al., 2012, Lautala et al., 2015). From a practical viewpoint, this paper is part of a European project, AgroInLog, where several stakeholders from Spain, Greece and Sweden are addressing the challenges of setting up and running economically feasible bio-supply chains. The aim of the project is to define and associate to supply chain management the coined concept of Integrated Biomass Logistics Center (IBLC). Four typical characteristics can be associated to an IBLC: (i) integrated value approach towards food and bio based markets; (ii) regional availability of biomass; (iii) logistics, storage operations and pretreatment; and (iv) exploiting the central position (Annevelink et al., 2017). Hence, future research will concern the application of the framework to different cases established in the mentioned European project. Particularly, the application can be performed by developing simulation models where costs can be computed and traded off with potential profits.

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