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ORIGINAL PAPER

Overview of sustainable biomass supply chain: from concept to modelling

Boon Hooi Hong[1] · **Bing Shen How**[1] · **Hon Loong Lam**[1]

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Abstract The human dependency on finite fossil fuel has led to its drastic depletion. Along with its detrimental effects on the environment, such practice is now deemed unsustainable. This phenomenon has led to the growth for utilisation of biomass in the production of biofuels, biochemical and other related bioproducts. This waste-to-wealth strategy is no doubt highly beneficial to the society. However, the major challenge in the commercialisation of bioproducts production includes the complex conversion processes and the uncertainty in the supply and sources of biomass. Therefore, efficient supply chain management and optimisation is essential to overcome these barriers and variables that may constrain the development of a competitive and sustainable bioproducts market. This overview provides an extensional definition of biomass-to-bioproducts supply chain and systematically describes the problems and decisions along this chain. It also identifies the characteristics of a sustainable integrated biomass supply chain, and finally presents an overview of biomass supply chain synthesis and optimisation methods. Based on the existing research gap, the key challenges and potential future works are highlighted. This paper will provide readers with an initial point to understand the concept of sustainable biomass supply chain management and the synthesis and optimisation of sustainable biomass supply chain models.

✉ Boon Hooi Hong
boonhooi12@gmail.com

[1] Department of Chemical and Environmental Engineering, Centre of Excellence for Green Technologies, The University of Nottingham, Malaysia Campus, Jalan Broga, 43500 Semenyih, Selangor, Malaysia

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Introduction

Fossil fuel has been providing us with a very useful energy source, and is one of the pillars supporting our modern society and industries. To date, it is still dominant in the energy market, accounting for about 86 % of the global energy usage (BP 2015b). The world energy consumption has doubled since 1973 and it is projected to increase by another 100 % by 2040 (IEA 2015). The depletion of limited fossil fuel and its undesirable environmental impacts make it no longer sustainable. Consequently, the terminology of sustainability has been more familiar in each area of development and become one of the main focuses in the society. With the awareness of global sustainability, public has been focusing on primitive and clean renewable energy resources as an attractive and sustainable opportunity to achieve future energy security and fuel diversification (Klemeš and Lam 2009). Utilisation of renewable energy has been under intensive research and development (Klemeš et al. 2013). It is influencing the current energy development significantly and its contribution is predicted to increase from 3 to 8 % from 2015 until 2035 (BP 2015a).

Among all the renewable energy sources, bioenergy or biofuel, which are energies derived from biological material, is the most common and largest source of energy known to mankind. Utilisation of bioenergy is able to meet the ever-increasing energy demand and reduce greenhouse gas emission. In the past decades, food crops have been extensively utilised for first-generation biofuels production. In spite of that, "fuel vs food" appears to be the most controversial issue in the production of first-generation biofuels (Sharma et al. 2013). The commercialisation of first-generation biofuels leads to an expansion in the amount of crops being diverted away from the global food market. To avoid such ethical problem, this trend has shifted to second-generation and third-generation biofuels, which utilises non-food crops such as lignocellulosic biomass, organic residues and algae as feedstocks for biofuels generation. Besides, utilisation of the wastes provides an opportunity to solve waste management issue. Following the tactic in the crude oil and petrochemical industry, biomass-based manufacturing also aims to substitute crude oil-based manufacturing of carbon-containing products such as biochemicals, materials and polymers (Sadhukhan et al. 2014). It targets to produce chemical building blocks, simple yet highly functionalised molecules for industrial applications via organic synthesis. As compared to crude oil, biomass-based production is capable to synthesise more varieties of chemicals due to the presence of oxygen, a wider range of functional groups and bond types in the raw biomass.

Biomass appears to be a promising renewable feedstock for energy generation and chemical synthesis. However, the shift to biomass as a feedstock is yet to be proven feasible and sustainable at industry scale as it is full of challenges starting from the harvesting and pre-treatment of biomass to the production and delivery of bioproducts. The main obstacle to the development of a strong bioenergy sector is the economic potential of the biomass supply chain since handling and transport of biomass from the source location to the conversion facility induce a variety of economic, energetic and environmental implications. Obviously, high investment and operational cost of biorefinery oppose market penetration and inhibit fair competition with the traditional oil refinery. Besides these barriers, the uncertainty in the biomass supply, logistic, transportation, operation, production, price and demand obstruct the commercialisation of biomass supply chains. To link up these green technologies from pre-treatment to process and delivery, a sustainable biomass supply chain development is a key point in this green belt (Lam et al. 2015). Sustainable supply chain or network can be referred as the operational management method and optimisation approach to lessen the environmental impact and the cost of manufacturing along the life cycle of the bioproducts: from the raw material to the end product. These activities should lead to economic growth, environmental protection and social progress for the green technology utilisation. To achieve a sustainable development, the supply chain should not only focus on transportation/logistic task. The special focus must be given to the latest conservation of biomass (mass and energy) used in the process, the possibility of integrating green resources, the consideration of industrial symbiosis relationship and the network synthesis with multi-objectives of environmental, technical, economic, safety and social factors.

To date, there are plenty of research and works covering the different aspects of biomass supply chain. This paper aims to (1) review and organise these works into different aspects, (2) provide a clear understanding of sustainable biomass supply chain concept from different aspects and (3) highlight the future challenge and scope in supply chain based on the existing research gap. These references are reviewed and categorised into three different aspects: (1) scope of sustainable biomass supply chain, (2) elements in sustainable supply chain and (3) sustainable supply chain modelling methods as shown in Fig. 1. This paper is organised into 6 sections. "Introduction" section describes the importance of supply chain in introducing biomass as a clean and renewable feedstock for bioenergy and biochemical production in an industrial scale. "Overview of biomass supply chain" section presents an extensional definition for biomass-to-bioproducts supply chain and introduces the structure of a typical upstream biomass supply chain based on the review of traditional supply chain and biomass-to-energy supply chain. It also highlights the interrelationship and interdependence of the components within the chain, portraying the typical scope and decision considered in supply chain design and management. "Lean, agile, resilient and green in sustainable biomass supply chain" section introduces the roles of lean, agile, resilient and green elements in sustainable biomass supply chain. "Sustainable supply chain model" section discusses the methods of design and optimisation for supply chain and how the aforementioned decisions and scope are tackled. Based on the discussion and analysis, future potential work for an economic, energetic, social and environmental sustainable biomass-to-bioproducts network is outlined in "Future challenges and scope in sustainable biomass supply chain" section. Last but not least, the work is concluded in "Conclusion" section.

Overview of biomass supply chain

"Supply chain management" is a term that was first coined by Oliver and Webber (1982) when they discovered the advantages of the integration of core business entities of procuring, production, sales and distribution into a single unified structure. The advent of supply chain support for manufacturing in fact happened long before the term came into context in the mid-1980s. In general, a typical supply chain network contains four business functions which are supplier, manufacturer, distribution centres and customers (Beamon 1998). It involves the movement of products and

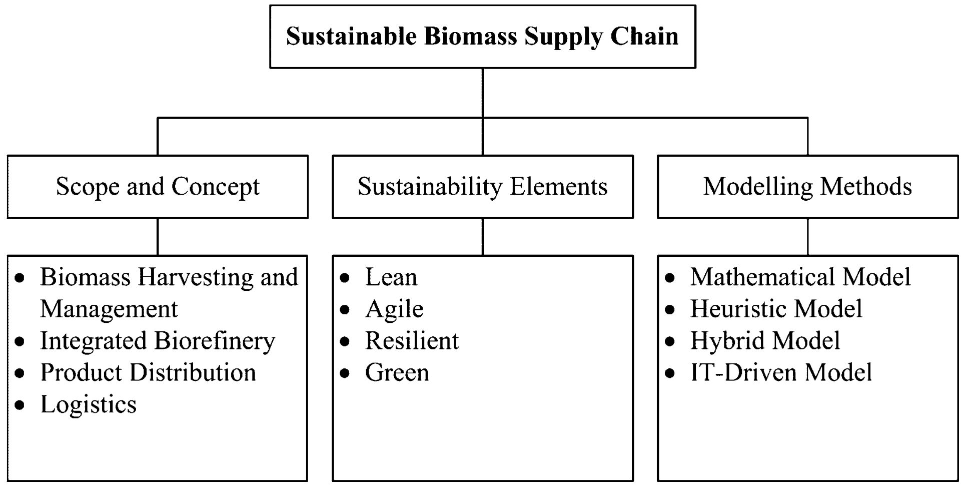


Fig. 1 Taxonomy of sustainable biomass supply chain

information from the inward bound to the outward bound of the business as well as from the supply source to the demand end user (Stevens 1989). Supply chain management aims to integrate all the business functions in such a way that the products are always synthesised and distributed at the right place, at the right time, fulfilling desired quantity, quality and service level along with minimising the total cost of the system (Simchi-Levi et al. 2013). The capability of the supply chain is influenced by the level of coordination and integration between the parties and entities, along with effective and efficient movement of materials and data (Beamon 1998).

The supply chain management in biomass industry on the other hand is a big management conundrum. It plays an important role in the management of bioenergy and biochemical production processes (Gold and Seuring 2011). Biomass supply chain differs from traditional supply chains due to several variabilities. These sources of variability include the uncertainty in biomass availability and supply due to weather and seasons, the fluctuating chemical and physical properties of biomass (Cundiff et al. 1997), the geographical distribution and low transport density of feedstock, the local transportation system and the distribution of infrastructure, as well as the inconsistent demand (Fiedler et al. 2007). The complexity deepens owing to the large number of stages which encompass the entire biomass value chain. A consistent, continuing, cheap and uninterrupted supply of desired quality raw feedstock is essential for the biorefinery industry to be competitive. To ensure the long-term viability of a biorefinery project, a proper assessment of the transport, storage and handling of biomass is required (Sukumara et al. 2015). Biomass supply chain management therefore manages the uncertainty in biomass source and availability, whereas the traditional supply chain management copes with market uncertainty to identify the economic feasibility of the industry.

To date, there are a number of definitions for biomass-to-bioenergy supply chain management. In general, it is identified as the integration of five discrete processes of harvesting and collection, pre-treatment, storage, transport and energy conversion (Iakovou et al. 2010). In biomass-to-bioproducts supply chain, the downstream segment, delivery of biofuels and biochemical to the customer and the interaction with market demand appears to be an important activity. In this paper, the product demand therefore is embedded as the last activity in the chain and these activities are categorised into 4 components. Hence, biomass supply chain is defined as *an integrated value chain with 4 components: production and management of biomass, integrated biorefinery, distribution of product and logistics linked through the flow of materials and information* as shown in Fig. 2. There were no distinct boundaries amongst these 4 components in the chain as they are interdependent and interconnected, resulting in varying degrees of overlapping. Materials change format and characteristics as they move through the chain and a huge number of logistical networks are possible depending on the crop supply and product demand.

Biomass harvesting and management

The biomass source of supply is the initial point for the planning and development of the entire supply chain. In the context of biomass as a renewable feedstock for biofuel production, it is most often defined as any organic or biological material which is obtainable on a renewable or regular basis and referred as lignocellulosic (Sadhukhan et al. 2014). It is usually plants or plant-based materials which are not meant for feeding purpose such as rice husk, paddy straw, palm kernel shell, empty fruit brunches, etc. Industrial and municipal waste which is biodegradable is also considered as part of biomass. In biomass harvesting

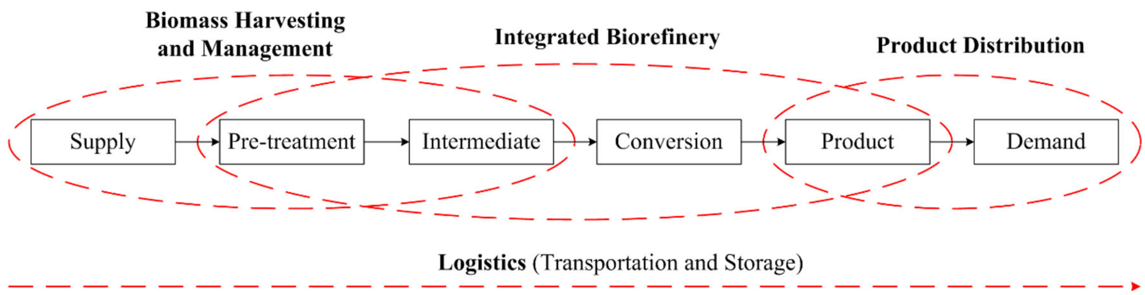


Fig. 2 Integrated biomass supply chain

and management, the main scope to deal with includes availability of raw biomass, composition of raw material, allocation of feedstock, harvesting scheduling and decentralisation of pre-treatment activities.

One of the major barriers in this component is to maintain constant and continuous supply of biomass feedstock. Biomass is usually locally available but the seasonality of biomass results in uncertain availability. Considering the climate change and weather, these uncertainties could result in an inconsistent and even shortage of biomass supply. The current feedstock management systems are not able to meet the requirements of a large-scale biorefinery development, because they are initially designed for small- or medium-scale handling and logistics requirements (Hoogwijk et al. 2003). In such circumstances, supply chain efficiency and careful inventory planning would become vital for the survival of large-scale biorefinery.

One of the characteristics of biomass is the simple fact that it remains a biologically living matter and it is also chemically active throughout the supply chain. The biological activity will alter the composition (i.e. carbon, moisture and ash content) of the material. This will affect the product conversion in the biorefinery. From a supply chain efficiency perspective, it is also critical to evaluate and maintain the quality of the biomass from time to time. Proper harvesting schedule can ensure that the quantity and quality of the raw biomass are within specification limit when it is sent to the doorstep of the respective biorefineries. Decentralisation of pre-treatment activity from the biorefinery to the biomass collection site can help maintain the desired specification of the raw material before sending to the processing facility. For instance, oil palm frond juice is extracted from the raw oil palm frond at the palm plantation as the juice has a longer storage life as compared to the raw frond. Pre-treatment such as pelletising converts dense biomass into less dense biomass to reduce handling, storage and transportation cost. This explains why pre-treatment can be categorised as an activity in this component in certain cases especially biomass with short shelf life and low transport density.

Integrated biorefinery

In a processing facility or biorefinery, raw biomass is first pre-treated into more useful processable segments, known as platforms or precursors (Fernando et al. 2006). These fractions are then converted into bioenergy (biofuels and electricity) and biochemical (Sadhukhan et al. 2014). Figure 3 shows a typical integrated oil palm biomass biorefinery. An integrated biorefinery that allows multiple feedstocks, swapping between feedstocks and blending of biomass source of a distinct or similar nature into highly diverse portfolio products is a very critical element in the entire supply chain. Similar to the traditional chemical plant, this complex system is capable to perform material and energy exchange to fulfil their needs and attain self-sufficiency. However, the primary focus here revolves around the conversion of pre-treatment and major processing technologies. The detailed design of the biorefinery is not our main concern.

One of the challenges that will be faced in this phase of supply chain will be the determination of facility location. This decision is usually made by considering sources of biomass, transportation infrastructure and logistics cost. Conversion technology selection decisions also play a key role in structuring of biomass supply chains as they influence/constrain the choice of biomass materials, type of pre-treatment needed and capital and operational costs of the supply chain. Given biomass feedstock and product requirement, a series of cost-effective technologies can be selected and thus form the optimum technology network for particular biorefinery. Prior to that, the sizing of the hub can also be estimated. In addition, the configuration of biomass supply chains is very much depending on the choice between centralised (with a large biorefinery) and decentralised (with several distributed small biorefineries) production hub (Yılmaz and Selim 2013). Usually, decentralised processing facility is preferred for biomass with low transport density and vice versa for cost-saving purpose.

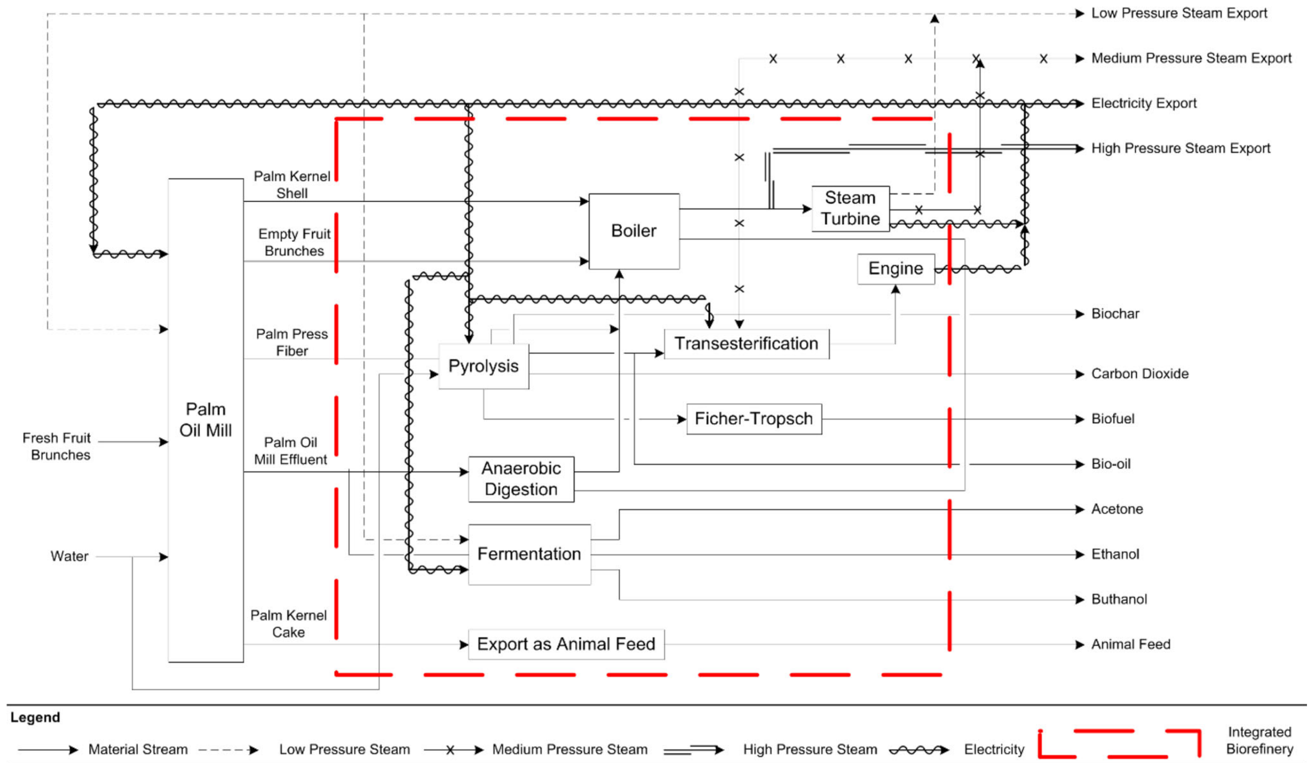


Fig. 3 Integrated oil palm biomass refinery (Kasivisvanathan et al. 2014)

Product distribution

Product distribution is defined as the manner in which the products move from the manufacturer to the consumer. In biomass-to-bioproducts supply chain, final products are distributed to the customers according to their respective demand. The logistic network will be greatly affected by product types. Product in biomass supply chain as mentioned can be grouped into two: bioenergy including heat, electricity and biofuels and biochemicals that can be utilised for various industry applications to satisfy human necessity such as nutrition, food and beverages, pharmaceuticals, fertilisers, biodegradable plastics, surfactants, fibres, adhesives, enzymes, etc. Bioenergy as a renewable source of energy has the potential to compete with fossil fuels due to the significance of such industry in future needs of sustainable energy. Biochemical on the other hand gains more attention in the industry especially the high-value products for pharmaceutical and cosmetics industry. Bioenergy in the form of electricity and heat can be transferred to the end user via electricity grid and convection. Solid, liquid or gaseous biofuels and biochemicals on the other hand can be transported through the existing transportation system (land, water or air). The supply chain must be robust and flexible in order to cope with the fluctuating market demand.

Logistics

The link that integrates all the components in the supply chain is logistics. Transportation and storage connects all the activities together. Typical decisions related to transport phase in biomass supply chain are transportation mode, schedule as well as transport routes and network. Transportation mode refers to the type and capacity of transportation whether land, water or air. It depends on the infrastructure system around the source, processing and demand point. Given the capacity of the transport and the amount of feedstock or product, the number of transports can be determined. To ensure that the feedstock and product can reach the doorstep of the respective biorefinery and customer on time, the schedule plays an important role. In fact, the decision of the complete transportation network and route is made to minimise supply chain costs and travel time, and also to minimise the environmental impacts of supply chain activities.

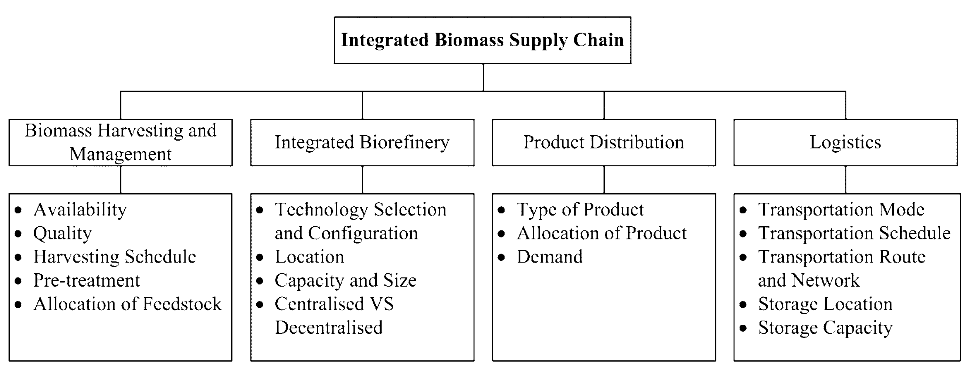
From an inventory planning perspective, choosing a proper storage system according to holding costs and storage risks of different types of biomass and bioproducts is a complex decision to make. It involves a large degree of uncertainty about the quality and quantity of biomass and bioproducts (Kudakasseril Kurian et al. 2013). Choosing an appropriate location for biomass storage facilities is not only influenced by the type and characteristics of biomass materials, but is also constrained by transportation options (Allen et al. 1998). For bioproducts, it is affected by the amount and type of material. Further, some researches recommended on-field biomass storage and on-site product storage to reduce the overall delivery costs (Huisman et al. 1997). In summary, Fig. 4 presents the scope and decisions for biomass supply chain management.

Lean, agile, resilient and green elements in sustainable biomass supply chain

When supply chain management was initially introduced, it targeted to minimise the cost or maximise the profit associated with the supply-to-demand process (Simchi-Levi et al. 2013). However, supply chain management has been growing drastically with the growing significance of the relationship with other suppliers since 1990s (Harland 1996). The main reason behind this was because of the emergence of a globalised marketspace (Slack 1991). Different types of supply chains arose progressively due to consumer influence, market demand and changes in technology (Nelson et al. 2012). Being more integrative among all the business firms along the supply chain is the key to strengthen the entire chain (Wood 1997). In the Japanese automotive industry (Womack et al. 2007) and the Italian craft-based industry (Lamming and Program 1989), it can be observed that these firms are becoming more integrative to their supply chain partners. The lean concept has added features that aided to reduce the vulnerability of the operational processes of the supply chain (Power 2005). The responsibility for business parties to become dynamically alert to the requests of customers has gradually been essential (Christopher 2000). There are three characteristics which contribute to the competitiveness of the business entities which are speed (fulfilling customer demand swiftly), agility (sensitivity towards customer demand) and leanness (doing more with less) (Power 2005). Besides, Hertz and Thomas (1985) discovered that the traditional risk management methods are not fully capable to evaluate the complexities of supply chain network, access the intricate interdependencies of dangers and cope with the unpredictable in the future (Starr et al. 2003). Realising these gaps, researchers and industry people started to recognise the significance of the concept of resilience along the supply chain. It is defined as the capability of an enterprise to endure, adjust and develop while facing turbulent change (Fiksel 2006). On the other hand, businesses have been gaining momentum to strive towards sustainability and social responsibility after the quality revolution in the late 1980s and the supply chain revolution in the early 1990s (Srivastava 2007).

Based on the evolution of supply chain as discussed above, the elements of sustainable supply chain management can be categorised as follows: lean, agile, resilient and green (LARGe). However, there were no distinct boundaries amongst them due to varying degrees of overlapping. In biomass-to-bioproducts supply chain, they play roles which are equally important in different phases of product life cycle, contributing to the sustainability of the entire value chain. Product life cycle is defined as a 4-stage cycle which every product goes through as shown in Fig. 5. When a product is first introduced in the market, the high production cost and low sales result in no profit. As the product sales grow, high demand will cause the production cost to drop and profit to increase. This phase evolves into one where product maturity occurs and demand becomes the highest and constant. In the decline stage, demand is reduced, resulting in lowered sales and decreased margins. Biorefinery is still a relatively new concept and uncommon to the public which makes bioproduct share a very small market demand. As shown in Fig. 5, bioproduct is labelled at the boundary between introduction and growth stage. Due to the presence of very competitive oil refinery, the market size for bioproducts is still small and inconsistent. On the other hand, the investment in research and development to ensure clean and cost-effective technologies and biomass feedstock is very high. Bioproduct therefore is still at the introduction stage and it is just about to grow. The following sub-sections will discuss the role of LARGe in the respective product life cycle stages of bioproducts.

Fig. 4 Scope of biomass supply chain management



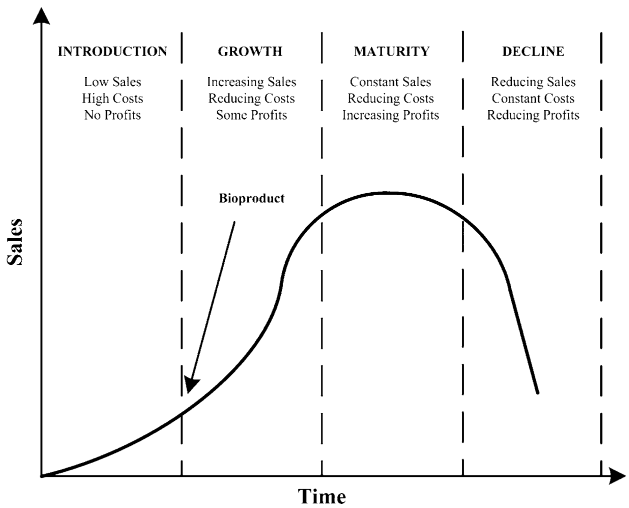


Fig. 5 Product life cycle of bioproduct

Lean biomass supply chain

Supply chain was first introduced with the main goal of producing what the customer demanded, with minimum attention paid to flexibility or conversation of resources (Lummus and Vokurka 1999). The concept lean was then introduced in supply chain which is about doing more with less. It aims to eliminate waste and non-value steps along the chain, striving for continuous improvement. The purpose of minimisation of waste is not meant for environmental but economic reasons. It targets to attain internal manufacturing efficiency and step up time reduction which allow economic production of small quantities, boost cost reduction and profitability as well as increase flexibility to some degree (Vonderembse et al. 2006). Just-in-time manufacturing is employed to ensure that the necessary materials arrive when they are needed in the right quantity resulting in a smooth flow of materials. The level of production is driven by market demand in order to avoid overproduction or underproduction. With effective setup time, lean supply chain is able to provide manufacturing flexibility for biomass-based products in their maturity state when their demand is predictable and the required volume is high. It helps maintain close-to-zero inventories and reduce work-in-process which can contribute to economical sustainability. However, it is the lack of external responsiveness to customer demands which makes it too brittle to withstand market fluctuation and unpredictable disruptions for now.

Agile biomass supply chain

Agile supply chain goes for quick responses to customer inquiries and market change while controlling cost and quality. It possesses a number of distinguishing characteristics as shown in Fig. 6. Firstly, it appears to be better to deal with market disturbances (More and Babu 2008), relating to the boundary between companies and markets, acting as an external perspective on flexibility (Vonderembse et al. 2006). The use of information technology such as enterprise resource planning (ERP) and multi-agent technology (both of these IT-driven models will be discussed in the "Sustainable supply chain model" section) to capture data on demand directly from the market allows the firm to be market sensitive and responsive. It also enables the sharing of information between biomass suppliers, bioproduct manufacturers and buyers, thus creating a virtual supply chain (artificial supply chain that is simulated by software) based on market demand. Sharing of data among biomass supply chain partners can only be completely achieved through process integration. Process integration is defined as the collaboration between all the players within biomass supply chain, joint feedstock, product and technology development, common systems as well as shared information (Christopher 2000). Through the incorporation of organisations, the supply chain appears as a network that is agile. The agility of the biomass supply chain depends on the strength of the network and the ability of organisations to structure, coordinate and manage the relationships with their partners. Agility is important for the current state bioproducts. As it is still in the introduction, the unpredictable market demand can be handled with elements of agile supply chain, making the entire biomass supply chain sustainable.

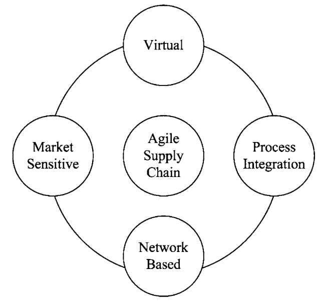


Fig. 6 Element of agile supply chain (Christopher et al. 2004)

Resilient biomass supply chain

Traditional risk assessment focuses on operational risks and familiar sources of potential disruptions that have caused trouble in the past. However, the risks in the supply chain are constantly evolving and unpredictable, making them rather difficult and challenging to cope with. Biomass supply chain risks can be grouped into 3 categories: internal operational risks, internal supply chain risks and external environmental risks as shown in Fig. 7 (Christopher and Peck 2004). Internal operational risks refer to disruptions to the operations of the biorefinery such as

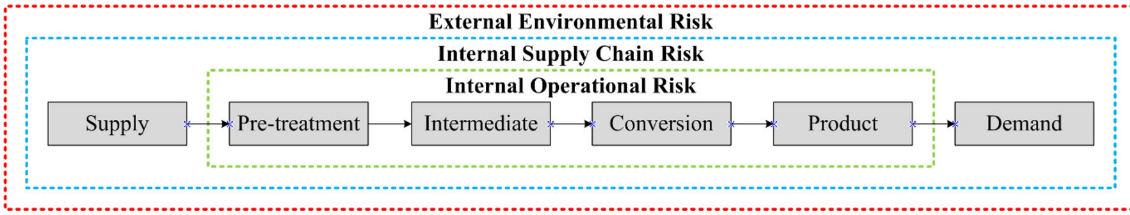


Fig. 7 Risk within biomass supply chain

product development, manufacturing, transport, distribution and infrastructure. Internal supply chain risks revolve around the upstream and downstream biomass supply chain partners. It is either caused by the interruptions to the flow of biomass feedstock/bioproducts or unpredictable customer demand. For external environmental risks, they are external forces that may impact the entire supply chain. It usually relates to economic, social, governmental and climate factors. For instance, climate change can affect the availability of the biomass feedstock. In a resilience improvement study, actions to reduce the impacts of a risk are defined regardless of the cause and the probability of occurrence. It is therefore able to prepare protective plans for all the events, even with a very low probability. A resilient biomass supply chain then has the capacity to overcome disruptions and continually transform itself to meet the changing needs and expectations of the public, market demand, shareholders and other stakeholders. It is essential for the entire enterprise to play their roles in creating and maintaining the resilience of biomass supply chain throughout its product life cycle.

Green biomass supply chain

Green supply chain management exposes the applications of the most important sustainable development issues. It demonstrates how green technologies and practices can be implemented and, in line with this, the motivation of money saving and improved efficiency. There are plenty of existing green supply chain interpretations, which all

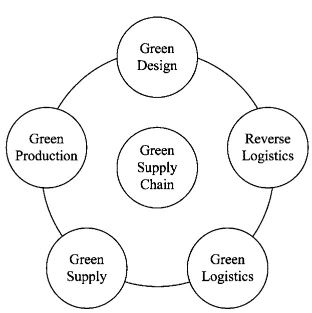


Fig. 8 Concept of green supply chain

basically circulate around the aim of reducing environmental impact along the process (Srivastava 2007). Figure 8 shows the important features of green supply chain. Green design refers to the design of the supply chain that encourages environmental awareness. Life cycle analysis (will be discussed in detailed in "Sustainable supply chain model" section) is an important sub-concept to green design. It was introduced to measure environmental impact of the entire supply chain, from biomass harvesting, bioproducts processing, bioproducts distribution and disposal. In fact, the economic, environmental and social sustainability are normally accepted as the triple bottom lines, which should be systematically assessed and enhanced throughout the life cycle analysis (Liu and Huang 2015). Biomass supply chain itself is a green supply chain. Green supply and green production can be achieved by utilising less polluting feedstock and clean technologies. In biomass supply chain, biomass feedstock is claimed to have zero carbon footprint. Meanwhile, researches are working towards cleaner and more cost-effective conversion technologies. Green logistics describe all attempts to measure and minimise the environmental impact of logistics activities. It is attainable by proper transportation network and scheduling planning. At the final stage, reverse logistics are necessary to ensure economic, environmental and societal sustainability (Ramezani et al. 2013). Reuse, recycling, remanufacturing and refurbishing should be incorporated into biomass supply chain to eliminate the production of waste. For instance, fermented soybean paste residue can be reused for livestock feed. These green concepts should be incorporated into biomass supply chain to strive for sustainability.

Sustainable supply chain model

There are a number of modelling approaches that are applied to synthesise and solve supply chain problems. To ease the evaluation and appraisal of supply chain models, they are first categorised based on the main mathematical optimisation methodology. Mathematical optimisation techniques are represented by sets of variables and equations that define the reality phenomena (Min and Zhou

2002). The mathematical models are categorised as (1) mathematical programming, (2) heuristics approach, (3) hybrid model and (4) IT-driven models. Mathematical programming approaches, like linear programming (LP) and mixed integer linear programming (MILP), determine the values of the decision variables that optimise (maximise or minimise) an objective function among all sets of values that satisfy the given constraints. Heuristic approaches, like genetic algorithms, search for satisfactory (i.e. local) but not necessarily global optimal solutions to reduce runtime. Hybrid model employs mathematical modelling together with theoretical and hierarchical approaches such as life cycle analysis for decision making in supply chain. IT-driven model reflects the current advances in IT for improving supply chain efficiency. IT-driven models aim to integrate and coordinate various phases of supply chain planning on a real-time basis using application software so that they can enhance visibility throughout the supply chain.

Mathematical programming

In mathematical modelling, the problem will be represented by a mixed integer programming (MIP) or mixed integer linear programming (MILP). These models can be solved using the conventional ε-constraint method (Guillén et al. 2005a). The main benefit of using traditional mathematic programming is that the optimum solution can always be found. However, it is not capable to solve the real-time optimisation of large-scale problem which is often fuzzy (Turan et al. 2012). The required computation time will increase significantly when the problem size increases.

In the early days, mathematical programming often focused on single-objective optimisation (i.e. economic) (Robinson and Satterfield 1998). It is utilised to solve resource allocation and product distribution (Lee and Kim 2000). The focus is often on the logistics and transportation network (Syam 2002). Recently, Lam et al. (2013) emphasised technologies selection as one of the important components in biomass supply chain. A two-stage mathematical optimisation model was proposed for optimal technologies selection as well as logistics and transportation network. Uncertainties inherent in biomass value chain can also be captured via mathematical modelling (Peidro et al. 2009). Sustainable biomass supply chain management does not focus on the economic aspect entirely. Mathematical model is capable to cope with multi-objective optimisation, taking into consideration the other aspects (i.e. environment and social) (Liang 2008). Scheduling is one of the scopes which can be solved using mathematical models. Amaro and Barbosa-Póvoa (2005) proposed mathematical formulation to optimise scheduling for industrial supply chain. The list of works which implemented mathematical modelling technique in solving sustainable supply chain problem is tabulated in Table 1.

Heuristic approach

To overcome the coordination problem in supply chain network synthesis, Akanle and Zhang (2008) proposed a heuristic algorithm, called genetic algorithm, to dynamically solve the supply chain synthesis problem. During the past few decades, genetic algorithm has often been implemented to solve single-objective and multi-objective optimisation problems in production and operational management that are non-deterministic polynomial-time hard (NP-hard). Recently, genetic algorithm technique has been modified to suit each specific problem. The publications related to genetic algorithm implemented in supply chain management are listed in Table 2.

Another technique which also has been widely used is ant colony optimisation is meta-heuristic technique. This technique is one of the nature-inspired meta-heuristics that mimics the behaviour of ant colonies and the evaporation effect of the pheromones during their food search process. Despite that optimum solution is not guaranteed, it provides a useful compromise between the amount of computation time necessary and the quality of the approximated solution space (Moncayo-Martínez and Zhang 2011). Ant colony optimisation was initially used to solve the decision-making problems which involve only single-objective function (Bullnheimer et al. 1999). Recently, it has been proven that ant colony optimisation is capable to solve many real-world problems efficiently and effectively. In supply chain, it is commonly used to solve capacity planning (i.e. centralisation vs decentralisation), resource allocation and scheduling problem. Table 3 shows the list of works which implemented ant colony optimisation technique in supply chain management.

On top of that, another swarm-based optimisation model, bee algorithm, has been introduced by Pham et al. (2005). Similar to ant colony optimisation, bee algorithm is also a nature-inspired heuristic. Bee algorithm is actually an algorithm that mimics foraging behaviour of honey bees to find the best source of food. Recently, bee algorithm has proven to be a more powerful optimisation tool which is able to determine better Pareto solutions for the supply chain network synthesis problem compared with the aforementioned ant colony optimisation technique (Mastrocinque et al. 2013). A list of works which applied bee algorithm in supply chain management is tabulated in Table 4.

Table 1 Mathematical programming in supply chain synthesis

Author (year)	Remark
Robinson and Satterfield (1998)	Development of a multidisciplinary framework that considers the interactions among firm's distribution strategy, market share and cost
Petrovic et al. (1998)	Introduction of a supply chain fuzzy model to analyse the behaviour of a serial supply chain under uncertainty
Dogan and Goetschalckx (1999)	Formulation of a mixed integer programming and an integrated design methodology based on primal decomposition for multi-period production and distribution system in supply chain
Li and O'Brien (1999)	Introduction of an integrated decision model for assessing potential partners in a supply chain
Lee and Kim (2000)	Introduction of a hybrid simulation approach which is a specific problem-solving procedure to solve the production distribution problem
Jayaraman and Pirkul (2001)	Development of a heuristic procedure to plan and coordinate production and distribution facilities for multiple commodity supply chain
Syam (2002)	Extension of the traditional location models by introducing several logistic components
Cakravastia et al. (2002)	Development of an analytical model of the supplier selection process in designing a supply chain network
Jayaraman and Ross (2003)	Solving of the new combinatorial problem that incorporates cross-docking in supply chain environment using simulated annealing methodology
Yan et al. (2003)	Introduction of a strategic production–distribution model for supply chain design with consideration of bills of materials
Amaro and Barbosa-Póvoa (2004)	Introduction of a discrete model to ease the decision-making process at the operation level of industrial supply chain
Erol and Ferrell Jr (2004)	Development of an integrated methodology to solve two fundamental decisions making, i.e. assigning suppliers to warehouse and warehouse to customer
Chen and Lee (2004)	Formation of a multi-product, multi-stage and multi-period scheduling model to deal with multiple incommensurable goals for a multi-echelon supply chain network
Amaro and Barbosa-Póvoa (2005)	Synthesis of a new continuous-time mathematical formulation for the optimal schedule of industrial supply chains
Ryu (2005)	Presentation of a multi-level programming framework in capturing complex supply chain decision-making processes
Graves and Willems (2005)	Formulation of a two-state dynamic model to minimise the total supply chain cost which includes cost of goods sold, safety stock cost and pipeline stock cost
Guillén et al. (2005a)	Development of a two-stage stochastic model to take into account the effect of uncertainty in production
Amiri (2006)	Presentation of a computational study in investigating the value of coordinating production and distribution planning
Liang (2006)	Development of an interactive fuzzy multi-objective linear programming method for solving the transportation problems
Guo and Tang (2009)	Introduction of an evaluation model to analyse the feasibility of planning by comparing the planned cost with the anticipated cost
Liang (2008)	Development of a fuzzy multi-objective linear programming model with piecewise linear membership function to solve the integrated multi-product and multi-period production/distribution planning problem
Peidro et al. (2009)	Formulation of a fuzzy mathematical programming model for supply chain planning which considered process uncertainties
Franca et al. (2010)	Introduction of a multi-objective stochastic model that used Six Sigma to evaluate the financial risk in supply chain
Xu and Zhai (2010)	Utilisation of fuzzy number to depict customer demand and investigate the optimisation of the vertically integrated two-stage supply chain under different scenarios
Paksoy et al. (2012)	Development of a fuzzy multi-objective programming model to minimise the total transportation cost
Seifert et al. (2012)	Development of a model for three-echelon supply chain with price-only contracts
Afshar and Haghani (2012)	Formulation of a mathematical model that controls the flow of commodities from sources through the supply chain and finally to the recipients
Li and Womer (2012)	Development of a mathematical model to optimise the sourcing and planning decision simultaneously while exploiting their trade-offs
Ramezani et al. (2013)	Introduction of an evaluating technique to evaluate the systematic supply chain configuration maximising the profit, customer responsiveness and quality as objectives of the logistic network
Lam et al. (2013)	Development of a two-stage optimisation model for the optimal operation and logistics management of the waste
Ng et al. (2013)	Synthesis of an optimal rubber seed supply network which maximises the utilisation of rubber seed oil using mixed integer linear programming

Table 1 continued

Author (year)	Remark
Ng and Lam (2014)	Development of a functional clustering approach integrated in an industrial resource optimisation
Čuček et al. (2014)	Formulation of an MILP model for multi-period synthesis for regional biorefinery supply network
Ng et al. (2015)	Introduction of a novel algebraic method for supply chain development which allows concurrent setup of material allocation
Paulo et al. (2015)	Development of an MILP model to determine the optimal design of the residual forestry biomass to power generation in Portugal
Hong and Lam (2015)	Development of an MILP model for multiple biomass supply chain

Table 2 Genetic algorithm for supply chain synthesis

Author (year)	Remark
Syarif et al. (2002)	Development of a spanning tree-based genetic algorithm to solve the logistic system design in supply chain
Gen and Syarif (2005)	Proposal of a spanning tree-based genetic algorithm to solve the production and distribution problem in supply chain with the aim of minimising the cost
Truong and Azadivar (2005)	Proposal of a methodology which integrated mixed integer programming and genetic algorithm to determine the optimal configuration of a supply chain
(Lin et al. 2008)	Development of an agent-based distributed coordination mechanism that integrates negotiation techniques with genetic algorithm to plan the schedule
Yun et al. (2009)	Development of a genetic algorithm approach with adaptive local search scheme to effectively solve the multi-stage supply chain problem
Altiparmak et al. (2009)	Proposal of a solution procedure based on steady-state genetic algorithm with a new encoding structure for the synthesis of a single-source, multi-product and multi-stage supply chain network
Zegordi et al. (2010)	Development of a gendered genetic algorithm which considered two different chromosomes with non-equivalent structure to solve the two-stage (i.e. production speed and vehicle speed) supply chain optimisation problem
Chang (2010)	Proposal of a genetic algorithm which combines the co-evolutionary mode and constraint satisfaction mode capacity in order to shorten the solving time
Kannan et al. (2010)	Solution to the multi-echelon, multi-period, multi-product closed-loop supply chain model using genetic algorithm
Che and Chiang (2010)	Proposal of a Pareto genetic algorithm to solve the multi-objective optimisation of a build-to-order supply chain
Yeh and Chuang (2011)	Development of an optimum mathematical planning model for green partner selection using genetic algorithm
Zamarripa et al. (2012)	Proposal of genetic algorithm to solve the supply chain planning under uncertainty
Ghasimi et al. (2014)	Proposal of genetic algorithm for optimising a novel mathematical model of the defective goods supply chain network
Bandyopadhyay and Bhattacharya (2014)	Modification of the non-dominated sorting genetic algorithm to solve the tri-objective supply chain problem
Pasandideh et al. (2015)	Utilisation of non-dominated sorting genetic algorithm and non-dominated ranking genetic algorithm to solve the multi-product, multi-period three-echelon supply chain problem

Hybrid model

One of the very first hybrid models was proposed by Lam et al. (2010a). They combined Pinch graphical approach together with mathematical modelling regional biomass supply chain carbon footprint minimisation. It is a demand-driven approach which utilises regional resource management composite curve (RRMCC), an analogy of the Process Integration approach to show the energy imbalances helping in trading-off resources management. This approach provides straightforward information on how to manage the surplus resources in a region.

Life cycle analysis (LCA) is an important concept in the design of sustainable supply chain. It is the most scientifically reliable method (Ness et al. 2007), which was introduced to measure environmental and resource-related products to the production process (Srivastava 2007). This measurement involves in stages from extraction of raw

Table 3 Ant colony optimisation in supply chain synthesis

Author (year)	Remark
Silva et al. (2004)	Development of an integrated framework which merged the concept of agents and ant colony
Silva et al. (2009)	Introduction of ant colony optimisation technique to solve the supply chain management
Wang (2009)	Development of a two-phase ant colony algorithm to solve the multi-echelon defective supply chain network design
Wang and Chen (2009)	Proposal of an ant algorithm to solve capacity planning and resource allocation problem in a decentralised supply chain
Moncayo-Martínez and Zhang (2011)	Proposal of a Pareto ant colony optimisation to solve the multi-objective supply chain design problem
Moncayo-Martínez and Zhang (2013)	Proposal of a modified ant colony optimisation which utilised a bi-objective MAX–MIN function to solve the supply chain problem
Moncayo-Martínez and Recio (2014)	Determination of a set of supply chain configurations using the Pareto ant colony optimisation
Cheng et al. (2015)	Proposal of an improved ant colony optimisation to solve the scheduling problem for the production in supply chain
Wang and Lee (2015)	Proposal of a revised ant colony optimisation to improve the original ant algorithm using efficient greedy heuristic to solve the supply chain problem

Table 4 Bee algorithm in supply chain synthesis

Author (year)	Remark
Koc (2010)	Improvement of the bee algorithm using combined neighbourhood size change and site abandonment strategy
Mastrocinque et al. (2013)	Proposed bee algorithm in dealing with multi-objective supply chain model to find the optimum configuration which minimises the total cost and total lead time
Teimoury and Haddad (2013)	Implementation of bee algorithm to solve the parallel batch production scheduling in a supply chain
Chen and Ju (2013)	Proposal of a novel artificial bee colony algorithm for solving the mixed integer non-linear supply chain network model
Yuce et al. (2014)	Development of an enhanced bee algorithm with adaptive neighbourhood search and site abandonment strategy to solve the multi-objective supply chain model
Zhang et al. (2014)	Proposal of the hybrid artificial bee colony algorithm to solve the environmental vehicle routing problem with minimisation of overall travel distance and travel time
Zhang et al. (2016)	Introduction of artificial bee colony-based approach for supply chain design

materials, production, distribution, and remanufacturing, recycling and final disposal. Gungor and Gupta (1999) commented that LCA assesses the impact of a particular product on the environment based on the materials and energy used and wasted through its production, usage and disposal (Finnveden and Moberg 2005). Government regulations are also an added factor for organisations to work towards LCA. ISO 14040 has also been developed for LCA to provide a general framework, terminology and principles. Moreover, these standards provide transparency and consistency in LCA studies (Cambero and Sowlati 2014). Generally, LCA can be divided into 4 stages: (i) define the goal and scope of study, (ii) life cycle inventory (LCI), (iii) life cycle impact assessment (LCIA) and (iv) interpretation. It is worth noting that LCA results are strongly dependant on the methodological choices and parameters associated with each analysed case. Therefore, it should not be used to provide the basis for comparative declarations of the overall environmental preferability among the products. Nevertheless, LCA results are useful to compare environmental impacts of the alternative configurations of a supply chain. Life cycle optimisation (LCO) can be applied to synthesise an optimum supply chain (Wan et al. 2015). Many studies related to LCA implemented in sustainable supply chain synthesis are summarised in Table 5. A lot of future research contributions are required for the successfulness and completeness of integration of LCA into biomass supply chain.

Game theory was firstly introduced by Von Neumann and Morgenstern (1947) and has been widely used in various research fields. It offers a valuable tool in the identification of dominant strategy for increasing performance along each objective (Zhao et al. 2012). Many research works have commented and discussed the

Table 5 LCA in supply chain synthesis

Author (year)	Remark
Laínez et al. (2008)	Application of LCA to evaluate the environmental impact while IMPACT 2002 + methodology is selected
Nwe et al. (2010)	Conduction of an approach integrating LCA indicators and dynamic simulation for supply chain design and action
Guest et al. (2011)	Conduction of an LCA for biomass-based combined heat and power plant.
Kostin et al. (2011)	Integration of bio-ethanol sugar supply chain with economic and environmental concern where LCA is used to assess the latter criterion
Pucker et al. (2012)	Conduction of a greenhouse gas and energy analysis for a biomass supply chain
Murphy et al. (2014)	Application of LCA to evaluate greenhouse gas emission and primary energy balances in Ireland
Ren et al. (2015)	Life cycle cost optimisation of biofuel supply chain under uncertainties via interval linear programming
Cambero et al. (2015)	Economic and life cycle environmental optimisation of forest-based biorefinery
Lim and Lam (2016)	Introduction of biomass element life cycle analysis for biomass supply chain optimisation

Table 6 Game theory in supply chain optimisation

Author (year)	Remark
Cachon and Netessine (2004)	Introduction of Game theory to solve the supply chain coordination problem
Huang et al. (2007)	Optimisation of the supply chain network design using three-move dynamic game-theoretic approach
Zhu and Dou (2007)	Development of an evolutionary game model to investigate the effect of government subsidies and penalties
Sobel and Turcic (2008)	Proposal of a general model for supply chain contract negotiation with risk aversion
Nagarajan and Sošić (2008)	Application of cooperative bargaining model to allocate profit between supply chain members
Chen and Sheu (2009)	Creation of a differential game model to design environmental regulation strategies
Esmaeili et al. (2009)	Proposal of several game models of seller–buyer relationship in a supply chain
Zhao et al. (2010)	Application of cooperative game theory approach to address the supply chain coordination issues
Sheu (2011)	Derivation of bargaining game model to seek negotiation in supply chain management
Huang et al. (2011)	Utilisation of three-level dynamic non-cooperative game model to solve the coordination problem and other selection, pricing and replenishment decision in supply chain network
Barari et al. (2012)	Introduction of a dynamic evolutionary game model to solve the coordination of players in supply chain
Nagurney and Yu (2012)	Utilisation of an oligopoly game model to design a sustainable fashion industrial supply chain
Zhao et al. (2012)	Application of game theory to select appropriate strategies in supply chain with the aim of maintaining sustainability
Zamarripa et al. (2013)	Application of game theory optimisation-based tool to improve the decision making of supply chain
Tang et al. (2015)	Analysis of palm biomass supply chain in Malaysia via game theory approach

application of game theory (normally cooperatives game) to the supply chain, see Table 6. In addition, several game models have been formulated for the application to sustainable supply chain, for instance, evolutionary game model (Zhu and Dou 2007), differential game model (Chen and Sheu 2009), bargaining model (Sheu 2011), oligopoly game model (Nagurney and Yu 2012) and dynamic evolutionary game model (Barari et al. 2012). It is worth to note that the major limitation in the previous work is the lack of interaction between the upstream and downstream business. Thus, as a natural extension of research works, future studies should consider the coordination issues in biomass supply chain (Zhao et al. 2010).

P-graph framework was initially introduced by Friedler et al. (1992) and has been implemented in systematic optimal design, including industrial process synthesis and supply chain network synthesis. This framework has been proven to be highly effective in solving industry-scale process synthesis problems. One of the attractive attributes of this approach is that it can generate optimum and near-optimum solutions simultaneously. P-graph is a directed bipartite graph associated with several combinatorial instruments. First are the axioms which must be satisfied for combinatorial feasible solution structures and algorithms which ensure the consistency of the resulting maximal structure and solution networks. These algorithms include maximal structure generator (MSG), solution structure generator (SSG) and accelerated branch-and-bound (ABB) algorithm. Generally, MSG defines the structure model; SSG generates each of the solution structure; and ABB determines the optimum structure using an improved branch-and-bound algorithm. Figure 9 represents a P-graph with the operating units O1, O2 and O3 and materials M1, M2, M3, M4, M5 and M6.

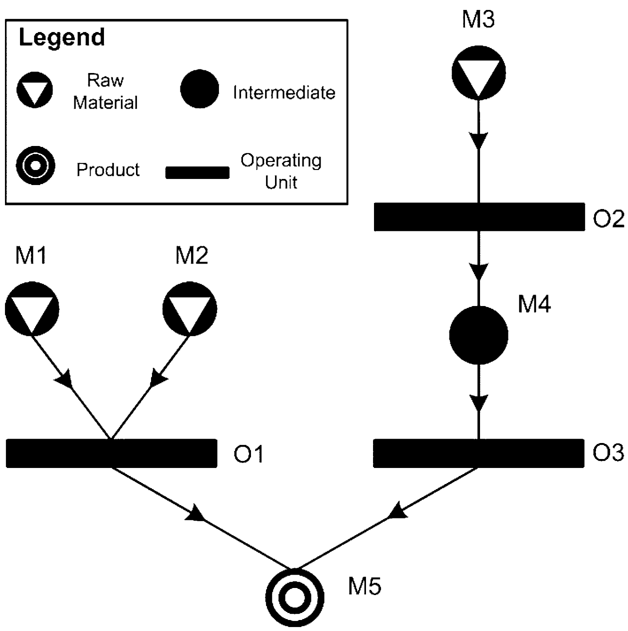


Fig. 9 P-graph illustration

Recently, the applications of P-graph are getting extended to several fields, including synthesis of azeotropic distillation system (Feng et al. 2003), reaction pathway identification (Fan et al. 2012), logistics design (Barany et al. 2011), evacuation route planning (García-Ojeda et al. 2013), retrofit planning (Chong et al. 2014) and biomass supply chain synthesis and optimisation (Lam et al. 2010a, b). Other publications related to the use of P-graph approach in supply chain synthesis and optimisation are tabulated in Table 7.

IT-driven model

The development of IT is the major driving force for supply chain innovations. IT-driven models target to integrate and coordinate various phases of supply chain planning on a real-time basis using application software to enhance visibility throughout the supply chain. One of the commonly used models in supply chain is enterprise resource planning (ERP). It is an integrated information system which is designed to automate and integrate all the business processes and operations together. Kandananond (2014) pointed out that the development of sustainable supply chain will not be possible and feasible without the implementation of ERP in organisation. In order to improve the effectiveness and successful rate of the implementation of the ERP in the organisation, a lot of research works were conducted during twentieth to twenty first centuries (see Table 8). However, some research works showed that despite ERP system being implemented in the organisations, some of them still fail to achieve the

Table 7 P-graph approach for supply chain synthesis

Author (year)	Remark
Fan et al. (2009)	Application of P-graph to synthesise an optimal and/or near-optimal enterprise-wide supply network
Lam et al. (2010b)	Optimisation of regional energy supply chain via P-graph approach
Süle et al. (2011)	Extension of the algorithms and software of P-graph for generating optimal and near-optimal supply network with given reliability of each production option
Barany et al. (2011)	Proposal of P-graph framework in solving vehicle assignment problem in a supply network
Kalauz et al. (2012)	Proposal of extended P-graph methodology, algorithm and software to improve supply networks where quality is measured by cost and response time
Bertok et al. (2013)	Introduction of a methodology to model the supply chain as well as to synthesise optimal and alternative solutions while taking into account structural redundancy
Lam (2013)	Demonstration of the extension of P-graph via case studies in supply chain systems, carbon emission reduction system and cleaner production process synthesis
Vance et al. (2013)	Proposal of a computer-aided methodology for designing a sustainable energy supply chain using P-graph
How et al. (2015)	Synthesis of multiple biomass supply chain via P-graph approach

Table 8 ERP in supply chain

Author (year)	Remark
Al-Mashari and Zairi (2000)	Re-engineering of supply chain by applying ERP
Marinos and Zahir (2003)	Introduction of Enterprise Application Integration technique to integrate ERP and supply chain
Lee et al. (2003)	Integration of enterprise with ERP and EAI
Kelle and Akbulut (2005)	Information sharing, cooperation and cost optimisation in supply chain management by implementation of ERP
Koh and Saad (2006)	Integration of supply chain management and ERP
Basoglu et al. (2007)	Organisation adoption of ERP
Law et al. (2010)	Introduction of full life cycle of ERP
Kuhn and Sutton (2010)	Introduction of a continuous auditing system in ERP
Goni et al. (2011)	Introduction of the critical success factor for ERP
Lopez and Salmeron (2014)	Dynamic risk modelling in ERP
Brooks et al. (2012)	Introduction of Sustainable Enterprise Resource Planning (S-ERP)
Kandananond (2014)	Implementation of ERP in sustainable supply chain system

supply chain integration due to being complex, non-flexible and un-collaborative with others (Themistocleous et al. 2001). To solve this problem, an Enterprise Application Integration (EAI) technology is proposed to support the efficient incorporation of information system, resulting in integration of supply chain (Linthicum 1999). On the other hand, the supply chain development has raised environmental pressure and attendant business responsibilities. Moreover, climate change, resource depletion, human health problem and negative social impact are leading to a point of no return (Carvalho et al. 2013). Therefore, sustainable development is now more important than ever. However, the sustainability data are yet to be sufficiently integrated and used for decision making. Chofreh et al. (2014) have proposed Sustainable Enterprise Resource Planning (S-ERP) system to support the sustainability initiatives. S-ERP shows difference compared to the traditional ERP as its information system is driven by sustainability consideration that covers all aspects of the supply chain. Figure 10 shows the illustration of S-ERP life cycle. As shown in the figure, in order to extend the development of S-ERP system, the development of Cloud S-ERP might be a potential research direction in the future.

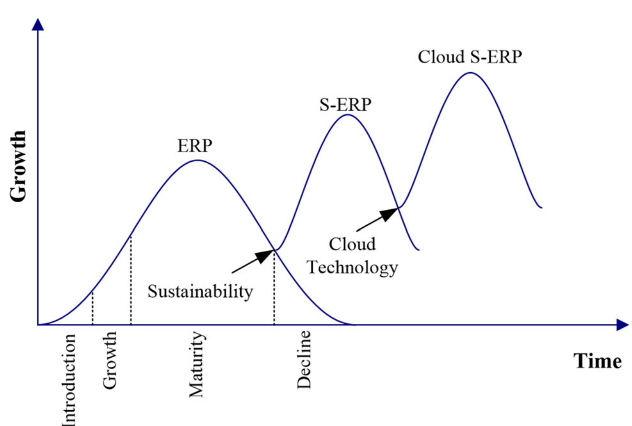


Fig. 10 Life cycle of ERP and S-ERP (Chofreh et al. 2014)

Multi-agent technology is another common computerised system which was firstly introduced by Swaminathan et al. (1998). Using this technique, supply chain is structured as a virtual library of structural elements (i.e. production and transportation) and control elements (i.e. flow, inventory, supply and demand). All of them are represented by agents that interact with each other in order to determine the optimal configuration. The major strength of this technique over the conventional mathematical modelling is its flexibility. It is able to interpret new information from time to time, allows exchange between agents and also enables new policies (Ahn et al. 2003). In spite of all the benefits mentioned above, finding an appropriate methodology to coordinate the agents is still a major challenge. Table 9 shows the list of publications which are related to multi-agent technology in supply chain models.

Future challenges and scope in sustainable biomass supply chain

As discussed in the previous section, no model can capture all aspects of supply chain processes considering the broad spectrum of a supply chain. To compromise the dilemma between model complexity and reality, a model builder should define the scope of the supply chain model in such a way that it is reflective of key real-world dimensions, yet not too complicated to solve. Based on literature review done in this work, the future scope of biomass supply chain is highlighted as follows:

Table 9 Multi-agent technology for supply chain

Author (year)	Remark
Swaminathan et al. (1998)	Development of a simulation-based framework for developing customised supply chain model
Fox et al. (2000)	Investigation of the issues and presentation of the solutions for the construction of agent-oriented software architecture
Kaihara (2003)	Formulation of the supply chain as a discrete resource allocation problem with dynamic environment
Silva et al. (2004)	Development of an integrated framework which merged concept of agents and ant colony
Fischer and Gehring (2005)	Development of a multi-agent system for supporting transhipments of imported finished vehicles
Guillén et al. (2005b)	Application of an agent-oriented simulation system to model each entity in supply chain as an independent agent
Lin and Lin (2006)	Introduction of multi-agent negotiation mechanism to solve the distributed constraint satisfaction problem
Liang and Huang (2006)	Development of a multi-agent system to simulate a supply chain where agents operate these entities with different inventory system
Zhang et al. (2006)	Proposal of an agent-based approach to integrate, optimise, simulate, restructure and control the supply network dynamically and cost effectively
Zhang and Zhang (2007)	Formulation of an agent-based model of consumers purchase decision making which combines consumers' psychological personality and the interactions in market
Forget et al. (2008)	Proposal of a multi-behaviour planning agent model using different planning strategies when decisions are supported by a distributed planning system
Lin et al. (2008)	Development of an agent-based distributed coordination mechanism that integrates negotiation techniques with genetic algorithm to plan the schedule
Lim et al. (2009)	Proposal of an interactive agent bidding mechanism which performs dynamic integration of process planning and production
Hanafizadeh and Sherkat (2009)	Proposal of a fuzzy-genetic learner model based on multi-agent system in order to tackle the distribution and allocation problems in supply chain
Giannakis and Louis (2011)	Development of a framework for the design of a multi-agent-based decision support system and risk mitigation in supply chain management
Zolfpour-Arokhlo et al. (2013)	Development of a route planning model based on multi-agent system for supply chain management
Sitek et al. (2014)	Introduction of the concept of hybrid multi-agent approach for the modelling and optimisation of supply chain management
Pal and Karakostas (2014)	Proposal of a multi-agent and web service framework for collaborative material procurement systems
Fu and Fu (2015)	Development of a new intelligent system framework of adaptive multi-agent system to improve the collaborative cost management in supply chain

Systematic framework for centralisation versus decentralisation

Centralisation and decentralisation of processing facilities have been studied and modelled. The decision is always made based on the economic factors such as cost of logistic and processing facility. However, the logistic network and infrastructure are also greatly affected by the characteristics of biomass such as availability, transport density and shelf life. To date, there are still no proper definition and systematic framework to refer to. Depending on these factors, the processing facility/facilities may be centralised as a single processing hub (for biomass with long shelf life and high density), decentralised and located locally in the farms (for biomass with short shelf life and low density) or a mixture of centralised and decentralised processing hubs. The decision of processing facilities' centralisation or decentralisation is very critical to ensure the optimum performance of the supply chain. Therefore, a proper framework is needed to be a decision-making tool in the biomass industry which helps synthesise an optimum logistic network of the supply chain.

Systematic scheduling approach

Scheduling is usually done to reduce the production cost and time of a particular process in traditional supply chain. However, there are a lot of constraints associated with biomass supply chain such as shelf life and availability of biomass. These may result in a different configuration in biomass harvesting and bioproducts production. Besides, different harvesting and processing techniques may also affect the economic performance and throughput of the entire chain. Hence, a systematic approach should be developed to aid the scheduling of the value chain, minimising the time and cost as well as fulfilling other constraints simultaneously.

Sustainable index

A number of optimisation models have been proposed, some are single objective and some are multi-objective. There is not any proper standard to measure the performance of biomass supply chain so far. However, it is usually measured in terms of economic potential and environmental impact. Social impact is another important element in sustainable supply chain model. A standardised sustainable index therefore should be proposed to quantify and compare the effectiveness of supply chains.

Debottlenecking of existing supply chain

Biorefinery is still relatively new as compared to petrochemical industry. As it becomes mature, the demand of bioproducts will increase, causing the capacity of biorefinery to flex up. To maximise the capacity of the supply chain, debottlenecking can be done to align the capacity at each step as the capacity of the entire chain is constrained by the capacity of its bottleneck process. Debottlenecking is the process of successively identifying the binding constraint, eliminating that constraint, aligning other processes to the new throughput levels and pursuing the next constraint. Debottlenecking is very challenging because the supply chain system involves different business parties.

Qualitative study

The commercialisation of biomass supply chain needs the cooperation from both the academic researchers and the industry players. A lot of research works have been done on biomass supply chain, yet the commercialisation of biorefinery is still not proven feasible. Qualitative study plays an important role in linking the researchers to the industry people. Qualitative research is a technique of inquiry employed in various academic disciplines, traditionally in the social sciences, but also in market research, business and other contexts including service demonstrations by non-profits. It aims to investigate the opinions and thoughts of the industry people and fill the gap between research and industry.

Conclusion

Biorefinery produces energy and useful chemicals from biomass, an environmental-friendly renewable source. Supply chain management is very significant when it comes to commercialisation of a competitive biorefinery industry. Despite the pressure from global warming and environmental issues, there are many potential benefits while making the supply chain sustainable. This paper has presented a general overview of the development of sustainable biomass supply chain in terms of scope, sustainability elements and modelling approach. This classification will aid academicians, practitioners and researchers to understand sustainable biomass supply chain management from a wider perspective. Based on the review, the existing research gap and the future challenges in sustainable supply chain are highlighted. Having these potential undeveloped subjects and scope done in this area, biomass supply chain will definitely move a step nearer to commercialisation and sustainability. The ultimate and most important goal to be pinpointed here is the implementation of effective and sustainable supply chain worldwide. The mature and effective biomass supply chain implementation in developed countries should be the role model to the developing countries. The strengths, weaknesses, opportunities and threats (SWOT) in these successful cases should be evaluated and identified as guidance for the synthesis of sustainable biomass supply chain. New ideas should always be encouraged to strive for continuous improvement in sustainable biomass supply chain management.

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