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A proactive model in sustainable food supply chain: Insight from a case study

Fabio Sgarbossa [a,*], Ivan Russo [b]

[a] Department of Management and Engineering, University of Padova, Stradella San Nicola, 3 36100 Vicenza, Italy
[b] Department of Business Administration, University of Verona, Via dell'Artigliere, 19 37129 Verona, Italy

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ABSTRACT

Recently more and more companies are adopting proactive sustainable strategies and developing sustainable supply chain management practices. Researchers identify Closed-Loop Supply Chain (CLSC) models as one of the major contributors to realising sustainable operations. Such models typically use flows concerning the products only as the unit of analysis.

This paper intends to provide a basis for developing new CLSC models, extending them to recovery resources from general outputs (e.g. unavoidable waste) with no value in terms of products. The new models affect also the configuration of the CLSC, with different set of resource suppliers and logistics providers.

The case study analysed in this paper derives from the food sector, in which the waste produced is reused as a resource, avoiding the disposal of different materials through resource-recovery activities that allow waste to be returned to the main supply chain as valuable inputs to configure a new supply chain.

The principal objective of this study is to create a new sustainable model of CLSC using and recovering waste from meat processing. A profitability indicator, an energy self-sufficiency one and a qualitative assessment of social implications are introduced to evaluate global sustainability opportunities for activating new loops.

1. Introduction

In the contemporary business world, focus is not only placed on reducing costs to increase profits, but there has been a shift towards achieving sustainability and a balance between social responsibility, environmental preservation and economic prosperity. These factors are led by the objective of achieving sustainability (Akkerman et al., 2010; Bogataj and Bogataj, 2007; Bogataj et al., 2013, Carter and Rogers, 2008; Corrêa and Xavier, 2013; Manzini and Accorsi, 2013; Sarkis et al., 2011). Evidence in the current literature increasingly finds that firms are moving towards more proactive sustainability strategies and developing sustainable supply chain management practices (Gunasekaran and Spalanzani, 2012; Wu and Pagell, 2011; Battini et al., 2014; Ortolani et al., 2011; Bouras et al., 2009). However, ultimately, research into the area of sustainability has reached a point where supply chains need to be considered from new perspectives (Brandenburg et al., 2014; Pagell and Shevchenko, 2014). Research identifies CLSC practices and models as one of the major contributors to realising sustainable operations, through the recovery of value from product-recovery. For these reasons, there is increasing attention on finding ways to create more efficient, lower cost, and sustainable closed-loop systems.

For instance, the European Commission adopted a new ambitious 'circular-economy package' at the end of 2015 as part of its strategy to move into a more competitive resource-efficient economy. The package has been designed to address a range of economic sectors, including waste. Furthermore, CLSC management research is responding to European Commission research priorities, calling for new business models to be identified in the Horizon 2020 programme. A recent study by the McKinsey Center for Business and Environment (2015) provides new evidence that a circular economy, enabled by the technology revolution, will allow Europe to grow its resource productivity by up to three per cent annually. These new business models stress the need to increase product lifespans, material reuse, recycling and recovery, which leads to a closed-loop processes and new business model, particularly in the food industry.

* Corresponding author at: Department of Management and Engineering, University of Padova, Stradella San Nicola, 3 36100 Vicenza, Italy.
E-mail address: fabio.sgarbossa@unipd.it (F. Sgarbossa).

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A CLSC is referred to as ‘reverse logistics’ (Das and Chowdhury, 2012; Kumar and Putnam, 2008; Lai et al., 2013; Rogers et al., 2012; Faccio et al., 2014, 2011) or ‘product-recovery management’ (Fleischmann et al., 1997; Östlin et al., 2008; Thierry et al., 1995; Toffel, 2004). Generally, in CLSC models, all types of waste residues, such as returned products and/or their components, are fed back into the value chain and firms face the complexity of having to decide between different reprocessing operations. The models developed by those scholars have product flows as their unit of analysis, and aim to reintroduce returned products and/or their components into the forward flow by implementing reprocessing operations such as direct reuse, recovery, recycling remanufacturing, refurbishing or repairing (Bogataj and Bogataj, 2011, Ferguson et al., 2011; French and LaForge, 2006; Guide and Van Wassenhove, 2001; Jayaraman et al., 1999; Schenkel et al., 2015). These processes allow firms to save resources, reduce costs, enhance their competitive position, improve their green reputation, meet sustainability goals and enhance customer loyalty (Atasu et al., 2008; Blackburn et al., 2004; Govindan et al., 2015; Mollenkopf et al., 2011; Russo et al., 2016; Souza, 2013). Bell et al. (2013) demonstrates that given the scarcity of natural resources, CLSC strategies may enable firms to gain comparative advantages in resources and lead to long-term superior firm performance. Practitioners are perceiving the urgency of that challenge as for example the CEO of Danone that pointed out “*we need a comprehensive response to tackle growing resource scarcity, which both drives the efficient use of those resources through the supply chain and brings healthy food to as many people as possible*” (Magnin, 2016).

As a result, there are calls for research to identify new quantitative methods and models, specifically developed and adapted to the planning, design and control of CLSC systems and their performance. There is still much room for the development of new models and solution approaches for helping the decision-making process in CLSCs, especially in the process industry (Stindt and Sahamie, 2014). Circular models such as the CLSC involve networks of businesses that generate new economic value through the continuous exchange of resources facilitated by innovative logistics and supply chain ecosystems. These systems operate with the particular objective of helping managers and practitioners to create a lower cost and sustainable closed-loop systems that use all kinds of waste in the process industry to recover new resources.

In this context, an industry sector that is receiving growing attention is food waste because the large scale of food waste's negative environmental, social and economic effects is becoming increasingly evident. Food waste is increasingly recognised as central to a more sustainable resolution of the global waste challenge across supply chain (Gibbs and Salmon, 2015). The global relevance of food, the dynamics of the industry, and the decisions of the policy makers qualify this industry to receive strong research focus on how to build a new sustainable business model through CLSC modelling.

Currently, there is specific technical knowledge about how to convert the waste of food processed (e.g. the waste resulting from the slaughtering processes in the meat industry) into an output of a new supply chain that they could be returned to other chains through CLSC (Chen et al., 2016). However, there is a limited knowledge of specific CLSC model, about an overall managerial point of view able to define new loops in the supply chain and to evaluate them.

The contribution of our approach is going beyond that traditional model of CLSC (Govindan et al., 2015), including the resource recovery from food waste into the configuration of new closed loops in the food supply chain. In the traditional CLSC model (Fig. 1), it can be noted the waste goes to disposal stage of supply chain and this approach analyzes the flows concerning just the products, without any considerations about the other outputs, typically unavoidable process waste, generated by each actor of supply chain.

Considering the resource flow in the CLSC brings to new configurations of the networks and as a consequence to new models for the design and management of CLSC to include also resource recovery into traditional approaches.

For example, the introduction of new resource recovery plants from the unavoidable waste, as new loops in the supply chain, will affect the configuration of the network, avoiding the necessity of external sources for primary resources, such as electrical or thermal energy. New logistics providers will be required to manage the waste flows from the production phase to the recovery facilities. It will be relevant to consider these aspects in the traditional problems, such as inventory management, network design, production scheduling.

The purpose of this paper is to provide a basis for the development of a new kind of CLSC, beginning from an analysis of the meat industry. This study will analyse the slaughtering waste that is reused by recovering new resources and configuring it to a new

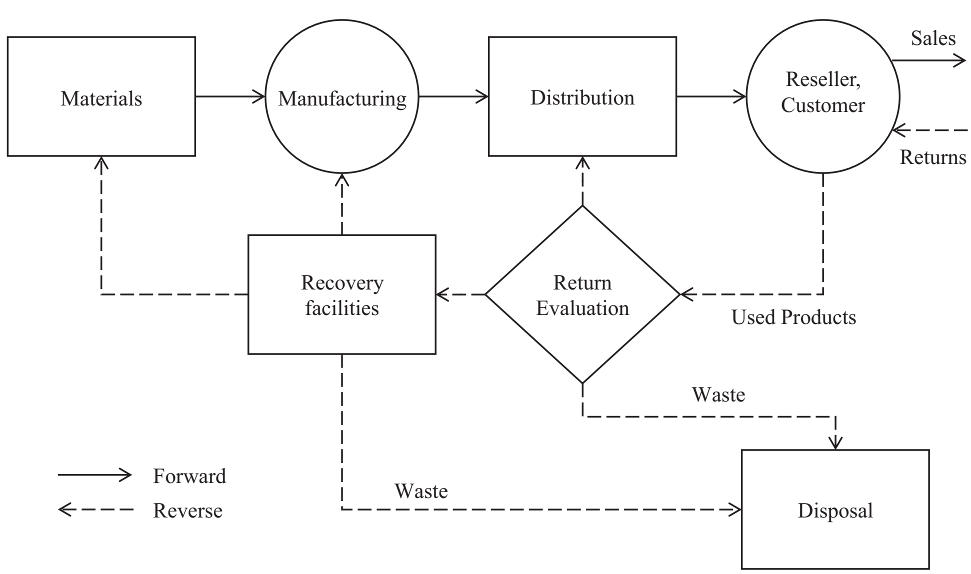

Fig. 1. Traditional CLSC. Adapted from Govindan et al., 2015.

supply chain. We use a specific profitability indicator to evaluate the cost opportunity of developing a new loop in the supply chain model and to justify such investment within a new business model. The emphasis of this contribution is related to ensuring the achievement of the self-sufficiency of a company's resources through recovering waste from the slaughtering process to the degree that resources are able to be saved for use in a period of scarcity. Finally, covering the social aspect of the sustainability triple-bottom-line approach, a qualitative assessment of the implications of the new loop for the people is introduced.

Our paper is organised as follows. First, we present in Section 2 the literature review on CLSC and resource recovery in the food supply chain. Subsequently, we detail in Section 3 our methodology and our data-collection process, achieved through the analysis of a case-study company. Consistent with the global nature of prior studies, we conduct our assessment in the context of the Italian food-chain industry and, more precisely, the meat sector. We then present in Section 4 the results of our study and draw conclusions in Section 5 by discussing the study's limitations and opportunities for future research. Finally, we present the implications for managers involved in CLSC projects.

2. CLSC and resource recovery in the food supply chain

In the following subsections, our analysis overviews and summarises state-of-the-art practices in the main areas of interest in relation to CLSC and resource recovery in the food chain for transforming waste into a new valuable input.

2.1. Closed-loop supply chain

The closed-loop relationships discussed here may have a direct connection between the organisation, its suppliers and its customers, or between internal loop suppliers, customers and within the organisation (i.e. our case study). For a comprehensive overview of CLSC research, we primarily refer to Guide and Van Wassenhove's (2001) extensive analysis of the evolution of CLSC research. For more recent developments in this field, we refer the reader to latest reviews by Souza (2013) and Brandenburg et al. (2014) because they are the most comprehensive studies in this research stream. As a recovery option of resources, CLSC has generally been discussed in relation to several products and industry sectors (e.g. French and LaForge, 2006 and Govindan et al., 2015), but research tends to consider the product as the unit of analysis, rather than the waste. Following this stream, Stindt and Sahamie (2014) analyse CLSC research in different sectors of the process industry, defining manufacturing returns as returns that emerge during the production process, for example, production scrap materials, rejected parts, surplus products, and by-products.

2.2. Food supply chain

There are several studies examining the food supply chain. These studies focus on particular features of the food supply chain, and reveal challenging operations aspects for inventory management, processing, production, distribution and the supply chain (Govindan et al., 2015; Handayati et al., 2015; Li et al., 2014; Manzini and Accorsi, 2013; Sarkis, 2012, Savino et al., 2015, Savino and Apolloni, 2007). The food supply chain includes food procurement and manufacturing companies, wholesale and distribution firms, brokers, food-service firms and restaurants, and retail grocery firms (Fredriksson and Liljestrand, 2015; Mattevi and Jones, 2016). There is an increasing consciousness in society that the waste of perishable foods involves a loss of natural resources and should be avoided (van Donselaar and Broekmeulen, 2012). Beske et al. (2014) investigate supply chain sustainability management practices and the dynamic capabilities of the food industry, in a context where consumers demand high food quality and safety and call for future empirical research that uses real data and business cases to expand knowledge on sustainable supply chain practices in food.

Recently, Meneghetti and Monti (2015) studied the food supply chain and proposed an optimisation model for sustainable design with a model that analyses the effect of supply chain decision variables, storage temperature and the incoming-product temperature on costs, energy use and carbon dioxide emissions. McCarthy et al. (2015) show that the process of producing portions has very high environmental impacts due to the extra raw materials that are required; they provide new insights into the food supply chain by examining the relationship between vertically integrated supply chains and environmental performance, and the use of consolidation as a way of reducing the environmental impact, which has not been examined in the past.

Fredriksson and Liljestrand (2015) present an extensive and structured literature review of studies on food and perishability using a logistics, supply chain and production perspective; their study calls for more research that clarifies models on how environmental and sustainability concerns affect the food supply chain. In their recent study, Bloemhof et al. (2015) state that the most important indicators of sustainability in the food logistics chain are energy consumption, land use, employment possibilities, revenue, waste production, production costs and percentage of food loss, food safety, and environmental monitoring systems.

Waste-management policies should be accompanied by and integrated into wider policies on food. Further research is required to provide the evidence base to support a shift to a more sustainable food surplus and waste management (González-García et al., 2013), taking under investigation not only the return products but also the waste in food processing, with the aim of creating a new loop across the supply chain. The possibility of changing the production process with the aim of reducing waste and improving environmental sustainability should also be attempted in other food industries such as the cheese-making industry (Govindan et al., 2015).

2.3. Resource recovery from food waste

Some scholars consider the issue of a wider supply chain in the food context and discuss the boundaries between food surplus and food waste, avoidable and unavoidable food waste, and waste prevention and management, attempting to create a hierarchy for food waste (Papargyropoulou et al., 2014). There is some doubt about the merits of the food-waste hierarchy and its effectiveness for minimising environmental impacts and natural-resource usage (Van Ewijk and Stegemann, 2014). Therefore, the European Commission aims to regulate the best way to limit waste throughout the food supply chain, and consider ways to lower the environmental impact of food production and consumption patterns (European Commission, 2011).

However, as Govindan et al. (2015) describes, one of the logistics flows of a generic CLSC concerns the unavoidable waste sent to the disposal stage, creating a serious effect on the environment.

Particularly in the food industry, one of the main environmental impacts of food waste is related to its final disposal in landfills, waste transportation, and the embedded carbon from the previous lifecycle stages of food before it becomes waste (Soysal et al., 2014). In addition to environmental and economic impacts, food waste has many social implications focusing around the ethical and moral dimension of wasting food, in particular in relation to the inequality between on the one hand wasteful practices, and on the other food poverty across different regions (Matopoulos et al., 2015).

Moreover, the large amount of waste produced in food production not only represents a serious economic and environmental problem, but also means the loss of potentially valuable materials (Mirabella et al., 2014).

Recently, the food processing waste has been utilised as a by-product in resource recovery, for example, in providing electric energy, producing methane gas or cleaning water from the waste using the appropriate technology (Bourlakis et al., 2014; Papargyropoulou et al., 2014). Possible alternative uses have been investigated in depth, with specific attention paid to the technical aspects or perspectives of sustainability of the single recovery process. Roda et al. (2016) aim to propose a sustainable use of resources; they show the possibility to produce vinegar starting from resources generally destined to waste. If it appears interesting the possibility to get a usable product derived from waste, the cost analysis highlights the need for further research to combine pre-treatments and to increase the scale of the process, in order to reduce the cost incidence.

Chen et al. (2016) conduct a bibliometric analysis of the scientific literature on food waste. They highlight that the majority of research in this field relates to treatment and disposal methods, energy products, operational conditions and innovative biohydrogen production. Moreover, the many journals that publish articles on resource efficiency in agri-food supply chains demonstrate the wide scope of the topic, the numerous disciplines involved, and how resource efficiency does not depend on only one actor in the supply chain (i.e. Iakovou et al., 2010; Matopoulos et al., 2015).

Recently, a great deal of research has focused on lifecycle assessment (LCA) and the sustainability aspects of waste treatment. Several studies deserve particular attention. Nguyen et al. (2010a, 2010b) analyse the environmental impact of several types of livestock (pig and beef) and the consequences of recovery of resources from their waste. Hall and Howe (2012) examine how anaerobic digestion is an opportunity to recover energy from waste in food processing. Bustillo-Lecompte et al. (2015) review slaughterhouse wastewater treatment, as well as trends and advances in this area, providing a general review of the environmental impacts, health effects, and regulatory frameworks relevant to wastewater management in meat industry.

The analysis of the research in this area demonstrates the necessity to extend the traditional approach to CLSC, particularly in the food industry. This extension must also include research into waste management and resource recovery as a new loop in the supply chain configuration. The majority of the research on waste management proposes specific technical approaches to the resource recovery from waste, in particular energy recovery (Chen et al., 2016). Some research introduces generic LCAs of several stages of food supply chains to evaluate their environmental impact. However, there is no research analysing the recovery process from the supply chain perspective to provide general parameters for estimating its effect on the new CLSC sustainability.

Consequently, we introduce a new model to include resource recovery from food waste in the configuration of new closed loops in the food supply chain. We adopt a global approach to assess the sustainability of the creation of a loop through the analysis of a case study and by using general sustainable indicators of the economic, environmental and social aspects.

3. Methodology

In business-to-business research, study profiles are continuously evolving with new practices; thus, the nature of our research area is explorative, as are other case studies in the literature (Barratt et al., 2011; Eisenhardt and Graebner, 2007; Ellram et al., 2008; Ting et al., 2014). From the explorative prospective, and subsequent to the initial literature review, qualitative research was performed to fill the gaps in the research that exist in this area. Case-study research consists of in-depth investigations conducted alongside data collection, with the aim of providing an analysis of the context and processes involved in the phenomenon under study (Yin, 2009). Case studies are not only useful for understanding and developing theories, but also form the most important means for testing the applicability of the theory (Holweg and Helo, 2014; Jouni et al., 2011; Ketokivi and Choi, 2014; Östlin et al., 2008; Pool et al., 2011; Stuart et al., 2002; Voss et al., 2002). Further, case-study research is particularly valuable when little is known about a phenomenon because theory building from case studies does not rely on previous literature or prior empirical evidence (Huberman and Miles, 2002; Eisenhardt and Graebner, 2007; Östlin et al., 2008). There is little research in the area of CLSC on how to recover food waste processed in the meat industry, and how to transform wastage in other by-products so that they can be returned to other chains as valuable inputs.

We undertook a case study in the meat industry in Italy using case-study methodology collecting primary and secondary data (Bloemhof et al., 2015; Dadhich et al., 2015; McCarthy et al., 2015). Through the case-study methodology, we are able to analyse data in a specific context, and investigate the phenomenon in its natural environment through a detailed analysis of several events in the real business context. Furthermore, case-study research offers a unique method by which to observe natural phenomena in the data (Yin, 2009) because unlike quantitative analysis, case-study research considers data on a microlevel (Eisenhardt, 1989).

3.1. Case study of meat supply chain

The supply chain of meat generally consists of four principal areas (Fig. 2):

- farmers/livestock: as sourcing of raw materials in this supply chain, these are typically placed close to the production plants
- production: including the slaughterhouse and meat processing, from the reception of animal and vegetable aromas to the cutting phase of meat for standardised products
- distribution: from the labelling department to the packaging area, including the temperature-controlled stock and shipment to final consumers
- sales: this area includes retailers and direct consumers such as restaurants and canteens where the meat is consumed.

A sustainable food supply chain is responsible for processing raw materials into final products, and managing recovery systems that enable all post-life treatments. In the food supply chain, the reverse flows of products concern the residual products, by-products, co-products, recycling, substitution, reuse, disposal, refurbishment, and repairing products and other waste, particularly packaging (Manzini and Accorsi, 2013).

3.2. Data collection

We collected data using primary data directly from the field, and then corroborated these data with secondary sources in which the unit of analysis was the production stage of the supply chain processes. The use of externally available datasets may increase the research reliability by eliminating bias in the fieldwork design (Calantone and Vickery, 2009) and enabling replication. This creates the opportunity to obtain data from secondary data, which is the most likely reason for which there has been a call for greater

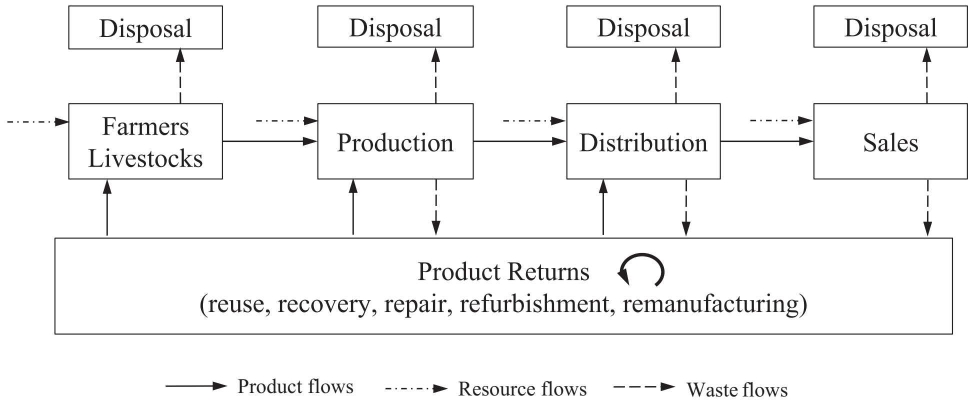

Fig. 2. Traditional CLSC in food sector.

use of secondary data, and an expansion in the methods used to analyse such data (Carter, 2011; Tate et al., 2010). This study aims to utilise both of these data-collection processes. Data were collected through visits to the two company's sites: the production area and the headquarters. The primary data were collected using various sources of information, including direct observations (e.g. production line of all the plants included in the study, a half day production meeting for every plant, and an initial group meeting with the project team), examination of the available documents and reports of the company, and qualitative semi-structured interviews with participants involved in the company's production plants (Strauss and Corbin, 1998). Semi-structured interviews with the informants, who were at managerial positions, including the roles of managing directors of the plants and operations managers took between 1 and 1.5 h each. The site visits included a plant tour to allow us a direct observation of the plants by the managing director; the interview questions included specific information about the biogas and cogeneration plants and a list of possible slaughter wastes reused; this information provided insights that were extremely helpful in developing our economic evaluation. The following specific information was provided by the company: investment cost for the plant, number of animals processed and tonnes of deboned meat every year, tonnes of animal fat and organic waste processed every year, electric energy and methane gas consumed every year by the plant, capacity of two motors and the relative annual production of electric energy and thermal energy.

The data were collected between January 2013 and December 2014. The meetings with the managers provided a robust opportunity to explore issues in depth and gather detailed information about the production process because it allowed our group of managers to elaborate on specific processes, problems and implementation practices. We were unable to obtain free access to recordings due to confidentiality concerns of the company. Thus, we combined primary data with a relevant amount of secondary data. In particular, we used the following documents to validate the interviewees' responses, allowing us to triangulate the data to verify the internal consistency of the data: Eurostat; Processors and Poultry Trade (AVEC) in the EU; World Bank Group; (UNIPEG, 2014) (English version). The data from the primary and secondary sources were used as inputs to the economic evaluation of the investment in the new node of supply chain with the introduction of cogeneration and biogas plants.

To ensure rigor in the data collection and analysis, we employed a sets of trustworthiness criteria that are appropriate for qualitative methodology (Omar et. al., 2012; Mollenkopf et al., 2007; Strauss and Corbin, 1998). We could assure transferability (by sampling and triangulation of interview sites); dependability (based on a long history of the company and due to the specific characteristics about the biogas and cogeneration plants); credibility (by the reviewed company results from interview participants and also we involved a well-known colleague expert in qualitative research); confirmability (by involvement of the researchers independently during the analysis); fit (covered through the methods used to address credibility, dependability, and confirmability); reliability, control and validity (several reports were undertaken allowing the researchers to obtain a clear view of slaughtering process, external reviewer was used and multiple data source were involved).

4. Closing the loop in the meat industry

In the meat industry, slaughterhouse waste consists of the portion of a slaughtered animal that cannot be sold as meat or used in meat products. Such waste includes bones, tendons, skin, contents of the gastrointestinal tract, blood, and internal organs. The slaughtering activities involve not only animal waste. Typically, used packaging, made in iron, aluminium or plastic, generates waste similar to that generated in urban environments. Moreover the production stage required high amount of water, so wastewater treatment is relevant.

Meat waste by-products constitute approximately 60–70% of the slaughtered carcass, of which nearly 40% is edible and 20% inedible (Bhaskar et al., 2007); however, many of these residues have the potential to be reused in other production or supply chain systems.

Water consumption in meat processing is also a relevant issue. Water consumption in meat processing accounts for approximately 24% of all the fresh-water consumption of the entire beverage and food industries (Bustillo-Lecompte et al., 2016), with the World Bank Group (2007) reporting that a meat-processing facility may consume between 2.5 and 40 m^3 of water per metric tonne of meat produced.

The recovery of resources from food waste needs to consider other configurations of the supply chain to influence the flow of food-waste output from the network nodes and introduce new nodes with flow relations connected with the other ones currently in the supply chain (Fig. 3). As presented in Fig. 3, the resources recovered by the new part of the supply chain could mainly be used in the principal supply chain and the surplus could be sent to the community or other supply chains. It must be remembered that this recovery process may still produce a minor part of unavoidable waste sent to final disposal.

The case-study company has six manufacturing plants in Italy, 1500 employees, 10 distribution platforms and over 550 million euros in revenue in 2014. The company is able to offer customers a full range of products of beef and pork. As a result of the unification of two cooperatives, the group was founded in 2004, and

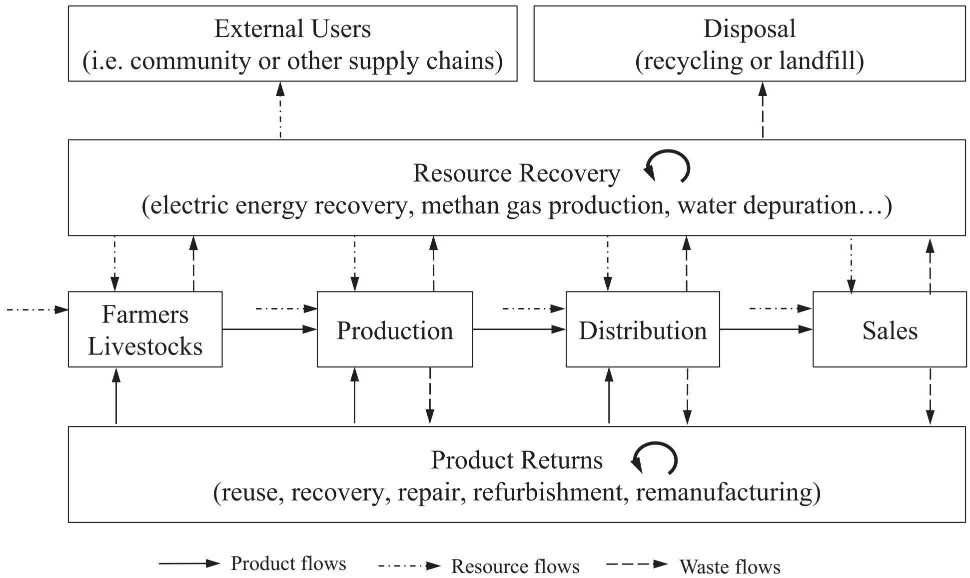

Fig. 3. Closing new loops in the food supply chain.

became the first company cooperative of beef and veal in Italy.

Slaughter and meat processing are performed in two plants located in Pegognaga (Mn) and Reggio Emilia, with a total production capacity of over 250,000 slaughtered animals per year and 42,500 t of boneless beef per year.

The production plants constitute the largest factory in the group and present advanced technology and a high level of automation. The industrial area covers 25,000 m^2. The layout of the plants and the sequences of the processing phases allow a linear flow of final goods and materials.

As stated, the case-study company is responsible for the production node of this meat supply chain and this particular stage of the network has the productivity, resource utilisation and waste generation described below.

Each year, the production plants process approximately 250,000 animals, obtaining approximately 42,500 t of deboned meat (Fig. 4). To do this, the plants require approximately 3 million standard m^3 of methane gas as thermal energy, and approximately 26 GW of electric energy each year. Other resources such as water and human labour are also necessary for performing the meat processing. These other resources are not under analysis in this study but should constitute a future extension of this research.

In addition to the traditional scheme of the supply chain, this case study highlights the relevance of another node of the network responsible for ensuring the energy supply of all processing activities, while also ensuring that the waste meat from slaughter is transformed into new resources (e.g. electric energy, methane gas or depurated water). During the past five years, the main objectives of this company have been to minimise the consumption of resources, reduce waste production, and maximise reuse and recycling. For these reasons, major investments have been made into the construction of biogas and cogeneration plants to create new closed loops in the traditional chain, where slaughter wastes can be reused to achieve self-sufficiency and energy independence.

The biogas plant, with an investment cost of approximately €5 million, receives approximately 22,500 t per year of organic waste from the slaughterhouses and provides a final output of approximately 157,000 standard m^3 of methane for thermal energy. Moreover, biogas can be combusted to produce electric energy. The engine has a power output of 526 kW fed by the biogas produced by the two anaerobic digesters and it produces

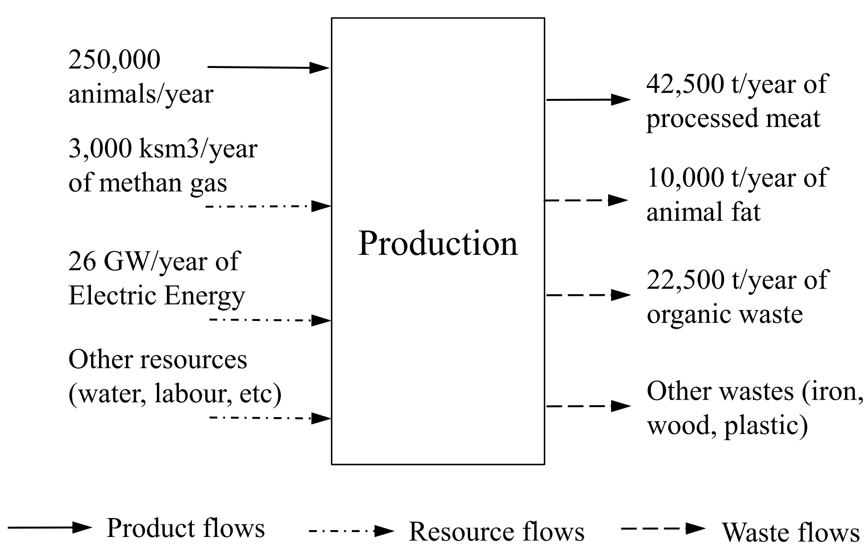

Fig. 4. Input and output flows in production phase.

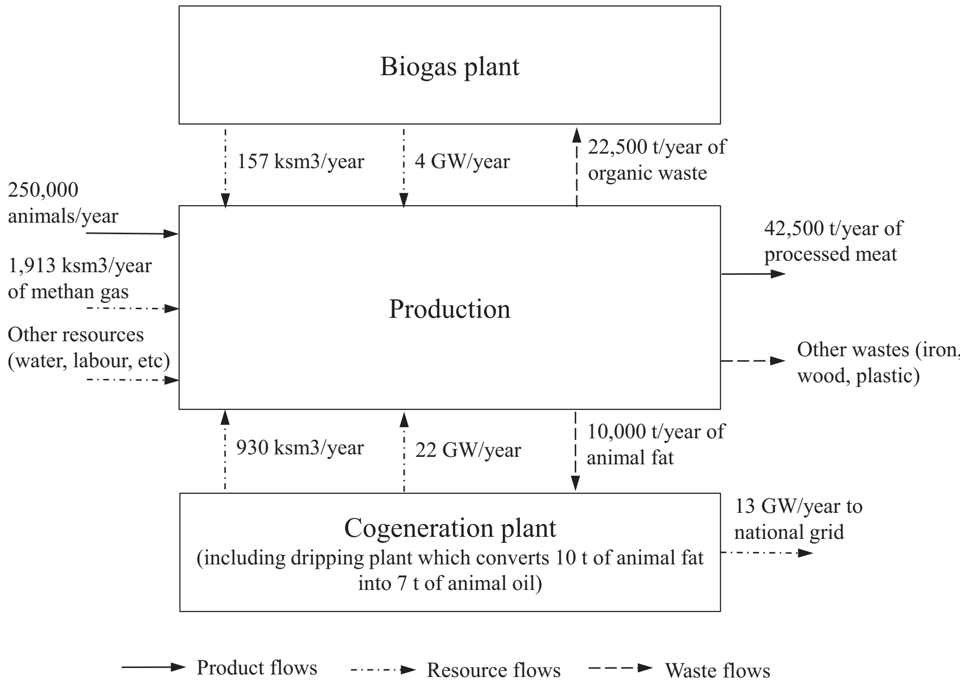

Fig. 5. New closed loops in meat production stage.

approximately 4 GW of electric energy per year.

The cogeneration plant of the company began the fat dripping activities produced by the two production plants. The animal fat is processed by a dripping plant to convert the fat into animal oil, which is a useful source in a cogeneration plant, to produce electric and thermal energy. The investment for the entire system was approximately €11 million.

The use of this cogeneration plant, which is characterised by two motors with an hourly capacity of 4600 kW and 5000 kW thermal power, allows an annual production of over 35 GW of electric energy and approximately 930,000 standard m^3 of methane gas for thermal energy.

As presented in Fig. 5, the entire required annual electricity of the production sites is approximately 26 GWh, which is covered by the electricity production of the biogas and cogeneration plants, with approximately 13 GWh each year sent to the national grid. Given that the thermal energy recovered by the two new plants is not sufficient to cover the company's total requirements, the remaining energy needed (approximately 1.9 million standard m^3) is supplied from a traditional external source. To summarise, the total energy generated by both plants accounts for 143% of the annual electricity demand of the production plant, while thermal recoveries cover 37% of the company's annual heat requirement. These are net values, so are depurated by the electric and thermal energy required by the operating of the plants.

Moreover, in addition to treatment in a single site, and the controlled processing of biomass waste and animal oil with energy that produces a high environmental impact, the initiative also results in a decrease of 15–20% of the volume of logistics transportation in and out of the plant in favour of resources (electric and thermal energy) that produce a low environmental impact with their transportation.

4.1. *Evaluation of 'closing-the-loop' sustainability*

The recovery of food waste for conversion into new resources for the supply chain is an interesting approach to closing the loop in the food supply chain. However, it is necessary to evaluate the sustainability of this model to understand the value of investment in a new actor of supply chain and the reduction of the environmental and social impact of the new closed loop.

According to Bloemhof et al. (2015), several key performance indicators have been introduced to assess the sustainability of the new configuration of the supply chain: the profitability indicator (PI) to estimate the economic value of the investment; the energy self-sufficiency indicator, as the environmental assessment; and qualitative evaluations of the social implications.

4.1.1. *Economic evaluation*

The profitability indicator (PI) is used to calculate the economic evaluation of investment in the new node of supply chain with the introduction of cogeneration and biogas plants (Caputo et al., 2003). The profitability indicator considers the total capital investment (TCI, €), the total operating cost (TOC, €/year) of the new plant, the revenue gained from the sale of energy (or the avoided energy-supply cost) (R_E, €/year), and the avoided disposal cost, including transportation and management costs (R_{AD}, €/year).

All the economic variables are connected to the productivity (Q) (processed animal per year) of the node of the supply chain where waste is generated through a parameter (w) (tonnes of animal fat/processed animal or tonnes of organic waste/processed animal), and introducing other energy parameters (CP_{EE} and CP_{ET}), the treated waste is converted into electric energy and thermal energy.

The unitary disposal cost is defined by c_D and it is estimated by our interviews and from data available in the scientific literature (Van Horne and Bondt, 2013; Marquer et al., 2015).

If assuming the revenue and operating costs are constant in time, the annual revenue can be modelled by the following formulas:

$$R_{AD}=c_D\cdot w\cdot Q \tag{1}$$

$$R_E=w\cdot Q\cdot CP_{EE}\cdot P_{EE}+w\cdot Q\cdot CP_{TE}\cdot P_{TE} \tag{2}$$

where P_{EE} is the average market price of produced electricity and P_{ET} is the average market price of methane gas.

Table 1
Economic evaluation of investment.

	Biogas plant	Cogeneration plant
Q	250,000 animals/year	
w	0.09 t of organic waste/animal	0.04 t of animal fat/animal
c_D	33.33 €/t	25.00 €/t
CP_{EE}	177.78 kWh/t	2200.00 kWh/t
CP_{TE}	6.98 sm^3/t	93 sm3/t
P_{EE}	0.10 €/kWh	
P_{TE}	1 €/sm^3	
R_{AD}	750,000€/year	250,000€/year
R_E	400,000€/year	22,000,000€/year
TCI	5,000,000€	11,000,000€
TOC	500,000€/year	1,100,000€/year
i	10%	
Life of plant	15 years	15 years
PI	1.23	1.57
PBT	10	6

The annual cash flow F_k of the investment can be defined per each year as

$$F_k = R_E + R_{AD} - TOC \tag{3}$$

According to this formulation, the profitability indicator (PI) is the ratio between the net present value of annual cash flow F_k and the total capital investment TCI:

$$PI = \frac{\frac{\sum_k F_k}{(1+i)^k}}{TCI} \tag{4}$$

where i is the annual interest rate and k refers to the k-th year of evaluation.

Moreover, it is possible to extend the analysis, including the calculation of the payback time (PBT) as the time required to cover the total capital investment to the annual cash flow.

In this case study, the PI has been calculated for the biogas and cogeneration plants, demonstrating the economic value of both investments (Table 1). As reported in Table 1, the investments in both plants are profitable. This estimation of profitability considers the operating life of the plants to be approximately 15 years, which means the payback time is acceptable for this investment.

Table 1 reveals that the main reason for the PI values is the large number of animals processed in the production stage can than then be used to produce a sufficient amount of waste to cover the initial investment.

The economic analysis shows the convenience of these investments and the payback time values are similar to the typical ones in these industrial sectors, where complex energy plants have an operation lifetime of more than 15–20 years.

4.1.2. *Environmental-impact assessment*

The environmental impact has been evaluated by using the energy self-sufficiency indicator. If a system produces the energy necessary for its own functioning, it does not require any other external source of energy typically produced from limited resources (e.g. fossil combustibles) that have higher environmental impacts.

This parameter indicates the ratio between the energy (EE_P or TE_P) produced by the new node introduced in the supply chain for recovery of energy by using waste and the energy required by the node of supply chain where the waste is produced (EE_R or TE_R):

$$ESS_{EE} = \frac{EE_P}{EE_R} = \frac{w \cdot Q \cdot CP_{EE}}{EE_R} \tag{5}$$

$$ESS_{TE} = \frac{TE_P}{TE_R} = \frac{w \cdot Q \cdot CP_{TE}}{TE_R} \tag{6}$$

These KPIs are related to every single node introduced in the supply chain dedicated to recovering electric and thermal energy (respectively) from waste processing. The total energy self-sufficiency $TESS_{EE}$ and $TESS_{TE}$ values will be the sum of previous indicators calculated for each kind of recovered energy.

In particular, the energy EE_P and TE_P have been calculated using the productivity parameters of the node (CP_{EE} and CP_{TE}), which indicate the unitary amount of energy produced by the node from a ton of recovery waste. Their values are typical of the recovery process and used plant.

As described before, the production stage (Fig. 5) consumes about 26 GW of electric energy and 3,000,000 sm^3 of methane gas as thermal energy per year. The biogas plant is able to process approximately 22,500 t of organic waste, producing about 4 GW of electric energy and 157,000 sm^3 of methane gas, each year. This new loop has an energy self-sufficiency indicator of 0.154 for electric energy ESS_{EE} and 0.082 for thermal energy ESS_{TE}.

The cogeneration plant recovers energy from 10,000 t of animal fat for an amount of 35 GW of electric energy and 930,000 sm^3 of methane gas per year. The new loop of the cogeneration plant has an energy self-sufficiency indicator of 1.346 for electric energy ESS_{EE} and 0.486 for thermal energy ESS_{TE}.

In considering the overall investment, the energy self-sufficiency KPIs are the sum of the previous ones. Given that the $TESS_{EE}$ is 1.5, the plant is completely self-sufficient in electric energy and surplus energy is sent to the national grid; however, the $TESS_{TE}$ is 0.568, which means it is necessary to use an external source to obtain the full required amount of thermal energy (Table 2).

Analyzing the values of these environmental KPIs, it can be noticed that the cogeneration plant is more energy self-sufficiency due to the higher productivity and efficiency. The main reason is the higher energy remaining in the processed animal waste compared to the one of organic waste.

4.1.3. *Evaluation of social implications*

Another relevant dimension of sustainability is the social dimension, which is traditionally connected to corporate social responsibility, which refers to actions made by corporations that are not required by law, but further the social good beyond the explicit, transactional interests of a firm (Ashby et al., 2012; Sarkis et al., 2011).

As discussed by Bloemhof et al. (2015), one of the most important indicators of the social dimension of sustainability is the employment possibilities. The introduction by the case-study company of the new industrial processes required new employees. The new initiatives required manual and direct employees as well as employees to fill managerial roles. In particular, new higher

Table 2
Environmental evaluation based on energy self-sufficiency.

	Biogas plant	Cogeneration plant
Q	250,000 animals/year	
EE_R	26 GW/year	
TE_R	1,913,000 sm^3 of methane gas/year	
w	0.09 t of organic waste/animal	0.04 t of animal fat/animal
CP_{EE}	177.78 kWh/t	2,200.00 kWh/t
CP_{TE}	6.98 sm^3/t	93 sm^3/t
EE_P	4 GW/year	35 GW/year
TE_P	157,000 sm^3	930,000 sm^3
ESS_{EE}	0.154	1.346
ESS_{TE}	0.082	0.486
$TESS_{EE}$	1.500	
$TESS_{TE}$	0.568	

skilled positions in all the levels of the organization have been created, from the operators responsible of more supervising activities of complex automatic system, to environmental and innovative industrial engineers and managers. If it appears that the new processes are costly in their early adoption, they could provide important environmental benefits, such as less resources waste, but also reduce costs associated with firm reputation in the social context where the company is doing business; surely social issues generate positive externalities that go beyond numerical and financial results.

While environmental sustainability emphasises the management of natural resources, social sustainability is concerned with the management of social resources. For example, practices related to internal human resources such as health and safety practices, practices related to the external population such as those affecting resource scarcity, and practices related to stakeholder participation such as those related to stakeholders' expectations of companies' decision making and macrosocial performance in socio-economic and socio-environmental issues (Ashby et al., 2012).

It is difficult to evaluate the social-dimension effect of the case-study company's introduction of the new loops. However, it can be concluded that these new loops allowed the creation of new working places, and that the company's promotion of practices such as recycling, reuse and resource conservation, positively contributed to various aspects of social sustainability.

5. Discussion

Our study shows a new sustainable model of Close Loop Supply Chain (CLSC) using and recovering waste from meat processing. In particular, we built a profitability index, an energy self-sufficiency parameter and a simple qualitative evaluation of social implications to evaluate the global sustainability opportunities to activate the new loops in a context of supply chain.

The profitability index shows the convenience of investments on these recovery plants and the payback time values are similar to the typical ones in these industrial sectors. Moreover, these energy plants allow reducing the global environmental impact of this food supply chain, thanks to their energy self-sufficiency. About the social implications, they have introduced new higher skilled positions in all the levels of the organization and they have improved firm reputation in the social context where the company is doing business.

Thus our study makes a significant contribution to gaining a deeper understanding of the role of production economics and its implications for the field of supply chain management by helping managers and practitioners to create a more efficient, lower cost and sustainable closed-loop systems (Li et al., 2014; Mirabella et al., 2014; Pagell and Shevchenko, 2014; Stindt and Sahamie, 2014). Particularly, we demonstrate how the dimensions of sustainability offer a new solution to addressing the issue of food waste, introducing new loops into the CLSC able to recover resources from the unavoidable waste. First, we demonstrate the cost opportunity of developing new loops at the production stage. Second, we measure the environmental impact to demonstrate how to activate a circular economy through a new CLSC business model that enables energy self-sufficiency using waste. Third, we introduce CLSC strategies as a way to improve the competitiveness of a firm in an era of resource scarcity. The example we present provides a clear explanation of how a business model can be dramatically changed to transform waste products into new and valuable products in the food-processing industry.

6. Conclusion and future research

We began this paper by stating the need for a new research business model for CLSC, particularly in industries for which it is becoming urgent to develop new practices and research frameworks such as food supply industry. Our literature review indicates that there is a lack of research on the food supply chain in relation to issues such as how inevitable waste can be avoided, the costs involved in recovering food waste back into the supply loop, and methods for recovering new resources from the food-production process. Our results provided an analysis of a case study derived from the food sector, in which, the produced wastes are reusing as a resource, avoiding the disposal of different materials by resources-recovery activities, as they could be returned to the main supply chain like valuable inputs and closing new loops.

Then, a more general approach to considering sustainability in its global definition can begin by using the following indicators: the profitability, payback time, total energy self-sufficiency and social evaluation. These indicators can be used to calculate a holistic sustainability indicator of a new loop. This holistic metric would provide a qualitative measurement of the sustainability of the investment. Several models can be used to calculate this indicator, particularly those models based on multi-criteria decision-making theory (Saaty, 2008), where all previous indicators are qualitatively evaluated and compared each other using different weights and criteria.

The extension of the concept of CLSC to include also the unavoidable waste flow and the resource recovery permits to open new research streams about global sustainable design and management of supply chains, such as sustainable production planning and control, sustainable inventory management and waste management, sustainable logistics network.

This research provides an additional building block in the process of developing new competitive models in this area. Moreover, it is interesting to note that new businesses will be created about the management of these flows with the introduction of new plants and new logistics providers. These are the main implications for the practitioners, responding to the necessity to tackle growing resource scarcity, with both more efficient production and logistics system and recovery the resources from all the outputs of the node of the supply chain. Other industries may have similar supply chain structures, but different contextual conditions. Therefore, further investigation is required to determine similarities and differences with our findings.

Future research should investigate other industries (e.g. the electronics, wood and heavy industries) from a CLSC perspective to enrich our model. Then future studies should focus on this profit indicator, varying the productivity of the supply chain to discover the effect this has on recovered-waste and energy-process performance. Moreover, future inquiry should use LCA to better understand how carbon dioxide emissions could be reduced by using new loops at the production stage. This would also be very important in measuring the effect of such a model extended to other supply chains, where the amount of waste is not enough to make convenient this new node in the CLSC. In this case, new solutions such as industrial symbiosis approaches can be helpful for the managers of different supply chain to make their network more sustainable. Finally, future research should develop a CLSC model using this first study included also social implications in an investment convenience model in a contest of unavoidable waste.

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