Krmac, Evelin (Ed.)

Book

Sustainable supply chain management

Reference: (2016). Sustainable supply chain management. Rijeka, Croatia : InTech.
doi:10.5772/61491.

Chapter 1

Economic Performance, Greenhouse Gas Emissions, Environmental Management, and Supply Chains in India: A Comparison with Japan

Hitoshi Hayami, Masao Nakamura and Kazushige Shimpo

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/62535

Abstract

Using input–output tables and data on wastes from the Japanese industrial sectors, we have provided empirical evidence that, in Japan environmental performance of their upstream suppliers contributes positively to the performance of their final product assembly firms or economic sectors. In this paper, we propose to investigate the same hypothesis for firms and other establishments in manufacturing and other sectors in India. Indian supplier firms that sell goods and services to their client assembler firms are not generally structured in the form of efficient supply chains as in advanced economies. So, the environmental performance of these suppliers may not have positive impacts on the performance of their assembler firms or economic sectors, but this is yet to be verified empirically.

In our study on Japan, we measured supply chains' environmental performance using various amounts of waste materials and also CO_2-equivalent greenhouse gas emissions generated in their production processes. Unfortunately, the only environmental performance data we have for the Indian economic sectors is their CO_2 emissions. So, we investigate the impact of CO_2 emissions by supplier firms on the economic performance of their assembler firms in India.

Keywords: greenhouse gas emissions, supply chains, environmental management, firm performance, India

1. Introduction

Limiting the amounts of industrial wastes generated in firms' manufacturing processes has been of policy interest in recent years. A type of waste of our interest in this paper is greenhouse gases (represented by the carbon dioxide equivalent below). Even though it is not harmful to human health, CO_2 is being regulated like toxic industrial wastes in many developed countries including Japan. More recently, the importance of limiting CO_2 emissions globally has been recognized by both developed and developing nations, and an international treaty to strengthen the former Kyoto protocol was signed in Paris.[1]

One of the topics of research interest, which has not received much empirical attention, is the extent to which CO_2 emissions, as an industrial waste, are generated along firms' supply chains. Although we see large corporations (e.g., 3M, Sony) promoting green procurement policies and claiming to use environment-friendly suppliers, we have little empirical evidence yet to suggest how such environmental management methods based on supply chains might benefit large downstream firms economically. We do not have much empirical evidence either about the impacts on final products of environmental management policies conducted by firms in their supply chains emerging in developing countries like India.

In this paper we present empirical estimates for the amounts of greenhouse gas (GHG) emissions generated by Indian manufacturing and other economic sectors, and their supply chains. (GHG emissions are measured in carbon dioxide (CO_2) equivalent in this paper.) We then estimate their contributions to firm performance measured in terms of value added. **Figures 1** and **2** show CO_2 emissions per person and per income, respectively, in India and

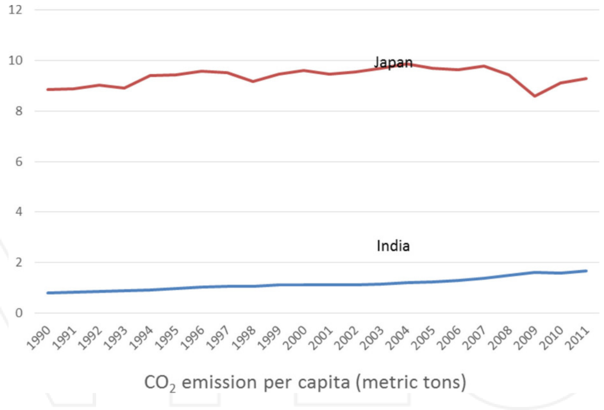


Figure 1. CO_2 emissions per capita: India and Japan, 1990–2011. Source: Prepared by the authors using figures in [2–5].

[1] The 2015 United Nations Climate Change Conference, held in Paris, France, from November to December 2015 was the 21st yearly session of the Conference of the Parties (COP) to the 1992 United Nations Framework Convention on Climate Change (UNFCCC) and the 11th session of the Meeting of the Parties to the 1997 Kyoto Protocol. The Paris Agreement, a global agreement on the reduction of climate change, the text of which represented a consensus of the representatives of the 196 parties attending it, was signed. It needs to be ratified to become a world treaty [1].

Japan over time. We see from these figures that while Japan emits more CO_2 than India per capita, Japan generates less CO_2 emissions per dollar than India does.

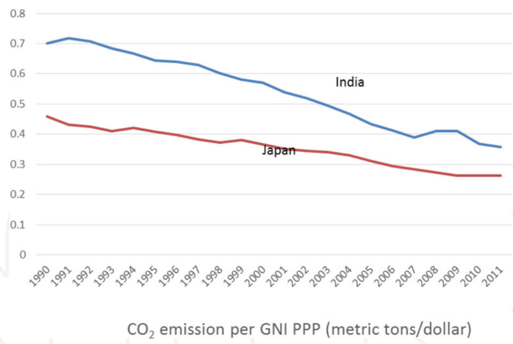


Figure 2. CO_2 emissions per GNI (gross national income): India and Japan, 1990–2011. Source: Prepared by the authors using figures in [2–5].

The rest of the paper is organized as follows. After a brief review of earlier studies in Section 2, we discuss our method and approach toward the analysis of the generation of industrial waste (CO_2 emissions here) by supply chains in Section 3. Our data are briefly introduced in Section 4. We show and analyze certain patterns that are found in the generation of CO_2 emissions in Indian and Japanese industries in Sections 5 and 6. Section 6 presents our empirical results that relate the value added to the generation of wastes by downstream and upstream firms. Section 7 concludes.

2. Literature

There are relatively few research studies that use nations' input–output (I–O) tables as the data source for analyzing the relationships between supply chains and firms' environmental performance. Hayami et al. [6] present a framework in which I–O tables can be used for analyzing the effects, at the sector level, of the environmental management performance of firms in supply chains on their downstream assembly firms' performance. They present references on the literature that discusses many aspects of environmental management at upstream supply chains as related to their downstream customer firms [7,8]. Discussions on supply chains in India are also found [9–11]. Details of I–O analysis and applications to the Indian economy and environmental management are found in papers contained in [12].

3. Our approach to estimating output and waste along the stages of a supply chain

As noted earlier, certain downstream producers in developed countries are beginning to practice "green procurement," by which upstream suppliers with greener production processes become the preferred suppliers of their downstream customer firms. For example, Cisco, NEC, Sony, and Toshiba discuss their corporate green procurement guidelines in [13–16]. We apply this notion to India and investigate empirically the extent to which the same notion holds in India.

In order for the government to evaluate the potential benefits (i.e., the greening) of upstream firm production processes resulting from promoting downstream instruments, it is essential that we estimate relationships that describe the generation of waste materials at both upstream and downstream firms in a national economy. However, to our knowledge, only Hayami et al. present an empirical framework to achieve this objective using available data [6]. They also present an empirical model that allows us to estimate downstream firms' benefits of reduction of their suppliers' environmental wastes.

We apply the above model to India and derive some preliminary empirical estimates that evaluate the relative importance of the waste materials generated along the supply chain. Our findings in this chapter provide complementary evidence to the importance of environmental management in supply chains reported, for example, for individual firms, obtained using survey data and methodologies different from ours [8,17].[2],[3]

3.1. Estimation of output along a supply chain

Our methodology is based on the input–output (I–O) analysis originally developed by Leontief [19,20]. (Applications of the I–O analysis to waste management and other environmental issues are found, for example, in [12,21–23]. Additional uses of input–output analysis in environmental management are found in [24]. We divide an economy into industrial and other economic sectors where production of goods and services takes place. We define I–O technical coefficients a_{ij} (i,j = 1,2,…,n) to be the amount of input from sector i per unit amount of output from sector j. To ensure positive output values, it is customary to assume the Hawkins–Simon condition [25] that a_{ij} lie between 0 and 1 and their column sums are less than 1.

Suppose x_j denotes the output from sector j. Then a_{ij} are estimated as follows:

$$a_{ij} = \left(X_{ij} / x_j \right),$$

where X_{ij} denotes the amount of input from sector i that is required for the production of x_j. Using supply chain terms, we say a_{ij} connect downstream output from sector j to its immediate predecessor upstream input from sector i.

We denote by A an $n \times n$ matrix with elements a_{ij}, and by x an $n \times 1$ vector in which each component x_j represents domestic production (output) of sector j (j = 1,2,..,n). We also denote

[2] A questionnaire-based survey across 124 companies from eight industrial sectors in Taiwan was used [17] in one study, while survey data on a sample of 122 firms drawn from electronics manufacturers listed on the database of the Taiwan Stock Exchange Corporation (TWSE) market and the Gre Tai Securities Market (GTSM) in Taiwan was used in another study [8].

[3] See [18] where Indian manufacturers' approaches to green supply chain management are explained.

http://dx.doi.org/10.5772/62535

by f_i the final downstream demand for sector i. We denote by f the corresponding $n \times 1$ final downstream demand vector. For example, $f_i = 1$ means a unit final downstream demand for output from sector i. (For simplicity, we ignore the impacts of international trade.)

In order to produce the final downstream demand f, the total amount of input required from sector i in the immediate predecessor stage (denoted by $k = 1$) is given by

$$x^{(k=1)} = Af.$$

$x^{(1)}$ is also interpreted to be the indirect demand for the previous stage (k = 1) production process, which is induced by final demand f, because without the production of $x^{(1)}$, the final demand cannot be met. In order to produce $x^{(1)}$, the total amount of input required from sector i in the immediate predecessor stage (denoted by $k = 2$) in the supply chain is given by the ith element of the following vector:

$$x^{(2)} = Ax^{(1)} = A^2 f.$$

Generally, we can trace production activities along the supply chain backward, starting from the final demand, and we get

$$x^{(k)} = Ax^{(k-1)} = A^k f, k = 1,2,....$$

We call $x^{(k)}$ the kth stage indirect effect of final demand f (k = 1,2,…) in the supply chain.

In order to be able to produce final demand f, the following total indirect output must be produced:

$$x^{(indirect)} = Af + A^2 f + ... + A^k f + ... = A(I - A)^{-1} f,$$

where $(I - A)^{-1}$ is the Leontief inverse matrix which exists provided that the a_{ij} satisfy the Hawkins–Simon condition given above.

We have shown that our input–output analysis identifies the successive upstream production processes that are followed by the average supply chain for the final demand vector f. This is summarized as follows. The input–output analysis describes all economic activities of the average supply chain in a national economy by following input–output transactions for all goods and services. The analysis typically starts from the final stage of downstream demand as shown above and moves backward by backtracking all predecessor upstream stages of production.

In this paper, we consider CO_2 (defined here to be the combined greenhouse gases measured in CO_2 equivalent) as a waste material associated with industrial production activities.

3.2. Graphical representation of connectedness of I–O sectors

Different sectors tend to be more connected in modern developed economies than in developing economies. This is because, in a modern economy, unproductive sectors will become more productive, with inputs from more productive sectors to survive. In addition, primary sectors and supplier sectors of manufacturing are connected to assembly sectors of manufacturing in a functional and efficient manner in supply chains. These functional connections are often missing in developing economies. **Figures 3–5** show the degrees of 35 I–O sectors' connectedness to each other in India and Japan. These 35 sectors are as follows:

No.	Name
1	Agriculture, Hunting, Forestry, and Fishing
2	Mining and Quarrying
3	Food, Beverages, and Tobacco
4	Textiles and Textile Products
5	Leather and Footwear
6	Wood, and Products of Wood and Cork
7	Pulp, Paper, Printing, and Publishing
8	Coke, Refined Petroleum, and Nuclear Fuel
9	Chemicals and Chemical Products
10	Rubber and Plastics
11	Other Nonmetallic Minerals
12	Basic Metals and Fabricated Metals
13	Machinery, NEC
14	Electrical and Optical Equipment
15	Transport Equipment
16	Manufacturing, NEC; Recycling
17	Electricity, Gas, and Water Supply
18	Construction
19	Sales, Maintenance, and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel
20	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles
21	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods
22	Hotels and Restaurants
23	Inland Transport
24	Water Transport
25	Air Transport
26	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
27	Posts and Telecommunications
28	Financial Intermediation
29	Real Estate Activities
30	Renting of m&eq and Other Business Activities
31	Public Administration and Defense; Compulsory Social Security
32	Education
33	Health and Social Work
34	Other Community, Social, and Personal Services
35	Private Households with Employed Persons

Source: [5,32].

List of 35 aggregate I–O sectors used in **Figures 3–5**

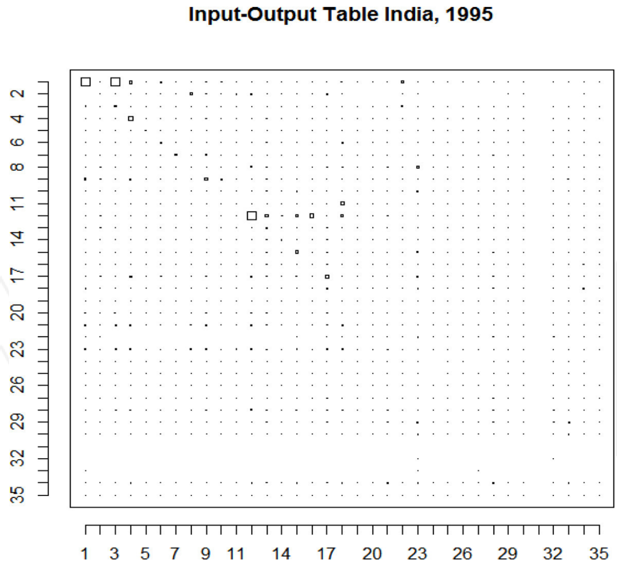


Figure 3. Degrees of connectedness of 35 I–O sectors: India, 1995. Note: The size of each square represents the amount of relevant input for the cell measured in terms of US $million dollars at current price. Numbers on vertical and horizontal axes represent 35 I–O sectors for India and Japan defined in the text.

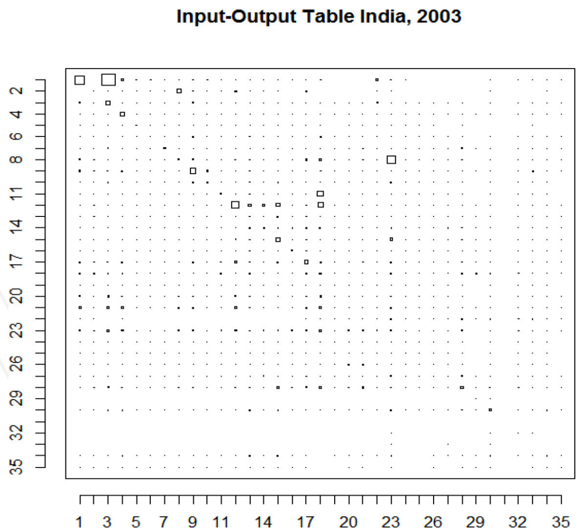


Figure 4. Degrees of connectedness of 35 I–O sectors: India, 2003. Note: The size of each square represents the amount of relevant input for the cell measured in terms of US $million dollars at current price. Numbers on vertical and horizontal axes represent 35 I–O sectors for India and Japan defined in the text.

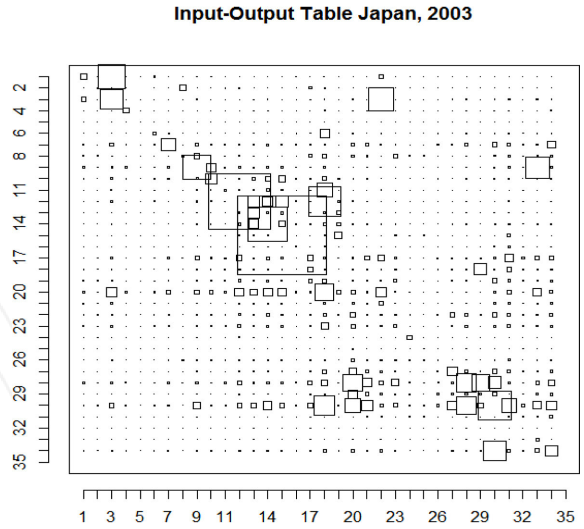


Figure 5. Degrees of connectedness of 35 I–O sectors: Japan, 2003. Note: The size of each square represents the amount of relevant input for the cell measured in terms of US $million dollars at current price. Numbers on vertical and horizontal axes represent 35 I–O sectors for India and Japan defined in the text.

Intuitively speaking, **Figures 3–5** show the degrees of connectedness between sectors in terms of economic transactions. For example, sectors whose transactions are mostly within themselves are depicted as single dots. On the other hand, if two different sectors have more transactions with each other, then those two sectors are connected by a box. Multiple sectors with transactions, such as sectors that define supply chains, are shown with larger boxes containing them. As expected, **Figures 3** and **4** show that sectors of the Indian economy are not much connected to each other, though there are considerably more connectedness observed during 2003 than during 1995. This implies that there are increasingly more supply chain type relationships emerging in the Indian economy in recent years. The Japanese economy has developed well-defined supply chain based relationships among sectors in many industries [6]. This is clearly observed in **Figure 5**. We speculate from these figures, for example, that environmental management performance of upstream suppliers affect the performance of downstream firms much more in Japan than in India.

3.3. Estimation of wastes along a supply chain[4]

In the I–O analysis presented in Section 3.1, it is customary to include output which has economic value.[5] It is also customary to assume that industrial waste has no economic value in the form it is generated. For these reasons, industrial wastes are not included in our analysis

[4] Waste here denotes CO_2, but our formulation applies to other waste materials as well.

[5] In reality, most waste materials have positive or negative economic value. For example, CO_2 has economic value in the GHG market currently [26].

http://dx.doi.org/10.5772/62535

in Section 3.1.[6] We treat waste materials separately here. Suppose we have estimated $E1_j$, the amount of waste generated per unit of output produced in sector j (j = 1,2,..,n). We denote by E the corresponding $n \times n$ diagonal matrix with $E1_j$ in the jth diagonal position. Then the amounts of waste produced by the output of sector j along the successive stages of a supply chain are given as follows:

Denote by w_j the amount of waste generated in sector j, and denote by w an $n \times 1$ vector consisting of w_j (j = 1,2,..,n).

Then in the final stage, stage 0 (k = 0), of a supply chain, the demand is f, and the waste generated is

$w^{(0)} = EA^0 f = Ef$, which is the waste generated from assembly operations of final output f.

In the immediate predecessor upstream stage, stage 1 (k = 1), of the supply chain, the amount of waste generated (called indirect output for stage 1) is

$$w^{(1)} = EAx^{(0)} = EAf.$$

Similarly, we can derive the amount of waste generated along the upstream stages (k = 2, 3, …,) of the supply chain as follows:

$$w^{(k)} = EAx^{(k-1)} = A^k f, k = 2, 3, \ldots$$

This is shown in the last row of **Table 1**.

Upstream	**Stages of a supply chain (→ → → closer to the final demand → → →)**					**Downstream: final stage of a supply chain (final demand)**
Total indirect output and waste in upstream stages (k = 1,2,…)	← ← ←	Indirect output for the m-th stage in upstream (k = m)	← ← ←	Indirect output for the second stage in upstream (k = 2)	Indirect output for the first stage in upstream (k = 1)	
Production output along the stages of a supply chain						
$x^{(\text{indirect})} = Af + A^2 f +$	← ← ←	$x^{(n)} = Ax^{(n-1)} = A^n f$	← ← ←	$x^{(2)} = Ax^{(1)} = A^2 f$	$x^{(1)} = Af$	f (direct output)

[6] Actual statistical treatment of industrial waste materials depends on the nature of each waste material, which we will not discuss here.

Upstream	Stages of a supply chain (→ → → closer to the final demand → → →)					Downstream: final stage of a supply chain (final demand)
$\ldots + A^k f + \ldots = A(I - A)^{-1} f$						
Waste output generated along the stages of a supply chain						
$w^{(\text{indirect})} = AEf + A^2Ef + \ldots. + A^kEf + \ldots = A(I - A)^{-1}Ef$	← ← ←	$w^{(n)} = A^nE$	← ← ←	$w^{(2)} = A^2Ef$	$w^{(1)} = AEf$	Ef (direct waste generated)

Table 1. Production and waste output along the stages of a supply chain.

3.4. Output along a firm-specific supply chain and statistically obtained average output along the average supply chain

We do not have data on individual firm-specific supply chains that expand from downstream to upstream stages of production. However, element a_{ij} of input–output matrix $A = \{a_{ij}, i, j = 1,2,..,n\}$ is in fact the statistically estimated average fraction of output of sector i that goes to sector j. This statistical method of obtaining matrix A (called the commodity flow method) thus allocates input X_{ij} from the data of total output x_j [27], that is, a_{ij} connects downstream sector j to its immediate upstream sector i statistically. We have used this property of matrix A to obtain the average production and waste output along the stages of the average supply chain, $x^{(k)}$ and $w^{(k)}$, $k = 1,2,\ldots$, given downstream demand vector f. If we had data on production and waste output for the stages of all firm-specific supply chains for given f, then our I–O based estimates give the first-order approximation to the average output of the quantities for all such firm-specific supply chains. (The first-order approximation arises because of the linearity of a_{ij} which defines the I–O matrix A.)

4. Data

4.1. Input–output matrix

As we have noted in Section 3.1, our estimation methodology uses an $n \times n$ matrix A consisting of

I–O technical coefficients a_{ij} $(i,j = 1,2,\ldots,n)$, where n is the number of economic sectors being considered. Since 1973, estimated values for a_{ij} $(i,j = 1,2,\ldots,n)$ are published every 5 years as I–O tables by the Government of India [9,28]. In this paper, we primarily use the Indian I–O tables for the years 1998–1999 and 2003–2004, with 130 sectors ($n = 130$). The I–O sectors consist of 37 primary sectors, 68 secondary (manufacturing) sectors, and 25 service sectors.

In addition to the I–O matrix $A = \{a_{ij}\ (i,j = 1,2,\ldots,n)\}$, the Indian I–O table includes additional information on relevant economic quantities for each of the 130 sectors including final demand f for the Indian economy (see Appendix A1).

4.2. Waste and y-products surveys, and I–O matrix A

The environmental input–output table that we use here, based on greenhouse gas emission estimates (GOI, 2010), I–O table, material table, calorific table, combustion ratio table, and other data, was constructed by [9,12,29,30].

4.3. Calculating the amounts of waste materials

Using application of the input-output analysis described above, we used the estimated quantities of CO_2 for each of the 130 Indian I–O sectors, which we use in our regression analyses. We also used value-added estimations for each of these I–O sectors.

Using I–O analysis, we estimated the amounts of CO_2 generated per unit output for each of the 130 I–O sectors.

We are interested in studying the behavior of CO_2 emissions in firms' decision processes. In this paper, we denote by CO_2 emissions the total emissions in carbon dioxide equivalents of all greenhouse gases. CO_2 has certain characteristics in common in terms of their implications for firms' own economic incentives and government regulations.[7] For example, CO_2 emissions, like some other nontoxic wastes, are harmless to human health. On the other hand, CO_2 emissions, like some other waste materials, may also mean firms' excessive use of costly inputs (fossil fuels in case of CO_2). (Note that CO_2 emissions and fossil energy use are highly correlated [32, 33].

5. Waste output along supply chains: example of an auto industry

One topic of research interest is to evaluate the relationships that might exist between downstream and upstream firms in terms of their waste behavior. Input–output analysis identifies statistically average economic relationships that exist between upstream and downstream firms. It is then possible to use input–output analysis also to find the average amounts of wastes that are generated by upstream firms in supply chains in response to production activities for the final products of downstream firms.

5.1. Example of an auto industry example

Table 1 illustrates how our production of output and waste takes place along a supply chain starting from the final downstream demand. By tracing backward, final assembly plant

[7] In addition to direct regulations of various types pertinent to toxic wastes and CO_2, indirect regulations often dictate firms' management of some of nontoxic wastes as well. For example, firms' nontoxic wastes are sometimes indirectly regulated in terms of the amounts of such waste materials that firms are allowed to bring to landfills and other waste processing facilities. Some nontoxic wastes have commercial value as well.

receives inputs from suppliers in upstream stage 1, who in turn receive their inputs from suppliers in upstream stage 2. As we have shown, I–O analysis allows us to estimate inputs between two successive stages of production along a supply chain.

5.2. A numerical example, India and Japan

This example illustrates the supply chain effects in the propagation of waste (CO_2) generation along supply chains in India and Japan.

	Amounts generated (tons)	Cumulative amounts (tons)	Ratio to total
	CO_2		
Direct	0.107625	0.107625	0.020439
Indirect (first stage)	0.706568	0.814193	0.15462
Indirect (second stage)	1.205888	2.020081	0.383625
Indirect (third stage)	1.151894	3.171974	0.602376
Indirect (fourth stage)	0.896974	4.068948	0.772717
Total (all stages)	5.26577	5.265770	1

Source: Authors' calculations.

Table 2. Supply chain effects, auto industry in Japan: CO_2 emissions generated by production of one passenger car with a 2000 cc engine.

	Amounts generated (tons)	Cumulative amounts (tons)	Ratio to total
	CO_2		
Direct	0.1346605	0.1346605	0.03002061
Indirect (first stage)	1.919879	2.054539	0.4580298
Indirect (second stage)	1.238733	3.293272	0.7341874
Indirect (third stage)	0.6406156	3.933888	0.8770033
Indirect (fourth stage)	0.3034687	4.237357	0.9446573
Total (all stages)	4.485602	4.485602	1

Source: Authors' calculations.

Table 3. Supply chain effects, auto industry in India: CO_2 emissions generated by production of one passenger car with a 2000 cc equivalent engine.

Tables 2 and **3** show how much CO_2 emissions occur along the auto supply chains in producing passenger cars with certain characteristics: median size cars in India and cars with 2000 cc engines in Japan.

We see from **Table 2** that firms along the auto supply chain in Japan generate 5.26577 tons of CO_2 emissions, but only 2% of this amount is generated by the final assembler firms. The remaining 98% of CO_2 emissions are generated by suppliers and other upstream firms in the supply chain. In comparison, the corresponding figures for India are: 4.485602 tons of total CO_2 emissions per car are generated in total, of which 3% is generated by the final assembler firms and the rest (97%) of the emissions are generated by suppliers (**Table 3**). This similarity in the patterns of CO_2 emissions along auto supply chains between India and Japan suggests that production technology of autos is reasonably standardized, perhaps due to the fact that many auto plants in India are owned and operated to a large extent by Western automakers. Another noteworthy point is that total CO_2 emissions per car produced is somewhat lower in India than in Japan. This difference occurs in part because of the sizes of passenger cars considered here that are different between India and Japan, and also in part because of the difference between India and Japan in the amounts of CO_2 emissions induced by imported car parts. The use of more imported parts implies lower levels of domestic CO_2 emissions, which is the case for India. For passenger car production, this ratio is 0.05846 for India and 0.02316 for Japan.

Based on the results given in **Tables 2** and **3**, we conclude that government environmental regulations about greenhouse gas emissions need to include not only the final auto producers but also many upstream suppliers, in order to be effective.

We noted that our results in **Tables 2** and **3** are consistent with the possibility that downstream firms might be able to upload the processing of CO_2 in particular to their upstream suppliers, while processing relatively large amounts of nonenergy-intensive tasks themselves in-house. This could easily happen in practice, since processing energy-intensive tasks is generally expensive.

We also note that this hierarchical structure of processing of the waste materials emitted by firms in assembly-based industries is likely to be typical. This is because of the nature of the types of assembly-based industries, which are most efficiently done by streamlining their supply chains so that assembly operations come last. In addition, assembly firms are generally more powerful than suppliers in their supply chains and hence have the most bargaining power.

Detailed processes of generation of CO_2 emissions by upstream and downstream firms are presented in **Tables 4** and **5**.

Auto: CO_2	**Tons per passenger car (2000 cc equivalent)**										
Direct		**First indirect**		**Second indirect**		**3rd indirect**		**4th indirect**		**Total Generation**	
Passenger motor cars	0.1076	Electricity	0.1722	Electricity	0.5514	Electricity	0.3349	Pig iron	0.3230	Electricity	1.2982
		Motor vehicle parts and accessories	0.1013	Cast and forged materials (iron)	0.1115	Pig iron	0.1840	Electricity	0.1315	Pig iron	1.0449
		Internal combustion engines for motor vehicles and parts	0.0663	Road freight transport	0.0474	Private power generation	0.1040	Private power generation	0.1290	Private power generation	0.4804
		Private power generation	0.0601	Miscellaneous ceramic, stone, and clay products	0.0372	Coal products	0.0927	Coal products	0.0831	Coal products	0.3476
		Road freight transport	0.0599	Private power generation	0.0349	Self-transport by private cars (passengers) P	0.0393	Crude steel (converters)	0.0319	Road freight transport	0.1471
		Sheet glass and safety glass	0.0598	Nonferrous metal castings and forgings	0.0345	Crude steel (converters)	0.0287	Self-transport by private cars (passengers) P	0.0185	Cast and forged materials (iron)	0.1211
		Research and development (intra-enterprise)	0.0282	Self-transport by private cars (passengers) P	0.0268	Miscellaneous ceramic, stone and clay products	0.0268	Petroleum refinery products (inc. greases)	0.0162	Self-transport by private cars (passengers) P	0.1082
		Motor vehicle bodies	0.0209	Research and development (intra-enterprise)	0.0260	Hot rolled steel	0.0244	Paper	0.0144	Motor vehicle parts and accessories	0.1080
		Coastal and inland water transport	0.0165	Synthetic rubber	0.0225	Self-transport by private cars (freight) P	0.0225	Petrochemical basic products	0.0132	Passenger motor cars	0.1076
		Tires and inner tubes	0.0158	Hot rolled steel	0.0212	Road freight transport	0.0209	Hot rolled steel	0.0120	Crude steel (converters)	0.0910
		Plastic products	0.0114	Coated steel	0.0207	Cold-finished steel	0.0202	Self-transport by private cars (freight) P	0.0107	Miscellaneous ceramic, stone and clay products	0.0895
		Waste management services (private)	0.0106	Thermoplastics resins	0.0190	Paper	0.0193	Road freight transport	0.0095	Petroleum refinery products (inc. greases)	0.0695
		Self-transport by private cars (passengers) *P*	0.0093	Cold-finished steel	0.0158	Synthetic rubber	0.0166	Aliphatic intermediates	0.0089	Hot rolled steel	0.0689
		Cold-finished steel	0.0093	Petroleumrefinery products (inc. greases)	0.0154	Thermoplastics resins	0.0161	Miscellaneous ceramic, stone and clay products	0.0087	Internal combustion engines for motor vehicles and parts	0.0687
		Hot rolled steel	0.0076	Plastic products	0.0153	Petroleum refinery products (inc. greases)	0.0148	Coastal and inland water transport	0.0055	Research and development (intra-enterprise)	0.0638
		Miscellaneous ceramic, stone, and clay products	0.0071	Other rubber products	0.0131	Aliphatic intermediates	0.0135	Pulp	0.0051	Sheet glass and safety glass	0.0605
		Self-transport by private cars (freight) *P*	0.0049	Coastal and inland water transport	0.0129	Petrochemical basic products	0.0124	Cyclic intermediates	0.0048	Self-transport by private cars (freight) P	0.0597

Auto: CO_2	Tons per passenger car (2000 cc equivalent)										
Direct		First indirect		Second indirect		Third indirect		Fourth indirect		Total generation	
		Electrical equipment for internal combustion engines	0.0046	Self-transport by private cars (freight) *P*	0.0128	Coastal and inland water transport	0.0091	Paperboard	0.0042	Paper	0.0537
		Electric bulbs	0.0044	Coal products	0.0124	Cast and forged materials (iron)	0.0080	Waste management services (private)	0.0041	Cold-finished steel	0.0509
		Petroleum refinery products (inc. greases)	0.0037	Cast and forged steel	0.0115	Air transport	0.0071	Cold-finished steel	0.0039	Coastal and inland water transport	0.0499
		Air transport	0.0032	Other final chemical products	0.0104	Waste management services (private)	0.0069	Industrial soda chemicals	0.0036	Synthetic rubber	0.0424
		Abrasive	0.0030	Wholesale trade	0.0100	Research and development (intra-enterprise)	0.0065	Crude steel (electric furnaces)	0.0035	Thermoplastics resins	0.0392
		Advertising services	0.0029	Crude steel (converters)	0.0099	Cyclic intermediates	0.0063	Air transport	0.0031	Nonferrous metal castings and forgings	0.0385
		Other rubber products	0.0024	Paper	0.0073	Aluminum (inc. regenerated aluminum)	0.0062	Ferro alloys	0.0031	Petrochemical basic products	0.0327
		Coated steel	0.0024	Air transport	0.0066	Other industrial organic chemicals	0.0050	Cement	0.0029	Aliphatic intermediates	0.0307
		Wholesale trade	0.0023	Motor vehicle parts and accessories	0.0061	Other resins	0.0044	Thermoplastics resins	0.0028	Plastic products	0.0305
		Harbor transport service	0.0023	Steel pipes and tubes	0.0056	Hired car and taxi transport	0.0038	Petrochemical aromatic products (except synthetic resin)	0.0024	Waste management services (private)	0.0300
		Sewage disposal	0.0020	Inorganic pigment	0.0053	Coated steel	0.0037	Synthetic rubber	0.0022	Coated steel	0.0282
		Hired car and taxi transport	0.0019	Waste management services (private)	0.0050	Industrial soda chemicals	0.0037	Research and development (intra-enterprise)	0.0019	Air transport	0.0226
		Coal products	0.0018	Electrical equipment for internal combustion engines	0.0050	Crude steel (electric furnaces)	0.0036	Other industrial organic chemicals	0.0018	Motor vehicle bodies	0.0219
30 sectors Subtotal	0.6983		1.1338		1.1338		1.0656		0.8655		4.8061
Subtotal	0.1076		0.7066		1.2059		1.1519		0.8970		5.2658
Cumulative	0.1076		0.8142		2.0201		3.1720		4.0689		1.1968
Cumulative/Grand total	0.0204		0.1546		0.3836		0.6024		0.7727		1.0000

Table 4. Generation of CO_2 by supply chains per production of a passenger car with a 2000 cc engine: Japan.

Auto: CO2	Tons per passenger car (2000 cc equivalent)										
Direct		First stage indirect		Second stage indirect		Third stage indirect		Fourth stage indirect		Total generation	
Motor	0.1347	Electricity	0.8633	Electricity	0.7269	Electricity	0.4384	Electricity	0.2209	Electricity	
Vehicles		Iron steel and ferroalloys	0.8470	Iron steel and ferroalloys	0.2832	Iron steel and ferroalloys	0.0799	Iron steel and ferroalloys	0.0266	Iron steel and ferroalloys	1.2545
		Iron and steel casting and forging	0.0405	Petroleum products	0.0456	Petroleum products	0.0296	Petroleum products	0.0152	Motor vehicles	0.1489
		Land transport including pipelines	0.0388	Nonferrous basic metals	0.0384	Nonferrous basic metals	0.0152	Cement	0.0063	Petroleum products	0.1239
		Petroleum products	0.0205	Iron and steel casting and forging	0.0305	Land transport including pipelines	0.0126	Land transport including pipelines	0.0057	Iron and steel casting and forging	0.0872
		Synthetic fibers and resin	0.0146	Land transport including pipelines	0.0254	Cement	0.0113	Nonferrous basic metals	0.0051	Land transport including pipelines	0.0872
		Nonferrous basic metals	0.0141	Synthetic fibers and resin	0.0174	Iron and steel casting and forging	0.0109	Iron and steel casting and forging	0.0034	Nonferrous basic metals	0.0759
		Motor vehicles	0.0125	Coal and lignite	0.0090	Synthetic fibers and resin	0.0072	Synthetic fibers and resin	0.0029	Synthetic fibers and resin	0.0442
		Air transport	0.0119	Cement	0.0077	Coal and lignite	0.0050	Paper, paper products, and newsprint	0.0022	Cement	0.0313
		Other nonmetallic mineral products	0.0071	Paper, paper products, and newsprint	0.0060	Paper, paper products, and newsprint	0.0041	Coal and lignite	0.0021	Paper, paper products, and newsprint	0.0186
		Trade	0.0055	Railway transport services	0.0055	Inorganic heavy chemicals	0.0031	Inorganic heavy chemicals	0.0016	Coal and lignite	0.0182
		Insurance	0.0046	Other nonmetallic mineral products	0.0052	Railway transport services	0.0031	Railway transport services	0.0014	Air transport	0.0180
		Paper, paper products, and newsprint	0.0043	Inorganic heavy chemicals	0.0049	Natural gas	0.0025	Other nonmetallic mineral products	0.0012	Other nonmetallic mineral products	0.0169
		Hand tools and hardware	0.0041	Natural gas	0.0045	Other nonmetallic mineral products	0.0024	Natural gas	0.0012	Railway transport services	0.0150
		Railway transport services	0.0040	Trade	0.0037	Trade	0.0018	Other chemicals	0.0009	Inorganic heavy chemicals	0.0128
		Rubber products	0.0040	Air transport	0.0036	Other chemicals	0.0017	Trade	0.0008	Trade	0.0123
		Plastic products	0.0038	Coal products	0.0023	Air transport	0.0015	Fertilizers	0.0007	Natural gas	0.0092
		Other chemicals	0.0034	Other chemicals	0.0021	Coal products	0.0013	Crude oil	0.0006	Other chemicals	0.0087
		Banking	0.0033	Plastic products	0.0019	Crude oil	0.0010	Air transport	0.0006	Plastic products	0.0070
		Inorganic heavy chemicals	0.0020	Motor vehicles	0.0014	Fertilizers	0.0009	Coal products	0.0005	Insurance	0.0066
		Other transport equipment	0.0018	Banking	0.0013	Plastic products	0.0008	Plastic products	0.0003	Banking	0.0057
		Other nonelectrical machinery	0.0017	Insurance	0.0013	Construction	0.0006	Construction	0.0003	Rubber products	0.0053
		Miscellaneous metal products	0.0007	Construction	0.0010	Banking	0.0006	Banking	0.0002	Hand tools and hardware	0.0048
		Art silk and synthetic fiber textiles	0.0006	Iron ore	0.0009	Insurance	0.0004	Structural clay products	0.0002	Coal products	0.0045
		Communication	0.0006	Rubber products	0.0008	Structural clay products	0.0004	Insurance	0.0002	Fertilizers	0.0028
		Coal and lignite	0.0005	Communication	0.0007	Water transport	0.0004	Water transport	0.0002	Crude oil	0.0027
		Construction	0.0004	Hand tools and hardware	0.0006	Iron ore	0.0003	Other oil seeds	0.0002	Construction	0.0025
		Electronic equipments including TV	0.0004	Water transport	0.0006	Communication	0.0003	Communication	0.0001	Other nonelectrical machinery	0.0022
		Jute hemp and mesta textiles	0.0004	Miscellaneous manufacturing	0.0006	Storage and warehousing	0.0003	Storage and warehousing	0.0001	Other transport equipment	0.0021
		Community, social, and personal services	0.0003	Miscellaneous metal products	0.0005	Rubber products	0.0003	Jute hemp and mesta textiles	0.0001	Communication	0.0018
30 sectors subtotal	0.1347		1.9167		1.2333		0.6376		0.3020		4.4656
Subtotal	0.1347		1.9199		1.2387		0.6406		0.3035		4.4856
Cumulative	0.1347		2.0545		3.2933		3.9339		4.2374		4.4856
Cumulative/Grand total	0.0300		0.4580		0.7342		0.8770		0.9447		1.0000

Source: Authors' calculations.

Table 5. Generation of CO_2 by supply chains per production of a passenger car with a medium size engine: India.

Tables 4 and **5** show the amounts of CO_2 emissions generated by the final auto producers, as well as their suppliers and other upstream firms, in producing a passenger car with a 2000 cc engine. These tables provide details on the amounts of waste materials generated by each of the industrial sectors, based on which figures reported in **Tables 2** and **3** were obtained.

http://dx.doi.org/10.5772/62535

6. Estimating the contributions of direct and indirect CO_2 emissions

6.1. Relative contributions of direct and indirect CO_2 emissions to the total sectorial emissions

It is intuitively clear that final output (called output from downstream sectors), whether assembled manufactured products, or output from primary sectors such as mining and agriculture, uses much output produced in their predecessor sectors including suppliers (upstream sectors). It is then likely that the total emissions attributable to any final product (e.g., a passenger car) consist of significant amounts of indirect emissions from upstream sectors and direct emissions which are emitted from the final car assembly stage in the downstream part of the supply chains. **Figures 6** and **7** show the breakdown of direct and indirect emissions for 16 sectors. Industries 9–13 with asterisks are thought to be assembly-based manufacturing industries.

We see in these figures that CO_2 emissions are skewed toward upstream firms in manufacturing supply chains. This is particularly evident for Japan (**Figure 7**). **Figure 7** also shows that proportions of toxic wastes show a similar pattern.

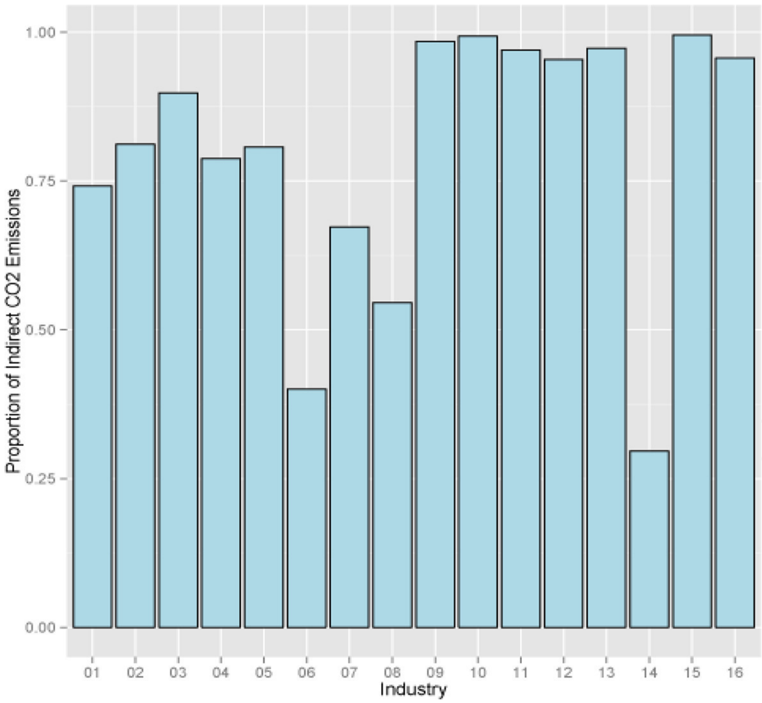


Figure 6. CO_2 emissions by industry: proportions of indirect emissions for India.

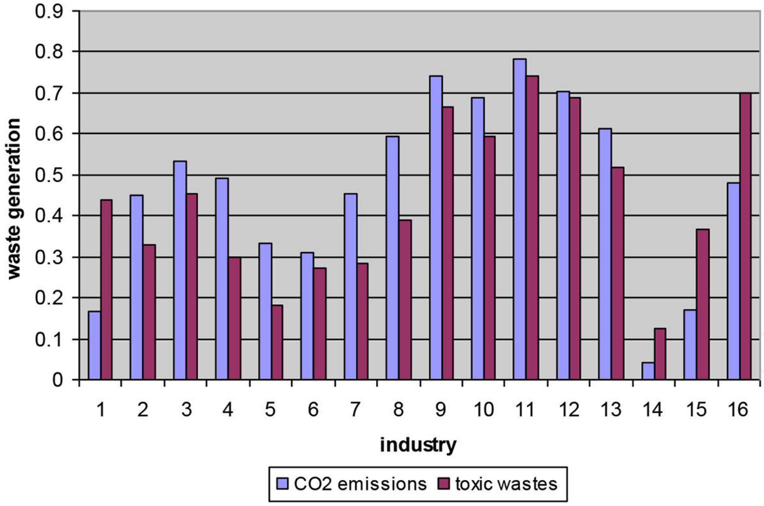


Figure 7. CO_2 emissions by industry: proportions of indirect emissions for Japan. Notes: In this graph for Japan, proportions of indirectly generated amounts of toxic waste (solid and liquid) materials other than CO_2 are also shown.

1	**Mining**
2	Food production
3	Textiles
4	Pulp/paper
5	Chemicals
6	Petrol/Coal production
7	Basic metals
8	Nonferrous metals production
9*	General machinery
10*	Electric machinery
11*	Auto
12*	Transportation machinery
13*	Precision machinery
14	Electric power
15	Public utility
16	Service

*Assembly-based manufacturing industries.

List of industries used in **Figures 6** and **7**

Are the patterns of CO_2 emissions across upstream and downstream economic sectors that we observed in **Figures 6** and **7** consistent with downstream firms' profit maximization behavior? We are interested in testing the following hypothesis:

H1: Downstream firms' performance (measured by their value added) is affected by their upstream firms' CO_2 emissions as well as their own.

In general, we expect upstream firms' generation of toxic wastes such as CO_2 to be a negative factor in firms' value added, but generation of nontoxic wastes may not be, since most nontoxic wastes have commercial value. We first focus on the impacts of downstream firms' immediate predecessor upstream firms on downstream firm performance, because the impacts, if any, of downstream firms' environmental management policies such as green procurement can extend most effectively to their immediate predecessor upstream suppliers.

	A	B	C	D
	India		Japan	
Dependent variable	Value added	Value added	Value added	Value added
Constant	0.5213***	0.6965***	0.4640***	0.5087***
	(0.0415)	(0.0578)	(0.0099)	(0.0204)
Direct CO_2waste (downstream)	−0.0043	0.0649**	−0.0018*	−0.0016
	(0.0034)	(0.0194)	(0.0011)	(0.0011)
Indirect CO_2waste (upstream total, all stages)	–	−0.1266***	–	−0.0150**
		(0.0347)		(0.0070)
Indirect CO_2waste (upstream, first stage)	−0.0107***	–	−0.0115***	–
	(0.0115)		(0.0030)	
Adjusted R^2	0.01846	0.27258	0.04373	0.12097
No. of observations	130	130	396	396

*Significance level at 10%.
**Significance level at 5%.
***Significance level 1%.
Notes: The dependent variable (value-added) is measured per sector output.
Neither Harisson-McCabe nor Breusch-Pagan tests for heteroskesdasticity detected statistically significant level in the regressions reported above.
We have also run regressions with log of value-added as the dependent variable. We obtained estimation results which are qualitatively the same. Further, we experienced considerable multicollinearity when indirect emissions from both first and all stages entered regressions. Therefore, we only report regressions with either one of the indirect emission variables here.
These regression results were calculated by the authors. Results for Japan in columns E and F are also reported in [6].

Table 6. Determinants of downstream firms' value added: effects of direct and indirect CO_2 emissions by upstream firms, India and Japan.

We test this hypothesis empirically by estimating the following regressions using a sample of economic sectors corresponding to Indian input–output sectors for which usable data are available. The data used includes value added and the amounts of CO_2 emissions generated during direct and indirect stages of production for each of the input–output sectors in the sample. (Descriptive statistics for these variables for India and Japan are presented in Appendix 2.)

In our specification, we regress value added on the amounts of CO_2 generated directly by downstream firms as well as the amounts of CO_2 generated indirectly by their upstream producers. Our OLS regression results for India are given in columns A and B of Table 6. Columns C and D show the corresponding results for Japan.[8]

Even though CO_2 is not thought to be one of the industrial wastes in a traditional sense, the amounts of CO_2 emissions represent the levels of firms' inputs of fossil fuels. As such, like some other toxic wastes, firms have economic incentives, even without government regulations, to reduce such emissions of CO_2, since the cost of energy can be a significant portion of firms' production costs. Furthermore, from policy perspectives, some policies introduced by the governments of developed countries have been promoting energy-efficient production processes for many years (e.g., beginning in the late 1970s, after the second oil crisis in Japan). And also, in recent years, CO_2 emission quota policies of various sorts are being introduced in Japanese, EU, and other nations' industries.

From Column C of Table 6, we see that 1 ton of direct waste output of CO_2 contributes to −0.0018 of firms' value added per yen of firms' output. On the other hand, contribution to firms' value added of the indirect waste output of CO_2 from their immediate upstream predecessor suppliers is −0.0115, which is numerically much larger and statistically more significant than our direct waste output. We conclude that firms face significant financial losses, measured by value added, when direct and indirect generation of CO_2 occurs in their own production processes. Generation of CO_2 emissions by firms' immediate upstream predecessor suppliers seems to have much larger negative effects on their value added than their own direct waste output. This suggests that downstream firms may have economic incentives to reduce waste output by their immediate predecessor upstream suppliers.

Comparing columns A (India) and C (Japan), we see similar patterns on how CO_2 emissions along supply chains affect final sectors' value added. As far as final sectors' direct emissions are concerned, direct CO_2 emissions have no impact on value added for India, since its coefficient (−0.0043) is statistically not significant. On the other hand, their immediate predecessor CO_2 emissions negatively affect final sectors' value added (with statistically significant coefficient (−0.0107). But direct emission coefficients in Column B are positive and statistically significant (0.0649), suggesting that the more fossil energy is used by the final sector, the more productive (in terms of value added) final sectors become. This might indicate inefficient use of fossil energy, but this is not clear, since the same coefficient in column A is statistically insignificant.[9] In all cases, indirect emissions from all supplier stages combined are statistically

---

[8] Various tests of heteroskedasticity and specification tests that we have done, respectively, show little heteroskedasticity and little specification errors.

[9] We speculate that there are multiple channels through which downstream and upstream firms' environmental policies affect downstream firms' value added.

http://dx.doi.org/10.5772/62535

significant and negative. From these results, we tentatively conclude that, for India, environmental management policies encouraging suppliers in supply chains to reduce their CO_2 emissions will likely improve final sector firms' performance measured in terms of value added. These results for India are consistent with but are not as strong as the policy conclusions obtained for Japan [6].

7. Concluding remarks

Recent advances in supply chain based management methods have made it possible for many firms to organize their production and other business activities as part of the supply chains they belong to. Efficiency gains are realized in terms of reduced inventories, reduced lead times for new product development, and shorter delivery lags, among many other benefits. Our results suggest that including certain supply chain level environmental management schemes, such as "how to manage toxic and nontoxic wastes, as well as CO_2 emission for a supply chain as a whole," in such supply chain management methods might improve not only downstream firms' economic performance but also advanced economies' environmental performance significantly.

Consideration of such schemes may underlie some firms' proposals for green procurement policies. In many sectors of an advanced economy, as supply chain management becomes more sophisticated in pursuing economic efficiency, larger downstream firms tend to become more dominant as the primary driver of management decisions associated with their supply chains. (Note, however, that this phenomenon is not limited to assembly-based manufacturing industries. In retail industries, Walmart and the like have become the primary decision makers for their entire global supply chains.) It is possible that, as a national economy develops and increases its sophistication in logistic capabilities, organic connections between upstream and downstream firms become more prevalent, as we see in Japan. This might make it easier for some downstream firms to adopt green procurement policies.

Another factor that might be important to consider in supply chain based environmental policies is firm ownership structures. Ownership structures of firms involved in supply chains are complex but tend to share some systematic patterns. Dominant downstream firms generally influence business decisions of their upstream suppliers via some forms of partial ownership and/or certain guaranteed purchase agreements. Dominant firms do not necessarily extend their partial ownership to all other firms in their supply chains, but, nevertheless, dominant firms often have significant influence over smaller upstream firms through various sorts of business relationships.

Current public policies on waste management in Japan focus on firms and/or establishments. Because of the reasons stated above, this is not appropriate for an advanced economy in which many firm decisions are made at their supply chain levels in interrelated ways. Our empirical results present limited evidence, for both India and Japan, that downstream firms' economic performance is affected not only by their own environmental policies but also by the environmental behavior of their upstream suppliers. Some profit-maximizing firms may see it to their advantage to implement green procurement policies. As we have shown, improving suppliers' environmental performance may lead to immediate improvements in downstream firms' economic performance. We suppose that government environmental policies need to accommodate this supply chain effect as well. As of now, few environmental regulations for downstream firms have serious implications for upstream firms' environmental behavior.

Acknowledgements

The authors thank Keio University for their generous support to conduct research reported in this Chapter. This research was also in part supported by the Social Science and Humanities Research Council of Canada.

Appendix A1. 130 Sectors of the input–output Table: India, 2003

Code	Name	Code	Name
1	Paddy	41	Edible oils other than vanaspati
2	Wheat	42	Tea and coffee processing
3	Jowar	43	Miscellaneous food products
4	Bajra	44	Beverages
5	Maize	45	Tobacco products
6	Gram	46	Khadi and cotton textiles in handlooms
7	Pulses	47	Cotton textiles
8	Sugarcane	48	Woolen textiles
9	Groundnut	49	Silk textiles
10	Coconut	50	Art silk and synthetic fiber textiles

http://dx.doi.org/10.5772/62535

11	Other oil seeds	51	Jute hemp and mesta textiles
12	Jute	52	Carpet weaving
13	Cotton	53	Ready-made garments
14	Tea	54	Miscellaneous textile products
15	Coffee	55	Furniture and fixtures (wooden)
16	Rubber	56	Wood and wood products
17	Tobacco	57	Paper, paper products, and newsprint
18	Fruits	58	Printing and publishing
19	Vegetables	59	Leather footwear
20	Other crops	60	Leather and leather products
21	Milk and milk products	61	Rubber products
22	Animal services (agricultural)	62	Plastic products
23	Poultry and eggs	63	Petroleum products
24	Other livestock products	64	Coal products
25	Forestry and logging	65	Inorganic heavy chemicals
26	Fishing	66	Organic heavy chemicals
27	Coal and lignite	67	Fertilizers
28	Natural gas	68	Pesticides

29	Crude oil	69	Paints, varnishes, and lacquers
30	Iron ore	70	Drugs and medicines
31	Manganese ore	71	Soaps, cosmetics, and glycerin
32	Bauxite	72	Synthetic fibers and resin
33	Copper ore	73	Other chemicals
34	Other metallic minerals	74	Structural clay products
35	Limestone	75	Cement
36	Mica	76	Other nonmetallic mineral products
37	Other nonmetallic minerals	77	Iron, steel, and ferroalloys
38	Sugar	78	Iron and steel casting and forging
39	Khandsari and boora	79	Iron and steel foundries
40	Hydrogenated oil (vanaspati)	80	Nonferrous basic metals
Code	**Name**	**Code**	**Name**
81	Hand tools and hardware	116	Trade
82	Miscella neous metal products	117	Hotels and restaurants

http://dx.doi.org/10.5772/62535

83	Tractors and agricul tural implements	118	Banking
84	Industrial machinery for food and textiles	119	Insurance
85	Other industrial machinery	120	Ownership of dwellings
86	Machine tools	121	Education and research
87	Other nonel ectrical machinery	122	Medical and health
88	Electrical industrial machinery	123	Business services
89	Electrical cables and wires	124	Computer-related services
90	Batteries	125	Legal services
91	Electrical appliances	126	Real estate
92	Communication equipment	127	Renting of machinery and equipment
93	Other electrical machinery	128	Community, social, and personal services
94	Electronic equipments including TV	129	Other services
95	Ships	130	Public administration

	and boats		and defense
96	Rail equipment	121	Education and research
97	Motor vehicles	122	Medical and health
98	Motor cycles and scooters	123	Business services
99	Bicycles and cycle-rickshaw	124	Computer-related services
100	Other transport equipment	125	Legal services
101	Watches and clocks	126	Real estate
102	Medical precision and optical instruments	127	Renting of machinery and equipment
103	Gems and jewelry	128	Community, social, and personal services
104	Aircraft and spacecrafts	129	Other services
105	Miscell aneous manufacturing	130	Public administration and defense
106	Construction	121	Education and research
107	Electricity	122	Medical and health
108	Water supply	123	Business services
109	Railway transport services	124	Computer-related services
110	Land	125	Legal services

http://dx.doi.org/10.5772/62535

	transport including pipelines		
111	Water transport	126	Real estate
112	Air transport	127	Renting of machinery and equipment
113	Supportive and auxiliary transport activities	128	Community, social, and personal services
114	Storage and warehousing	129	Other services
115	Communication	130	Public administration and defense
Final Demand			
PFCE	Private final consumption expenditure		
GFCE	Government final consumption expenditure		
GFCF	Gross fixed capital formation		
CIS	Changes in stocks		
EXP	Exports		
IMP	Imports		
COMOUT	Domestic output (product)		
VA	Value added		
NIT	Net		

	indirect tax
GVA	Gross value added
INDOUT	Domestic output (industry)

Source: [28,31].

Appendix A2. Descriptive statistics for regression variables: India, 2003 and Japan, 2000

India						
Variables	**Mean**	**Std. dev.**	**Median**	**Minimum**	**Maximum**	**No. obs.**
Value added (dep. variable)	0.47978	0.23504	0.38890	0.00908	1	130
GHG emissions (CO_2equivalent): India, ton-CO_2per million Rupees						
Direct emissions (from current sector)	1.4699	5.4709	0.1885	0.0000	48.1495	130
Indirect emissions (emissions from all previous sectors/stages combined)	2.4667	3.2255	1.9813	0.0000	27.4213	130
Indirect emissions (emissions from immediate predecessor sector/stage)	3.2817	2.5990	2.9807	0.0000	18.5870	130
Japan						
Variables	**Mean**	**Std.dev.**	**Median**	**Minimum**	**Maximum**	**No. obs.**
Value added (dep. var.)	0.444286	0.180905	0.408066	0	0.929868	396
GHG emissions (CO_2equivalent): Japan, ton-CO_2per million Yen						
Direct emissions (from current sector)	1.81488	8.02313	0.24814	0	104.2946	396
Indirect emissions (emissions from all previous sectors/stages combined)	2.99029	3.99268	1.98527	0	52.4515	396
Indirect emissions (emissions from immediate predecessor sector/stage)	1.42372	2.99584	0.71593	0	44.9873	396

Source: India—The dataset is compiled by the authors using *The Central Statistical Organisation, India* at current million Indian Rupees [28]. Japan—The dataset is compiled by the authors using data available from http://www.stat.go.jp/english/data/io/index.htm and Ministry of Economy, Trade and Industry.
Notes. Value added and direct waste outputs are measured per sector output. Indirect waste output for each stage is measured per total indirect output (all stages combined).

Author details

Hitoshi Hayami[1], Masao Nakamura[1,2*] and Kazushige Shimpo[1]

*Address all correspondence to: masao.nakamura@gmail.com

1 Keio University, Tokyo, Japan

2 University of British Columbia, Vancouver, BC, Canada

References

[1] Wikipedia, 2015. United Nations Climate Change Conference, 2016. Available from: https://en.wikipedia.org/wiki/2015_United_Nations_Climate_Change_Conference.

[2] Oak Ridge National Laboratory. Carbon Dioxide Information Analysis Center, 2016. Available from: http://cdiac.ornl.gov/.

[3] OECD, Statistics Directorate. Purchasing Power Parities (PPPs) Data, 2016. Available from: http://www.oecd.org/std/.

[4] World Bank, 2016. Available from: http://data.worldbank.org/.

[5] World Input Output Data, 2016. Available from: htttp://www.wiod.org/new_site/database/niots.htm.

[6] Hayami H., Nakamura M., and Nakamura A. Economic performance and supply chains: the impact of upstream firms' waste output on downstream firms' performance in Japan. International Journal of Production Economics 160, February 2015, 47–65.

[7] Kovacs G. Corporate environmental responsibility in the supply chain. Journal of Cleaner Production 16, 2008, 1571–1578.

[8] Wong C.W.Y., Lai K-H., Shang K-C., Lu C-S., and Leung T.K.P. Green operations and the moderating role of environmental management capability of suppliers on manufacturing firm performance. International Journal of Production Economics 140, 2011, 283–294.

[9] Goldar A., Bhanot J., and Shimpo K. Prioritizing towards a green export portfolio for India: an environmental input-output approach. Energy Policy 39, 2011, 7036–7048.

[10] Rinoj P. K. Supply Chain Challenges for the Indian FMCG Sector. *International Journal of Scientific Research,* Vol.3, Issue 8, August 2014, 211–212.

[11] Thakkar J., Kanda A., and Deshmukh S.G. Supply chain issues in Indian manufacturing SMEs: insights from six case studies. Journal of Manufacturing Technology Management 23, 2012, 634–664.

[12] Shimpo K. and Shukla M. (Eds.). Input-Output Analysis for the Indian and the World Economy. Proceedings of the Conference, 17 December 2007, New Delhi, The Energy and Resources Institute, New Delhi, 2008.

[13] Cisco. Cisco's green supply chain, Cisco, 2010. Available from: http://newsroom.cisco.com/dlls/2008/ekits/g5_Cisco_Green_Supply_Chain_030308.pdf.

[14] NEC. Green Procurement Guidelines (for Suppliers). NEC Corporation, Tokyo, 2004. Available from: http://www.nec.co.jp/eco/ja/products/green/pdf/050131-NEC_green_procurement_E_Ver3.Pdf.

[15] Sony. For Suppliers—Green Procurement, Tokyo, 2010. Available from: http://www.sony.net/SonyInfo/procurementinfo/green.html.

[16] Toshiba. Green Procurement Guidelines, Toshiba Corporation, Tokyo, 2006. Available from: http://www.toshiba.co.jp/procure/pdf/en_green.pdf.

[17] Chiou T.-Y., Chan H.K., Lettice F., and Chung S.H. The influence of greening the suppliers and green innovation on environmental performance and competitive advantage in Taiwan. Transportation Research Part E: Logistics and Transportation Review 47, 2011, 822–836.

[18] Bhateja A.K., Babbar R., Singh S., and Sachdeva A. Study of green supply chain management in the Indian manufacturing industries: a literature review cum an analytical approach for the measurement of performance. International Journal of Computational Engineering & Management 13, 2011, 84–99.

[19] Leontief W.W. Environmental repercussions and the economic structure: an input-output approach. Review of Economics and Statistics 52, 1970, 262–271.

[20] Leontief W.W. Air pollution and the economic structure: an input-output computations. In Leontief W.W. (Ed.), Input–Output Economics, 2nd ed., Oxford University Press, New York, 1986.

[21] Hayami H., Nakamura M., Suga M., and Yoshioka K. Environmental management in Japan: applications of Input-output analysis to the emission of global warming gases. Managerial and Decision Economics 18, 1997, 195–208.

[22] Hayami H. and Nakamura M. Greenhouse gas emissions in Canada and Japan: sector-specific estimates and managerial and economic implications. Journal of Environmental Management 85, 2007, 371–392.

[23] Suh S. (Ed.). Handbook of Input-Output Economics in Industrial Ecology, Springer, Berlin, 2009.

[24] Pires A., Martinho G., and Chang N-B. Solid waste management in European countries: a review of systems analysis techniques. Journal of Environmental Management 92, 2011, 1033–1050.

[25] Solow R. On the structure of linear models. Econometrica 20, 1952, 29–46.

[26] Luckow P., et al. Carbon Dioxide Price Forecast, Synapse Energy Economics, Inc., Cambridge, MA, 2015. Available from: http://www.synapse-energy.com/sites/default/files/2015%20Carbon%20Dioxide%20Price%20Report.pdf.

[27] United Nations. Handbook of Input-Output Table Compilation and Analysis, Studies in Methods: Handbook of National Accounting, Series F, 74, 1999. Available from: http://unstats.unorg/unsd/publication/SeriesF/SeriesF_74E.pdf.

[28] GOI (Government of India). Input-output transaction table 2003-04. Central Statistical Organization, Ministry of Statistics and Programme Implementation, New Delhi, 2008.

[29] Shimpo K., Mathur R., Ganju R., Goldar A., Madan A., and Taneja G. Input Output Table for Environmental Analysis for 2003/04 for India. Keio Economic Observatory, Keio University, Tokyo, 2010.

[30] Hikita K., Shimpo K., Shukla M., Nakano S., and Okamura A. Making input-output tables for environmental analysis for India: 1993/94 and 1998/99. In: Input-Output Analysis for the Indian and the World Economy. Proceedings of the Conference: The Energy and Resources Institute, New Delhi, December 2007, pp. 25–44.

[31] GOI (Government of India). Greenhouse gas emissions 2007, Indian Network for Climate Change Assessment. Ministry of Environment and Forests, 2010.

[32] Timmer M.P., Dietzenbacher E., Los B., Stehrer R., and de Vries G.J. An illustrated user guide to the world input–output database: the case of global automotive production. Review of International Economics 23, 2015, 575–605.

[33] National Institue for Environmental Studies (NIES). Embodied Energy and Emission Intensity Data for Japan Using Input–Output Tables, Tokyo, 2010. Available from: http://www-cger.nies.go.jp/publication/D031/eng/index_e.htm.

[34] Nakano S., Hayami H., Nakamura M., and Suzuki M. The Input-Output Tables for Environmental Analysis and its Applications (Kankyo Bunsekiyo Sangyo Renkanhyo to sono Oyo) [in Japanese]. Keio University Press, Tokyo, 2008, 219 pages. ISBN 978-4-7664-1512-4.

[35] Ministry of Economy, Trade and Industry (METI). The Waste and By-Products Surveys of Japanese Establishments, 2006. Available from: http://www.meti.go.jp/policy/recycle/main/data/research/h16fy/160406-1_cjc.html.

INTECH

Chapter 2

Identification of Environmental Criteria for Selecting a Logistics Service Provider: A Step Forward towards Green Supply Chain Management

Patricija Bajec and Danijela Tuljak-Suban

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/62533

Abstract

Green environmental performance increases the competitiveness of the supply chain. However, the greening of the supply chain depends on the manufacturer who drives the green initiative, as well as on all the members of the supply chain who take part in the process. The manufacturer's attention has been largely focused on the environmental performance of the supplier and retailer, whereas logistics service providers have been somehow neglected. It is, in fact, the case is that logistics service providers have begun to play a critical role in supply chain management and could therefore significantly improve environmental sustainability. They have already undertaken a green initiative that unfortunately has rarely, if at all, been required by the manufacturer. The lack of requirements for logistics providers hinders the progress of a green initiative. To take a step forward towards green supply chain management, this chapter aims to introduce all the necessary criteria for the selection of a logistics service provider (LP), with an emphasis on environmental criteria. The environmental selection criteria, with all related subcriteria, were achieved on the basis of a systematic literature review. It has been found that buyers of logistics services still strive to minimize costs, expect quality logistics services, a well-positioned LP, all the while overlooking environmental issues. The most frequently applied environmental selection criteria are value-added reverse logistics services, followed by environmental expenditures, pollutants released, energy consumption, clean materials and energy use. The findings presented here are useful particularly for researchers, as issues regarding sustainable LP selection and its limitations are highlighted, related to selection criteria identification. These findings may be of less use to managers. However, future phases of this study, richer for the evaluation of logistics experts, will be much more applicable to buyers and providers of logistics services.

Keywords: environmental logistics, environmental selection criteria, reverse logistics service provider, green supply chain management, logistics outsourcing

1. Introduction

Green supply chain management has recently been of increased interest mainly because of increased environmental awareness and significantly, economic motivation (corporate image, higher profits, marketing exposure) [1], which affect the competitiveness and differentiation [2] of the supply chain. Bacallan [3] even argued that some companies have become more competitive because of better environmental performance. An environmentally friendly supply chain depends on the eco-efficiency and synergy of all partners in the supply chain [4], from supplier to manufacturer, distributor and retailer to the customer. Manufacturers are one of the main drivers of the green initiative and play a crucial role in increasing the environmental performance of the supply chain [5]. A greening of the supply chain, therefore, depends on the requirements of the manufacturers who have consequently devoted considerable attention to green purchasing over the past decades [6–10]. Green product design has also been frequently studied in the literature by many researchers [1, 11], as well as green operations related to product manufacturing. The only activity that has been somewhat neglected in this respect is logistics. Most of the literature published on this topic has been directed towards transport, namely green transportation planning, use of intermodal solutions, information and communication technologies for managing green transport, etc. [12–14]. The number of publications on this topic is not surprising as transportation is one of the most significant polluters of the environment. Much more surprising is the fact that external providers of logistics services are rarely the object of research. LPs actually provide transport and other logistics services for companies (so-called logistics outsourcing).

Logistics outsourcing is not a new phenomenon. It has become a necessity and not just a fad. Companies use logistics outsourcing for three reasons. The first reason is the importance of logistics for supply chain efficiency [15], second is the inability of companies to provide the high level of logistics services that is currently required and expected and the third reason is the difficulties inherent in focusing on the core business when also taking care of logistics services. Logistics outsourcing enables a higher quality of logistics services, lower flexibility and a higher level of differentiation. In addition, companies can focus on their core business, which is crucial to survive and contend in a global and competitive environment.

Accordingly, LPs are significant partners in the supply chain and who bear the same degree of responsibility for protecting the environment as other supply chain partners (suppliers, manufacturers, distributors, retailers, etc.). According to Cooper et al. [16], LPs have a very significant impact on the overall sustainability of the supply chain. They should, therefore, be subject to the green requirements of manufacturers. A brief literature review revealed the following, contradictory facts. First, the studies on buying logistics services (which are, in fact, quite limited) show that there is a lack of green demand on the part of companies buying logistics services [11, 17, 18]. LPs are still selected based on a “traditional” selection criteria, namely price, quality, provider status, while environmental criteria have received minimum attention [19]. Second, the logistics industry itself is focused on environmental initiatives. “Important commitments to environmental sustainability improvements have been made by LPs during the past several years” [14]. And third, green logistics depends on the buyer’s

http://dx.doi.org/10.5772/62533

requirements and expectations of LPs. In summary, it would seem that the first and quite important step towards eco-efficiency has already been taken by LPs. Nevertheless, further actions towards sustainability are needed by the buyers of logistics services as well. The next challenge would, therefore, be to integrate environmental requirements into the manufacturer/logistics provider partnership, starting with the identification of relevant environmental criteria.

There is extensive literature that covers selection criteria in logistics outsourcing. Studies mainly focus on general selection criteria such as costs, service level and the status of the logistics service provider, while the environmental consideration is more or less neglected. Few studies address environmental criteria and we assert that special attention must be paid to this as well because of its important role in achieving a competitive business. The main objective of the chapter is, therefore, to introduce all the criteria for the selection of logistics service providers, focusing, in particular, on environmental criteria, which will be achieved by a systematic literature review. The research questions are as follows: (1) How common are articles on the selection of reverse LPs? How often are environmental issues taken into account when selecting a LP? (2) Which are the most commonly used environmental criteria? (3) Are they well-defined? (4) Do they cover all environmental aspects?

After the introduction, the rest of the chapter will be organized as follows: first, the logistics outsourcing selection process will be introduced. In the second part, the methodology of the literature review will be presented. Review results will be reported and critically analysed in the third section, followed by the conclusion.

2. Evaluation and selection of outsourcing provider

When a company identifies the need to outsource one or more services, the next step is to evaluate and select a suitable provider to meet its requirements. Outsourcing provider selection is one of the most important steps of the outsourcing process [20]. It is composed of a few different phases from determining selection criteria, making a list of possible providers and evaluating all possible providers to making the final selection of the most appropriate partner [21, 22]. The selection phase has a strong influence on the business performance of both outsourcing partners. Its success depends on the company's knowledge of outsourcing methodology, appropriate communication between the buyer and outsourcing provider, a comparable request for proposal [23], the selection of appropriate criteria as well as the right decision-making method or methods [24].

Selection criteria (sometimes called attributes) are actually the requirements of the buyer from the outsourcing provider, covering all skills, knowledge, staff requirements, infrastructure and suprastructure requirements, etc. They represent a base for evaluating and selecting the best outsourcing provider [25]. Each criterion and its weight are absolutely dependent upon the buyer's needs, the strategy and also the external environment [26–28]. There is no general formula suitable for all cases. Criteria can also be further divided into various subcriteria.

Additionally, there are also many decision-making methods important for determining the optimal solution and their suitability changes from case to case. An individual approach is, therefore, required in each instance of outsourcing implementation. Even if the company chooses the correct decision-making method but has imprecise and inadequate criteria, the selection process will not be successful. Outsourcing will consequently not meet the expectations of either partner or could even be doomed to failure.

Criteria have been a frequently discussed topic in the relevant literature. Different authors use very different criteria and subcriteria to select a provider. However, the two most frequently mentioned selection criteria are cost savings and service quality, followed by operational capability and provider status. Environmental criteria appear only in recent studies. There have been periodic changes detected on the importance of criteria [26]. From 1994 to 1999, quality was the most important criteria. By 2003, price took first place [29]. Selection criteria could be classified into five main groups, namely (1) operational capability, (2) service level, (3) costs, (4) provider status and (5) environmental capability. Operational capability could be further divided into six subgroups (breadth of services, value-added services, technical and technological capability, optimization capability and information technology), service level into seven subgroups (quality, flexibility, responsiveness, network coverage, reliability, information exchange and risk management), costs into two subgroups (fixed price and variable price), provider status into six subgroups (culture recognition, financial stability, degree of reputation, experience, staff quality and empathy) and last, environmental capability into three subgroups (pollutants released, energy consumption, clean material and energy used, environmental expenditures, etc.).

3. Research methodology

After determining the need for a review, the first step is to set the research target and discuss some general facts related to the evaluation and selection process – which actually represents *the first phase* of a systematic literature review approach – *Planning the review*, and the next step is to explain its other two phases, namely *Implementation of the review*, representing *the second phase* and *Reporting the results*, representing *the last phase* [30].

The implementation phase began with a systematic search in the leading electronic databases, namely, Elsevier, Emerald, Taylor & Francis, Springer Wiley Online Library, and Inderscience Publisher, covering comprehensive journals that very frequently publish studies from the field of logistics, sustainable logistics, logistics outsourcing, supply chain management, etc. (e.g., The Journal of Multi-Criteria Decision Analysis, International Journal of Physical Distribution & Logistics Management, International Journal of Logistics Research and Applications, Supply Chain Management: An International Journal, International Journal of Logistics Research and Application: A Leading Journal of Supply Chain and Management, International Journal of Shipping and Transport Logistics, International Journal of Logistics Research and Applications and Operations and Supply Chain Management, International Journal of Production Research, Expert Systems with Applications, Journal of Applied Sciences, International Journal of Fuzzy

Systems, Journal of Manufacturing Technology Management, Journal of Modelling and Management, Management Decision, Journal of Intelligent Manufacturing, The International Journal of Management Science, Journal of Applied Research and Technology and International Advances in Economic Research). Non-peer-reviewed and non-international publications were also included. Moreover, searches for conference proceedings, master's theses, books and book chapters as well as personal requests were also conducted. Seventy-six percent of the articles related to the selection of LPs were published in journals, 13% in conference proceedings, 4% in book chapters or books and 4% in master's theses (**Figure 1**).

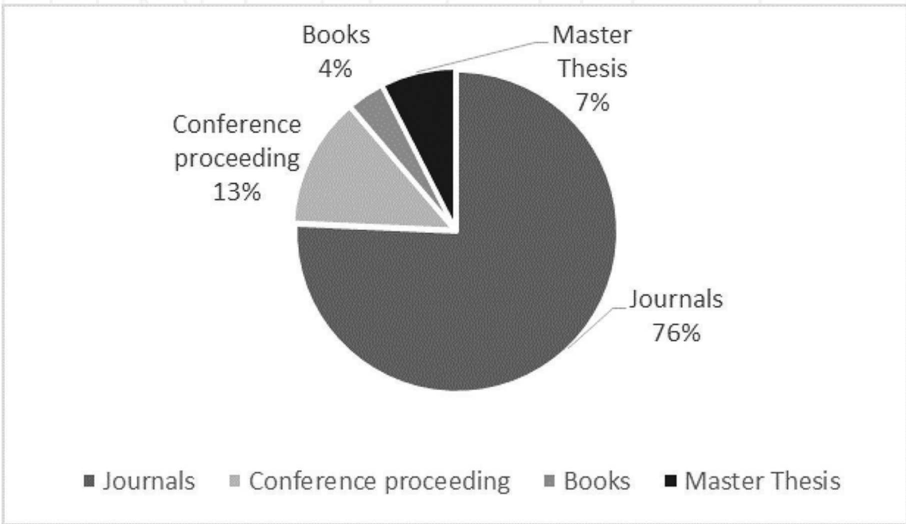


Figure 1. Distribution of publications over publication type.

The review was not limited by time frame for two reasons. Firstly, we wanted to demonstrate how the focus on selection criteria has increased over time and secondly, we wished to see which significant changes have occurred over the years. The search therefore covers articles published from 1999 to 2015. We have limited our review to studies written in English only.

Figure 2 presents a distribution of the articles over time. The oldest paper was published in 1999. The distribution is more peaked than a Gaussian distribution, since kurtosis is positive (0.47) and asymmetrical with a long tail to the left (lower values), since skew is negative (−0.78). The value of mean and median is 2010 and the value of mode is 2013. The highest growth, therefore, appeared between 2010 and 2015, when 63 articles were published. Moreover, 2013 is the year with the maximum number (17) of publications.

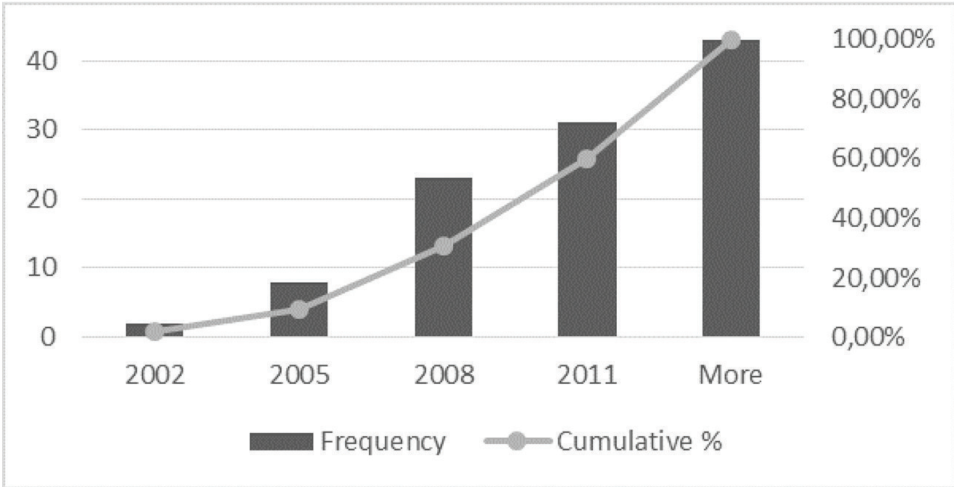


Figure 2. Distribution of publications over time.

Defining the search terms signified the end of the implementation phase and started the process of selecting articles for the systematic review. The selection of articles consisted of two steps. First, we searched for the keywords "selection process" AND "selection criteria" AND "logistics outsourcing" and "logistics service provider" in electronic databases (e.g. Elsevier, Emerald, Taylor & Francis, Springer Wiley Online Library, Inderscience Publisher). This process resulted in 25 articles; three of them were excluded following our exclusion criteria. To find more so-called "grey publications" [31], we first searched Google Scholar and Web of Science, which added another 6 publications to the pool (N=31). Second, we traced references from the pool of publications which resulted in a further 15 publications. In summary, the first step generated 46 publications. As the defined search terms did not bring the desired number of publications, we decided to take a new, second step. The whole above written process was repeated, using additional search terms, namely "decision making methods" AND "selection of third party logistics providers" OR "selection of LP" AND "full name of method, acronym of method". The reason for these keywords stems from the fact that the selection criteria are very often listed in the articles which are related to the decision-making method and not directly to selection criteria. This additional search was indeed very successful, if not time-consuming. Searching electronic databases led to an additional 33 papers; a manual search on Google Scholar and Web of Science added an additional 7 papers and tracing references gave us an additional 9 papers. Ultimately, our search resulted in 95 articles which were further analysed in the third and last phase, *Reporting the result*, presented in the next section.

http://dx.doi.org/10.5772/62533

4. Descriptive analysis

Each article from our pool of publications was analysed with respect to the selection criteria, in particular, to the environmental criteria, their classification, frequency of use, distribution over time interval and the limitations of these criteria.

4.1. Distribution of articles on selection of reverse LPs

The LP selection process has received a great deal of attention from researchers since 1994, when the first paper was published. Ninety-five publications directly or indirectly related to selection criteria were identified. The reason for such a surge in popularity is globalization that (1) increases the need to establish a more robust LP evaluation and selection process [21] and also (2) increases service requirements (selection criteria) because of a higher demand for logistics outsourcing, and consequently the complexity of the selection process. New approaches that handle multiple, and in most cases also conflicting, criteria have emerged as a result of this need.

In contrast, publications on the selection of LPs able to manage reverse logistics flow are rare. Only 11 of the 95 articles were published on this topic [32–42]. Three were written by the same author and co-author. All the articles mentioned have been published in recent years, from 2008 to 2015, which clearly indicates the growing importance of green logistics.

4.2. Selection criteria applied for the logistics industry, with an emphasis on environmental criteria

LP selection is a multi-criteria problem that takes into consideration many qualitative and quantitative, tangible and intangible [43] criteria that are often in conflict with one another [23]. Some of these criteria are client-based and depend on specific customer requirements, and others are general and applicable in all cases [26, 43].

Our investigation revealed (1) the significantly diverse classification of selection criteria and subcriteria; (2) that some authors use a very detailed and reasonable classification of criteria and subcriteria, while the others are very unsystematic and in some cases superficial; (3) that the number of criteria vary from six to more than twenty and (4) that environmental criteria are very rarely used. The above-mentioned confusion caused us some difficulty in determining the proper classification of criteria and subcriteria. Nevertheless, we believe that we were able to devise a very useful classification of criteria and subcriteria for the logistics industry. We have managed to capture the largest possible number of criteria in a systematic manner that is neither too limited nor overly detailed. Criteria were, therefore, arranged in five groups, further divided into several subgroups. **Figure 3** presents a summary of all frequently cited evaluation criteria and their subcriteria, followed by a detailed explanation of each.

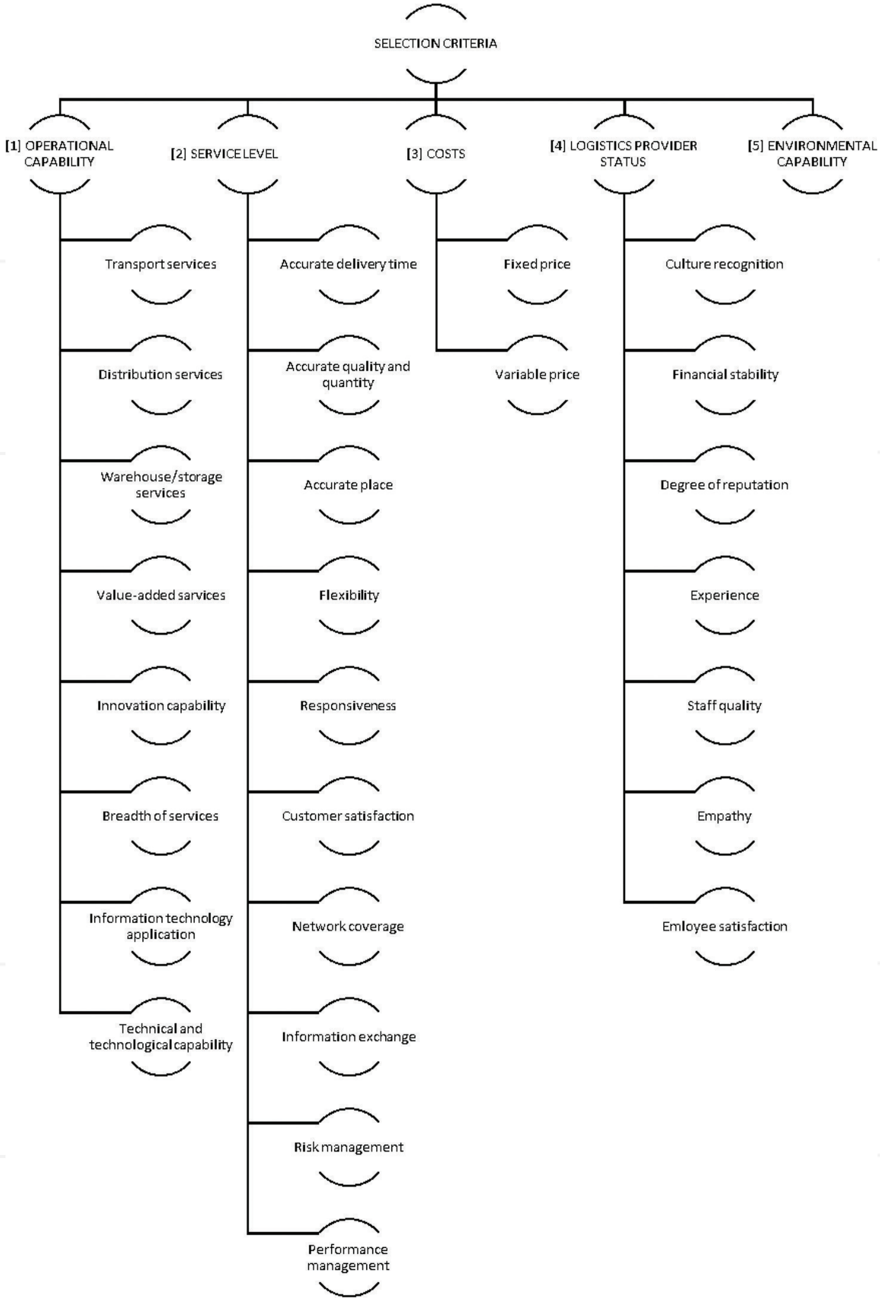


Figure 3. Various criteria and subcriteria for an LP selection.

http://dx.doi.org/10.5772/62533

4.2.1. Operational capability

Transport services

Transport management includes fleet management, technical and technological capabilities [42] and freight forwarding [41]. It refers to accurate or mistaken deliveries [44], frequency of transport services, transportation costs, etc.

Distribution services

Distribution management refers to the delivery to the final customer and is characterized by order cycle time, fill rate, response to customer inquiry, number of returns, back orders, etc. [44].

Warehouse/storage services

Warehouse management is extremely important in the case of reverse logistics as many activities (reassembly, repackaging, etc.) are executed at the warehouse [41]. Warehouse management reverse logistics includes inventory management, infrastructure and suprastructure ownership, customer order processing, warehouse efficiency [44], inventory carrying costs [44], inventory turnover [44], cross docking possibility [42] and more.

The size and quality of the infrastructure (warehouses, distribution centres, etc.) and suprastructure (fleet, manipulation technology, etc.) increase delivery performance, which has a positive impact on final customer satisfaction as well as the competitiveness of the buyer looking to outsource [45, 46].

Value-added services and Innovation capability

Value-added services as well as innovation capability play a very important role. They somehow improve the buyer's services, which is absolutely necessary in this very competitive environment. It should, therefore, be used as selection criteria; however, our literature review revealed that this has not yet been put into practice [26, 28, 41, 42, 47–49].

Breadth of services

The range of services provided is currently a highly desirable characteristic, since enterprises look for a single sourcing provider capable of offering the widest range of services (transportation, warehousing, inventory management, freight forwarding, etc.) and not just a single activity [50].

Information technology (IT) capability

IT capability became one of the key selection criteria in the LP selection process. IT ability represents management related to information systems that control and support logistics functions [34, 41, 42] having a significant positive impact on quality, operational performance

[45], inventory level, lead time, etc. It also reduces the bullwhip effect and consequently the cost [51, 52].

IT ability can be increased using a variety of sophisticated software such as Enterprise Resource Planning (ERP), EDI networking, simulation software, Transport Management System (TMS), Warehouse Management System (WMS), Customer and Supplier Relationship (CRM, SRM), among others. Hardware such as servers, networking, internet/intranet connections, radio frequency devices, bar code printers and scanners are an essential component of IT capability [50].

4.2.2. Service level

Service level is a key selection criterion as well. Because of its positive impact on reputation and consequently market share, the level of service provided plays a very important role on the strength of the supply chain [26]. It integrates several subcriteria, which are described as follows.

Reliability (accurate time, accurate place, accurate quality and quantity)

Reliability refers to accuracy and providing consistent quality [51, 53]. Delivery reliability, therefore, consists of elements such as accurate time in providing logistics services, accuracy in delivering to the correct location, accurate quality and quantity of shipments delivered, and documents [54]. Time reliability describes the "number of shipments which respect the agreed upon time-frame" [55, 56]. Place reliability is characterized by the number of deliveries that conform to the agreed delivery location. Quality reliability describes the capability of LPs to minimize any damage [25, 57], shipment losses or other problems that affect the customer [46, 55]. The quality of the services also has a positive impact on end-customer satisfaction [45].

A systematic review of the literature showed that in determining the selection criteria, customers often choose specific sub-attributes such as accurate time and not the whole attribute (delivery reliability). It, therefore, makes sense to split delivery reliability criteria into individual subcriteria, namely, accurate time, accurate place, accurate quality and quantity. Subcriteria associated with discrepancies, lost or damaged goods [35] and loss rate [58] belong to the reliability-related criteria.

Flexibility and responsiveness

Flexibility in delivery and performance is characterized by the ability to meet the customer's changing needs including specific and non-routine business requirements or personalized customer needs [53, 59, 60]. Responsiveness is the ability of a LP to react quickly to unexpected events and emergencies. This may include urgent deliveries because of a sudden rise in product demand [27, 45].

Flexibility-related criteria as well as responsiveness-related criteria encourage and enhance reliability-related criteria [26]. Flexibility-related criteria are, therefore, often treated as reliability-related criteria [25]. We believe that this is not recommended as they have an important impact on the service level. If they are not required, competitiveness may be threatened. It is, therefore, our position that flexibility-related and responsiveness-related criteria should be included in the selection process.

Customer satisfaction

Customer satisfaction is a rarely used criterion [24, 34, 35, 38, 61–63]. It covers effective communication, service improvement [25, 34, 47], cost savings, profitability [61], optimization capabilities [47], the ability to meet or exceed promises [64], successful relationships, etc. [34].

Network coverage

Network or geographical coverage, market size and market share belong to the same criteria, which indicate that the countries in which LPs are present with offices, branches, warehouses, etc. [65]. This criterion is important for two reasons; first, buyers of logistics services look for a single logistics provider able to cover as many logistics services in the larger area as possible [53] and second, international LPs can help the buyer expand their business globally [52] and also save money on product distribution and marketing [46]. A global presence-related attribute, used by many authors [47, 49, 66, 67], could therefore be integrated into this attribute as well. Network coverage-related attributes are an indication of the financial stability of the LP [24], level of customer satisfaction, reputation [46] and create better access to the market [60].

Information exchange

Information sharing ability relates to providing high quality information between the buyer and the LP. It indicates the maturity of both parties and consequently ensures healthy business practices [53]. Such information sharing requires a high degree of confidence. Information sharing as well as confidence is the foundation of long-term cooperation and the continuous improvement of logistics services [24, 60].

Risk management

"Risk management is the capability of the provider to address any unforeseen problem. It is needed to ensure the continuity of the services" [24, 46].

Service level-related criteria with all subcriteria (accurate quality, quantity, time and place, as well as flexibility, responsiveness, reliability, order fill rate, inventory turnover, space utilization, document accuracy, system security, confidentiality of sensitive data and the other subcriteria) as well as performance-monitoring capability (identifying key performance indicators – KPI), implementing Six-Sigma, ISO standards, fault diagnosis capability, statistical data reporting and many more [24, 45, 46, 50, 65] have also been integrated in just one criteria, referred to as performance criteria by many authors [24, 66, 68]. Nevertheless, we believe that this concept covers an excessive number of quite different elements that require individual identification. Merging all these elements under the umbrella of a single criterion is simply not appropriate.

Performance management

Performance monitoring capability refers to key performance indicators (KPI) identification as well as quantitative and qualitative performance evaluation. The aim of such a measurement is the evaluation of LP quality and identification of any problems [24, 46].

4.2.3. Price/Costs

The price of the service, sometimes referred to as service costs, is the total costs of logistics outsourcing [24, 46, 51, 60, 69], consisting of transportation costs, warehousing costs, freight forwarding, packaging costs, value-added costs, etc. [52]. Because of its role in ensuring a competitive advantage, price is the most commonly used criterion; however, it is no longer the most important [50].

Cost-related criteria could cover only the basic price or it could be divided into basic and variable prices including discounts. This further division demonstrates the degree of LP flexibility [25] and should therefore be treated as flexibility in billing and payment-related subcriteria. This subcriterion that increases consideration between the LP and the buyer [24, 46, 51, 60] often appears in the literature. Credit terms, error-free bills [37], payment accuracy, payment method and payment speed and open-book accounting [53] are part of this attribute as well [37, 63].

4.2.4. Provider status

LP status, often referred to as strategic evaluation status, is the foundation of many strategic subcriteria, namely, culture comparability, reputation, financial stability, quality of personnel and empathy.

Culture recognition

Compatibility with the user's culture and traditions refers to the similar values, size, comparable culture, business processes, technology capability, etc. of the LP and the buyer. It is the basis for working together and achieving common goals [24, 45, 51]. Moreover, it is one of the key elements for establishing a long-term and strategic relationship [26, 45, 50, 68].

Financial stability

Financial stability, often indicated as being an essential requirement for logistics providers [45], shows that any given LP has a sound financial position that ensures continuity of services, regular upgrading of infrastructure and suprastructure, the ability to respond to an ever-changing environment [53, 60] and a low risk relationship as well [45].

Financial stability-related criteria could be determined by total annual revenue [52], indicated by balance sheets and income statement, which demonstrate liquidity, operating, profitability and other financial performance indicators [27, 65].

http://dx.doi.org/10.5772/62533

Provider reputation

A provider's reputation reflects the image of the LP in the market [53] (how good it is at outsourcing, its position in the industry). Jharkharia and Shankar [24] in addition to Çakir [46] consider this attribute to be of vital importance, especially in the initial evaluation of the providers. Qureshi et al. [45] have put forward that reputation encourages the buyer of logistics service to begin a long-term relationship.

Provider experience

A provider's experience demonstrates that a LP has the knowledge of the specifics and critical issues [53] of some industries or certain products. LPs with this characteristic have a significant advantage over others [24]. This criterion ensures a smooth transition to logistics outsourcing and a lower degree of risk associated with unsuccessful outsourcing.

Staff quality

Quality of personnel or staff quality represents the specialized, extensive knowledge of the workforce [50], which consequently ensures a higher level of service [45] and enhances the responsiveness and flexibility of the supply chain [53]. Quality management promotes a long-term relationship and boosts information sharing and trust [24, 45, 46].

Empathy

Empathy is the term used to encompass employee courtesy [54], customer respect and care, the goodwill of the LP [56], a readiness to provide dedicated services [53], the ability to understand the buyer's needs [53], the possibility of establishing a long-term strategic relationship [24, 25, 45, 48, 53, 68] based on trust, risk and benefits sharing [40, 49, 53, 54, 62, 70], conflict resolution [61], controlling the opportunistic behaviour of providers [46], etc.

The willingness to use logistics manpower-related subcriteria [46, 71], which refers to the willingness of the LP to hire those employees who would otherwise remain unemployed, could also be classified in this group [24, 64].

Employee satisfaction

Employee satisfaction level was a rarely used criterion [72–74]. It refers to human resource management [75, 76], human relationships and human resource policy [24, 46, 47, 49, 60, 71, 77]. It affects the quality and smooth execution of logistics services.

4.2.5. Environmental sustainability

Environmental sustainability is quite a broad term. It is best divided into a further two subcriteria:

- so-called green logistics and
- reverse logistics services (**Figure 4**)

Green logistics is characterized by the level of pollutant emissions or the pollutants released, energy consumption [58], the use of clean materials and energy as well as environmental expenditures [35, 36, 78].

Pollutant emissions or pollutants released refer to emissions generated from one of the logistics services. Energy consumption refers to all energy used for one part of logistics services. The use of clean materials and energy relates to the use of renewable energy resources (sun, wind, etc.) and fuels (fossil fuels, etc.). Environmental expenditures describe the costs ensued to ensure an eco-efficient logistics processes (costs for fleet optimizations, eco-efficient vehicles, new network design, eco-efficient standard implementation, staff training, etc.) [40, 79].

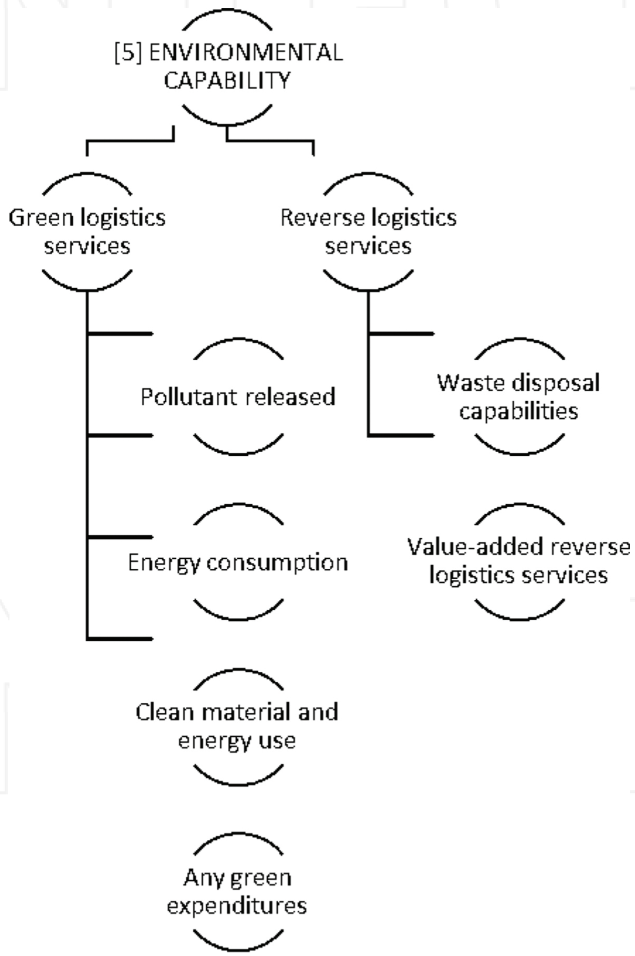


Figure 4. Environmental criteria and subcriteria for an LP selection.

Reverse logistics services related to criteria includes some criteria that are general in nature and useful for broader purposes (not only for the purpose of sustainable development) as well as some more specific criteria.

General criteria relate mainly to transportation services (reverse transportation costs [33, 40], redelivery costs, etc. [40]), distribution services (number of returns, number of back orders [44]), warehouse/storage services (infrastructure ownership, inventory carrying costs [44]), reverse logistics costs (inspection, transportation, inventory, and packaging costs) [33, 42, 49, 80, 81].

Specific criteria refer mainly to value-added reverse logistics services and waste disposal capabilities.

Value-added reverse logistics services include the reassembly (deconstruction of the product for reuse or recycling) [33, 41, 42], repackaging (products are repacked before being resold) [41], remanufacturing of a product before being resold, refurbishment or renovation of products (making minor repairs on products) [34, 42, 82] and recycling [34]. Recycling capability criteria refer to recycling costs [33, 40], recycling plant capacity and ownership [33, 36, 39, 83], satisfying the quality specifications for recycling [33], recycling equipment [38], advanced technology level of recycling and disassembling, speed of the recycling centre [40], etc.

Waste disposal activities include the screening, collecting, sorting, packaging and storage of waste [32, 34, 40, 41].

Despite the complexity of the environmental sustainability-related criteria, some authors do not find it reasonable to use subcriteria [28, 35, 49, 79, 84, 85]. We assert that by not using subcriteria, they lose critical data on the competencies of LP and are not aware of what the exact environmental competence of the LP actually is. We, therefore, consider the division into subcategories both reasonable and necessary.

The most commonly used environmental criteria are value-added services, used by 11 authors, followed by environmental expenditures, identified in 9 articles. Return order process capability was detected in six cases, reverse logistics cost in five cases, pollutants released and energy consumption in four cases and clean material and energy was used by just two authors [**Figure 5**].

The most commonly used criteria of them all (not just environmental criteria) is price, used in 99 cases, followed by information technology application, used in 61 cases (**Figure 6**). Accurate delivery time was used by 60 authors, accurate quality and quantity by 51 authors, technical and technological ownership by 49 authors, staff quality by 47 authors, flexibility in operations by 46 authors, network coverage by 45 authors and empathy and degree of reputation by 42 authors. All the other criteria were used less frequently, namely experience and culture recognition in 39 cases, reliability in 36 cases, information exchange ability in 35 cases and accurate delivery place in 31 cases. Environmental-related criteria are the least selected criteria, used in less than 12 cases.

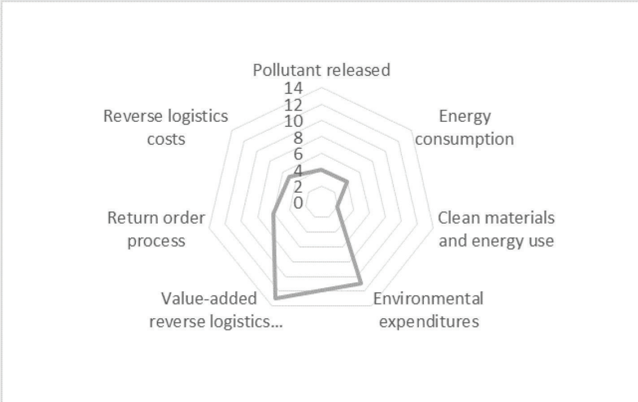


Figure 5. The frequency of the use of individual environmental criteria.

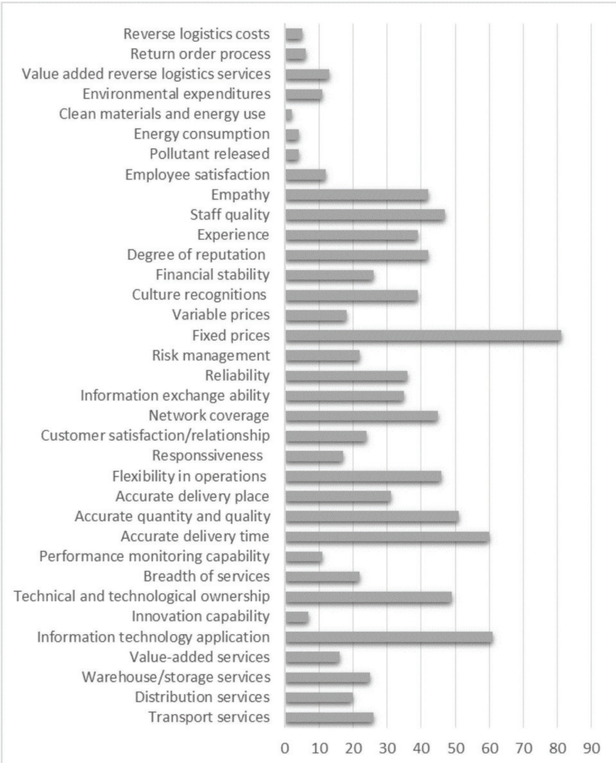


Figure 6. The frequency of the use of all (not just) environmental criteria.

5. Critical analysis of the environmental criteria in terms of quality and quantity

The buyers of logistics services mainly focus their attention on traditional logistical services (the physical flows of products from the manufacturer to the consumer) [86], when defining criteria for selecting an LP. Environmental logistics services are only very rarely applied. Regarding the literature review, environmental criteria could be divided into two main groups. The first is green logistics activities-related criteria and the second is reverse logistics activities-related criteria. The most frequently mentioned green logistics activities were pollutants released, energy consumption, clean materials and energy use and environmental expenditures. Value-added reverse logistics services and reverse logistics costs are the most frequently used reverse logistics criteria. Value-added reverse logistics services are further divided into the following activities: reassembly, remanufacturing of product before being resold, refurbishment or renovation of products, recycling capability, recycling equipment, advanced technology level of recycling and disassembling, speed of recycling centre, etc. Waste disposal activities included screening, collecting, sorting, packaging, storages of wastes.

To make a critical analysis, in recent years there were few published articles on the topic of the framework of reverse logistics services [87–89]. Environmental logistics activities are, according the published articles, very different in content and aim. Some are focused on resource reduction, some on maximizing reuse, some on recycling and others on disposal activities [90]. It would, therefore, be best to classify reverse logistics services into three main groups, namely reverse logistics processes, waste management and green logistics activities.

Reverse logistics processes refers to reverse physical flows, directed from the final consumer to the manufacturer. They are further divided into four main groups, namely (1) collection; (2) integrated function, which includes inspection, selection and sorting process; (3) direct recovery and (4) redistribution [87]. Collection is the process of bringing products to the place of recovery where they are first inspected. They are then selected and finally sorted as to the type of recovery. The types of recovery are reuse, resale, redistribution and reprocessing, further divided into repair (process used for products), refurbishing (process used for modules), remanufacturing (process used for components), recycling (process used for material), etc. [87, 88].

Green logistics refers to providing environmentally friendly methods of traditional or forward logistics services, directed from the manufacturer to the final consumer [87]. It covers packaging reduction, recycling, remanufacturing, reusable packaging, air and noise emission reduction, environmental impact of mode selection [91], measuring the environmental impact and energy reduction [92].

There are differing opinions on the need to distinguish between green and reverse logistics. Some authors believe that reverse logistics should be included in green logistics [92]; others claim that they only share some common activities and are otherwise very different in nature [91]. We believe they are different enough to be treated as independent selection criteria.

Waste management refers to the management of waste generated during production, distribution, usage of final products, etc. It includes prevention, collecting, recycling or recovery, any treatment of waste, the optimum final disposal of wastes and improved monitoring [93].

There were no significant differences between the results of a systematic review on the selection criteria and the brief review of the literature on the framework of green and reverse logistics. There were two detected differences that should be considered. First, the classification of waste disposal activities as separate criteria, not integrated within value-added reverse logistics services, and second, adding measuring the environmental impact as subcriteria of green-related criteria. Moreover, further distribution of value-added reverse logistics activities-related criteria into subcriteria is also recommended. All three suggestions will most certainly improve the quality of selection criteria. Nevertheless, additional evaluation and examination of the validity of selection criteria on the part of experts from the logistics industry who have knowledge and expertise is also required.

6. Conclusion

This review has taken an extensive look at criteria and subcriteria for LP selection, focusing in particular on environmental criteria. Ninety-five studies on LP selection have been systematically analysed to identify the most frequently used general and environmental criteria, which were critically analysed further in terms of quality and quantity.

The systematic literature review revealed how rare publications on this topic actually are as only 11 papers were found. The situation was quite similar when the use of environmental selection criteria were analysed. The frequency of the use of environmental selection criteria was found to be far behind that of cost-related criteria, which held first place and followed by service level and LP status.

Criteria that focused on environmental issues were found to be surprisingly very well defined, covering the whole range of environmental logistics activities, namely green logistics activities, reverse logistics activities and waste disposal activities. All three groups were further divided into subcriteria. The additional evaluation of the defined selection criteria by the experts from different fields will significantly improve the quality and quantity of criteria. We find this survey very helpful for decision makers, logistics managers as well as researchers. It is our contention that decision makers and logistics managers could apply the results of this paper in practice, while researchers may find the results useful for further studies. We believe that a step forward towards green logistics management has been made.

Author details

Patricija Bajec and Danijela Tuljak-Suban*

*Address all correspondence to: danijela.tuljak@fpp.uni-lj.si

Faculty of Maritime Studies and Transportation, Portorož, Slovenija

http://dx.doi.org/10.5772/62533

References

[1] Srivastava SK. Green supply-chain management: A state-of-the-art literature review. International Journal of Management Reviews 2007;9[1]:53-80.

[2] Colicchia C, Strozzi F. Supply chain risk management: A new methodology for a systematic literature review. Supply Chain Management: An International Journal. 2012;17[4]:403-418.

[3] Bacallan JJ. Greening the supply chain. Business and Environment. 2000;6[5]:11-12.

[4] Rao P, Holt D. Do green supply chains lead to competitiveness and economic performance? International Journal of Operations & Production Management. 2005;25[9]: 898-916.

[5] Evangelistia P, Huge-Brodin M, Isaksson K, Sweeney E. The Impact of 3PL's Green Initiatives on the Purchasing of Transport and Logistics Services: an Exploratory Study. Vision 20/20 - Preparing today for tomorrow's challenges. In: Proceedings of the 20th International Purchasing and Supply Education and Research Association (IPSERA), Conference, Maastricht University; April 2011; Maastricht

[6] Zhu Q, Geng Y. Integrating environmental issues into supplier selection and management. Greener Management International. 2001;2001[35]:26-40.

[7] Markley MJ, Davis L. Exploring future competitive advantage through sustainable supply chains. International Journal of Physical Distribution & Logistics Management. 2007;37[9]:763-774.

[8] Blome C, Hollos D, Paulraj A. Green procurement and green supplier development: Antecedents and effects on supplier performance. International Journal of Production Research 2014;52[1]:32-49.

[9] Klassen RD, Vachon S. Collaboration and evaluation in the supply chain: The impact on plant-level environmental investment. Production and Operations Management 2003;12[3]:336-352.

[10] Lindgreen A, Swaen V, Maon F, Walker H, Brammer S. Sustainable procurement in the United Kingdom public sector. Supply Chain Management: An International Journal. 2009;14[2]:128-137.

[11] Walker H, Di Sisto L, McBain D. Drivers and barriers to environmental supply chain management practices: Lessons from the public and private sectors. Journal of Purchasing and Supply Management 2008;14[1]:69-85.

[12] McKinnon A, Cullinane S, Browne M, Whiteing A. Environmental sustainability. Green logistics: improving the environmental sustainability of logistics. 1st ed. London: Kogan Page Limited; 2010.

[13] Eglese R, Black D. Optimizing the routing of vehicles. In: Green Logistics: Improving the Environmental Sustainability of Logistics. KoganPage; 2010:215-228.

[14] Lieb KJ, Lieb RC. Environmental sustainability in the third-party logistics [3PL] industry. International Journal of Physical Distribution & Logistics Management. 2010;40[7]:524-533.

[15] Fadavi A, Khanghah AS, Asli MN. A hybrid model for supplier selection in outsourcing: Evidence from Shima Film Company in Iran. Research Journal of Applied Sciences, Engineering and Technology 2013;5[12]:3298-3305.

[16] Cooper J, Black I, Peters M. Creating the sustainable supply chain: Modelling the key relationships. In: Banister D, editors. Transport Policy and the Environment. 1st ed. London: E & FN Spon; 1998. p.176-203.

[17] Björklund M. Influence from the business environment on environmental purchasing —Drivers and hinders of purchasing green transportation services. Journal of Purchasing and Supply Management 2011;17[1]:11-22.

[18] Halldórsson Á, Kovács G, Wolf C, Seuring S. Environmental impacts as buying criteria for third party logistical services. International Journal of Physical Distribution & Logistics Management. 2010;40[1/2]:84-102.

[19] Selviaridis K, Spring M. Third party logistics: a literature review and research agenda. The International Journal of Logistics Management. 2007;18[1]:125-150.

[20] Zhu Z, Hsu K, Lillie J. Outsourcing – a strategic move: The process and the ingredients for success. Management Decision 2001;39[5]:373-378.

[21] Keramydas C, Tsolakis N, Xanthopoulos A, Aidonis D. Selection and evaluation of 3PL providers: A conceptual decision-making framework. In: Folinas D, editors. Outsourcing Management for Supply Chain Operations and Logistics Service.1st ed. United States of America: IGI Global; 2012. p. 280.

[22] Aghazadeh S-M. How to choose an effective third party logistics provider. Management Research News. 2003;26[7]:50-58.

[23] Soh S. A decision model for evaluating third-party logistics providers using fuzzy analytic hierarchy process. African Journal of Business Management. 2010;4[3]:339-349.

[24] Jharkharia S, Shankar R. Selection of logistics service provider: An analytic network process [ANP] approach. Omega 2007;35[3]:274-289.

[25] Lehmusvaara A, Tuominen M, Korpela J. An integrated approach for truck carrier selection. International Journal of Logistics: Research and Applications. 1999;2[1]:5-20.

[26] Bansal A, Kumar P. 3PL selection using hybrid model of AHP-PROMETHEE. International Journal of Services and Operations Management. 2013;14[3]:373-397.

[27] Yayla AY, Oztekin A, Gumus AT, Gunasekaran A. A hybrid data analytic methodology for 3PL transportation provider evaluation using fuzzy multi-criteria decision making. International Journal of Production Research.2015;53[20]:6097-6113.

[28] Bansal A, Kumar P, Issar S, editors. 3PL selection: A multi-criteria decision making approach. Industrial Engineering and Engineering Management [IEEM], 2013 IEEE International Conference on; 2013 10-13 December 2013.

[29] Aguezzoul A. The third party logistics selection: A review of literature. In: Proceedings of the International Logistics and Supply Chain Congress; November 2007; Istanbul. Turkey: 2007. p. 7 <hal-00366527>

[30] Tranfield DR, Denyer D, Smart P. Towards a methodology for developing evidence-informed management knowledge by means of systematic review. British Journal of Management 2003;14:207-222.

[31] Briner RB, Denyer D. Systematic review and evidence synthesis as a practice and scholarship tool. Handbook of Evidence-Based Management: Companies, Classrooms and Research. 2012:112-129.

[32] Choudhary D, Madaan J, Narain R. An integrated decision model for selection of third party recovery facilitator [3PRF] for product recovery operations. Journal of Operations and Supply Chain Management. 2014;7[2]:37-58.

[33] Sasikumar P, Haq AN. Integration of closed loop distribution supply chain network and 3PRLP selection for the case of battery recycling. International Journal of Production Research 2010;49[11]:3363-3385.

[34] Zareinejad M, Javanmard H. Evaluation and selection of a third-party reverse logistics provider using ANP and IFG-MCDM methodology. Life Science Journal. 2013;10[6s]: 350-355.

[35] Efendigil T, Önüt S, Kongar E. A holistic approach for selecting a third-party reverse logistics provider in the presence of vagueness. Computers & Industrial Engineering 2008;54[2]:269-287.

[36] Saen RF. A new look at selecting third-party reverse logistics providers. Information Technologies, Methods, and Techniques of Supply Chain Management. 2012:246.

[37] Farzipoor Saen R. A mathematical model for selecting third-party reverse logistics providers. International Journal of Procurement Management. 2009;2[2]:180-190.

[38] Momeni E, Azadi M, Saen RF. Measuring the efficiency of third party reverse logistics provider in supply chain by multi objective additive network DEA model. International Journal of Shipping and Transport Logistics. 2015;7[1]:21-41.

[39] Saen R. A new model for selecting third-party reverse logistics providers in the presence of multiple dual-role factors. International Journal of Advanced Manufacturing Technology 2010;46[1-4]:405-410.

[40] Zhang R, Zhang H, Liu B. Selection of reverse-logistics servicer for electronic products with fuzzy comprehensive evaluation method. Grey Systems: Theory and Application. 2012;2[2]:207-216.

[41] Cheng Y-H, Lee F. Outsourcing reverse logistics of high-tech manufacturing firms by using a systematic decision-making approach: TFT-LCD sector in Taiwan. Industrial Marketing Management 2010;39[7]:1111-1119.

[42] Khodaverdi R, Hashemi SH. A grey-based decision-making approach for selecting a reverse logistics provider in a closed loop supply chain. International Journal of Management and Decision Making 2015;14[1]:32-43.

[43] Aguezzoul A. Third-party logistics selection problem: A literature review on criteria and methods. Omega 2014;49[0]:69-78.

[44] Cooper O, Tadikamalla P, Shang J. Selection of a third-party logistics provider: Capturing the interaction and influence of performance metrics with the analytical network process. Journal of Multi-Criteria Decision Analysis 2012;19[3-4]:115-128.

[45] Qureshi M, Kumar D, Kumar P. An integrated model to identify and classify the key criteria and their role in the assessment of 3PL services providers. Asia Pacific Journal of Marketing and Logistics. 2008;20[2]:227-249.

[46] Çakir E. Logistics outsourcing and selection of third party logistics service provider [3PL] via fuzzy AHP. Master Thesis from Institute of Science, Industrial Engineering, TC Bahceshir University, Istanbul; 2009.

[47] Liu H-T, Wang W-K. An integrated fuzzy approach for provider evaluation and selection in third-party logistics. Expert Systems with Applications. 2009;36[3, Part 1]: 4387-4398.

[48] Yan J, Chaudhry PE, Chaudhry SS. A model of a decision support system based on case-based reasoning for third-party logistics evaluation. Expert Systems 2003;20[4]: 196-207.

[49] Sahu NK, Datta S, Mahapatra SS. Decision making for selecting 3PL service provider using three parameter interval grey numbers. International Journal of Logistics Systems and Management. 2013;14[3]:261-297.

[50] Bottani E, Rizzi A. A fuzzy TOPSIS methodology to support outsourcing of logistics services. Supply Chain Management: An International Journal. 2006;11[4]:294-308.

[51] Kumar P. An integrated model of AHP and TOPSIS for 3PL evaluation. Asia Pacific Business Review. 2008;4[3]:14-21.

[52] Singh R, Shankar R, Kumar P, Singh RK. A fuzzy AHP and TOPSIS methodology to evaluate 3PL in a supply chain. Journal of Modelling in Management. 2012;7[3]:287-303.

[53] Thakkar J, Deshmukh S, Gupta A, Shankar R: Selection of third-party logistics [3PL]: A hybrid approach using interpretive structural modeling [ISM] and analytic network process [ANP]. Supply Chain Forum: An International Journal. 2005; 6[01]:38-46.

[54] Bourlakis M, Melewar T, Banomyong R, Supatn N. Selecting logistics providers in Thailand: A shippers' perspective. European Journal of Marketing 2011;45[3]:419-437.

[55] Aloini D, Dulmin R, Mininno V. A hybrid fuzzy-PROMETHEE method for logistics service selection: Design of a decision support tool. International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems. 2010;18[04]:345-369.

[56] Niestrój K. The conformity assessment of lead logistics provider and third party logistics preferences using analytic hierarchy process method [AHP]. Journal of Economics & Management/University of Economics in Katowice. 2013;[12]:61-74.

[57] Choy KL, Chow HK, Tan K, Chan C-K, Mok EC, Wang Q. Leveraging the supply chain flexibility of third party logistics–Hybrid knowledge-based system approach. Expert Systems with Applications. 2008;35[4]:1998-2016.

[58] Zhang H, Zhang G, Zhou B. Research on selection of the third-party logistics service providers. Integration and Innovation Orient to E-Society Volume 1. Springer; 2007. 211-221.

[59] Jianguo X, Zhong Q. The research on service quality influencing factors of the logistics enterprises based on gray relative analysis. Journal of Advanced Management Science. 2013;1[2]:236-240.

[60] Rajesh R, Pugazhendhi S, Muralidharan C, Ganesh K. Development of a composite model for selection of third party logistics service provider. International Journal of Electronic Customer Relationship Management. 2009;3[4]:375-401.

[61] Pang B, Bai S. An integrated fuzzy synthetic evaluation approach for supplier selection based on analytic network process. Journal of Intelligent Manufacturing 2013;24[1]: 163-174.

[62] Li D-F, Wan S-P. Fuzzy heterogeneous multiattribute decision making method for outsourcing provider selection. Expert Systems with Applications. 2014;41[6]: 3047-3059.

[63] Wang Y, Gao X, Yang L. Logistics outsourcing and selecting of logistics service provider of the e-commerce companies: A fuzzy TOPSIS approach. 2014.

[64] Kannan G, Pokharel S, Kumar PS. A hybrid approach using ISM and fuzzy TOPSIS for the selection of reverse logistics provider. Resources, Conservation and Recycling 2009;54[1]:28-36.

[65] Çatay B, Göl H. Logistics outsourcing and 3PL selection: A case study in an automotive supply chain. Supply Chain Management: An International Journal. 2007.

[66] Zhang H, Li X, Liu W. An AHP/DEA methodology for 3PL vendor selection in 4PL. Computer Supported Cooperative Work in Design II. Springer; 2006. 646-655.

[67] Singh Bhatti R, Kumar P, Kumar D. Analytical modeling of third party service provider selection in lead logistics provider environments. Journal of Modelling in Management. 2010;5[3]:275-286.

[68] Işıklar G, Alptekin E, Büyüközkan G. Application of a hybrid intelligent decision support model in logistics outsourcing. Computers & Operations Research 2007;34[12]: 3701-3714.

[69] Akman G, Baynal K. Logistics service provider Selection through an Integrated Fuzzy Multicriteria Decision Making Approach. Journal of Industrial Engineering.2014; 2014[article ID 794918]: 1-16. DOI:10.1155/2014/794918

[70] Zhi-hong Y, Qiang L, editors. The grey comprehensive evaluation model of a third-party reverse ligistics provider selection. Artificial Intelligence, 2009 JCAI'09 International Joint Conference on; 2009: IEEE.

[71] Li C, Sun Y, Du Y, editors. Selection of 3PL service suppliers using a fuzzy analytic network process. Control and Decision Conference, 2008 CCDC 2008 Chinese; 2008: IEEE.

[72] Leina Z, Tiejun P, Guoqing Y, editors. The process integration evaluation method of the fourth party logistics using fuzzy theory. Management of e-Commerce and e-Government [ICMeCG], 2010 Fourth International Conference on; 2010: IEEE.

[73] Hsu C-C, Liou JJH, Chuang Y-C. Integrating DANP and modified grey relation theory for the selection of an outsourcing provider. Expert Systems with Applications. 2013;40[6]:2297-2304.

[74] Xianlong G, Yujie G. Research on functional logistics provider selection based on QFD modeling. Journal of Applied Sciences 2013;13[17]:3563-3568.

[75] Huang J-D, Hu M, Wee H-M. Evaluation of lead logistics provider using the SMART Process: A case study in a Tiwan automotive industry. Operations and Supply Chain Management. 2013;6[1]:9.

[76] Göl H, Çatay B. Third-party logistics provider selection: Insights from a Turkish automotive company. Supply Chain Management: An International Journal. 2007;12[6]:379-384.

[77] S-h So, Kim J, Cheong K, Cho G. Evaluating the service quality of third-party logistics service providers using the analytic hierarchy process. JISTEM-Journal of Information Systems and Technology Management 2006;3[3]:261-270.

[78] Gupta R, Sachdeva A, Bhardwaj A. Selection of logistic service provider using fuzzy PROMETHEE for a cement industry. Journal of Manufacturing Technology Management 2012;23[7]:899-921.

[79] Yang I-z. A 3PL provider selection model for companies adopting a pro-active environmental strategy in the context of green supply chain management [Master]. National Central University; 2010.

[80] Govindan K, Grigore MC, Kannan D, editors. Ranking of third party logistics provider using fuzzy Electre II. Computers and Industrial Engineering [CIE], 40th International Conference on; 2010; Japan; 2010: IEEE.

[81] Kannan G, Murugesan P, Senthil P, Noorul Haq A. Multicriteria group decision making for the third party reverse logistics service provider in the supply chain model using fuzzy TOPSIS for transportation services. International Journal of Services, Technology and Management 2009;11[2]:162-181.

[82] Chiang Ziping, Tzeng G-H. A third party logistics provider for the best selection in fuzzy dynamic decision environments. International Journal of Fuzzy Systems. 2009;11[1]:9.

[83] Saen RF. A new model for ranking 3PL providers. Australian Journal of Basic and Applied Sciences 2010;4[8]:3762-3769.

[84] Gupta R, Sachdeva A, Bhardwaj A. A framework for the selection of logistic service provider using duzzy delphi and fuzzy topcis. In: Ao S-I, Amouzegar M, Rieger BB, editors. Intelligent Automation and Systems Engineering. Lecture Notes in Electrical Engineering. 103. New York: Springer; 2011. 189-202.

[85] Mehri S, Roghanian E, Khodadadzadeh T. A methodology for outsourcing resources in reverse logistics using fuzzy TOPSIS and fuzzy linear programming. Uncertain Supply Chain Management. 2013;1[2]:107-114.

[86] González-Benito J, González-Benito Ó. The role of stakeholder pressure and managerial values in the implementation of environmental logistics practices. International Journal of Production Research 2006;44[7]:1353-1373.

[87] De Brito MP, Dekker R. A framework for reverse logistics: Reverse logistics. Springer; 2004. 3-27.

[88] Yusuf I: Reverse logistics: an empirical study for operational framework. Proceedings of the Pakistan Academy of Sciences. 2013;50[3]:201-210.

[89] Pokharel S, Mutha A. Perspectives in reverse logistics: A review. Resources, Conservation and Recycling 2009;53[4]:175-182.

[90] Carter CR, Ellram LM. Reverse logistics: A review of the literature and framework for future investigation. Journal of Business Logistics. 1998;19[1]:85.

[91] Rogers DS, Tibben-Lembke R. An examination of reverse logistics practices. Journal of Business Logistics 2001;22[2]:129-148.

[92] Sbihi A, Eglese R. Combinatorial optimization and green logistics. 4OR. 2007;5[2]: 99-116.

[93] Hester R E, Harrison R M, editors. Environmental and health impact of solid waste management activities. 1st ed. Cambridge: The Royal Society of Chemistry; 2002. p. 171-182. DOI:10.1039/9781847550767

Chapter 3

Analysing the Adoption of Energy-Saving Technologies in Manufacturing Firms

Marc Pons, Josep Llach and Andrea Bikfalvi

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/62852

Abstract

The present book chapter aims to (i) map the adoption of energy-saving technologies (EST) in manufacturing and (ii) identify structural and operational characteristics that are expected to correlate with EST implementation. The empirical evidence is collected through the European Manufacturing Survey. The analysis presented corresponds to the Spanish subsample 2012 edition. Our main result points to a relatively low implementation of EST, also interpretable as a still unexploited potential these technologies have for manufacturers. Other main findings show (i) a relatively still modest implementation of most EST and (ii) a possible relationship between high implementation of EST and perceived energy efficiency as a consequence of implementation. The chapter draws implications for practice and research.

Keywords: energy-saving technology, energy efficiency, manufacturing, European Manufacturing Survey, Spain

1. Introduction

Sustainable development, meaning meeting the needs of present generations without jeopardising the ability of the future generations to meet their own needs [1], implicitly calls for an energy- and resource-efficient society, in which all pillars of the quadruple helix—academia, industry, government and citizens—are challenged to move towards energy and resource efficiency. Generating and enriching the current knowledge base by academia, implementing energy-efficient solutions and producing goods/services by companies towards this end, setting goals and promoting policy measures by local, regional, national and supranational bodies, as well as making informed choices by users/consumers are some of the generic musts towards sustainable societies.

Even some progress has already been made; new energy systems are gradually adapting, while the scale of challenge increases. Industrial activity, in particular, is reputedly a primary cause of pollution situating manufacturing firms in the centre of the focus. Nowadays, firms are facing strong pressure from their stakeholders to implement environmental management policies and practices. Moreover, the energy efficiency of the manufacturing processes is gaining importance due to the rising energy costs and the effects of the gas emissions over climate. From the perspective of manufacturers, the challenge is to improve the overall environmental performance of products throughout their life cycle and to boost the demand for better products and production technologies.

In one of the most recent studies on energy efficiency and saving potential in Europe-wide industry [2], the authors make a comprehensive study of the topic, using a sectoral approach as well as detecting barriers and policy measures towards further advances. Global results point towards market competitiveness remaining the strongest driver for energy-efficiency solutions, where the internal barriers to access energy-saving opportunities are not well understood. Another valuable finding is the taxonomy provided by the authors, distinguishing between a series of external and internal aspects that play an important hampering role in implementing energy efficiency and energy-saving potential. The same report calls for innovation as a catalyst towards more energy-efficient manufacturing.

Innovation is a key aspect and possible contributor towards novel solutions' implementation in order to achieve higher energy efficiency. Efforts should be deployed by the targeted promotion and commercialisation of existing solutions, as well as R&D support for emerging alternatives/technologies. The implementation of technologies in the production processes of manufacturing firms falls under process innovation typology.

Defined by the Oslo Manual [3] process, innovation is understood as 'the implementation of a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software' (p. 49). According to the same source, the main effects that process innovation might cause are: reduced time to respond to customer needs, improved quality of goods and services, improved flexibility of production or service provision, increased capacity of production or service provision, reduced unit labour costs, reduced consumption of materials and energy, reduced product design costs, reduced production lead times, achievement of industry technical standards, reduced operating costs for service provision, increased efficiency or speed of supplying and/or delivering goods or services, improved IT capabilities, improved communication and interaction among different business activities, increased sharing or transferring of knowledge with other organisations, increase in the ability to adapt to different client demands, development of stronger relationships with customers , improved working conditions, reduced environmental impacts or improved health and safety and meeting regulatory requirements (p. 108).

Monitoring particular, singular and specific energy efficiency technologies ultimately means the disposing of firm-level data in all manufacturing areas and in more than one country.

http://dx.doi.org/10.5772/62852

Regularly conducted large-scale surveys on innovation (see the Community Innovation Survey) are often multipurpose and remain conceptually global. Having argued the importance and possible benefits of energy-saving technologies (EST) as well as the lack of data on detailed and multiple technologies in manufacturing, we detect a possible gap worth filling with our contribution.

Therefore, the objective of this chapter is to map the implementation degree of energy-efficient technologies in manufacturing firms, as well as to identify and understand the structural and operational characteristics that are expected to introduce variations in adoption. The authors also link energy-efficient technologies with perceived saving potential. Using data from the European Manufacturing Survey, we argue the necessity to provide recent data on EST implementation

The chapter is structured as follows. After the introduction, we present the research methodology and methods used to analyse the characteristics of ESTs' adoption and their adopters. The results and findings are presented for the manufacturing firms with the use of descriptive statistics and simple correlation tests. Finally, we discuss our results and present some implications.

2. Methodology

Our research is based on data from the European Manufacturing Survey (EMS), 2012 edition [4]. EMS is coordinated by the Fraunhofer Institute for Systems and Innovation Research—ISI, which is the largest European survey in manufacturing activities conducted, to date.

The 2012 edition of the EMS was carried out in 19 countries, mainly the European ones including Russia and Turkey, plus PR of China and Brazil, covering the 70% of firms within the European manufacturing sector with at least 20 employees, NACE codes from 15 to 37 [5].

However, our study will only include data from EMS Spanish subsample, formed by 170 responses (**Table 1**). In this case, no other subsamples from additional countries have been included in order to analyse the major number of different available EST, given that the rest of the subsamples do not contain five of the ESTs kept in the Spanish one for the 2012 edition of the EMS. These five excluded technologies were considered for the 2008 edition of the EMS, but not for the 2012 one in the majority of the involved countries. This fact occurs because, apart from the main body of questions inside the survey, each participant country's partner can include a limited number of particular questions of its interest.

Universe	Spanish manufacturing firms with at least 20 employees CNAE 2009; codes from 10 to 32 16.183 companies
Target population	4000 firms
Sample	170 firms
Confidence margin	95%

Variance	Maximum indetermination $p = q = 50\%$
Documentation	Paper (8 pages questionnaire) + Return envelope + Presentation letter
Channel	Postal
Period conducting the survey	May–September 2012
Reference period	2009–2011; 2011
Fieldwork	OGEDP Department, University of Girona – Girona (Spain)
Data base recording and creation	DAP GmbH—Passau (Germany)
Sample distribution	
By technological sector	Low technology: 38; medium–low technology: 67; medium–high and high technology: 64 (59 + 5)
By relative energy efficiency group	Less efficient: 16; equal efficient: 50; more efficient: 71

Table 1. Technical details for the Spanish subsample of the European Manufacturing Survey 2012 edition.

In summary, the EMS 2012 Spanish subsample considers nine ESTs, which are as follows:

– T0: Dry process/Minimum lubrication; $N = 162$

– T1: Control system for shutdown of machines in off-peak periods; $N = 164$

– T2: Electrical motors with speed regulation; $N = 162$

– T3: Compressed air contracting; $N = 156$

– T4: Highly efficient pumps; $N = 158$

– T5: Low-temperature joining processes; $N = 157$

– T6: Energy retrieval; $N = 164$

– T7: Bigeneration/Trigeneration; $N = 167$

– T8: Use of waste materials for energy generation; $N = 157$

T0, T1, T6 and T7 are the ESTs included in the main body of the 2012 survey for all the countries, of which T0 was not included in the 2008 EMS edition. T2, T3, T4, T5 and T8 are only considered in EMS 2008 and the Spanish subsample of the EMS 2012.

All these ESTs are evaluated for each firm in terms of use, yes or no, and their extent of use, grouped in three categories: 'low' for initial attempts, 'medium', when partially utilised and 'high' for extensive use. This extent of use is represented with an ordinal variable containing values 1, 2 or 3, for low, medium or high, and it is always relative, comparing the present to the most reasonable potential use.

In the present study, the EST for this sample of firms will be characterised through descriptive and frequency analyses.

Another descriptive analysis will be presented for the companies inside the sample, including parameters such as number of employees, turnover in 2008 and 2011, firm R&D expenditures, exportation intensity, implementation of environmental management systems, such as ISO 14000 and ISO50001:200, and energy-saving potential according to the several elaborated homogenous groups, based on their technological intensity or their energy efficiency level. Averages for these descriptive parameters mentioned above were directly calculated from variables obtained from the survey.

In particular, the parameter of energy-saving potential becomes a key factor for our study, since it represents a measure of the energy efficiency degree resulting after different implementation levels of EST in manufacturing firms. In this sample, the energy-saving potential is represented by percent, and it corresponds to the relative amount of energy a company could save if it is highly implemented in its production system and in all the available EST nowadays.

Characteristics of EST adopters will be presented according to OECD's taxonomy of industries, classified by their technological intensity [**6**]. In this regard, firms have been classified and also presented in three groups: 'Low technology', for firms from NACE codes 15, 16, 17–19, 20–22, 36–37; 'Medium technology', with medium–low technology firms from NACE codes 23, 25, 26, 351, 27, 28; and 'High technology', with medium–high and high technology firms from NACE codes 24, 31, 34, excluding 2423, 352+359, 29, and 353, 2423, 30, 32, 33.

As shown in **Table 2**, only five firms of this sample have NACE codes 353, 2423, 30, 32 and 33, corresponding to a high technology industry. It is for this reason that medium–high and high technology firms from the OECD's taxonomy have been grouped together in a 'High technology' category ($N = 64$), in order to reduce the number of groups and maintain their significance.

	Low technology	**Medium–low technology**	**Medium–high and high technology**	**Total**
N	38	67	64 (59 + 5)	169
%	22%	40%	38%	100%
Number of employees in 2011, $N = 37 + 66 + 63$	97 ($\sigma = 107$)	112 ($\sigma = 165$)	276 ($\sigma = 820$)	171
Number of employees in 2009, $N = 36 + 63 + 61$	98 ($\sigma = 113$)	116 ($\sigma = 173$)	279 ($\sigma = 875$)	160
Turnover 2011 [M€], $N = 34 + 59 + 57$	44 ($\sigma = 70$)	188 ($\sigma = 893$)	183 ($\sigma = 747$)	154
Turnover 2009 [M€], $N = 31 + 57 + 55$	35 ($\sigma = 58$)	341 ($\sigma = 2381$)	224 ($\sigma = 1099$)	229
Firms with R&D expenditures, $N = 38 + 67 + 62$	53%	60%	61%	59%
High exportation intensity firms, $N = 35 + 60 + 57$	40%	48%	33%	41%
Firms with ISO 14000 implemented, $N = 37 + 61 + 57$	38%	36%	46%	40%
Firms with ISO50001:2001 implemented, $N = 36 + 63 + 59$	3%	2%	2%	2%

	Low technology	Medium–low technology	Medium–high and high technology	Total
Energy saving potential, $N = 29 + 54 + 54$	15%	13%	15%	14%
T0: dry process/minimum lubrication, $N = 36 + 65 + 61$	6%	15%	13%	12%
T1: control system for shut down of machines in off-peak periods, $N = 36 + 66 + 62$	14%	14%	23%	17%
T2: speed regulation, $N = 38 + 64 + 60$	76%	63%	72%	69%
T3: compressed air contracting, $N = 37 + 62 + 57$	38%	40%	44%	41%
T4: highly efficient pumps, $N = 37 + 63 + 58$	43%	30%	40%	37%
T5: low-temperature joining processes, $N = 36 + 62 + 59$	3%	15%	7%	9%
T6: energy retrieval, $N = 36 + 66 + 62$	14%	5%	18%	12%
T7: bigeneration/trigeneration, $N = 38 + 66 + 63$	24%	2%	10%	10%
T8: waste material for energy, $N = 36 + 63 + 58$	14%	5%	14%	10%

Table 2. Summary of descriptive features of the sample by technological intensity.

A discrete variable 'TechLevel', with value 1 for 'Low technology', value 2 for 'Medium technology' and value 3 for 'High technology', following the previously explained criteria, was calculated from the NACE code data for each firm in the survey. Corresponding dummy variables 'LowTech', 'MedTech' and 'HighTech', with values 0–1, were also elaborated to obtain three subsets of 38, 67 and 64 manufacturing companies, respectively, according to their technological level.

In a similar way, a second classification of firms in the sample, according to their relative energy efficiency level, was performed. To do that, a response in the survey regarding the potential energy saving in the company was utilised. Firms answered to a question on what percent of their current energy consumption could they save if they utilised all the available technical possibilities in the present.

Those percentages are represented by a variable in the survey that was used to elaborate three new dummy variables, 'Low Efficient', 'Equal Efficient' and 'More Efficient', with values 0–1. The purpose was to use these dummy variables to obtain three separated groups according to their relative energy efficiency level, comparing its present situation with a hypothetical stage where the company highly used all the available EST today.

To build these categories and collapse the continuous variable with percentage data into three approximately equal groups, a frequency analysis calculating percentiles at 33.33 and 66.66% was performed [7]. The obtained cut-off points for the percentiles 33.33 and 66.66% were 10 and 20%, respectively. In consequence, firms with a relatively low percent of energy-saving potential from 0 to 10% are considered in the 'More Efficient' group ($N = 71$). The reference group 'Equal Efficient' ($N = 50$) includes companies with relative energy-saving potential greater than 10% and lesser than 20%. The rest of the firms with relative energy-saving potential greater than 20% are included in the 'Less Efficient' group ($N = 16$).

Finally, in order to explore the possible relationships and their strength and direction (positive or negative) between several continuous and dichotomous variables describing firms' characteristics and the use or extent of use of ESTs, a simple bivariate Pearson correlation analysis has been conducted. When a positive correlation between a pair of variables is significant, it indicates that as one variable increases, so does the other. Analogously, a negative significant correlation indicates that as one variable increases, the other decreases.

Given that the data corresponding to the size of the companies in the survey do not follow a normal distribution, neither in the number of employees, nor in the case of the turnover, a transformation of these variables is required to use parametric statistics [7]. As these data in the histogram appear left-skewed, a recalculation, using the logarithm of the original values, has reset the histogram into a normal bell-shaped distribution.

Other mapping analyses were performed on the EMS 2008 edition Spanish samples, as in the case of [8], and from Spanish and Slovenian samples in [9]. Palcic et al. also mapped EST implementation in manufacturing firms, following a similar methodology.

3. Results and findings

3.1. Descriptive analysis

Results about the typology of the manufacturing firms in our sample, with regard to their technological intensity according to the OECD's taxonomy, are shown in **Table 2**.

We can observe that companies with higher technological level have, on average, a considerably higher number of employees (276 vs. 112 and 97 in 2011), a strong use of environmental management systems such as ISO 14000 [10], but a lower number of firms with a high exportation intensity (more than 50% of sales abroad).

'Medium–Low Technology' and 'High Technology' groups have higher number of companies with R&D expenditure compared with the low technology ones.

Firms in low technology industrial sectors also had an average turnover in 2009 and 2011, of less than a quarter of each one of the other two technological groups (35 vs. 341 and 224 M€ in 2009, and 44 vs. 188 and 183 M€ in 2011).

No significant differences can be observed with regard to energy-saving potential according to the firms' technological intensity. These averages of energy-saving potential for each technological group are represented by a percentage, with values between 13 and 15%.

With regard to the ESTs, according to each technological intensity group, we can stress that low technology firms have a relatively lower use of T0 but a higher use of T7, compared with other industrial sectors with higher technological intensity. 'Medium–Low technology' firms have a higher percentage of use of T5, and a lower percentage for T2, T4, T6, T7 and T8.

Companies in high technology sectors have a considerably higher percentage of use of T1 and a slightly higher one for T3. Percentage of use of T3 increases homogenously with the technology intensity of the sector.

In the case of MST (T9 and T10), their percentage of use decreases with the technology intensity of the sector.

Results about the typology of the manufacturing firms in our sample and their relative energy efficiency are shown in **Table 3**.

	Less efficient	Equally efficient	More efficient	Total
N	16	50	71	137
%	12%	36%	52%	100%
Number of employees in 2011, $N = 15 + 49 + 71$	83 ($\sigma = 75$)	136 ($\sigma = 289$)	236 ($\sigma = 755$)	171
Number of employees in 2009, $N = 14 + 49 + 68$	81 ($\sigma = 73$)	138 ($\sigma = 295$)	243 ($\sigma = 809$)	160
Turnover 2011 [M€], $N = 14 + 44 + 65$	19 ($\sigma = 21$)	41 ($\sigma = 55$)	137 ($\sigma = 519$)	154
Turnover 2009 [M€], $N = 13 + 44 + 63$	17 ($\sigma = 16$)	36 ($\sigma = 49$)	73 ($\sigma = 244$)	229
Firms with R&D expenditures, $N = 16 + 49 + 70$	63%	61%	58%	59%
High exportation intensity firms, $N = 16 + 45 + 65$	25%	33%	48%	41%
Firms with ISO 14000 implemented, $N = 16 + 47 + 64$	38%	47%	38%	40%
Firms with ISO50001:2001 implemented, $N = 16 + 47 + 65$	0%	2%	2%	2%
Energy saving potential, $N = 16 + 50 + 71$	32%	18%	7%	14%
Technology level (1–3 from low to high), $N = 16 + 50 + 71$	2.25	2.10	2.23	2.15
T0: dry process/minimum lubrication, $N = 15 + 50 + 67$	20%	6%	16%	12%
T1: control system for shutdown of machines in off-peak periods, $N = 16 + 50 + 67$	19%	22%	15%	17%
T2: speed regulation, $N = 16 + 49 + 71$	81%	78%	61%	69%
T3: compressed air contracting, $N = 16 + 47 + 67$	50%	38%	46%	41%
T4: highly efficient pumps, $N = 16 + 49 + 68$	50%	41%	38%	37%
T5: low-temperature joining processes, $N = 16 + 49 + 66$	19%	4%	11%	9%
T6: energy retrieval, $N = 16 + 50 + 68$	13%	20%	7%	12%
T7: bigeneration/trigeneration, $N = 16 + 50 + 69$	6%	12%	9%	10%
T8: waste material for energy, $N = 14 + 48 + 69$	7%	10%	10%	10%

Table 3. Summary of descriptive features of the sample by relative energy efficiency in production.

As it is observable in **Table 3**, companies with higher relative energy efficiency have, on average, a considerably higher number of employees (236 vs. 136 and 83 in 2011) and a considerably higher average turnover in 2009 and 2011, compared with the other two relative energy efficiency groups (73 vs. 36 and 17 M€ in 2009, and 137 vs. 41 and 19 M€ in 2011). Both, the average number of employees and the average turnover, are directly proportional to the relative energy efficiency level. The same effect occurs with the average exportation intensity (more than 50% of sales abroad) being significantly higher in the case of the more efficient group than in the other two groups (48 vs. 33% and 25%, respectively). On the other hand, the average of R&D expenditures is slightly higher in the lower relative energy efficiency groups.

The 'Equally Efficient' group has a higher percentage of firms with ISO14000 environmental management system. A very low percentage of firms have implemented ISO 50001:2001 (2%). The average relative energy saving is 7% for the group of 'More Efficient' firms, 18% for the 'Equally Efficient' group, and a 32% in the case of the 'Less Efficient' ones. On an average, manufacturing companies in Spain could have declared a 14% of relative potential energy saving.

In relation to the implemented ESTs according to each relative energy efficiency group, we can stress that firms in 'More Efficient' group have a relatively lower use of T8 but a higher use of T4, compared with other industrial companies in less relative energy efficiency groups. Firms in the 'Equally Efficient' group have a higher percentage of use of T1 and T7 and a lower percentage for T0, T3 and T5.

Companies in the 'Less Efficient' group have a considerably higher percentage of use of T4 and a slightly lower one for T8. Percentage of use of T4 decreases in groups with higher relative energy efficiency.

3.2. EST use and extent of use

In **Figure 1**, we can observe the use of the different analysed EST. In the first place, T2 is the most implemented EST with 69% of the companies in the sample; second comes T3 (with 41% and in the third place T4 with 37%).

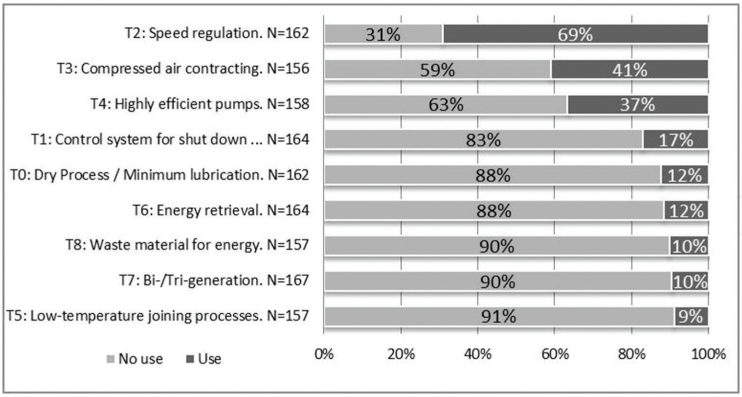


Figure 1. Use of EST for all manufacturing sectors.

The rest of the ESTs are implemented by a significantly lower percentage of the firms compared with the top ranked ones.

Furthermore, the most used EST, that is T2, has a considerably higher percentage of use than the rest of the ESTs. This fact could be caused by a wide interpretation of the concept 'electric motors with speed regulation', as almost any system producing movement or rotation powered by an electric motor with a basic speed control could be included in such category. The problem is that, sometimes, this is not an option for this system that could be considered an EST, but a mere intrinsic characteristic of these particular machines.

An exploration of the extent of use of each of these ESTs according to their degree of implementation, ranked from the highest to the lowest percentage for the 'High degree' group, is shown in **Figure 2**. The first effect perceived when studying the extent of use of the ESTs is the radical variation in the ranking for the group of firms that has an extensive use of ESTs and a perceptible reduction of the variance between percentages of high use.

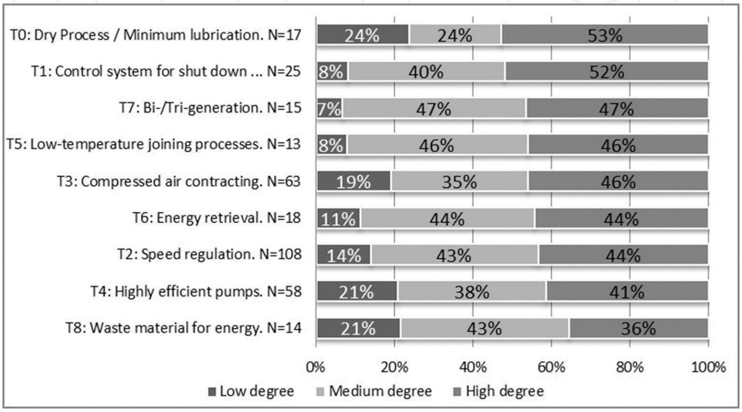


Figure 2. Degree of implementation of EST for all manufacturing sectors.

This effect also supports the idea stressed above, regarding a possible wide interpretation of the concept of T2 that now is in seventh position for the group of companies with higher level of implementation of ESTs. Only 14% of the companies declared an intensive use of this technology of the 69% that had declared its use.

T0 is the first EST in the ranking of high implementation with 53% of the firms that use it, followed by T1 with 52% and T7 with 47%.

Only 36% of the companies that use T8 declared an extensive use of it, representing the lowest percentage for the 'High degree' group.

3.3. ESTs implementation by firms' technology level

A classification of the companies that have implemented ESTs by technological sector is presented in **Figure 3**. The ESTs are ranked in the graphic, according to percentages in the 'High Tech' group.

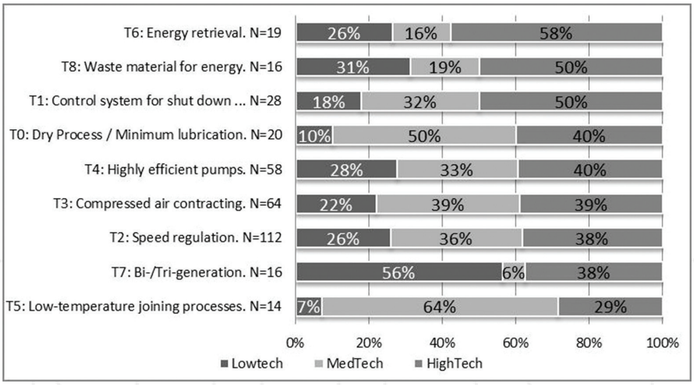


Figure 3. Implementation percentage of EST by technological sector.

Companies using T5 are mainly 57.9% of firms within the High Tech group. Moreover, 50% of the companies that have implemented T7 and T1 are the high technological ones.

T6 is implemented by 56.3% companies in the 'Low Tech' group. Only 7.1% and 10% of firms using T4 and T0, respectively, belong to the 'Low Tech' group, while 64% and 50% of the companies in the 'Med Tech' group, respectively, implemented these particular ESTs.

When the same classification is made, considering only an intensive use of the ESTs by technological levels in **Figure 4**, and also ordered according to the percentages in the High Tech' group, a new ranking is established.

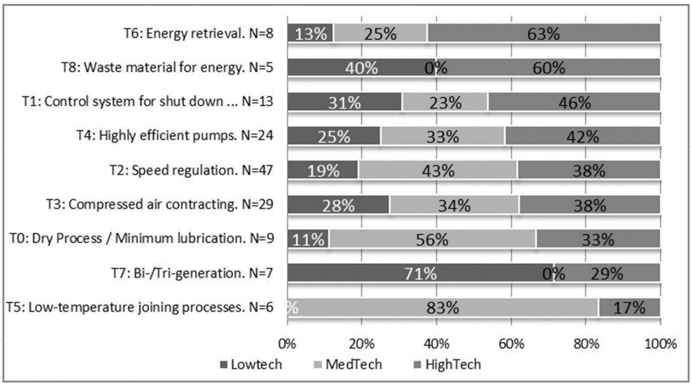


Figure 4. High implementation percentage of EST by technological sector.

About 63% and 60% of companies with an intensive use of T6 and T8, respectively, are firms within the 'High Tech' group. On the other hand, only 17% within this group highly implemented T5.

Otherwise, 71% of the companies that have an intensive use of T7 are the low technological ones. However, only 11% of firms using T0 belong to the 'Low Tech' group, and there is not any company in this group with a high implementation of T5.

T5 is implemented by 83% companies in the 'Med Tech' group; 56% of the intensive users of T0 also belong to this group.

3.4. ESTs' implementation by firms' relative energy efficiency group

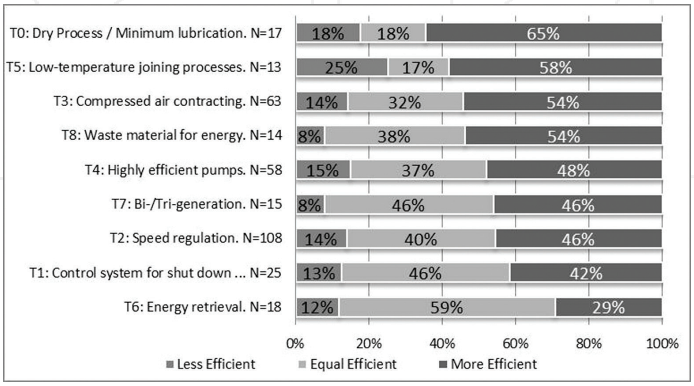


Figure 5. Implementation percentage of EST by level of efficiency relative to the energy-saving potential.

Results in **Figure 5** are obtained by classifying companies according to their relative energy efficiency level and ranking the percentages of the ESTs' use from the 'More Efficient' group.

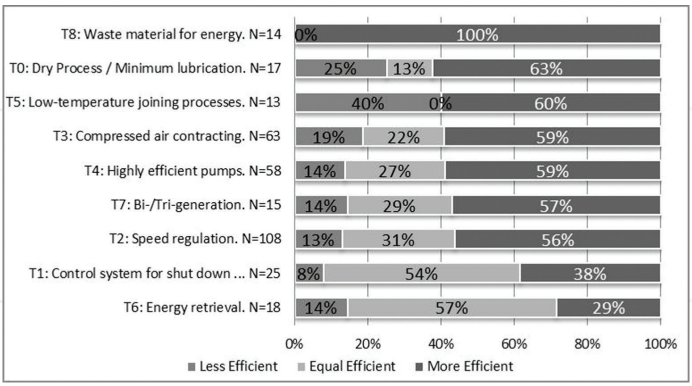


Figure 6. High implementation percentage of EST by level of efficiency relative to the energy-saving potential.

More than 50% of the companies implementing T0, T5, T3 and T8 belong to the 'More Efficient' group. Firms in the 'Less Efficient' group do not represent more than 25% of the companies

http://dx.doi.org/10.5772/62852

using any of the analysed ESTs. These results point to a probable relation between the use of ESTs and the relative energy efficiency of a company.

Results in **Figure 6** are obtained by analysing the same relative energy efficiency groups, considering only an intensive use of the ESTs.

Generally, the average percent in the intensive use of ESTs in the 'More Efficient' group is higher than that when considering only their use, apart from the cases of T0, T1 and T5 that are slightly lower, but quite close. In seven of the nine ESTs studied, the percentage of companies belonging to the 'More Efficient' group that have highly implemented them, represents more than 50% of the firms. Only companies in this group have highly implemented T8.

These facts suggest that a high implementation of the ESTs also contributes to the relative energy efficiency of manufacturing firms.

However, T6 and T1 are highly implemented at 57% and 54%, respectively, by companies in the 'Med Tech' group.

Possible relationships between use or high use of ESTs in manufacturing companies and other parameters such as technological level, size, environmental management systems implemented, export intensity, R&D expenditure and potential energy saving are presented in **Table 4**, by means of a correlation test.

		Number of EST implemented	**Number of EST highly implemented**	**Technology level**	**Firm size log 10 (turnover)**	**Firm size log 10 (employees)**	**ISO14031 implemented**	**ISO50001 implemented**	**High export intensity (>50% of sales)**	**R&D expenditure**	**Potential energy saving**
Number of EST implemented	Pearson correlation	1	0.713	.013	0.210	0.157	0.131	0.178	0.073	0.027	0.098
	Sig. (two-tailed)		0.000	0.864	0.010	0.044	0.105	0.025	0.375	0.728	0.253
	N	169	169	169	150	166	155	158	152	167	137
Number of EST highly implemented	Pearson correlation		1	0.001	0.208	0.14	0.049	0.05	0.027	0.099	–0.001
	Sig. (two-tailed)			0.985	0.011	0.070	0.541	0.530	0.743	0.205	0.987
	N		169	169	150	166	155	158	152	167	137
Technology level	Pearson correlation			1	0.12	0.160	0.069	–0.027	–0.070	0.015	0.019
	Sig. (two-tailed)				0.151	0.039	0.396	0.740	0.394	0.851	0.825
	N			169	150	166	155	158	152	167	137
Firm size log 10 (turnover)	Pearson correlation				1	0.632	0.344	0.14	0.005	0.113	–0.171
	Sig. (two-tailed)					0.000	0.000	0.094	0.958	0.170	0.059
	N				150	149	139	142	138	149	123
Firm size log 10 (employees)	Pearson correlation					1	0.378	0.05	–0.047	0.121	–0.132
	Sig. (two-tailed)						0.000	0.540	0.568	0.124	0.127
	N					166	153	155	150	164	135

		Number of EST implemented	Number of EST highly implemented	Technology level	Firm size log 10 (turnover)	Firm size log 10 (employees)	ISO14031 implemented	ISO50001 implemented	High export intensity (>50% of sales)	R&D expenditure	Potential energy saving
ISO14031 implemented	Pearson correlation						1.000	0.180	–0.061	0.100	–0.001
	Sig. (two-tailed)							0.027	0.474	0.215	0.994
	N						155	151	142	155	127
ISO50001 implemented	Pearson correlation							1	–0.024	–0.136	–0.077
	Sig. (two-tailed)								0.780	0.089	0.387
	N							158	143	158	128
High export intensity (>50% of sales)	Pearson correlation								1	0.084	–0.160
	Sig. (two-tailed)									0.307	0.074
	N								152	150	126
R&D expenditure	Pearson correlation									1	0.035
	Sig. (two-tailed)										0.684
	N									167	135
Potential energy saving	Pearson correlation										1
	Sig. (two-tailed)										
	N										137

**

Correlation is significant at the 0.01 level (two-tailed).

*

Correlation is significant at the 0.05 level (two-tailed).

Table 4. Correlation matrix between environmental management systems use, export intensity, R&D expenditure, potential energy saving and the use and high use of EST.

We can find different author criteria for the determination of the strength of relationships from the value of Pearson's correlation coefficient (r); however, Cohen [11] suggests the following guidelines that will be used in the present study: small strength for $|r|$ = 0.10–0.29; medium strength for $|r|$ = 0.30–0.49 and large strength for $|r|$ = 0.50–1.

The quantity of EST implemented in a company results in having a positive relationship with the firm size, in terms of turnover as well as number of employees, and with ISO50001:2001 implementation. This relationship is more significant (at 0.01 level; two-tailed) with respect to the company's turnover.

When the extent of use of these ESTs is considered, only a significant relation with its turnover remains at a medium level of strength.

Firms' technology level in our sample has only a light significant relationship with companies' size in terms of number of employees.

http://dx.doi.org/10.5772/62852

Firms' size, both in terms of turnover and in terms of number of employees, is also interrelated in a medium level of significance.

With regard to the environmental management systems, in the case of ISO14000 implementation, a medium level of strength relationship appears with the company size, both in terms of turnover and number of employees.

For the case of ISO50001:2001, there are small strength relationships with ISO14000 implementation and also with EST use.

High export intensity in companies and the existence of R&D expenditures are not linked with any other studied firms' characteristics according to this test.

Furthermore, and directly related to the main objectives of this study, no significant relationships are revealed between the relative potential energy saving and any other variable in the correlation, especially with the use and high use of ESTs.

In a previous study [12], a relationship was determined between the use, and mainly a high implementation level, of ESTs and energy efficiency in manufacturing firms.

For that reason, an additional Chi-square test is presented in **Table 5**. In this table, a crosstab is shown between the number of ESTs highly implemented in a firm and the relative potential energy saving, scaled according to the three energy efficiency groups: 'More Efficient' (value = 3), 'Equal Efficient' (value = 2) and 'Less Efficient' (value = 3). This test can be done between two categorical variables as is the case, and it allows the exploring of their possible relationship.

Crosstab					
		Relative potential energy saving (scaled in three groups)			
		1 (Less efficient)	**2 (Equal efficient)**	**3 (More efficient)**	**Total**
Sum high use EST0	Count	7	29	33	69
	Expected count	8.1	25.2	35.8	69.0
	% within sum high use EST	10.1	42.0	47.8	100.0
	% within potential saving scale	43.8	58.0	46.5	50.4
	% of total	5.1	21.2	24.1	50.4
1	Count	2	14	15	31
	Expected count	3.6	11.3	16.1	31.0
	% within sum high T0	6.5	45.2	48.4	100.0
	% within potential saving scale	12.5	28.0	21.1	22.6
	% of total	1.5	10.2	10.9	22.6
2	Count	5	2	14	21
	Expected count	2.5	7.7	10.9	21.0
	% within sum high use EST	23.8	9.5	66.7	100.0
	% within potential saving scale	31.3	4.0	19.7	15.3

Crosstab

		Relative potential energy saving (scaled in three groups)			
		1 (Less efficient)	**2 (Equal efficient)**	**3 (More efficient)**	**Total**
	% of total	3.6	1.5	10.2	15.3
3	Count	0	2	7	9
	Expected count	1.1	3.3	4.7	9.0
	% within sum high use EST	0.0	22.2	77.8	100.0
	% within potential saving scale	0.0%	4.0%	9.9%	6.6%
	% of total	0.0	1.5	5.1	6.6
4	Count	2	1	0	3
	Expected count	0.4	1.1	1.6	3.0
	% within sum high use EST	66.7	33.3	0.0	100.0
	% within potential saving scale	12.5	2.0	0.0	2.2
	% of total	1.5	0.7	0.0	2.2
5	Count	0	2	2	4
	Expected count	0.5	1.5	2.1	4.0
	% within sum high use EST	0.0	50.0	50.0	100.0
	% within potential saving scale	0.0	4.0	2.8	2.9
	% of total	0.0	1.5	1.5	2.9
Total	Count	16	50	71	137
	Expected count	16.0	50.0	71.0	137.0
	% within sum high use EST	11.7	36.5	51.8	100.0
	% within potential saving scale	100.0	100.0	100.0	100.0
	% of total	11.7	36.5	51.8	100.0

Chi-square tests

	Value	**df**	**Asymp. sig. (two-sided)**
Pearson Chi-square	22.812	10	0.011
Likelihood ratio	22.850	10	0.011
Linear-by-linear association	0.010	1	0.921
N of valid cases	137		

a.
11 cells (61.1%) have expected count less than 5. The minimum expected count is 0.35.

Table 5. Chi-square test crosstab between the number of highly used ESTs and the relative energy-efficiency group.

However, despite this, there exists a low significance in the relationship between these variables, as the Pearson Chi-square is 0.011 < 0.05, and the assumption required for this test concerning the minimum expected cell frequency of 5 or more in the 80% of the cases is not respected.

4. Conclusions

In the increasingly competitive and changing world, the use of EST has emerged as a strategic imperative for most companies, especially for the manufacturing firms, due to the progressively stricter legislation. Therefore, it is important to have an overall awareness of the current use of those technologies in order to establish future policies for encouraging a higher adoption.

In order to map the current situation of the degree of use of these ESTs in the manufacturing sector, this chapter provides evidences based on data from the 2012 European Manufacturing Survey edition. The case of the Spanish survey is specifically exceptional, since it is a national survey that includes the highest number of ESTs. In total, nine ESTs are included in the analysis. Moreover, the technology intensity variable and the self-elaborated parameter energy efficiency degree are also included in order to contrast their role in the energy-saving performance of the adopters. Finally, some control variables (number of employees, turnover in 2008 and 2011, firm R&D expenditures, high exportation intensity and implementation of environmental management systems such as ISO 14000 and ISO50001:2001) are also included. According to the results, five main conclusions can be formulated.

A general observation on the use of EST shows that their adoption in manufacturing firms is still relatively low. Except for the case of speed regulation (T2, 69.1%), possibly due to a wide interpretation of the term, the technology with the highest percentage of adoption is compressed air contracting (T3, 41%). However, it is interesting to point out how these results vary according to the degree of implantation. Dry process/minimum lubrication (T0) and control system for the shutdown of machines in off-peak periods (T1) are the technologies with the highest degree of implementation, both over 50%.

Second, it has been observed that the more relative energy-efficient companies are, on average, characterised as relatively bigger, both in terms of turnover and number of employees, than the equal and less efficient ones. This group of companies also has a higher average of export intensity (more than 50% of sales abroad). However, R&D expenditures are, on average, higher in the less relative energy-efficient group of firms, and the equal relative energy-efficient group is the one with a higher percentage of environmental management systems implemented.

Third, according to the technology intensity, six out of nine ESTs are implemented higher in low and medium–low technology sectors. Only the control system for shutdown of machines in off-peak periods (T1, 23%), compressed air contracting (T3, 44%) and energy retrieval (T6, 18%) are implemented higher in the group of high technology firms.

Fourth, the results are more significant when the degree of adoption is contrasted with the energy efficiency of the firm, since none of the ESTs are mostly adopted by firms that declare being more efficient than the other firms of the sector. Five ESTs are mostly implemented in less efficient group and four in the equally efficient group.

Fifth, in analysing ESTs, we focused on manufacturing firms that showed high implementation of these technologies. We have analysed these technologies according to their use in different technology-intensive sectors and based on the energy efficiency of the firms. We found that the analysed ESTs are predominately highly implemented in low and medium–low technology groups, except for two technologies, namely, waste material for energy (T8) and energy retrieval (T6). However, we could discard the significance of these ESTs, since the number of adopters is very low. Therefore, we could conclude that most of the highest implemented ESTs are more usual in sectors of low technology, confirming the same conclusion obtained when we generalised for all degrees of implementation. On the other hand, in seven out of nine ESTs studied, a high implementation of these ESTs occurs in the majority of the cases inside the more efficient group of companies. This fact could suggest a possible positive relationship between the high use of ESTs and firms' energy efficiency. However, this potential relationship has not been demonstrated for this sample with the Pearson correlation and Chi-square analysis.

Our research has two main limitations: the statistical analysis applied and the geographical scope of the sample. The first is that only descriptive statistics and correlation tests were used to map the characteristics of EST and their adopters. Therefore, the next step is to use several advanced statistical methods to draw further conclusions. Related to the narrow geographical coverage, the option to focus our analysis on the Spanish survey is explained by the fact of having higher number of technologies. Practical and academic implications of having detailed, single and high number of ESTs convert into a strong argument towards a shared list of such ESTs, which remains further explorable in forthcoming EMS rounds.

In conclusion, this study contributes to disclose to practitioners that Spanish manufacturing companies are recognised to have, on an average, 14% of relative energy-saving potential. It has also been illustrated which ones of these ESTs are the most implemented for each firm typology, in terms of use and extent of use. Moreover, firms have been characterised according to the relative energy efficiency groups to facilitate policy makers to take the right decisions, oriented to improve the energy efficiency in these sectors. Some clues have been pointed at for further researches in order to explore the possible relationships between energy efficiency and the implementation of ESTs, using more powerful statistical tools.

Acknowledgements

The authors are grateful for the financial support from the University of Girona (Spain) MPCUdG2016/093.

Author details

Marc Pons*, Josep Llach and Andrea Bikfalvi

*Address all correspondence to: marc.pons@udg.edu

Department of Business Administration and Product Design, Department of Business Administration and Product Design, University of Girona, Girona, Spain

References

[1] European Commission. (2015, September) *Sustainable development*. [Online]. Available from http://ec.europa.eu/environment/eussd/

[2] ICF Consulting Limited. (2015, December) *Study on energy efficiency and energy saving potential in industry and on possible policy mechanisms*. [Online]. Available from https://ec.europa.eu/energy/sites/ener/files/documents/151201%20DG%20ENER%20Industrial%20EE%20study%20-%20final%20report_clean_stc.pdf

[3] OECD, European Commission – Eurostat. (2005) *Oslo manual*. [Online]. Available from http://www.oecd.org/sti/inno/2367580.pdf

[4] ISI. (2016) *Project EMS*. [Online]. Available from http://www.isi.fraunhofer.de/isi-en/i/projekte/fems.php

[5] L. Christian (2014, December) *European Manufacturing Survey (EMS)*. [Online]. Fraunhofer Institute ISI. Available from https://ec.europa.eu/growth/tools-databases/regional-innovation-monitor/sites/default/files/report/European%20Manufacturing%20Survey.pdf

[6] OECD (2005) *Directorate for Science, Technology and Industry, stan indicators (2005 ed.): 1980–2003*. [Online]. Available from http://www.oecd.org/industry/industryandglobalisation/40230754.pdf

[7] B.G. Tabachnick and L.S. Fidell, *Using Multivariate Statistics (3rd ed.)*. New Nork, NY: Harper Collins, 1996.

[8] J. Llach, A. Bikfalvi, and R. de Castro, "The use and impact of technology in factory environments," *International Journal of Advanced Manufacturing Technologies (2010)*, Vol. 47, Issue 1, pp. 181–190, 2009.

[9] I. Palcic, M. Pons, A. Bikfalvi, J. Llach, and B. Buchmeister, "Analysing energy and material saving technologies' adoption and adopters," *Journal of Mechanical Engineering*, vol. 6, no. 59, pp. 409–417, 2013.

[10] ISO 14000, *Environmental management - The ISO 14000 family of internationsl Standards*. Geneva: International Organization for Standarization, 2004.

[11] J. Cohen, *Statistical Power Analysis for the Behavioral Sciences (2nd ed.)*. Hillsdale, NJ: Lawrence Erlbaum Associates, Publishers, 1998.

[12] M. Pons, A. Bikfalvi, J. Llach, and I. Palcic, "Exploring the impact of energy efficiency technologies on manufacturing firm performance," *Journal of Cleaner Production*, vol. 52, pp. 134–144, 2013.

Chapter 4

Fuel Cell as Range Extender in Battery Electric Vehicles for Supply Chain Fleets

Javier De La Cruz Soto and Ulises Cano Castillo

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/62792

Abstract

The aim of this chapter is to present an outlook about implementation of a range extender system based on fuel cells for battery electric vehicles. Such a system is highly feasible to be implemented in electric vehicles, in particular those used by beverage industry in city centres. The tourism is another industry that uses electric vehicles, for instance in resorts, hotels, airports, zoos, etc. As well, public transportation is another sector involved with this vehicular technology. These sectors are all the time looking for high efficiency and low costs; however, they also need to extend the range of the vehicles to fulfill some logistics requirements in a route. This chapter presents a numerical example for illustrating an implementation of fuel cell range extender system. Advantages, disadvantages, and business opportunities in fuel cell technology are presented.

Keywords: fuel cells, range extender, electric vehicles, supply chains, utility cars, renewable energies

1. Fuel cell overview

In the beginning of 2016, the Fuel Cell Technologies Office of the US Department of Energy (DOE) released its 2015 recapitulation on the advances on fuel cells and related application technologies.[1] Fuel cells are electrochemical devices, similar to batteries, that convert the chemical energy of a compound (i.e.) directly into electricity; therefore they are electricity generators. The

[1] It is well recognized that DOE's technology and economic goals are taken as serious global reference for those involved and interested in advanced technologies, such as fuel cells, that can bring promising alternatives for the transportation sector. (Fuel Cell Technologies Office: 2015 Recap and the Year Ahead, email news service sent to authors and generated on behalf of the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy).

main difference of a fuel cell, compared to a battery, is that the fuel is stored outside the fuel cell and is continuously fed to the generator. As the fuel is physically stored in a tank, there is no need to recharge the fuel cell but instead the fuel tank is refilled, which only takes a few minutes. In spite of the cost needed to produce it and store it, the preferred fuel for transportation fuel cells is compressed hydrogen gas. Hydrogen has almost three times more energy[2] (33.33 kWh/kg) than gasoline (≈12.0 kWh/kg) per unit mass and when fed to a fuel cell, the energy conversion efficiency for electricity generation is much higher (up to 60%) compared to internal combustion engines. Besides, when using hydrogen as a fuel, the only emission is pure water and some heat.

DOE's communication highlights several recent accomplishment but what stands out as the "most notable" fact is the availability today of commercial personal vehicles by Toyota and Honda using fuel cells technology. Using fuel cells in a car means electrical traction (electric transportation) with zero emissions, similar or larger range compared to conventional gasoline cars and the possibility of having a replacement for gasoline, i.e. hydrogen fuel. What is also interesting about hydrogen is that although it does not exist freely in nature, it is contained in several available compounds, notably in water. Besides, when combined with renewable energy sources for its production, for example via electrolysis, hydrogen becomes a sustainable and clean fuel for energy use.

The same way gasoline is an added value product, hydrogen is also seen as an energy carrier once produced and stored, an important fact is that its availability can be seen as the other attractive side of the fuel cells business.

Besides these two car companies, other international car manufacturers have fuel cell cars programs with the intention of selling them in the near future. Beyond recognizing a car market of more than 82 million cars sold annually according to consulting firm IHS Automotive [1], is that the automotive industry will have to renew its infrastructure industry, including its value and supply chains, as fuel cell cars are completely different from conventional cars in its components. Instead of an internal combustion engine, FC cars have an electricity generator which is coupled to an electric motor that provides power for traction. To properly operate, the electric motor will require power electronics to condition the unregulated d.c. voltage electricity coming from the fuel cell. Fuel cell devices are a completely different technology from what we know now, they incorporate electrochemical engineering components like electrodes, electrolytes, electric and structural pieces that give rise to a brand new industry. Fuel cells as generators will need its own balance of plant (BOP), which will keep the fuel cell operation at a level that ensures power delivery as specified. BOP components include gas valves, fuel piping, sensors, and activated elements, supervised by an electronic control. Such electronic control takes care of variables such as fuel pressure and flow, fuel cell temperature, oxidant (typically air) flow into the fuel cell, and a very complex balance of water content inside the system produced by the reaction and that is needed to lower electrolyte resistance but if abundant it may lower power production.

[2] Hydrogen lower heating value, taken as reference from *HyWeb The Hydrogen and Fuel Cell Information System*, managed by Ludwig-Böw-Systemtechnik GmbH, Germany

http://dx.doi.org/10.5772/62792

If the car industry is going to switch to electric cars as the main technology and where probably fuel cells are the preferred choice, then car manufacturers will need to change their actual production line based on mechanical and thermal components to a more chemical engineering and electric/electronics-like industry.

As the fuel cell industry has consistently grown in the last few years at a 30% rate and with more than 50,000 fuel cells totaling over 180 MW capacity shipped in 2014, that amounts sales of more than $2.2 billion that year, this technology is being reaching maturity with an undeniable impact in energy markets, including transportation and definitely in our society.

While the latter is true, the economics still depend on the production volume to approach competitive targets, at least in the transportation sector, particularly personal mobility vehicles. An example of this is that state-of-the-art fuel cell system technology is projected to reach a cost of $55/kW at a volume of 500,000 units per annum (upa) or $270/kW at 20,000 upa. On the fuel side of the story, high-volume cost projections for 700 bar compressed hydrogen storage systems based on composite materials are $15/kWh. This gives an idea of what the retail costs can be when fuel cell-based vehicles are introduced in the transportation market.

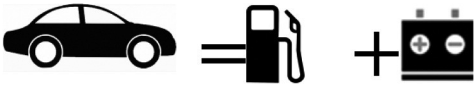
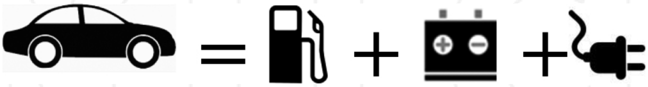
Another subsector in transportation is the utility vehicles market that covers a large proportion of vehicles sold in the world. In this subsector, costs are a second priority against productivity. An example of this is the possibility of extending the range or the number of hours of operation of utility vehicles such as forklifts, auxiliary vehicles at airport operations. A similar situation presents when we talk about backup systems that increase reliability to critical operations like banks, hospitals, data handling centers, among other industries. It is important to mention that the economic activities and investment opportunities go beyond the final sale of a fuel cell system. The application of fuel cell technologies also represents the need for value chains, especial technical services, new tools and instruments, as well as protocols during services, new components specifically dedicated to the application. Examples are power electronics, sensors, new fuel storage systems, their testing, etc. There is no doubt that the introduction or now arrival of these technologies means a varied range of opportunities for new businesses.

2. Classification of electric vehicles

A typical classification of the electric vehicles is illustrated in **Table 1**, as well some main features of each [2].

This chapter deals with the implementation of a range extender system in a BEV, which means in practical terms that a BEV is converted to an FCEV. The typical powertrain of an FCEV is shown in **Figure 1**.

The fuel cell is connected to the inverter (DC-AC converter) through a DC-DC converter; meanwhile, the battery bank is directly connected to the inverter. The traction motor is driven by both power sources to provide mechanical power to the tires.

Hybrid electric vehicles (HEVs)

HEV uses a battery-powered electric motor to supplement its traditional combustion engine. The electrical system acts as a generator when a driver applies the brakes, converting kinetic energy into electrical energy. Combustion engine is still the primary motor. At low speed the vehicle operates with zero emissions.
Plug-in hybrid electric vehicles (PHEVs)

A PHEV operates similar to a HEV. However, it utilizes a larger battery bank that can be recharged by plugging the vehicle into an electrical outlet or charging station. After the battery energy is exhausted, the engine starts and the vehicle acts like a normal HEV.
Battery electric vehicles (BEVs)

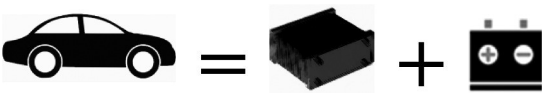
The BEV operates a 100% with the battery bank. They do not include a combustion engine and rely solely on their electric motor for propulsion.
Fuel cell electric vehicles (FCEVs)

The FCEV operates with a fuel cell as the main power source. The energy comes to the hydrogen tank. The batteries are used to absorb high peaks of currents, while fuel cell provides the principal energy requirement.

Table 1. Classification of electric vehicles

In the electrical vehicle classifications, BEV is one of the most supported by governments, in particular in china [3], because this vehicle has not an internal combustion engine to its operation. Therefore, there are no emissions in site. However, some important issues that limit the use of the BEVs are charging time and range of the vehicle [4]. Especially, when these vehicles are in a daily regimen of operation. A solution to overcome those issues is to install a fuel cell pack as the main power source of the vehicle. Unlike batteries, fuel cell systems can recharge the energy (hydrogen) in a few minutes. Fuel cell systems can reach a range similar to the internal combustion engine car, because the range depends of the hydrogen tank and as it was mentioned in Section 1, hydrogen has three times more energy than gasoline.

http://dx.doi.org/10.5772/62792

Table 2 shows the range of some BEVs, PHEVs, and an HEV [5]. The range for a BEVs is between 110 and 334 km. For PHEVs, the range is between 18 and 61 km, and the range for a HEV is 2 km.

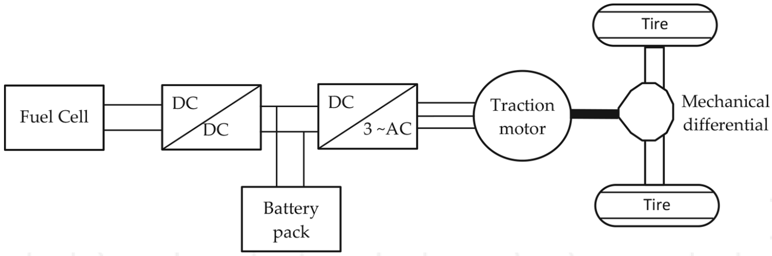


Figure 1. Typical powertrain for a FCEV.

	Type	EPA car class	Battery type	Energy storage	All-electric driving range	Full charge
Tesla Model S	BEV	Large	Li-ion	60 kWh	334 km	1 hour
BMW i3	BEV	Compact	Li-ion	18.8 kWh	128–160 km	3–6 hours
Chevrolet Spark	BEV	Compact	Li-ion	21 kWh	132 km	7 hours
Chevrolet Volt	PHEV	Mid-size	Li-ion	16.5 kWh	61 km	4 hours
Nissan Leaf S	BEV	Mid-size	Li-ion	24 kWh	135 km	4 hours
Toyota Prius Plug-in	PHEV	Mid-size	Li-ion	4.4 kWh	18 km	1.5 hours
Toyota Prius	HEV	Mid-size	Ni-MH	1.3 kWh	2 km	N/A
Ford Focus Electric	BEV	Large	Li-ion	23 kWh	122 km	3.6 hours
Honda Fit EV	BEV	Mid-size	Li-ion	20 kWh	132 km	3 hours
Smart for Two Electric	BEV	Two-seaters	Li-ion	17.6 kWh	110 km	6 hours

EPA car class: The United States Environmental Protection Agency (EPA) has developed a classification scheme used to compare fuel economy among similar vehicles. Passenger vehicles are classified based on a vehicle's total interior passenger and cargo volumes.

Table 2. Battery specifications of 2014 electric vehicles.

3. Electric vehicle fleets in sustainable supply chain

Since many years ago, there are companies taking advantage of features offered by electric vehicles. Just to mention a few, they are zero emissions, low noise, and low maintenance. These features make this kind of vehicle the most convenient to distribute products related with the beverage industry or any other in city centres. There are also other sectors like hotels, airports, zoos, resort, etc., where this kind of vehicle is widely used.

Some advantages that make this kind of vehicle a good alternative are listed below:

- *No emissions:* Many times, this is the main reason why industries decide to include electric vehicles in delivery process. Electric cars produce zero emissions on site, but emissions are at energy productions sites, but if energy is obtained by renewable sources, in practical terms, there aren't emissions.
- *Low maintenance*: An electric motor has lesser pieces in movement, in related with an internal combustion engine. Therefore, electric motor needs less lubrication and maintenance.
- *Lower noise production:* Electric motors have the capability of providing smooth drive with higher acceleration.

But also some disadvantages of electric vehicles are listed next:

- *Power source replacement:* It depends on the power source type, but in general terms, electric power sources (batteries and fuel cells) must be changed every 3–10 years.
- *Recharge points:* Both electric and hydrogen fuelling stations are not still in everywhere. Many efforts have to be done to install recharge points.
- *Recharge time:* Recharge time usually is an inconvenience in batteries because they need about 4–6 hours. But hydrogen recharge in fuel cells takes only few minutes.

The automotive industry, as one of the largest industries worldwide, has a big influence in the emission balance. The electric vehicles fleets for delivery goods purpose are a small portion of automotive market. However, this market is still growing due the advantages described before and many incentives like tax reduction, among others.

Several important companies in worldwide beverage industry, like Coca-Cola and PepsiCo, have electric vehicles fleets in their portfolio. It allows them, in addition to make more sustainable their process, deliver its products avoiding some restriction for driving in downtown of several cities.

Sustainability for such companies' represents not only an economic or environmental issue to deal with but also a regulation issue, because even when emission is a problem in big cities, not always they have constraints for movements of vehicles. When movement is a constraint, the only way to carry out many commercial activities is using electric vehicles.

In **Figure 2** is presented a general flowchart of supply chain delivery process used in the beverage industry. The process starts with the production of the syrup or some other raw material. Next, this raw material is used in the plant to filling the bottles. As is well known, bottling plants are in specific zones to provide the product for several cities. The bottled products are sent to distribution centers to conduct the supplying in the city. From distribution centers, the product is sent to supermarkets and many other points of sale (groceries, restaurants, etc.) in the city. Finally, the consumer goes to these places to buy the product.

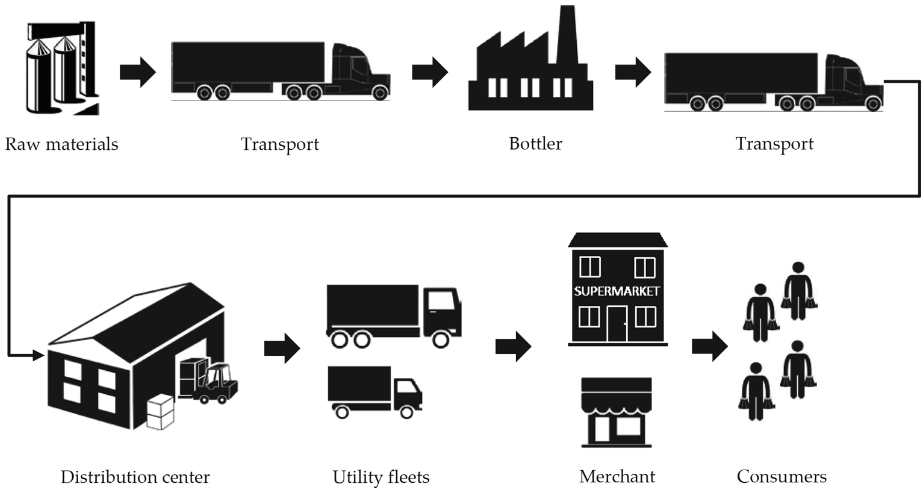


Figure 2. General supply chain in beverage industry.

The stage that we study in this supply chain is where utility vehicles fleets are used. In particular, we are going to evaluate the implementation of a fuel cell range extender system, taking into account that electric cars are used in this stage. As we mention before, many companies are using electric cars, among other things, to make sustainable their supply chain. However, there are some downsides like recharge time and range that must be addressed to overcome it. A highly efficient and friendly environmental solution is the implementation of a range extender based on fuel cells.

3.1. Market for electric vehicles

There is a wide size range of electric vehicles. For example, there are golf cars from about 500 kg, cars of 1200 kg, or heavy utility trucks of 12,000 kg. **Figure 3** illustrates those vehicles.

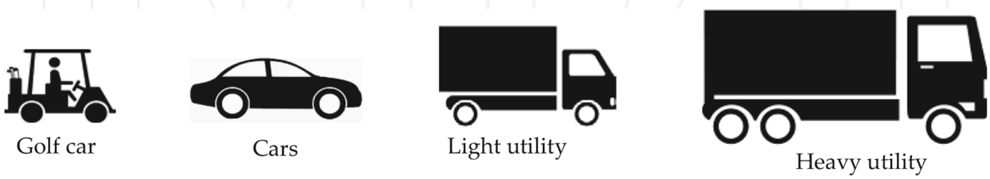


Figure 3. Electric vehicles.

An electric car type "Golf cars" is also usually used in places like airports or zoos. Cars are mainly used for personal transportation. Utility cars are used by companies for commercial purposes. The size of these cars depend on the specific application.

The next section presents a numerical example for a range extender system based in a fuel cell for a BEV. Some economical and technical issues related with such a system are shown.

4. Case study for a range extender

4.1. Methodology

This section presents a case of study of a BEV, in which as a proposal, the power source is modified to increase its range. For this purpose, a PEM fuel cell is dimensioned in such a way that the car is turned from a BEV to an FCEV. The processes for estimating it is conducted through a tool developed at Electrical Research Institute (IIE) and its flowchart is depicted in **Figure 4**.

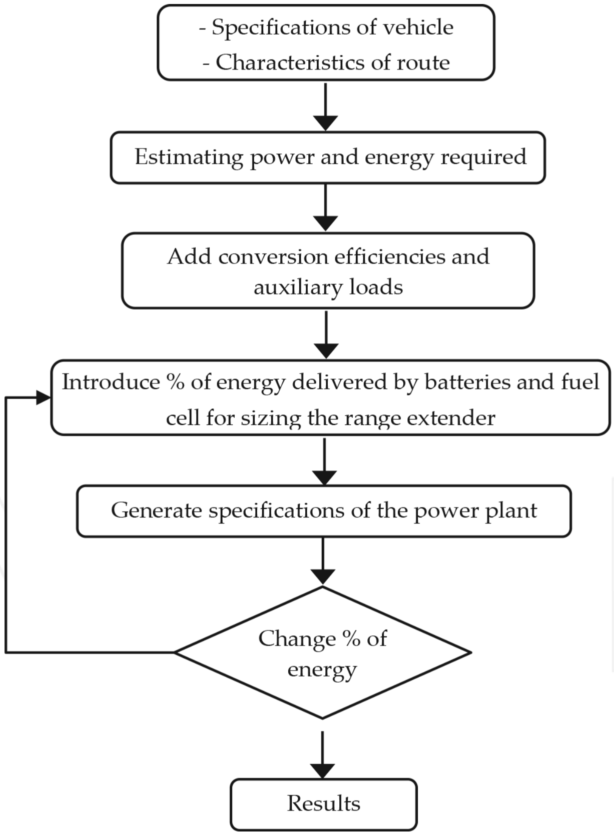


Figure 4. Flowchart to estimate a range extender based on fuel cell.

To conduct the study, first it is necessary to define some characteristics of the vehicle, like dimensions, weight, frictional coefficient, rolling resistance, etc. At the same time, the route is defined to evaluate the vehicle's performance. Next, the power and energy required in the vehicle power plant is calculated. Then, the conversion efficiencies of electronic and mechanical elements are added, as well as the auxiliary loads. It is important to take into account the foregoing to obtain a better estimation of the energy required for the power plant. After that, the specifications of the power plant based on batteries are generated. As a result, useful information such as weight, cost, volume,is shown The developed tool allows us also to estimate the size of the range extender system. For this purpose, we use the percentage of energy required from the battery bank and the fuel cells. We do it using both current and future prices of fuel cells. In summary, three cases of study were conducted. Finally, some conclusions are depicted to compare the performance of the vehicle using batteries and the range extender (batteries + fuel cells).

4.2. Cases of study

4.2.1. Characteristic of vehicle

For starting, this study defined the vehicle's characteristics and the route. While more information is used, results will be closer to a real operation. For this study, the vehicle information shown in **Table 3** is used.

Data	**Value**
Maximum height	1.82 m
Maximum width	1.2 m
Maximum length	3.0 m
Drag coefficient	0.80
Frontal area	2.18 m^2
Overall weight	700 kg
Rolling resistance coefficient	0.015

Table 3. Vehicle information

The characteristics described in **Table 3** are similar to the features of electric vehicles that are usually used in beverage industry fleets for distributing their products in city centres.

4.2.2. Characteristic of the route

The main concern of this chapter is the evaluation of range extender system, as well its impacts in supply chains; we used a simple route consisting of 32 km to be covered in 5.7 hours. This route consists of a first trip of 4 km, then, there are 60 delivery points where the vehicle stays

5 minutes in each. Finally, there is a trip of 4 km until the starting point. **Figure 5** depicts the characteristics along the route, in terms of distance and vehicle's speed.

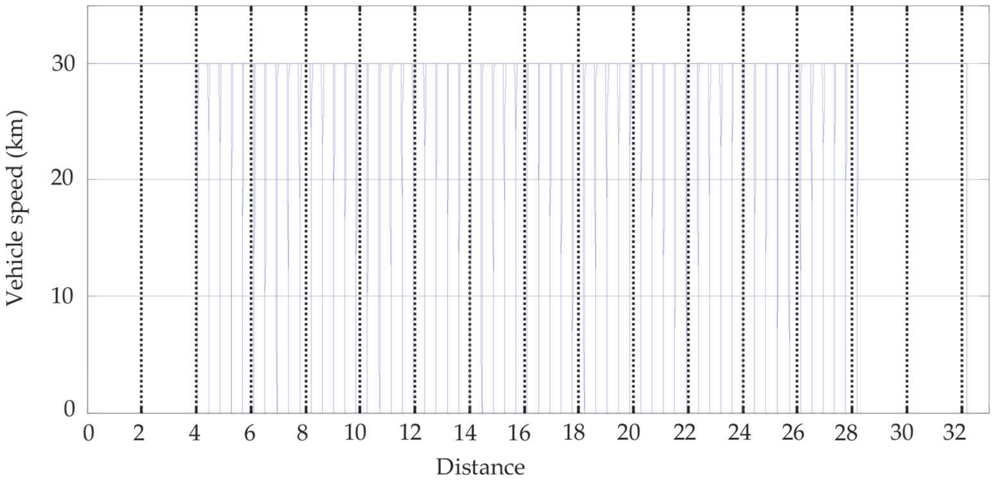


Figure 5. Speed along the route.

It is important to highlight that many other issues could be included in this analysis, like regeneration breaking system, as well a more specific route. However, it will depend on the specific system to be evaluated. Therefore, results presented in next section correspond to a scenario created to show the capabilities of the tool and issues related to the fuel cell range extender, to fulfill logistic requirements in some electric vehicles that frequently are used in a supply chain fleet.

4.2.3. Case studies description

Case	**Power plant**	**Net energy delivered by source (%)**	
Batteries	**Fuel cells**		
1	Current	100	0
2	Current	7	93
3	Future[a]	7	93

[a]Over a mass production rate of 20,000 units per year [6].

Table 4. Description of case studies

According to the information in **Table 4**, three case studies were conducted. Additional to this information, a conversion efficiency of 95% for motor controller (DC/AC) and DC-DC converter, 95% for electric motor, and 90% for mechanical differential were used, see **Figure 1**. In

http://dx.doi.org/10.5772/62792

the first case, the vehicle travels 32 km according to the route. However, in cases 2 and 3, the vehicle also travels 32 km but it has the availability for incrementing the delivery points from 60 to 120, according to the energy reserve in the battery bank.

4.2.4. Specification of power plants and results

Until now, there is enough information for sizing the power source in the vehicle. For this purpose, we used the physical characteristic of the vehicle described in **Table 2**, the speed illustrated in **Figure 5**, as well the efficiency values of electro-mechanical elements in the vehicle. As a result, Figure 6 shows the power demand along the route. The energy required for the power plant for this specific route corresponds to 2.2 kWh (kilowatt hour).

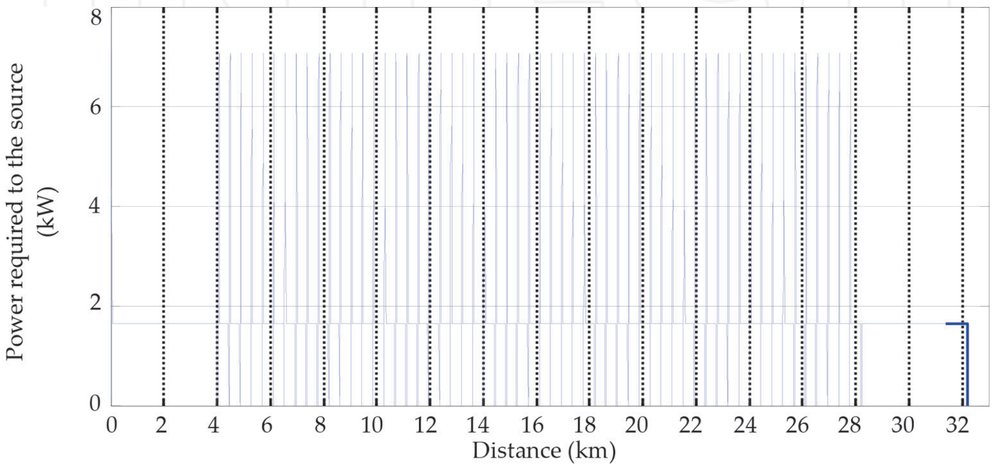


Figure 6. Distance vs power.

4.2.4.1. Case 1: Power plant based on batteries

Lithium-ion batteries	
Energy	2.7 kWh
Voltage	48 V
Weight	14.6 kg
Volume	0.004 m^3
Cost (USD)	$ 3550
Vehicle range	32 km

Table 5. Specification of the power source (batteries).

Table 5 illustrates the characteristics of the battery bank dimensioned for the vehicle. The features of this power source are generated specifically to supply the power demand shown in **Figure 6**.

The state of charge (SOC) of the battery bank is depicted in **Figure 7**. As it is shown, the energy in the battery bank is gradually reduced along the route, until it covers all delivered points. It is well known that battery banks always are dimensioned to keep some percentage of charge at the end of the route; either for facing some extra energy required in the route or to increase the useful life of the battery bank.

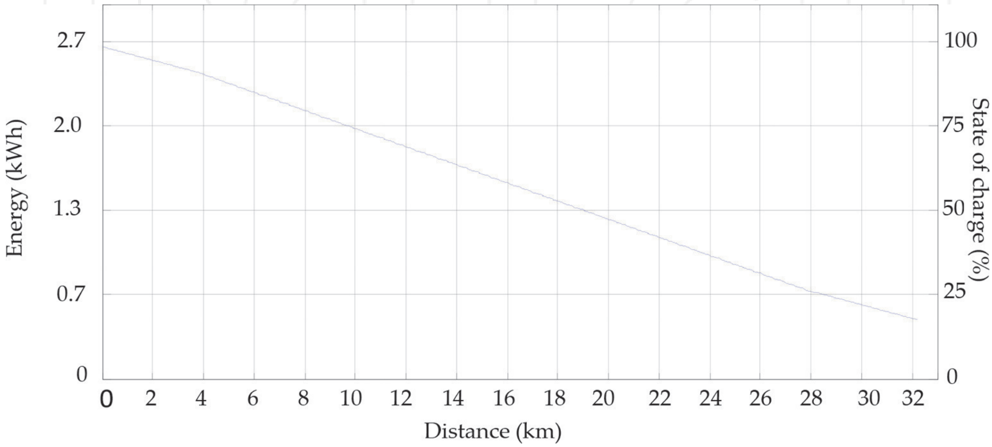


Figure 7. State of change of battery bank along the route.

4.2.4.2. Case 2: Power plant based on batteries and fuel cell (current prices)

What is important here is that the battery bank must provide main peaks of electric current, because dynamic operation of fuel cells makes it more complicated. Fuel cells are good providing big blocks of energy i.e. base load power instead of peak currents. For this case, the fuel cell provides almost all the energy required by the vehicle in the route, in such a way that at the end of the route, the battery bank will keep a SOC of over 92%.

Figure 8 shows the SOC in the battery bank, while the range extender based on fuel cells is used. As it is shown, the SOC keeps values around 90%. The final value of the SOC is 93%, which means that the vehicle has energy for traveling about 62 km. Therefore, if a fuel cell range extender is implemented, we obtain almost double the range, with only a cost increment of 43% in the power source. However, this price increment to the power source corresponds to about 15%–20% of the vehicle cost. That means that the current fleets of electric vehicles used by beverage industry or any other industry can increase the range without buying new more expensive electric vehicle, but rather using the current fleet with a fuel cell range extender.

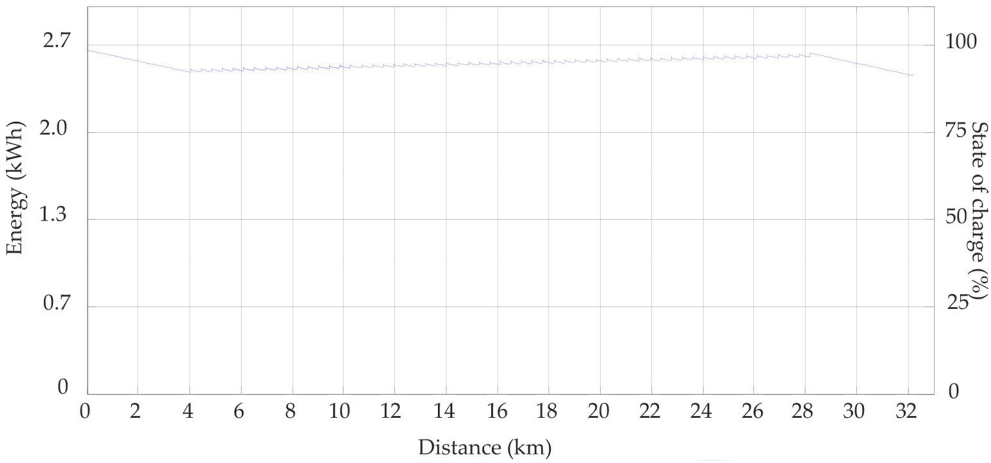


Figure 8. State of change of battery bank along the route: Case 2.

Another important issue related to the useful life in the battery bank is that its durability can be increased if the SOC is kept, as high as possible [6]. Hence, the implementation of a fuel cell range extender also helps to increase the useful life of batteries if the system is properly designed.

4.2.4.3. Case 3: Power plant based on batteries and fuel cell (future prices)

The previous case was conducted using current fuel cell prices. Nowadays, fuel cells are expensive due its low mass production. However, there are projections that indicate that future prices of fuel cells will fall, for a specific mass production value. For example, if mass production of fuel cells reaches a value of 20,000 upa, the fuel cell price by kW falls to 270 USD/kW [7]. In such a way, **Table 6** should be rewritten as shown in **Table 7**.

Lithium-ion batteries	
Energy	2.7 kWh
Voltage	48 V
Weight	14.6 kg
Volume	0.004 m^3
Cost (USD)	$ 3550
PEM fuel cell	
Type	PEMFC (proton exchange membrane fuel cell)
Nominal power (kW)	0.35 kW
Cost (USD) fuel cell + tank	$1550

Lithium-ion batteries	
Tank capacity	0.18 kg of H_2
Vehicle range:	62 km
Total cost (USD):	$5100

Table 6. Specification of the power source (batteries + fuel cell)

Lithium-ion batteries	
Energy	2.7 kWh
Voltage	48 V
Weight	14.6 kg
Volume	0.004 m^3
Cost (USD)	$3550
PEM fuel cell	
Type	PEMFC (Proton Exchange Membrane Fuel Cell)
Nominal power (kW)	0.35 kW
Cost (USD), fuel cell + tank	$595
Tank capacity	0.18 kg of H_2
Vehicle range:	62 km
Total cost (USD):	$4145

Table 7. Specification of the power source (batteries + fuel cell [future prices])

For this case, the increment of price of the power source corresponds to about 5–10% of the vehicle cost. That means once the mass productions of fuel cells starts, they will be (definitely) a feasible alternative in such systems.

The economic analysis in hydrogen production is not included in this chapter, but nowadays, there are many works [8–14] where assessment of hydrogen production is made using renewable energies. In this way, operation prices of electric vehicles driven by fuel cells are highly competitive, compared to electric vehicles driven by batteries, but with the added value of using a high efficiency and more environmental friendly technology.

5. Advantages, disadvantages, and business opportunities

Nowadays, fuel cell range extender systems are under study because the electric vehicle industry is rising. Practically, every big company in the automotive industry has an electric vehicle in their portfolio. In fact, there are companies, like Tesla Motors, that have as the main product an electric vehicle.

http://dx.doi.org/10.5772/62792

It is well known that fuel cell systems are environmentally friendly, as they present a high well-to-tank efficiency. The capability to extend the range in such a systems depends mainly of the tank capacity. For that reason, it is possible to have high-energy density, reducing the overall weight of the power plant.

Another important advantage is the fast energy charge rate, of a few minutes, for this system. If we compare it with the time required to charge batteries, in order of hours, we can obtain many logistics advantages, as well as more availability of the vehicles.

On the other hand, the main disadvantage of these systems is the high initial cost, because it is an emerging technology with low mass production; nonetheless, once mass production reaches a value of 20,000 units per year, initial costs falls to highly competitive costs. The lack of infrastructure to dispatch H_2, like gas stations, is another disadvantage to handle fleets of electric vehicle. This can be overcome, using storage and deliver systems of H_2 in the operation base of each fleet (as with batteries), the current technology of hydrogen allow it. Another disadvantage is the need for special consideration of power converters, because the output voltage of a fuel cell presents important variations under normal operational conditions. However, this issue has been addressed by experts in the last decade[15–23].

5.1. Business opportunities

The introduction of fuel cell technology in the operation of electric vehicles opens many business opportunities, from new manufacture companies of fuel cells and hydrogen tanks to new business in both hydrogen dispatching and production.

The renewable power sources are also another sector that can be included in the new business opportunities, because feeding of electricity to electric cars, ideally, must be using renewable energies in such a way that cars are going to be efficient and environmentally friendly.

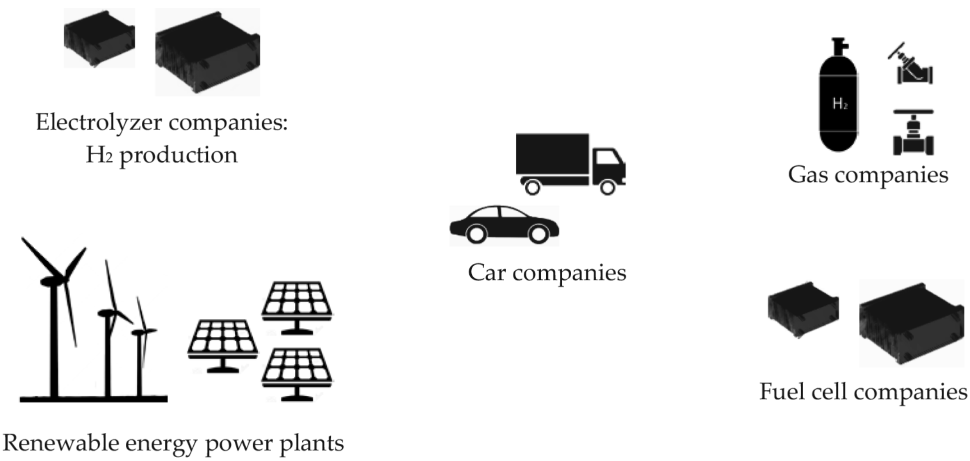


Figure 9. Sectors involved in the new business opportunities.

Figure 9 illustrates sectors involved in the new business opportunities with the mass production of fuel cell and the introduction of this technology in electric vehicles.

Companies that make electrolyzers are essential for developing the fuel cell car industry, due to the fact that hydrogen production must be conducted through electrolyzers by means of renewable energy power plants. If hydrogen is obtained using renewable energies, electric cars will be highly sustainable. For that reason, power plants based on renewable energies (solar, wind, etc.) will be involved in this new scheme, i.e. they will have a new potential user, either interconnected to the electric grid or by means of isolated systems. If we take into account the amount of energy consumed by cars, the size of the market is very high.

On the other hand, we can see (right side of **Figure 9**) that the fuel cell cars or automotive industry will need not only the fuel cell technology but also the technology of gas storage systems. Nowadays, fuel cell companies have several years operating but not at the production rate of automotive companies. That is why business opportunities appear, because more fuel cell manufacturers should be created. The same situation happens with hydrogen tanks manufacturers. The hydrogen tank is the part in the fuel cell vehicles that constraints the range of the vehicle and represents an important amount of the vehicle cost.

For sure, many other part supply companies can be created because for both mass production of fuel cells as well as electrolyzers, millions of components like elastomer seals, bipolar plates, membranes, gaskets etc, will be needed due to the fact that a fuel cell stack could need up to thousands of components.

6. Conclusion

beyond the fact that fuel cells are now a real option as an alternative power source in electric vehicles, they are an efficient and environmentally friendly technology. The use of this technology is a good way for obtaining zero emissions in electric vehicles when hydrogen is obtained from a renewable source, as we can avoid emitting CO_2. In the particular situation of the BEVs fleets, the fuel cells become an alternative to increase its range and to reduce environmental impact. In fact, fuel cells can be an alternative to increase the lifecycle of a battery bank, while fuel cells provide enough energy to keep the SOC at values where the aging of batteries is lowered.

The economics can be a matter to justify the uses of fuel cells, mainly as a range extender system. This happens because the hardware of existent BEVs can be used in such a way that the overall price of the vehicle can be increased just between 5% and 20% while the range is doubled.

New business opportunities are going to be opened not only in the automotive industry but also in renewable energies companies and the manufacture industry. The growth of the fuel cell industry will depend on adoption of this technology by electric vehicles, and also adoption of electric vehicles technology by companies that usually need fleets as a supply chain system.

Author details

Javier De La Cruz Soto[1*] and Ulises Cano Castillo[2]

*Address all correspondence to: javier.dlcruz@outlook.com

1 CONACYT Research Fellow, Electrical Research Institute, Cuernavaca, Mor., México

2 Electrical Research Institute, Cuernavaca, Mor., México

References

[1] CNBC, "Global auto sales hit record high of 82.8 million," Available from: http://www.cnbc.com/2014/01/09/global-auto-sales-hit-record-high-of-828-million.html. Accessed: February 2016.

[2] ConEdison, "Type of electric vehicles," Available from: http://www.coned.com/electricvehicles/types_of_evs.asp. Accessed: February 2016.

[3] Hong SHI, Hewu WANG, Minggao OUYANG, Fachao JIANG, "Analysis of response of China new energy vehicle markets to government policies," EVS28 International Electric Vehicle Symposium and Exhibition. Korea, May 3–6, 2015.

[4] L. La Vardera,"The electric vehicle market in the USA," Finpro Stamford, US EV Market–Finpro/Finnode, 2010.

[5] Y. Hee Kim, "A global analysis and market strategy in the electric vehicle battery industry," Master Thesis, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, June 2014.

[6] StarkPower, "Cycle life characteristics," Available from: http://www.starkpower.com/spnews/cyclife_char/. Accessed: February 2016.

[7] J. Spendelow and J. Marcinkoski, "Fuel cell system cost – 2013," USA, DOE Fuel Cell Technologies Office Record, June 12, 2014.

[8] F. Possoa, J. Sánchezc, J.L. Espinozad, and J. Siguenciac, "Preliminary estimation of electrolytic hydrogen production potential from renewable energies in Ecuador," International Journal of Hydrogen Energy. Volume 41, Issue 4, January 30, 2016, Pages 2326–2344.

[9] M.F. Orhan and B.S. Babu, "Investigation of an integrated hydrogen production system based on nuclear and renewable energy sources: comparative evaluation of hydrogen production options with a regenerative fuel cell system," Energy. Volume 88, August 2015, Pages 801–820.

[10] F. Possoa and J. Zambranob, “Estimation of electrolytic hydrogen production potential in Venezuela from renewable energies,” International Journal of Hydrogen Energy. Volume 39, Issue 23, August 4, 2014, Pages 11846–11853.

[11] C. Acar and I. Dincer, “Comparative assessment of hydrogen production methods from renewable and non-renewable sources,” International Journal of Hydrogen Energy. Volume 39, Issue 1, January 2, 2014, Pages 1–12.

[12] C.-C. Cormos, “Renewable hydrogen production concepts from bioethanol reforming with carbon capture,” International Journal of Hydrogen Energy. Volume 39, Issue 11, April 4, 2014, Pages 5597–5606.

[13] R. Roldán, “Technical and economic feasibility of adapting an industrial steam reforming unit for production of hydrogen from renewable ethanol,” International Journal of Hydrogen Energy. Volume 40, Issue 4, January 30, 2015, Pages 2035–2046.

[14] S. Ehsan Hosseini and M. Abdul Wahid, “Hydrogen production from renewable and sustainable energy resources: promising green energy carrier for clean development,” Renewable and Sustainable Energy Reviews. Volume 57, May 2016, Pages 850–866.

[15] M. Venkatesh Naik and P. Samuel, “Analysis of ripple current, power losses and high efficiency of DC–DC converters for fuel cell power generating systems,” Renewable and Sustainable Energy Reviews. Volume 59, June 2016, Pages 1080–1088.

[16] P. Hong, J. Li, L. Xu, M. Ouyang, and C. Fang, “Modeling and simulation of parallel DC/DC converters for online AC impedance estimation of PEM fuel cell stack,” International Journal of Hydrogen Energy. Volume 41, Issue 4, January 30, 2016, Pages 3004–3014.

[17] A. Kollib, A. Gaillarda, A. De Bernardinisb, O. Bethouxc, D. Hissela, and Z. Khatirb, “A review on DC/DC converter architectures for power fuel cell applications,” Energy Conversion and Management. Volume 105, November 15, 2015, Pages 716–730.

[18] M.A. Al-Saffar and E.H. Ismail, “A high voltage ratio and low stress DC–DC converter with reduced input current ripple for fuel cell source,” International Conference on Renewable Energy: Generation and Applications (ICREGA 2014), United Arab Emirates.

[19] A. Garrigós and F. Sobrino-Manzanares, “Interleaved multi-phase and multi-switch boost converter for fuel cell applications,” International Journal of Hydrogen Energy. Volume 40, Issue 26, July 13, 2015, Pages 8419–8432.

[20] W. Thammasiriroja, V. Chunkaga, M. Phattanasakb, S. Pierfedericic, B. Davatc, and P. Thounthongb, “Nonlinear single-loop control of the parallel converters for a fuel cell power source used in DC grid applications,” International Journal of Electrical Power & Energy Systems. Volume 65, February 2015, Pages 41–48.

http://dx.doi.org/10.5772/62792

[21] O.A. Ahmeda and J.A.M Bleijsb, “An overview of DC–DC converter topologies for fuel cell-ultracapacitor hybrid distribution system,” Renewable and Sustainable Energy Reviews. Volume 42, February 2015, Pages 609–626.

[22] Y-X. Wanga, D-H. Yua, S-A. Chena, and Y-B. Kima, “Robust DC/DC converter control for polymer electrolyte membrane fuel cell application,” Journal of Power Sources. Volume 261, September 1, 2014, Pages 292–305.

[23] A. Mansoura, B. Faouzia, G. Jamelb, and E. Ismahena, “International Journal of Hydrogen Energy,” Volume 39, Issue 3, January 16, 2014, Pages 1580–1592.

INTECH

Chapter 5

Food Supply Chain: A Review of Approaches Which Enhance Sustainability with a Focus on Social Responsibility

Danijela Tuljak-Suban

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/62536

Abstract

The sustainability of food supply chain management in a global market after the Economic Crisis is increasingly relevant; the economic and environmental pillars have been closely studied and examined, while the social pillar is considered only marginally and never independently. We propose a literature review focused on 28 articles regarding sustainability in the food supply chain. The proposed review (a) detects methods that could be used to enhance sustainability, (b) highlights the most used methods and their shortcomings, and with regard to social sustainability (c) highlights the fact that most of the studies were found to be based on empirical approach. Moreover, we propose the use of a fuzzy framework to evaluate sustainability (in particular, the social aspect), since fuzzy variables could better explain phenomena and situations generally described verbally.

Keywords: Sustainable Supply Chain Management (SSCM), Food, Information Technology, Social Sustainability, Literature review

1. Introduction

Globalization and the establishment of a global market have transformed the process of production, storage, transportation and the sale of perishable goods as well as the extension of delivery times and the scattering of production and storage locations. It therefore follows that the supply chain has become a complex process composed of many factors. Food as a perishable good is most certainly freight, which requires careful attention during the various stages and processes of the supply chain.

The sustainability of the supply chain is generally defined as a union of three dimensions: economic aspects, environmental performance and social responsibility [1]. The economic aspect is analysed in the majority of papers, while interactions with environmental performance are also taken into consideration. Social responsibility is examined only marginally and generally from the economic point of view.

In the case of food, the combined analysis of the three aspects could be hampered by the particular characteristics of this freight which deteriorates over time. In this chapter, we review approaches which enhance sustainability with a focus on social responsibility with regard to food.

The appearance of food is vital, being that appearance is often linked to quality. Food quality could be quantified according to its chemical, physical, microbiological or sensory characteristics. Factors which influence the kinetics of food deterioration are non-enzymatic browning, vitamin loss, microbial death or growth, oxidative colour loss and texture loss [2].

The transportation and handling of food are certainly sensitive parts of the supply chain, since it is during these phases that an increasing number of factors cause deterioration and quality changes. In particular, it becomes difficult to ensure stable conditions to limit deterioration, making it necessary to carefully monitor the entire process. It makes sense to include human resources and also use sensors and detectors in the process of verifying quality to improve performance. The proper use of suitable information technology (IT) allows one to maintain a high level of quality and to make corrections in real time.

In this chapter, we present a detailed review of the procedures and methods used to manage the supply chain of perishable goods, with a focus on food. The choice of literature database and keywords were carefully made, taking into account that food (as a perishable good) could be examined from very different angles (economic, biological, logistic, social, etc.), which are all not necessarily directly connected with supply chain management.

The time period examined in the review also includes that of the Global Economic Crisis to examine whether economic changes influence social responsibility (local production of food, shortening of the supply chain and development of the local economy) and environmental performance (reduction of waste—spoiled food and increase of recycling) with regard to food.

The chapter is composed of four sections and a conclusion. The relations between the sections are presented in **Figure 1**.

In the introduction, we present the motives that led to writing about the methods used to manage the supply chain of perishable goods with a focus on food.

Sustainability in the supply chain is defined in Section 1. A definition of sustainability related to the food supply chain is also proposed, with a particular focus on social responsibility with regard to food.

In Section 2, a step by step literature review of methods used to manage the food supply chain is defined. The starting point is the classical Economic Order Quantity (EOQ) model for perishable goods, with exponential inventory and deterioration function. The review is then extended to other differential and integral methods used to optimize the ordering period and to the network optimization methods applied to the supply chain network.

In Section 3 are classified procedures and methods used to manage the food supply chain. Detected critical factors (social, economic, technical, etc.) in the supply chain are highlighted, and IT implementation is examined or suggested.

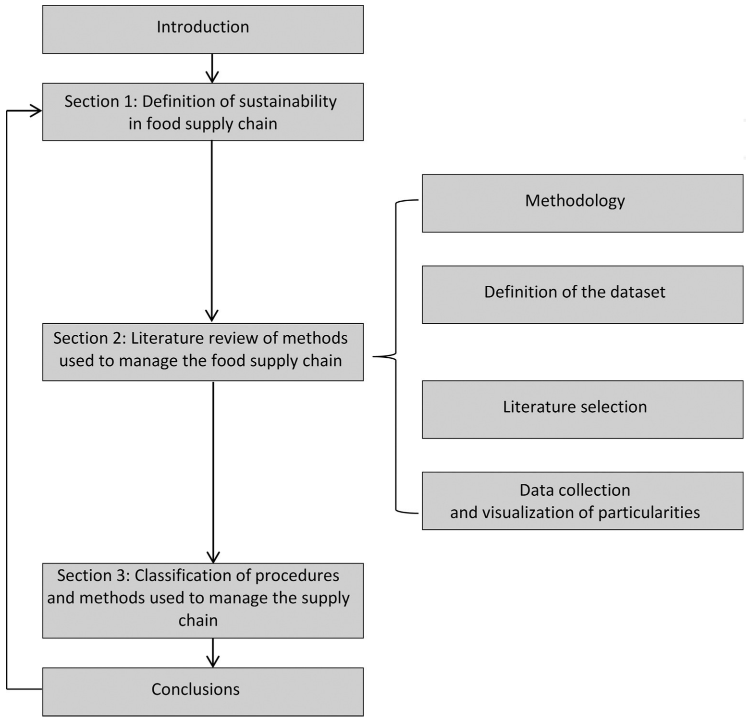


Figure 1. Structure and relations between the sections of the chapter.

The proposed classification is done to highlight:

a. Leading methods used to improve the sustainability of the supply chain,

b. Connectivity options between different approaches with a particular focus on the appropriate use of IT to improve sustainability, and

c. Neglected aspects of sustainability with a particular focus on social responsibility.

2. Definition of sustainability in the food supply chain

The first and most commonly known definition of sustainable development is from the Brundtland Report [3]:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

- *the concept of* ***needs****, in particular the essential needs of the world's poor, to which overriding priority should be given; and*
- *the idea* ***of limitations*** *imposed by the state of technology and social organization on the environment's ability to meet present and future needs."*

This definition is abstract and not balanced, because it is focused on the human factor. We consider it more advantageous to adopt a more stable and complete definition based on the three pillars: social, environmental and economic sustainability [1,4].

Economic sustainability has become increasingly important since the Global Economic Crisis; a concerted effort has been made to reduce bribery, antitrust claims, tax evasion and to prevent a new financial crisis [5].

In addition, the Climate Change Conference held in Paris at the end of 2015 confirmed that environmental sustainability is also of great significance, since pollution, emission of greenhouse gases, ozone depletion, excessive or unnecessary packaging, water scarcity, heat-waves, droughts and production of waste are deteriorating the planet and reducing quality of life. The reduction of these phenomena is necessary, but it is often connected to economic sustainability, and unfortunately environmental and economic aspects are generally not proportionate [5].

Social sustainability is connected to the reduction of risks related to excessive hours of work, unfair wages, child labour, discrimination, an unhealthy and unsafe work environment, exploitative hiring policies, unethical treatment of animals and social instability. The achievement of social sustainability is the most complex among the pillars of sustainability, since data and research regarding these issues are often insufficient or altered, and the social aspect is generally at odds with its other two counterparts [5].

On the basis of the data presented in the literature [1] one can note that in supply chain management, the economic and environmental dimensions of sustainability are the most analysed, while the social dimension is the less considered aspect. In addition, connections between the social aspect and the economic and environmental aspects are poorly considered. Hence, the social aspect of sustainability in supply chain management is the weakest aspect and requires further analysis and integration with its counterparts.

The integration of all the three aspects plays a central role in improving sustainability, but from the previously discussed findings it is possible to conclude that the social dimension needs much better integration with economic and environmental issues [6].

The three-pillar definition of sustainability is presented in **Figure 2**.

The below-given definition of sustainability in the supply chain can also be used with reference to food supply. In this case, the social aspect is connected with the production and consumption

http://dx.doi.org/10.5772/62536

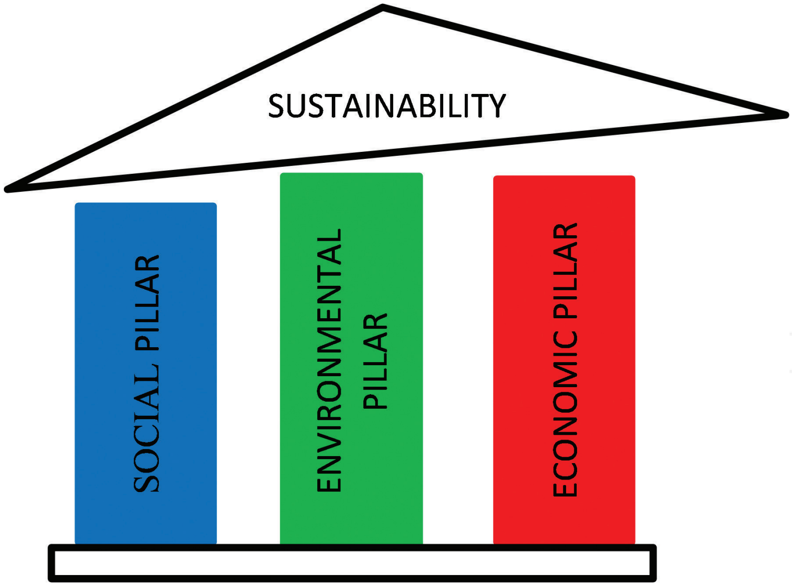


Figure 2. Three-pillar definition of sustainability.

of food. The relationships between the economic, environmental and social aspects become more complicated and at times conflictual in nature.

3. Literature review of methods used to manage the food supply chain

Over the last decade (from 2006), many literature review articles were written on the supply chain, which reviewed methods needed to improve the economic and environmental aspects of sustainability. The social aspect of sustainability was rarely considered and poorly examined. Among these articles, no literature review dealt with the food supply chain which focused on the social aspect of sustainability. **Table 1** presents the supply chain review articles. Highlighted are our findings and the sustainability aspects which were taken into consideration. Seventeen review articles were examined which were published in relevant journals found on the web platform, Science Direct (SD).

On the basis of the data from **Table 1**, it is possible to see that:

i. Almost all the papers reviewed (94%), except that by Seuring and Zhang [6], took into consideration the economic aspect of sustainability.

ii. In almost all the papers reviewed, two aspects of sustainability are dealt with—the environmental and the economic. Also, only the economic aspect is considered individually, except in the paper by Seuring and Zhang [6], where the environmental aspect is considered individually.

iii. Only 19% of papers reviewed investigated the social aspect of sustainability.

iv. The social aspect of sustainability is always aggregated to the other two aspects of sustainability.

v. In four review papers [12,13,15,16], sustainability in the food supply chain was analysed, but the social pillar was not considered. Of all the papers considered, only that by Beske et al. [12] dealt with the social aspect, and that too marginally.

The analysis of the data has shown a clear lack of research papers regarding the social aspect of sustainability in the food supply chain. Next, a literature review which attempts to fill this gap will be presented.

Authors and publication year	**Title**	**Sustainability aspect**	**Article focus**	**Findings**
Grillo et al., 2016 [7]	A review of mathematical models for supporting the order promising process under Lack of Homogeneity in Product and other sources of uncertainty	Economic aspect	Review of mathematical programming models	Support to the order process
Mulyati, 2016 [4]	Sustainability in Supply Chain Management Casebook: Applications in SCM: a book review	Economic aspect, environmental aspect and social aspect	Review of practical examples	Handbook
Wang et al., 2015 [8]	Service supply chain management: A review of operational models	Economic aspect	Review of operational models in service supply chain management	Identification of the research challenges
Eskandarpour et al., 2015 [1]	Sustainable supply chain network design: An optimization-oriented review	Economic aspect, environmental aspect	Review of network design	Identification of modelling, solution techniques and fields of application
Bazan et al., 2015 [9]	A review of mathematical inventory models for reverse logistics and the future of its modelling: An environmental perspective	Economic aspect, environmental aspect	Review of mathematical models for reverse logistics	Outline that an environmental issue in RL is not modelled. Presentation of a new

http://dx.doi.org/10.5772/62536

Authors and publication year	Title	Sustainability aspect	Article focus	Findings
				modelling approach for green RL
Sternberg and Andersson, 2014 [10]	Decentralized intelligence in freight transport—A critical review	Economic aspect	Review of network design	Overview of research on decentralized freight intelligence
Steadie Seifi et al., 2014 [11]	Multimodal freight transportation planning: A literature review	Economic aspect	Review of network design	Identification of strategic, tactical, and operational levels of planning
Beske et al., 2014 [12]	Sustainable supply chain management practices and dynamic capabilities in the food industry: A critical analysis of the literature	Economic aspect, social aspect	Link Sustainable Supply Chain Management with the Dynamic Capabilities Theory	Identification of specific Dynamic Capabilities for managing sustainable supply chains in the food industry.
Dabbene et al., 2014 [13]	Traceability issues in food supply chain management: A review	Economic aspect	Review of network design and optimization	Involvement of traceability issues in supply chain design and optimisation.
Martínez-Jurado and Moyano-Fuentes, 2014 [14]	Lean Management, Supply Chain Management and Sustainability: A Literatu re Review	Economic aspect, environmental aspect	Evaluation of the links between Lean Management, Supply Chain Management and Sustainability	Identification of contradictions and inconsistencies
Yared Lemma and Gatew, 2014 [15]	Loss in Perishable Food Supply Chain: An Optimization Approach Literature Review	Economic aspect	Review of literature	Identification of the main issues (production, transportation and inventory] of loss of food in agricultural supply chain
Dora et al., 2013 [16]	Food quality management system: Reviewing assessment strategies and a feasibility study for European food small and medium-sized enterprises	Economic aspect, environmental aspect	Review of quality management models	Identification of benefits from the implementation of QM principles
Seuring, 2013 [6]	A review of modelling approaches for sustainable supply chain management	Economic aspect, environmental aspect, Social aspect	Review of quality modelling approach es	Confirmation that the social dimension needs much better integration with the economic and environmental ones

Authors and publication year	Title	Sustainability aspect	Article focus	Findings
Govindan, 2013 [17,18]	Embedding Sustainability Dynamics in Supply Chain Relationship Management and Governance Structures: Introduction, Review and opportunities	Economic aspect, environmental aspect	Review of data	Adds governance and relationship aspects to agenda
Styles et al., 2012 [18]	Environmental improvem ent of product supply chains: A review of Europ ean retailers' performance	Environmental aspect	Review of data	Identification of European retailers' environmental improvement of supply chains.
Awudu and Zhang, 2012 [19]	Uncertainties and sustainability concepts in biofuel supply chain management: A review	Environmental aspect, social aspect	Review of mathematical simulations and programming	Summary of differences and sustainability concepts of the first, second, third and fourth generation biofuel
Gupta and Palsule-Desai, 2011 [20]	Sustainable Supply Chain Management: Review and Research Opportunities	Economic aspect, environmental aspect	Review of strategic considerations; regulation and government policies; integrative models and decision support tools	Development of an integrative framework to summarise literature

Note: Highlighted articles are related to the food supply chain.

Table 1. Literature review articles on sustainability in the supply chain.

3.1. Methodology

The starting point of all research is certainly a detailed analysis and classification of the results obtained by the researchers in this field. A methodical literature review could potentially bring to light the results obtained till date. In this paper, systematic methods of review will be used in order to summarize results presented by the authors of papers found in international publications (journals).

The classical narrative method of review will be used only as a complement to the systematic method of review, since a chronological list of articles and the accompanying results allow one to have an overall evaluation, but not to highlight the peculiarities or deficiencies of the searches.

The systematic method of review permits one to aggregate similarities, identify topics that have not yet been examined, classify results according to various criteria (country of origin, method of analysis, obtained solutions, etc.) while still maintaining an overall view. Also, some statistical methods typical for the meta-analysis of published data are adapted to the structure of the analysed database [21–23].

The systematic literature review used in the next paragraph is composed of the following main steps [24]:

I. Definition of the database

In this phase, the database is defined, and specifically, journals which are the basis for the article search will be collected.

II. Literature selection

The criteria used in the search are carefully defined. It is very important to detect proper keywords that entirely include the defined criteria and at the same time can be neither too general nor too restrictive. The database is searched for titles, abstracts and keywords which match the chosen search criteria.

III. Data collection and visualization of peculiarities

Articles are organized in a table which includes data regarding the authors, the name of the journal which published the article, publication date, the data related to the geographic region in question, methods used, results obtained and data regarding the examined aspects of risk in food supply chain management.

3.2. Definition of the database

The dataset composed of articles and books is extracted from the web platform, Science Direct (SD). This platform was chosen because access to all titles and abstracts of the articles is free for the researchers of the University of Ljubljana, and also the text of most articles is free. Non-academic users must subscribe to access the complete databases. In addition, articles from this database are all peer-reviewed and are representative of a majority of the studies and results in this field. All articles are in English; therefore, the same English keywords could be employed.

3.3. Literature selection

The keyword search is defined hierarchically by the definition of an initial large dataset of articles and other contributions through the use of keywords, which are not too specific, and then subsequently narrowing the search by increasing the specificity of the keywords.

In the first step, the general terms *supply chain management* were used, and then the selection was further restricted by using the term *sustainability*, and then by the term *food*. Keywords were combined by the Boolean operators AND and OR. The search was conducted between the Title words, Keywords and words in the Abstract. The term *sustainability* is also often used in the adjectival form *sustainable*; so, the search was extended to both forms. Also, the term *food* is often replaced by the terms *goods* or *perishable goods*; so, the search was extended also to the term *goods*. The replacement of the term food with terms *goods* or *perishable goods* did not produce additional results, which suggests that researchers do not use the term goods with regard to sustainability of food supply chain.

An additional condition used in the search was the publication year, as it is generally reasonable to avoid making use of literature which is more than 5 years old. However, for the purposes of this paper, a greater time interval was used from the year 2006 to the present. This allows one to measure the influence of the Global Economic Crisis and climate change on the sustainability of the food supply chain by detecting the number of related articles published during this period.

To verify the quality of the constructed dataset of articles, using the same keywords, Scopus and Web of Science platforms were also inspected. The obtained results were the same, with only a few different articles being found. Unfortunately, these articles are not freely accessible, and therefore were not included in the dataset.

Furthermore, the snowball or reverse search technique which enables obtaining additional articles by tracing citations from articles already included in the dataset was not used, since, on the basis of the literature review analysis presented in **Table 1**, it is possible to conclude that: (a) the contents of the cited articles are more general than the contents of the final set of articles on sustainability in food supply chain management, (b) they are dated before the articles already included in the dataset and (c) the results are abstracted in the original and review articles already included in the dataset.

Finally, it was necessary to remove from the list of contributions any article that contained the above-mentioned keywords, but which, upon closer inspection, was found to be not directly connected with the topics analysed in this article. Two articles about the biofuel supply chain management were removed. In **Figure 3**, the progress and results of the search are presented.

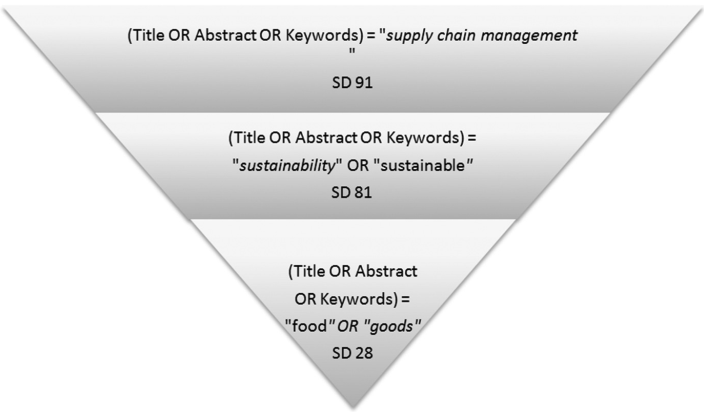


Figure 3. Search progress steps in the literature dataset definition.

http://dx.doi.org/10.5772/62536

The final dataset is composed of only 28 articles, even if the singular use of the keywords generated much larger sets. This would suggest that the aggregation of sustainability and food to the supply chain management has not been sufficiently examined by researchers.

3.4. Data collection and visualization of peculiarities

In this phase, it is necessary to encode the acquired data; each record in the dataset contains the following fields: (1) publication year, (2) author data, (3) title, (4) journal title, (5) considered sustainable aspect, (6) definition of the analysed method used, (7) use of IT and (8) case study. In **Table 2**, the original articles about sustainability in the food supply chain are presented.

Article data	Sustainability			Method used	IT	Case study
	Economic	Environmental	Social			
Al-Busaidi et al. [25]	■	■		SWOT analysis		■
Tidy et al. [26]		■	■	Data analysis		■
Verdouw et al. [27]	■			Network design	■	■
Saleh and Roslin [28]	■			Statistic approach/ Empirical test		■
Fedrigotti and Fischer [29]	■	■	■	Statistic approach/ Empirical test		■
Garrone et al. [30]		■	■	Availability Surplus Recoverability Waste (ASRW)		■
Grekova et al. [31]		■		Empirical model		■
Grimm et al. [32]	■			Qualitative analysis of critical factors		■
Papargyropoulou et al. [33]	■	■	■	Hierarchy method/ Statistic approach		
Li et al. [34]	■	■		Game theory		
Validi et al. [35]	■	■		Mathematical optimization model		■
Turi et al. [36]	■	■	■	Mathematical optimization model		

Article data	Sustainability			Method used	IT	Case study
	Economic	Environmental	Social			
Martikainen et al. [37]	■			Classification methods	■	
Eksoz et al. [38]	■			Empirical testing	■	
Chen et al. [39]	■			Analytical optimization model		■
Bourlakis et al. [40]	■			Empirical model/ Statistic approach		
Aung and Chang [41]	■			Clustering	■	
Ala-Harja and Helo [42]	■	■		Operation Research models	■	
Agustina et al. [43]	■			Mixed integer programming		■
Gold et al. [45]	■		■	Pyramidal method/ Qualitative approach		
Manzini and Accorsi [46]	■			Empirical testing		
Wang et al. [47]	■	■		Mathematical optimization model		
Zanoni and Zavanella [48]	■	■		Mathematical optimization model		■
Lazaridesa [49]	■	■		Empirical testing		

Table 2. Original articles about sustainability in the food supply chain.

4. Classification of procedures and methods used to manage the supply chain

In this section, the particularities of the original articles included in the dataset are explained. We propose different classifications and have highlighted the differences with respect to the results proposed in the review articles about the sustainable supply chain from **Table 1**.

http://dx.doi.org/10.5772/62536

The original papers considered do not address all the three dimensions of sustainability, that is, the economic, environmental and social aspects. In **Figure 4**, the distribution with respect those dimensions is proposed.

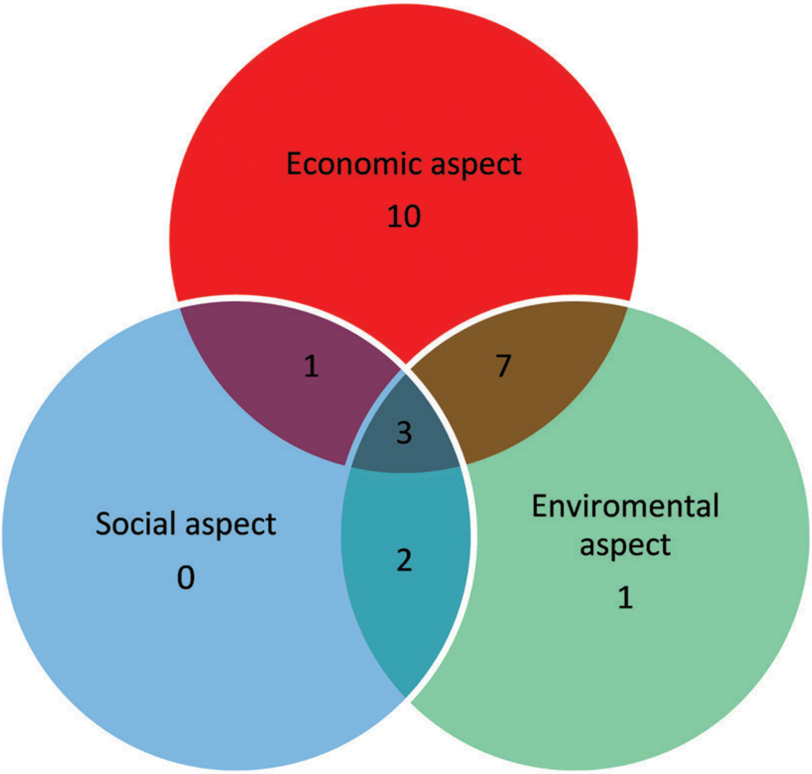


Figure 4. Distribution of the original articles with respect to the sustainability dimensions.

It is possible to see that the researchers considered the economic aspect most significant, since almost all the articles included this dimension in the analysis. The environmental aspect was the second most frequently considered dimension and was generally combined with the economic aspect, with the exceptions of the article by Garrone et al. [30], which did not consider the economic aspect but analysed the environmental and social aspects, and the article by Grekova et al. [31], which considered the environmental aspect individually in the case of Dutch food and beverage firms.

There were no articles which examined the social or environmental aspect individually. The social aspect is generally connected with the economic. The obtained results are in accordance with the findings on general sustainable supply chain highlighted by Eskandarpour et al. [1].

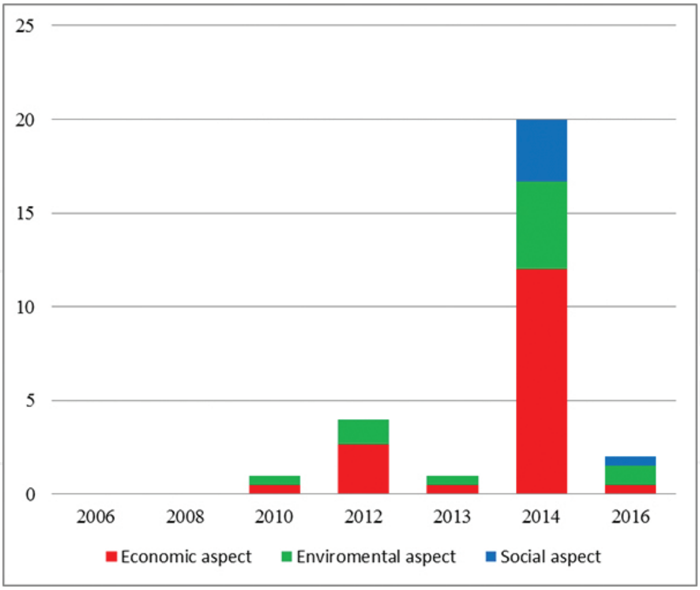


Figure 5. Distribution of the papers in the given time period.

In **Figure 5**, the distribution of the papers (review and original) is presented during the time period [2006–2016]. It is possible to note that sustainability in food supply chain management becomes a topic of consideration after the 2008 Global Economic Crisis. Social aspect of sustainability becomes relevant from 2014.

The number of articles increases and becomes relevant from 2010, while from the papers reviewed in **Table 1**, it is possible to note that sustainability in the supply chain has been consistently studied since the early 1990s.

The articles' dataset could also be classified with respect to the procedures and methods used:

a. Differential methods and integral methods used to optimize costs,

b. Network optimization applied to the supply chain network,

c. Detection of critical factors (social, economic, technical, etc.) in the supply chain, and

d. IT implementation.

In **Figure 6**, the rate of methods used to optimize and analyse the food supply chain is presented. It is possible to note that in accordance with the results of the general literature review papers from **Table 1**, the cost optimization methods based on the EOQ model and on mathematical optimization are the most commonly used (41% of the articles); SWOT analysis and other methods used to detect critical factor are also frequently used (38% of the articles).

In the analysed dataset, IT is associated with the other methods in 17% of the articles. Only in the article by Verdouw et al. [27] is the use of the Internet of Things proposed for use in managing the food supply chain.

Articles that present case studies (25% of the original articles) generally considered practical examples from European regions, with the exception of the article by Al-Busaidi et al. [25] that examined the seafood supply chain in the Sultanate of Oman.

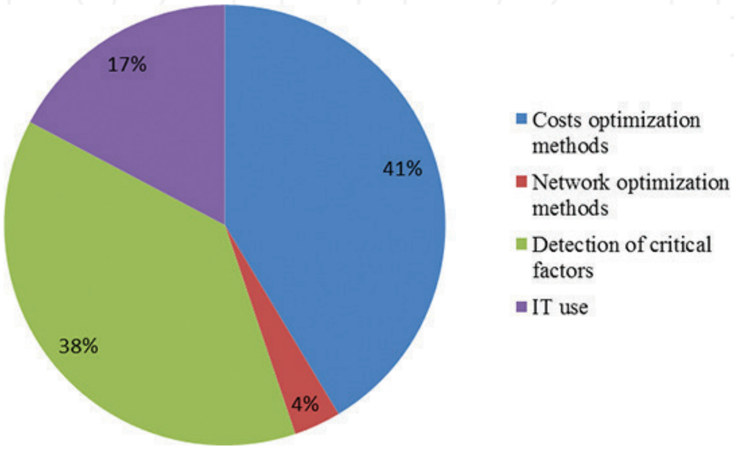


Figure 6. Distribution of the papers with respect to the investigation method used.

Studies which consider the social dimension in supply chain management are all generally based on empirical case studies, and there are no generic models which include all three dimensions of sustainability [1].

In the case of food supply chain management, there are studies which approach the social aspect of sustainability with quantitative mathematical optimization models [30,33,36,44]. These models are not generic but could be a good starting point to improve the importance of the social aspect of sustainability in a general model.

A limitation to all the analysed models is that the social aspect is subordinated to the economic (or environmental) aspect of sustainability. In the articles considered, general solutions on how to develop and improve sustainability as local production of food and shortening the supply chain are not proposed [25–27,29,39].

In **Table 3**, the main aspects and research approaches to the three pillars of sustainability are summarized.

Sustainability in the food supply chain		
Economic aspect	**Environmental aspect**	**Social aspect**
Costs optimization:	Waste management	Food quality
- production costs	Food quality	Work conditions
- inventory costs		Local production of food
- transport costs		
Mathematical optimization models based on costs and IT implementation		
[49]		
[34]		
[42]		
[47]		
[48]		
	Empirical models, statistic review of data, optimization models	
	[30]	
Empirical models, statistic review of data, optimization models		
[29]		
[33]		
[36]		

Table 3. Main topics and aspects of sustainability in food supply chain.

On the basis of the results summarized in **Table 3**, it is possible to note that there are no articles (detected with the keywords defined in Section 3.3) which use fuzzy reasoning to assess the three aspects of sustainability. The fuzzy approach is generally used to define parameters that are not usually crisp constant, but have values that are defined as words (small, medium, large) used by the experts to describe characteristics of the supply chain, food quality, working conditions, etc. [50].

Fuzzy reasoning could be used to evaluate the social aspect, since this category includes aspects that are usually evaluated descriptively; for this reason, empirical models are proposed to analyse this aspect. The environmental aspect is described by empirical models, but optimization models are also proposed. So, in this case, the introduction of fuzzy variables in a crisp optimization model could be appropriate. The economic aspect is the most studied, and many efficient crisp optimization models are detected in the review. An overall assessment of sustainability, taking into account all three aspects and their particularities, could be defined by a fuzzy logic reasoning model which analyses the economic, environmental and social aspects of sustainability and defines a score as much as the human brain does.

The rules used in the fuzzy evaluation model are defined on the basis of the priorities and particularities in the reviewed articles (see **Table 3**). In the model, fuzzy and crisp variables could be used. Fuzzy variables could be defined using three fuzzy terms (bad, good, very good) and triangular membership functions. In **Figure 7**, an example of the fuzzy model is proposed.

http://dx.doi.org/10.5772/62536

Since the proposed framework is very close to neural networks and expert systems, it could be expanded by the use of relevant IT in a smart tool to evaluate the sustainability level of the food supply chain management.

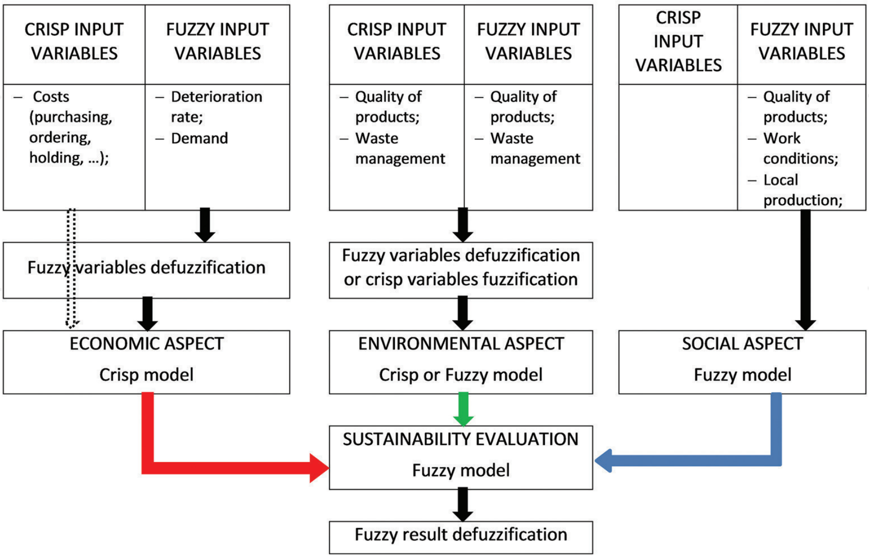


Figure 7. Evaluation of the sustainability level of the food supply chain.

5. Conclusion

The aim of the proposed manuscript is to improve upon the already published reviews of articles on the management of the food supply chain and to present a review of the methods explained in the articles, which are used to improve the food supply chain with a focus on the social aspect. There are many literature reviews regarding sustainable supply chain management (also dealing with perishable goods and food); however, social responsibility and the use of IT to improve social sustainability have not yet been satisfactorily investigated.

From the proposed classification of articles about food supply chain management, it is possible to highlight that:

I. the social aspect of sustainability is not sufficiently considered and is always combined with the economic or environmental aspect,

II. the proposed optimization models are local, and the social aspect of sustainability is included in the models only marginally in the conditions,

III. IT is used as a support to the mathematical or empirical models,

IV. sustainability has become a relevant issue after the Global Economic Crisis, and

V. there are no general models.

The articles listed in **Table 3** could be used to define a general frame of sustainability with regard to the food supply chain. The social aspect of sustainability requires further analysis to define qualitative indicators that permit one to measure the level of implementation of social responsibility in the food supply chain. For this purpose, a framework of a fuzzy evaluation model was explained.

We hope that this encourages the food industry to take into consideration the social aspect as a positive addition to the economic and environmental aspects. From the definition of sustainability and the results obtained in the review, it is possible to conclude that only the balanced implementation of the social, economic and environmental aspects of sustainability can be acceptable for the food industry and the customers. For this reason, a framework to define global assessment model of sustainability has been proposed.

Author details

Danijela Tuljak-Suban

Address all correspondence to: danijela.tuljak@fpp.uni-lj.si

University of Ljubljana, Faculty of Maritime Studies and Transport, Portorož, Slovenia.

References

[1] Eskandarpour M, Dejax P, Miemczyk J, Péton O Sustainable supply chain network design: an optimization-oriented review. Omega 2015; 54: 11–32.

[2] Tuljak Suban D, Suban V Influence of transportation mode to the deterioration rate: case study of food transport by ship. *International Journal of Biological, Biomolecular, Agricultural, Food and Biotechnological Engineering*, 2015; 9, 37–42.

[3] (WCED) WCoEaD. Our Common Future. Oxford: Oxford University Press, 1987.

[4] Mulyati H Sustainability in supply chain management casebook: applications in SCM: a book review. Journal of Cleaner Production 2016; 110: 198–199.

[5] Giannakis M, Papadopoulos T Supply chain sustainability: a risk management approach. International Journal of Production Economics 2016; 171, Part 4: 455–470.

[6] Seuring S A review of modeling approaches for sustainable supply chain management. Decision Support Systems 2013; 54: 1513–1520.

[7] Grillo H, Alemany MME, Ortiz A A review of mathematical models for supporting the order promising process under Lack of Homogeneity in Product and other sources of uncertainty. Computers & Industrial Engineering 2016; 91: 239–261.

[8] Wang Y, Wallace SW, Shen B, Choi T-M Service supply chain management: a review of operational models. European Journal of Operational Research 2015; 247: 685–698.

[9] Bazan E, Jaber MY, Zanoni S A review of mathematical inventory models for reverse logistics and the future of its modeling: an environmental perspective. Applied Mathematical Modelling 2015.

[10] Sternberg H, Andersson M Decentralized intelligence in freight transport—a critical review. Computers in Industry 2014; 65: 306–313.

[11] Steadie Seifi M, Dellaert NP, Nuijten W, et al. Multimodal freight transportation planning: a literature review. European Journal of Operational Research 2014; 233: 1–15.

[12] Beske P, Land A, Seuring S Sustainable supply chain management practices and dynamic capabilities in the food industry: a critical analysis of the literature. International Journal of Production Economics 2014; 152: 131–143.

[13] Dabbene F, Gay P, Tortia C Traceability issues in food supply chain management: a review. Biosystems Engineering 2014; 120: 65–80.

[14] Martínez-Jurado PJ, Moyano-Fuentes J Lean management, supply chain management and sustainability: a literature review. Journal of Cleaner Production 2014; 85: 134–150.

[15] Yared LDK, Gatew G Loss in perishable food supply chain: an optimization approach literature review. International Journal of Scientific & Engineering Research 2014; 5: 302–311.

[16] Dora M, Kumar M, Van Goubergen D, et al. Food quality management system: reviewing assessment strategies and a feasibility study for European food small and medium-sized enterprises. Food Control 2013; 31: 607–616.

[17] Govindan K Embedding sustainability dynamics in supply chain relationship management and governance structures. Journal of Cleaner Production 2013; 59: 1–2.

[18] Styles D, Schoenberger H, Galvez-Martos J-L Environmental improvement of product supply chains: a review of European retailers' performance. Resources, Conservation and Recycling 2012; 65: 57–78.

[19] Awudu I, Zhang J Uncertainties and sustainability concepts in biofuel supply chain management: a review. Renewable and Sustainable Energy Reviews 2012; 16: 1359–1368.

[20] Gupta S, Palsule-Desai OD Sustainable supply chain management: review and research opportunities. IIMB Management Review 2011; 23: 234–245.

[21] Ressing M, Blettner M, Klug SJ Systematic literature reviews and meta-analyses—Part 6 of a series on evaluation of scientific publications. Deutsches Ärzteblatt International 2009; 106: 456–463.

[22] Booth A, Papaioannou D, Sutton A Systematic Approaches to a Successful Literature Review. London: SAGE Publications, 2012.

[23] Fink A Conducting Research Literature Reviews: From the Internet to Paper. : London: SAGE Publications, 2005.

[24] Jesson J, Matheson L, Lacey FM Doing your Literature Review: Traditional and Systematic Techniques.Los Angeles, CA: SAGE Publications, 2011.

[25] Al-Busaidi MA, Jukes DJ, Bose S Seafood safety and quality: an analysis of the supply chain in the Sultanate of Oman. Food Control, London: SAGE Publications 2016; 59: 651–662.

[26] Tidy M, Wang X, Hall M The role of supplier relationship management in reducing greenhouse gas emissions from food supply chains: supplier engagement in the UK supermarket sector. Journal of Cleaner Production 2016; 112, Part 4: 3294–3305.

[27] Verdouw, C. N., Wolfert, J., Beulens, A. J. M., & Rialland, A. (2016). Virtualization of food supply chains with the internet of things. *Journal of Food Engineering*, 2016; 176, 128-136. doi:http://dx.doi.org/10.1016/j.jfoodeng.2015.11.009.

[28] Saleh ZM, Roslin RM Supply chain integration strategy: a conceptual model of supply chain relational capital enabler in the Malaysian food processing industry. Procedia—Social and Behavioral Sciences 2015; 172: 585–590.

[29] Fedrigotti VB, Fischer C Sustainable development options for the chestnut supply chain in South Tyrol, Italy. Agriculture and Agricultural Science Procedia 2015; 5: 96–106.

[30] Garrone P, Melacini M, Perego A Opening the black box of food waste reduction. Food Policy 2014; 46: 129–139.

[31] Grekova K, Bremmers HJ, Trienekens JH, et al. Extending environmental management beyond the firm boundaries: an empirical study of Dutch food and beverage firms. International Journal of Production Economics 2014; 152: 174–187.

[32] Grimm JH, Hofstetter JS, Sarkis J Critical factors for sub-supplier management: a sustainable food supply chains perspective. International Journal of Production Economics 2014; 152: 159–173.

[33] Papargyropoulou E, Lozano R, K Steinberger J, et al. The food waste hierarchy as a framework for the management of food surplus and food waste. Journal of Cleaner Production 2014; 76: 106–115.

[34] Li D, Wang X, Chan HK, Manzini R Sustainable food supply chain management. International Journal of Production Economics 2014; 152: 1–8.

[35] Validi S, Bhattacharya A, Byrne PJ A case analysis of a sustainable food supply chain distribution system—A multi-objective approach. International Journal of Production Economics 2014; 152: 71–87.

[36] Turi A, Goncalves G, Mocan M Challenges and competitiveness indicators for the sustainable development of the supply chain in food industry. Procedia—Social and Behavioral Sciences 2014; 124: 133–141.

[37] Martikainen A, Niemi P, Pekkanen P Developing a service offering for a logistical service provider—Case of local food supply chain. International Journal of Production Economics 2014; 157: 318–326.

[38] Eksoz C, Mansouri SA, Bourlakis M Collaborative forecasting in the food supply chain: a conceptual framework. International Journal of Production Economics 2014; 158: 120–135.

[39] Chen C, Zhang J, Delaurentis T Quality control in food supply chain management: an analytical model and case study of the adulterated milk incident in China. International Journal of Production Economics 2014; 152: 188–199.

[40] Bourlakis M, Maglaras G, Aktas E, et al. Firm size and sustainable performance in food supply chains: Insights from Greek SMEs. International Journal of Production Economics 2014; 152: 112–130.

[41] Aung MM, Chang YS Temperature management for the quality assurance of a perishable food supply chain. Food Control 2014; 40: 198–207.

[42] Ala-Harja H, Helo P Green supply chain decisions—Case-based performance analysis from the food industry. Transportation Research Part E: Logistics and Transportation Review 2014; 69: 97–107.

[43] Agustina D, Lee CKM, Piplani R Vehicle scheduling and routing at a cross docking center for food supply chains. International Journal of Production Economics 2014; 152: 29–41.

[44] Gold S, Hahn R, Seuring S Sustainable supply chain management in "Base of the Pyramid" food projects—A path to triple bottom line approaches for multinationals? International Business Review 2013; 22: 784–799.

[45] Manzini R, Accorsi R The new conceptual framework for food supply chain assessment. Journal of Food Engineering 2013; 115: 251–263.

[46] Wang Y-F, Chen S-P, Lee Y-C, Tsai C-T Developing green management standards for restaurants: an application of green supply chain management. International Journal of Hospitality Management 2013; 34: 263–273.

[47] Zanoni S, Zavanella L Chilled or frozen? Decision strategies for sustainable food supply chains. International Journal of Production Economics 2012; 140: 731–736.

[48] Lazaridesa HN Food processing technology in a sustainable food supply chain. Procedia Food Science 2011; 1: 1918–1923.

[49] Al-Busaidi MA, Jukes DJ Assessment of the food control systems in the Sultanate of Oman. Food Control 2015; 51: 55–69.

[50] Tuljak Suban D, Bogataj M An optimal ordering cycle at interactions of fuzzy parameters and high disposal fees of food or drug supply systems. IFAC-PapersOnLine 2015; 48: 2374–2379.

Chapter 6

Environmental and Social Sustainability in the Fresh Fruit and Vegetables Supply Chain: A Competitiveness' Asset

Nadia Tecco, Nicole Giuggioli ,
Vincenzo Girgenti and Cristiana Peano

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/63377

Abstract

The concern for products that meet the requirements of sustainability is a key factor that drives consumers and can be the engine of a successful economy in the food businesses. In the specific case of the fresh fruit and vegetables, more than ever, sustainability understood as a greater focus on the social and environmental performance of the product and of its supply chain, can be considered as a tool to counter the consumer's disaffection. The communication of the product's sustainability can indeed represent a tool to bring out the fruit and vegetable products from the anonymity, a strategy to will make it 'remember', relying not only on the traditional values recognized to the segment, but also on a set of the supply chain attributes that can differentiate it. However, how to get effectively to the consumer by using a multidimensional and complex concept as the product's sustainability of the product, how to make the sustainability attribute a factor to be considered in the final purchasing choices, how to involve the different stakeholders in the building of a sustainable supply chain (regardless of its length) are still open discussion topics. After presenting the main sustainability certification and communication tools adopted till nowadays for the fresh fruit and vegetables supply chain, the chapter investigates the relative potentialities and criticisms in order to turn them into a real competitiveness' asset.

Keywords: Sustainability, Fructicolture, Certification, Stakeholders, labels

1. Introduction

Even in one of the most important food categories—fresh fruit and vegetables—there is a current trend whereby consumers are increasingly looking for a sustainable form of trade. The agri-food industry[1]—and the fruit and vegetable sector in particular—must meet requirements that vary geographically and over time as a result of changing technology and consumer behaviour.

Eating habits have always been an important element of culture [1]. Numerous models have been adopted by different scientific disciplines to describe the choices and behaviour of food buyers [2–6]. Whereas in the past food choices were largely dictated by the necessity of satisfying a basic physiological need, nowadays the motivation is more social in nature [7], suggesting that external factors can affect what we choose to eat [8]. Of these new requirements, the 'emotional' aspects (security, love, esteem and self-fulfilment) are undoubtedly among the most interesting when it comes to understanding changes in food consumption [9,10]. Sociodemographic variables no longer seem sufficient to explain the behaviour of the modern consumer, who instead must be viewed with a multidisciplinary approach that takes additional aspects into consideration. This evolution has spawned the modern consumer of fruit and vegetables, who is more conscious of environmental sustainability and socio-economic issues and relies on these factors to inform his or her choices. More specifically, factors such as the type of product, its qualitative aspects, packaging [11] and distribution channel, although very different from one another, have become fundamental in guiding the purchasing behaviour of consumers [12,13]. Now more informed consumers tend to buy products that can be classed as sustainable, a definition that over time has become multidimensional [14]. This information is particularly relevant for the credence attributes of fruit and vegetables, which cannot be ascertained even after the consumption experience. These include, for example, aspects such as the local provenance of the product, how organic it is, producer support and respect for workers' rights [15]. In this case, the consumer's decision is based solely on how much confidence he or she has in the information on the label, the brand or other elements that help to build the product's reputation by sharing some of its extrinsic qualities. As a result, the information asymmetry is reduced and the credence attribute becomes a search attribute, which means that some information may be known to consumers before they buy, regardless of the consumption experience.

The increased focus on social and environmental balance and how to convey these aspects properly thus have considerable implications for the fruit and vegetable supply chain. To differentiate or promote new products, consideration must be given to the use of natural resources, as well as minimising the impact of farming on the environment and on the local community, how and where the produce is grown, the characteristics and socio-economic and environmental impact of processing, the health benefits of the product, its distribution channel, and finally waste recycling and management. Meeting these consumer expectations requires an industry-wide commitment to maintain, improve and promote the qualitative aspects of

---

[1] Defined as a group of activities between companies and sectors linked by business relations designed to add value to food on the journey from field to fork.

http://dx.doi.org/10.5772/63377

the product and producer, which in turn becomes an incentive for corrective action and improved performance by supply chain actors. The purpose of this paper is therefore to describe those instruments that have been developed thus far within the fruit and vegetable supply chain, discussing their main benefits, limitations and drawbacks.

2. An overview of certification schemes and communication tools for F&V

To address this growing demand for sustainability in a way that is appropriate and commensurate with the consumer's needs, a wide variety of schemes have been developed over the past decade—both in the fruit and vegetable supply chain and elsewhere—that differ in terms of their objectives, structure and operating methods. These consist of optional certification tools (voluntary product certification and standards), as well as self-declaration. The main examples are listed in **Table 1**. These schemes are not intended to demonstrate compliance with legal requirements. However, when used by operators to facilitate the transition with other actors in the fruit and vegetable supply chain by indicating conformity with legal requirements, it is clear that this type of tool cannot be used to differentiate products on the market.

2.1. Certification and standards

With regard to F&V certification schemes, a special arrangement whereby a certificate is issued by a third party guarantees compliance with a certain number of characteristics or attributes of the product or its production method or system, as defined in a standard. These include a wide range of initiatives at different points along the food chain (either before or after leaving the farm, along the entire food chain or in part of it, in all sectors or in a particular market segment).

	Tipology	**Standard of reference**	**Key features**
Integrated production	Voluntary third-party certification	UNI 11233	Selection of agronomic preventive measures and biological/physical/chemical methods are carefully selected and balanced taking into account the protection of health of both farmers and consumers and of the environment
Supply chain traceability	Voluntary third-party certification	ISO 22005 (2008)	Traceability
Quality management system	Voluntary third-party certification	ISO 9001	Minimization of harmful effects on the environment, conformity to applicable regulatory requirements, achievement of improvement of environmental performance

	Tipology	Standard of reference	Key features
Social responsibility	Voluntary third-party certification	SA 8000	Ethics
Food security management system	Voluntary third-party certification	ISO 22000 (2005), HACCP (FAO/OMS *Codex Alimentarius*)	Food security
Good Agricultural Practices (GLOBALGAP)	Voluntary third-party standard	*Chain of Custody Standard*	The certificate covers the process from farm inputs like feed or seedlings and all the farming activities until the product leaves the farm
British Retail Consortium (BRC)	Voluntary third-party standard	*BRC Global Standard Food*	Senior management commitment and continuous improvement, hazard and risk analysis, quality management system, site and building standards, vehicle operating standards, facility management, good operating practices, personnel
International Food Standard (IFS)	Voluntary third-party standard	GFSI Global Food Safety Standard	Senior management responsibility, quality and food safety management systems, resource management, production process, measurements, analysis, improvements and food defence
Eco management and Audit Scheme (EMAS)	Voluntary third-party certification	UNI EN ISO 14001	Environmental efficiency
Self-declared environmental claims	Type II environmental labelling	ISO 14021	Environmental: defined once for once, for example recyclable
Environmental Product Declaration (EPD®)	Type III environmental labelling	UNI ISO 14025:2006	Environmental: quantified product life cycle environmental performance information

Source: Re-elaboration with permission from Tecco et al. [16].

Table 1. Summary of the main certificates and other tools used in the fruit and vegetable supply chain.

Their use is particularly apt, given how complex the operator's commitments are, set out in detailed standards that require periodic verification.

Among the voluntary standards certified by third parties, Global Gap (until 2007 EurepGap), an initiative of the Euro-Retailer Produce Working Group (EUREP), is currently one of the initiatives with the most members in Europe and worldwide [17]. Certification is based on compliance with Good Agriculture Practices (hence the acronym GAP) for agricultural produce of plant origin. This addresses consumer expectations in terms of food safety, traceability, the environment and health and safety of workers. The protocol can be adopted for individual phases or for the entire supply chain, with a module-based certification system in which option 1 is for farms, while option 2 includes quality system management by commercial farms and F&V packaging, which take place downstream of agricultural production.

In addition to third-party certification, certification schemes may use labels or logos (the latter sometimes registered trademarks) as a communication tool. The labels used fall into the following classifications and descriptions of the International Standards Organisation (ISO):

- Type I label (ISO 14024)—often referred to as an eco-label[2], this is awarded by third parties in the public or private sector which operate independently of the producer. They involve the use of a logo associated with the certified product. These are based on a multi-criteria system that analyses each stage of the product life cycle, identifying the threshold values to be met;
- Type III label (ISO 14025)—in this case, an accredited third-party certification body analyses the entire product life cycle based on parameters previously established by a life cycle analysis (LCA); this system can be used with any type of production. The aim was to inform consumers by providing elements enabling them to compare functionally similar goods and services.

In the case of the Type I label used in the fruit and vegetable supply chain, the majority of organic production logos and the European environmental quality logo (Ecolabel) fall into this category for the primary sector. The other label in this category is the carbon neutral label; this is becoming increasingly widespread, especially among operators who produce and market tropical fruit.

In the case of AgroFair, the first farming cooperative in the world to market tropical fruit such as bananas and pineapple under the fair trade and welfare banner, the goal has been to extend fair trade and welfare recognition through additional certification demonstrating zero-emissions production. A similar approach has been taken by Dole Costa Rica to comply with environmental strategies defined according to the Costa Rica Carbon Neutral Strategy 2021 [18].

The EPD® (Environmental Product Declaration), a document that quantifies a product's environmental performance through appropriate categories of parameters calculated with LCA methodology, is considered Type III labelling. One example of the application to the F&V supply chain is Italian apples, produced under the aegis of the Italian Association of Apple Producers (Assomela). Here, an LCA was used to quantify the environmental impacts associated with the life cycle of apples in relation to the 2012, 2013 and 2014 harvest [19].

2.2. Self-declaration

Another scheme in the fruit and vegetable sector is self-declaration. Membership of these schemes is through self-declaration or selection by the operator of the scheme. Self-declaration

[2] The use of the term 'ecolabel' for this category can be confusing, since the European Union also has an Ecolabel scheme.

is generally regarded as suitable for relatively basic information concerning particular environmental aspects of the product, such as the absence of substances that are harmful to the environment, recycled content or biodegradability. It is also based on the use of a label or logo, although no external bodies are involved.

The labels used for this scheme are again covered by the ISO classification and are described as follows:

- Type II Label (ISO 14021)—Self-declared environmental claims. This is effectively done by the producers, importers and distributors of the products [20]. According to ISO 14021, self-certification must include clear information that is not misleading or open to misinterpretation, and which can be certified if necessary (for example, if asked to produce the documentation certifying the label, these must be supplied).

There has been widespread uptake of this tool in the fruit and vegetable supply chain for the self-certification of organic production, in parallel with the development of Participatory Guarantee Systems [21].

3. Benefits distribution of voluntary socially and environmentally responsible behaviour along the fruit and vegetables supply chain

The use of such schemes offers potential across the fruit and vegetable supply chain in terms of increased competitiveness, which benefits producers, intermediaries and end consumers.

Actors' categories	Benefits
 Producers	• Increased market access, market share and profit margins for certified products • Increased efficiency • Reduction in transaction costs • Enhanced reputation and image • Emphasis on uniqueness and local provenance • A guarantee that supports the continuity of distribution agreements • Enable premium price obtaining
 Intermediaries/retailers	• IGuarantee of compliance with certain standards • Protection in terms of product liability and reputation • Reduced civil liability risk • Enhanced reputation and image • A closer partner (supplier) relationship

http://dx.doi.org/10.5772/63377

Actors' categories	Benefits
 Consumers	• Obtain reliable and trustworthy information on product characteristics and processing • Reduction of information asymmetry

Source: Authors' elaboration.

Table 2. Benefits of regimes according to the actors' categories.

However, the distribution of these benefits within the fruit and vegetable supply chain is linked to the methods and frequency with which such tools are used by operators, as well as their visibility.

For this purpose, it is worth considering a further distinction, which allows the tools to be classified according to the type of relationship created: *Business to Business* (B2B), in the case of business-to-business relationships where the final recipient of the information is internal to the supply chain, or *Business to Consumer* (B2C), for relationships between distributors and consumers (**Table 3**).

Audience	B2B		B2C
			
Type of attestation:	Certification (third-party attestation)		Self-declaration
Objects of specific requirements	Mostly management systems	Mostly products (including services) and processes	Product and processes
Content of require ments	Baseline and above baseline	Mostly above baseline	Mostly above baseline

Source: Authors re-elaboration with permission from European Commission [22].

Table 3. Classifications of schemes according the kind of audience.

B2B tools are not shared with end consumers, who are often unaware of their existence. GlobalGAP, International Food Standard and ISO 22000 certification are all B2B standards whose goal in the fruit and vegetable supply chain, as well as in the food industry as a whole, is to facilitate trade between industry operators by offering assurances to buyers based on certifiable standards that form the basis of a common language on which to build trade relations.

B2C certification is a useful tool to show the market (customers, consumers, public opinion in general) that the products meet the stated requirements. The choice of requirements is therefore strategic for the success of the product and the certification, as the product takes on associations and becomes recognisable depending on the information conveyed.

Supermarket distribution, as the most important retail channel for fruit and vegetable produce with a market share of between 60 and 90%, depending on the Member State[3] [23], is the party that relies the most on the use of such schemes, both as a recipient of information via B2B certification, and as a provider of information to its own customers with B2C tools. By consulting the database of best practices in environmental and social sustainability, developed as part of the Retailers' Environmental Action Plan (REAP)[4] and adopted by leading European retailers, we can see how the initiatives taken by Delhaize Group, Eurocoop, Mercador, Kaufland and Rewe Group in the F&V supply chain signal an approach designed to support and communicate improvements in production and consumption systems, using certification as a dual means of assurance and communication. The intention of minimising the impacts of direct activities throughout the F&V supply chain is apparent, for example in the preference for products that wherever possible satisfy the requirements of the green economy, in the priority given to products that meet certain production standards, and in the optimisation of transport efficiency.

The use of B2C tools currently prevails in Europe [24]. The use of certification schemes that cover both applications using trademarks is also growing. The label used by Coop Italia for its own-brand fresh produce (**Figure 1**) is a good example of this combined approach. Quality assurance and product safety are certified by third-party controls that focus on four complementary aspects:

1. the provenance of products from integrated farming;
2. chemical residues 70% below the legal limits;
3. the absence of post-harvest chemical treatment;
4. strict control from field to point of sale.

In the F&V supply chain, therefore, it seems fairly obvious that environmental and social sustainability has now become an asset for competitiveness, especially in supermarket distribution, due both to its role as a hub or bottleneck [24] within the F&V supply chain, and for its ability to respond more quickly to this challenge, seizing the advantages [25] through third-party certification and the private label.

---

[3] More so in northern Europe than in the south.

[4] The outcome of this project, launched by the European Commission in 2009, was the construction of a multi-stakeholder platform to facilitate the virtual exchange of such actions among European supermarket operators. http://ec.europa.eu/environment/industry/retail/reap/browse-by-category_en.html

http://dx.doi.org/10.5772/63377

Figure 1. Coop logo on fresh produce.

4. Drawbacks of the status Quo across the fruit and vegetables supply chain

Looking then at the distribution of benefits among stakeholders and the relationships between them along the F&V supply chain, it is possible to present this synthetically, as proposed in **Figure 2**.

As well as demonstrating the dominant position of the retailer as a major beneficiary of the voluntary adoption of socio-environmental responsibility behaviours, the diagram shows the subordinate position both of producers and consumers in relation to the retailer.

As confirmation of the general trend observed in the spread and effectiveness of corporate sustainability strategies [26], even in the fruit and vegetable supply chain, the competitive outcome appears to be closely related to the mechanisms that link the various stakeholders and their sustainability enhancement actions.

Despite the predominance of B2C tools and the development of multi-information labels (**Figure 1**), a segmented communication strategy is emerging within the sector, as well as a lack of multidimensional cross-cutting tools with a 360° approach to sustainability.

The diversity and fragmentation of the fruit and vegetable production system, coupled with inconspicuous own-brand policies, lead to a situation in which the adoption of responsibility behaviours in terms of sustainability, and the resulting product differentiation is mostly dictated by the demands of supermarket chains [27], instead of being designed from the ground up to showcase the unique aspects and local nature of the production system. While this ensures that producers meet high standards and encourages the renewal of retailer distribution agreements, at times even securing a premium price (net of expenses and additional costs), the level of visibility and recognition of producers among final consumers

Figure 2. Illustration of the benefits distribution resulting from the voluntary adoption of socio-environmental responsibility behaviours and the reciprocal position within the F&V supply chain. Source: authors' elaboration.

remains low. The situation is even more complicated for producers who must join several schemes to fulfil their buyers' requirements. Producers who do not participate in the main certification schemes (through choice or due to difficulties inherent in the country of origin, in the case of the tropical fruit sector) face the risk of exclusion from the market. Non-adoption can therefore translate as a market barrier.

Even the act of purchasing 'sustainable' produce is beset by a series of difficulties linked to effective communication, from consumer motivation/education to the knowledge-action gap and behaviour-impact gap problems [28].

Strict communication rules require information to be presented clearly and concisely, given the limited space on the label. This physical limitation can lead to distortions, misleading consumers in a context where the meaning of sustainability attributes could be ambiguous for the end user [29]. On the one hand, the complexity of sustainability risks being reduced to a few synthetic messages/actions with purely cosmetic content [30]. In cases where compliance is certified with minimum requirements or by self-declaration, doubts may arise over the credibility of the information or the transparency of the requirements envisaged.

On the other hand, more information in a single label can be confusing, given the consumer's gaps, thus defeating the very purpose of the label [20,31]. Where the consumer is more socially and environmentally motivated, the buying decision will be more informed and the buyer more likely to use the information on the label correctly. In other words, the communicative effect of the label does not influence the 'average' consumer, but tends to work mainly with consumers who are already motivated [29]. Behavioural change is difficult when the information given is too complex to decipher or is based on conflicting values: in these situations, consumers have a tendency to seek refuge in their usual buying habits [28].

Furthermore, it is now known that discrepancies exist between the expected (stated) behaviour and the observed (actual) behaviour of consumers when making a purchase, fostering the creation of a gap between knowledge and action (the 'knowledge-to-action gap'). This inconsistency is linked to the fact that the judgement and selection criterion for a sustainable product have to compete with contingent factors influencing the intrinsic and extrinsic opinion of the product, such as sensory quality, nutritional value, price, brand and quantity, in which the sustainability of the product and/or the production process is merely seen as one of many final characteristics of the product category. A choice seen as sustainable does not always have the desired effect, leading to a gap this time between behaviour and impact (the 'behaviour-impact gap') [32]. In this case, information and cognitive barriers prevail alongside rebound effects [33] attributable to the presence of negative external factors within the supply chain or its interaction with the outside world. This risks having a marginal or zero effect on the commitment of parties who have adopted environmentally and socially responsible behaviours [32] and those who support them by buying their products.

5. Future challenges

Although in recent years certification schemes, as a means of private regulation and communication of the corporate sustainability commitment, have diverged enormously to increase the transparency of results and the disclosure of actions taken by producers in terms of their operating processes, significant efforts still need to be made before these become a win–win strategy for stakeholders in the fruit and vegetable supply chain. The greatest obstacle is fragmentation, in the sense of a compartmentalized and linear vision of the supply chain and an interpretation of sustainability based on size and components.

The predominance of a vertical approach represents a drag on the harmonisation process. The lack of horizontal relationships leads to unfair competition and undermines the effectiveness of these tools, especially for the end user.

While the general objective is to improve the sustainability of the fruit and vegetable supply chain, a systemic approach is needed in which—according to Nash's game theory—the best result is achieved when each stakeholder in the supply chain does what is best for itself and for the group at the same time. These represent the preconditions for a transition from the social responsibility of individual enterprises to that of an integrated supply chain or territory (depending on our point of view), in keeping with a social responsibility approach in which competitiveness derives not only from the ability to respond to the market, but also from a commitment to achieve adequate levels of sustainability guaranteed throughout the supply chain and to contribute to the economic development of the local area. In this sense, the supply chain builds and adds value, providing content and relational continuity for market transactions.

In this respect, power should be redistributed along the value chain and more consideration given to each end of the supply chain—that is producers upstream and consumers downstream—to respond to the needs of the fruit and vegetable sector by anticipating its needs.

The challenge is therefore to embrace and increasingly involve in this education and communication process the 'custodians' of sustainability, in other words operators engaged in day-to-day farming, who manage agricultural production inputs and control more or less consciously the impacts for the end consumer.

It is essential therefore that producers, individually or—better still—through producer organisations, as stakeholders with direct experience of the product on the ground, succeed in having a more active and visible role, so that socio-environmental responsibility behaviours are targeted as a worthwhile and strategic competitive advantage. The potential in terms of the reservoir of capital that can be tapped is considerable, ranging from human and organisational to relational and symbolic capital [26].

To communicate the potential for innovation and the creation of added value for the final market—and so for products that meet the 'green and social requirements'—the consumer must also be fully equipped to decipher the information contained in the label and to recognise its objectivity and verifiability.

This approach means adopting new mechanisms for coordination between stakeholders, with appropriate forms of control such as industry codes of conduct [34,35], collaborative practices such as participatory certification systems aimed at building trust, cross-cutting assessments and analysis tools for the sector, using F&V life cycle analysis not only to assess the environmental impacts, but to consider their social [16] and economic implications. The life cycle thinking approach is part of the broader theoretical framework of life cycle sustainability analysis (LCSA) [36–38]. It paves the way for the construction of an interdisciplinary methodology aimed at combining and integrating the assessment of sustainability issues.

All of these developments are desirable, even when examined as part of the transition towards an increasingly circular economy within agri-food systems [39].

6. A meaningful case study: Delizie di Bosco del Piemonte

In the light of these initial points and considerations, below is a summary of a green marketing initiative [25], that we consider significant, both because it is promoted directly by a group of small producers in an upland area in the Province of Cuneo (in the Piedmont region of northwest Italy), and because the marketing content is designed to convey to the end consumer the multidimensional nature of sustainability practices and responsibility (both environmental and social). The Agrifrutta cooperative, a member of the Ortofruitalia producer organisation (PO), in a bid to bolster its image and promote its small-fruit production, decided to reduce the environmental impact of its cultivation techniques, simultaneously quantifying the actions taken so that compensatory measures could be adopted if necessary. First and foremost, the production processes and practices related to cultivation and post-harvest management of strawberries [40] and small fruits [41] were analysed and evaluated using the life cycle assessment (LCA) tool. The relevance of this technique consisted of the possibility of evaluating all phases of the strawberry and small-fruit production process as interrelated and interdependent, and of having an objective evaluation and quantification method to analyse the different components of the impacts associated with strawberry and small-fruit production.

This has effectively meant a renewed approach to the existing production/commercial system, resulting in the adoption of new practices more suited to reducing the environmental/social

http://dx.doi.org/10.5772/63377

impact (such as reducing the volumes of substrate used in the nursery, and using biodegradable and compostable films for mulching and packaging), communicated to consumers by creating the 'Delizie di Bosco di Piemonte' brand (**Figure 3**).

Figure 3. Agrifrutta cooperative logo for strawberries and small fruit.

Following the impact assessment of production supply chains, a form of carbon offsetting was proposed through the development of silvicultural systems properly managed by the same small-fruit producers (**Figure 4**).

Figure 4. Offsetting scheme for the strawberry and small-fruit industry adopted by the Agrifrutta cooperative.

Indeed, unlike other primary sectors, agriculture is not only a source of carbon dioxide emissions, but has the undeniable advantage of being able to perform CO_2 sequestration, thus enabling internal carbon offsetting. The differentiated production model of the farms considered, which rotate different crops each season and comprise areas of woodland, pasture or meadow, makes them natural holders of a 'green credit' and thus able to offset fully the carbon dioxide generated in their production cycle. This allows them to create an environmental business plan which forms the basis for the conservation of the characteristic landscape and agro-biodiversity of the production area. The approach taken has prepared the ground for producer members and various industry stakeholders to forge stronger ties with the local area, and to leverage this to build a reputation capable of establishing new and lasting agreements with communities, distribution channels (supermarkets) and end consumers. The brand has strengthened the image of the product and the producer community. Creating a brand addressed the requirements imposed by a new market structure that requires ever greater product differentiation. It has also raised its profile in national and international markets, emphasising its close links with the surrounding area; even in national and international supermarket distribution, the cooperative's products can be identified and recognised, and thus distinguished from similar products.

The decision to offset emissions through management of existing local areas, as well as contributing to climate change mitigation, is also an opportunity to improve woodland management, environmental protection and the development of rural and mountain areas.

Acknowledgements

The authors acknowledge support from the Lagrange Project of the ISI Foundation funded by the CRT Foundation.

Author details

Nadia Tecco*, Nicole Giuggioli, Vincenzo Girgenti and Cristiana Peano

*Address all correspondence to: nadia.tecco@unito.it

Department of Agricultural, Forest and Food Sciences, University of Turin, Turin, Italy

References

[1] Harris M. Good to eat: riddles of food and culture [Paperback] [Internet]. 2nd ed. Long Grove, Illinois, USA: Waveland Pr Inc; 1998.

[2] Axelson ML, Brinberg D. A social-psychological perspective on food-related behavior. New York: Springer-Verlag; 1989.

[3] Glanz K, Hewitt AM, Rudd J. Consumer behavior and nutrition education: an integrative review. J Nutr Educ [Internet]. 1992;24(5):267–77. Available from: http://www.sciencedirect.com/science/article/pii/S0022318212812441

[4] DeVault ML, Mennell S, Murcott A, van Otterloo AH. The sociology of food: eating, diet and culture. Contemp Sociol. 1993. 22:871.

[5] Shepherd R. Overview of factors influencing food choice. BNF Nutr Bull. 1990;15(Suppl 1):12–30.

[6] Shepherd R. Influences on food choice and dietary behavior. Forum Nutr. 2005;(57):36–43.

[7] Herman CP, Roth DA, Polivy J. Effects of the presence of others on food intake: a normative interpretation. Psychol Bull. 2003;129(6):873–86.

[8] Arganini C, Saba A, Virgili F, Comitato R , Turrini A. Gender Differences in Food Choice and Dietary Intake in Modern Western Societies. Public Health: Social and Behavioral Health, Maddock J (Ed.), 2012; 83–102, ISBN: 978-953-51-0620-3, InTech, Available from: http://www.intechopen.com/books/public-health-social-and-behavioral-health/gender-differences-in-food-choice-and-dietary-intake-in-modern-western-societies

[9] Senauer B, Sur M. Ending global hunger in the 21st century: projections of the number of food insecure people. Rev Agric Econ [Internet]. 2001;23(1):68–81. Available from: http://aepp.oxfordjournals.org/content/23/1/68.abstract\nhttp://aepp.oxfordjournals.org/content/23/1/68.short

[10] Conner M. Armitage CJ. The social psycology of food. Buckingham: Open University Press; 2002.

[11] Koutsimanis G, Getter K, Behe B, Harte J, Almenar E. Influences of packaging attributes on consumer purchase decisions for fresh produce. Appetite. 2012;59(2):270–80.

[12] Booth DA, Shepherd R. Sensory influences on food acceptance: the neglected approach to nutrition promotion. Nutr Bull [Internet]. 1988;13(1):39–54. Available from: doi: 10.1111/j.1467-3010.1988.tb00267.x

[13] Randall E, Sanjur D. Food preferences—their conceptualization and relationship to consumption†. Ecol Food Nutr [Internet]. 2010;11(3):151–61. Available from: doi: 10.1080/03670244.1981.9990671

[14] Fabris G. The new consumer: toward postmodernism (orig. title *Il nuovo consumatore: verso il postmoderno*.) Milano, FrancoAngeli; 2003.

[15] Moser R, Raffaelli R, Thilmany-McFadden D. Consumer preferences for fruit and vegetables with credence-based attributes: a review. Int Food Agribus Manag Rev. 2011;14(2):121–42.

[16] Tecco N, Peano C. Future perspectives about the use of environmental and social life cycle assessment for the fruit and vegetables supply chain (orig. title Potenzialità dell' impiego dell'analisi ambientale e sociale del ciclo di vita del prodotto per la filiera ortofrutticola), Agriregionieuropa [Internet]. 2015;11(40). Available from: http://agriregionieuropa.univpm.it/it/content/article/31/40/potenzialita-dell-impiego-dellanalisi-ambientale-e-sociale-del-ciclo-di-vita

[17] Mascod A, Brümmer B. Determinants of Worldwide Diffusion of GlobalGAP Certification. Glob Discuss Pap [Internet]. 2014;(48):25. Available from: C:\Users\T420s\Documents\Citavi 5\Projects\Master Thesis\Citavi Attachments\Meyer-H?fer, Nitzko, Spiller-2013-RTG 1666 GlobalFood.pdf

[18] Kilian B, Hettinga J, Jiménez GA, Molina S, White A. Case study on Dole's carbon-neutral fruits. J Bus Res. 2012;65(12):1800–10.

[19] Environmental Product Declaration of Italian Apples [Internet]. 2015. Available from: http://gryphon.environdec.com/data/files/6/9832/epd369en_2015.pdf

[20] Horne RE. Limits to labels: the role of eco-labels in the assessment of product sustainability and routes to sustainable consumption. Int J Consum Stud [Internet]. 2009;33(2): 175–82. Available from: doi:10.1111/j.1470-6431.2009.00752.x

[21] Sacchi G. The evolution of Participatory Guarantee Systems for organic agriculture: a comparison among experiences through the world (orig. title L'evoluzione dei Participatory Guarantee Systems per l'agricoltura biologica: esperienze mondiali a confronto) Economia Agro-alimentare, 2015; 17:77–92.

[22] European Commission. EU best practice guidelines for voluntary certification schemes for agricultural products and foodstuffs (2010/C 341/04). Off J Eur Union. 2010;5–11.

[23] Promedio P, Venta MDE, February US. Fruit and vegetables in Europe (orig. title Frutas Y Hortalizas En Europa), 2016.

[24] Gawron J-C, Theuvsen L. Agrifood Certification Schemes in an Intercultural Context: Theoretical Reasoning and Empirical Findings. Eur Assoc Agric Econ Semin Sept 3–6, 2009, Chania, Crete, Greece [Internet]. 2009;15. Available from: http://purl.umn.edu/58018

[25] Peano C, Baudino C, Tecco N, Girgenti V. Green marketing tools for fruit growers associated groups: application of the Life Cycle Assessment (LCA) for strawberries and berry fruits ecobranding in northern Italy. J Clean Prod [Internet]. 2015;104:59–67; Elsevier Ltd. Available from: http://www.sciencedirect.com/science/article/pii/S095965261500462X

[26] Perrini F, Vurro C. Corporate sustainability, immaterial resources and competitiveness advantage (orig. title *Sostenibilità aziendale, risorse immateriali e vantaggio competitivo*), Symphonya, Emerging isuues in managment, 2010;2:33–45.

[27] Sodano V, Hingley M. A case study from the market for fresh produce Channel Management and differentiation strategies?: a case study from the market for fresh produce. 2007.

[28] Gorgitano MT, Sodano V. Sustainable food consumption: concept and policies. Qual Access Success. 2014;15(suppl 1):207–12.

[29] Grunert KG, Hieke S, Wills J. Sustainability labels on food products: consumer motivation, understanding and use. Food Policy [Internet]. 2014 Feb [cited 2014 Sep 3]; 44:177–89. Available from: http://www.sciencedirect.com/science/article/pii/S0306919213001796

[30] Vollero A. Il rischio di greenwashing nella comunicazione per la sostenibilita`: implicazioni manageriali. Sinergie, Riv Di Stud E Ric. 2013;(92):3–23.

[31] Grunert KG. Sustainability in the food sector: a consumer behaviour perspective. Int J Food Syst Dyn. 2011;2(3):207–18.

[32] Csutora M. One more awareness gap? The behaviour-impact gap problem. J Consum Policy. 2012;35(1):145–63.

[33] Hertwich EG. Consumption and the rebound effect: an industrial ecology perspective. J Ind Ecol [Internet]. 2005;9(1–2):85–98. Available from: doi:10.1162/1088198054084635

[34] FAO-OECD. Guidance for Responsible Agricultural Supply Chains. 2015.

[35] van Tulder R, van Wijk J, Kolk A. From Chain Liability to Chain Responsibility. J Bus Ethics. 2009;85:399–412.

[36] Kloepffer W. Life cycle sustainability assessment of products. Int J Life Cycle Assess [Internet]. 2008;13(2):89–95. Available from: doi:10.1065/lca2008.02.376

[37] Finkbeiner M, Schau EM, Lehmann A, Traverso M. Towards life cycle sustainability assessment. Sustainability. 2010;2(10):3309–22.

[38] Zamagni A, Pesonen H-L, Swarr T. From LCA to Life Cycle Sustainability Assessment: concept, practice and future directions. Int J Life Cycle Assess [Internet]. 2013;18(9): 1637–41. Available from: http://link.springer.com/10.1007/s11367-013-0648-3

[39] Jurgilevich A, Birge T, Kentala-lehtonen J, Korhonen-kurki K, Pietikäinen J, Saikku L, et al. Transition towards Circular Economy in the Food System. Sustainability. 2016;8,69.

[40] Girgenti V, Peano C, Baudino C, Tecco N. From "farm to fork" strawberry system: current realities and potential innovative scenarios from life cycle assessment of non-renewable energy use and green house gas emissions. Sci Total Environ [Internet]. 2014;473–474:48–53. Available from: doi: 10.1016/j.scitotenv.2013.11.133

[41] Girgenti V, Peano C, Bounous M, Baudino C. A life cycle assessment of non-renewable energy use and greenhouse gas emissions associated with blueberry and raspberry production in northern Italy. Sci Total Environ [Internet]. 2013;458–460:414–8; Elsevier B.V. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23685366

INTECH

Chapter 7

Performance Evaluation for the Sustainable Supply Chain Management

Xuemei Fan and Shujun Zhang

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/63065

Abstract

Supply chain SC activities transform natural resources, raw materials, and components into various finished products that are delivered to end customers. A high efficient SC would bring great benefits to an enterprise such as integrated resources, reduced logistics costs, improved logistics efficiency, and high quality of overall level of services. In contrast, an inefficient SC will bring additional transaction costs, information management costs, and resource waste, reduce the production capacity of all enterprises on the chain, and unsatisfactory customer relationships. So the evaluation of a SC is important for an enterprise to survive in a competitive market in a globalized business environment. Therefore, it is important to research the various methods, performance indicator systems, and technology for evaluating, monitoring, predicting, and optimizing the performance of a SC. A typical procedure of the performance evaluation (PE) of a SC is to use the established evaluation performance indicators, employ an analytical method, follow a given procedure, to carry out quantitatively or qualitatively comparative analysis to provide the objective and accurate evaluation of a SC performance in a selected operation period. Various research works have been carried out in proposing the performance indicator systems and methods for SC performance evaluations. But there are no widely accepted indicator systems that can be applied in practical SC performance evaluations due to the fact that the indicators in different systems have been defined without a common understanding of the meanings and the relationships between them, and they are nonlinear and very complicated.

In this chapter, the conception of SC performance is first presented, then relevant theories about supply chain performance evaluation are discussed and several common methods of supply chain performance evaluation are discussed. Finally, an evaluation model is presented for SC performance evaluation using 5 dimensional balanced scorecard (5DBSC) and Levenberg–Marquardt Back-propagation (LM-BP) neural network algorithm.

Keywords: SCM, sustainability, performance evaluation, KPI, neural network, 5DBSC, LM-BP

1. Introduction

Served as one of the three major US automobile companies, Chrysler Corporation was founded in 1912. After establishment, the company made a rapid growth due to the constant new car model strategies and shrewd management decisions. Without losing opportunities, a series of cars that can keep pace with the time were designed, developed, and launched. All those efforts demonstrated the courage of the company and have greatly enhanced the company's reputation. As a result, Chrysler was hailed as the designing leader of automobile industry. However, on 30 April 2009, as the company was in crisis, Chrysler Corporation filed for bankruptcy protection. Since then, Chrysler entered bankruptcy proceedings.

In fact, the term “bankruptcy” was not new for this century-old enterprise. In the company's history, there were several times that it was on the verge of bankruptcy, but it had always survived. The economic crisis in 1930s and recession in 2000 had seriously undermined development of the company. The financial deficit forced Chrysler to have massive layoffs, cut back production, and close factories. Rumors about bankruptcy of Chrysler were spread out every now and then. But by taking product diversification strategies and optimizing promotion channels, Chrysler overcame difficulties again and again.

People may ask, what is the exact reason of Chrysler going nearly into bankruptcy frequently?

General view of the US automobile industry is that even if not influenced by financial crisis, the problems that Chrysler accumulated over the years cannot be resolved overnight. The statistical figure shows that compared with BMW, Toyota, and some other automobile companies, extra cost of a single vehicle produced by Chrysler was more than 2000 dollars. In addition to the recognized “high labour costs,” Chrysler was also overwhelmed by excessive welfare and retirement policy adopted in 20th century. The most unacceptable problem to the US customers is that Chrysler was never bored with launching high-emission cars Jeep, which was contrary to the historical trend of saving oil and reducing emission. In short, the unsatisfactory performance of the supply chain (SC) made Americans believe that Chrysler will not recover again.

From the above discussion, it can be seen that SC performance evaluation and management are essential for an enterprise if it wants to develop in a long-term stable way. In this chapter, the conception of SC performance is first presented, then relevant theories about SC performance evaluation are discussed, and several common methods of SC performance evaluation are discussed. Finally, an evaluation model is presented for SC performance evaluation using 5 dimensional balanced scorecard (5DBSC) and Levenberg–Marquardt Back-propagation (LM-BP) neural network algorithm.

2. Discussion of performance evaluation of SCM

The biological law—natural selection and survival of the fittest—proposed by Darwin can also be applied to today's fierce business competition environment. Whether an enterprise has the ability to adapt rapid market demand change or not and whether it can deal with the increasing

http://dx.doi.org/10.5772/63065

competition pressure depend on if the enterprise has an effective way of SC management. In order to achieve an effective SC management, SC performance should be evaluated first. Only if SC performance is evaluated accurately and objectively, can existing problems of this SC be identified, and hence, corresponding solutions be found and SC competitiveness be improved ultimately.

2.1. Concept of SC performance evaluation

Nowadays, individual competition among enterprises has turned into group competition among different SCs. During the implementation process of SC management, a great deal of manpower, materials, and financial resources will be consumed and both internal and external pressure from SC partners will have to be dealt with. Hence, a strict SC performance evaluation must be conducted so that shortcomings can be found and corrected. By doing so, SC will be competitive. Serving as a significant part of supply strategy management, performance evaluation will help the enterprise or the organization to understand the daily activity performance of the SC, based on which, a long-term development strategy can be made.

Therefore, it is not difficult to understand the definition of SC performance evaluation: adopting certain SC performance evaluation indices, compared with a unified evaluation standard, using quantitative methods of statistics and operations research to comprehensively evaluate SC performance and costs in a period of time in accordance with regulated procedures in an objective, just and accurate way[1].

SC performance evaluation should serve the goal of the SC. Evaluation objects should cover the whole SC as well as each member of SC. Also, interior and exterior performance of an enterprise and comprehensive SC performance are involved in the performance evaluation which are revealed by all kinds of indicators relating to operation and relationships. From the time point of view, evaluation can be classified as prior, middle, and afterwards evaluation [1].

2.2. Principles and function of SC performance evaluation

Operation performance of the whole SC and members of the SC can be revealed by a good SC performance evaluation system: if logistics processes among the enterprises are reasonable, whether the quality and costs of the SC products are ideal or not. For example, if one supplier on the SC is individually evaluated, then the lower the product price is the better. However, considering such a low-priced raw material will jeopardize final product quality, increase production costs, and overall profit of the whole SC will be damaged, choosing this supplier will not be an appropriate decision.

In order to evaluate operation performance of logistics system objectively and accurately, some following principles must be complied with [2]:

1. Main point of performance evaluation should emphasize on the key performance indicators. To analyze these indicators, mathematical or information tools should be used.

2. Indicators that can reflect SC business processes should be used.

3. Indicators should not only reflect the performance of an individual enterprise but also the subsystem and the whole SC. This is important to achieve the sustainable SC management (SSCM).

4. Immediate evaluation methods should be used as much as possible, for doing so is more meaningful than analyzing afterward.

5. Make sure that goal of SC performance evaluation and goal of the overall SC strategy are consistent, otherwise, SC performance will not make considerable contributions to the strategic goal.

6. Indicators that support the strategic goal should be chosen.

7. One of the final targets of each SC is to make customers satisfied. In order to fulfill the real demand of customer, it is necessary for managers to understand what the demands are; meanwhile, they should also have a clear understanding about the SC performance from the customer point of view. Effective SC performance evaluation can play the following roles in the SC management process [2]:

    1. Deficiencies and shortcomings can be found and relevant improving measures can be identified.

    2. Serve as evaluation indicators of SC business processes reengineering, setting up time, cost, and performance-based SC optimized system will provide decision basis for sustainable SC management.

    3. By evaluating the member enterprise of a SC, excellent enterprises will be motivated, troubled enterprises will be removed, and new partners will be attracted. Meanwhile, partnerships will be evaluated too during SC performance evaluation.

3. Performance evaluation indicators

Companies not only have to concern themselves about environment issues but also have to deal with social performance pressures such as social reputation and social responsibility. As a result, although SSCM is a relatively new concept, it developed rapidly in the recent years.

Concept of sustainable SC should be understood before conducting management. There is not a unified definition about sustainable SC yet, but some of the definitions are recognized by most scholars, which are shown as follows.

Seuring and Müller defined SSCM as the management of material, information, and capital flows as well as cooperation among companies along the SC while taking goals from all three dimensions of sustainable development, that is, economic, environmental, and social, into account which are derived from customer's and stakeholder's requirements [3].

Carter and Rogers believed that SSCM can be defined as the strategic, transparent integration, and achievement of an organization's social, environmental, and economic goals in the

http://dx.doi.org/10.5772/63065

systemic coordination of key interorganizational business processes for improving the long-term economic performance of the individual company and its SCs [4].

Based on conceptions mentioned above, it is not difficult to find out that the inclusion of sustainability into the theory of SCM is most often based on the triple bottom line approach [5] that calls for equal consideration of all three pillars of sustainability, namely, environment performance, economic performance, and social performance. This means evaluation indicators can be chosen accordingly.

3.1. Environment indicators

In the area of SSCM, environment performance has been given a lot of attention. Sometimes, there are tradeoffs between environment performance and economic performance. For instance, ecofriendly materials may cost more so that it will have impact on economic performance. However, environment performance can positively influence economic performance. For example, waste products or some certain emissions can be recycled as raw materials for other products, and minimizing waste can also help to saving cost. In addition, an eco-friendly production method will save companies from a large amount of pollution control costs or environmental penalty. Therefore, in order to achieve a win-win target rather than tradeoffs, managers should evaluate SSC from an integration point of view and achieve balance between environment investment and cost efficiency. Here are some possible indicators for the environment performance evaluation: greenhouse gas emission, water usage, energy consumption, waste generation, the use of hazardous and toxic substance, waste recycle etc [6].

3.2. Economic indicators

Whether in SSCM or in SCM, economic performance has been paid a lot of attention. One final goal of a SC management is to make profit. Otherwise, it will be eliminated from the market. When considering sustainability of a SC, focal companies might be able to justify the long-term economic benefits of designing environmental and social initiatives at the supply-chain level and present a business case for sustainability, where firms benefitted financially from engaging in sustainability practices [7]. Various studies using SC modelling have traditionally focused on the economic aspects of the SC with cost minimization (or profit maximization) and service level maximization as the most predominant objectives. Here are some possible indicators for economic performance evaluation: SC cost (SC costs may include the cost of procurement, production, opening, and operating facilities as well as transportation and storage costs), cost reduction, service level (service level may include customer satisfactory, product/quantity flexibility, and backorders), SC revenue, SC profit, etc [8].

3.3. Social indicators

Among all the three aspects in SSCM, social performance is the most difficult one to assess, the indicators of which are not easy to be quantified and are often prone to subjectivity. However, social performance evaluation is indispensable. Not only can social issues threaten the company's brand image but they also impact the economic viability of the entire SC [8].

Several instances of this nature have been frequently reported in the past, jeopardizing the reputation of large multinational corporations such as Wal-Mart, Nike, Gap, and H&M through the violation of union rights and the use of underaged workers [9]. In the other way round, a well-performed social practice is capable of enhancing a company's image and reputation, which serves as a significant resource in the SC, and helps to increase market adaptability of products and services. Here are some possible indicators for social performance evaluation: labour practice and decent work, gender diversity and harassment, human rights, occupational health and safety, fair trade, fair labor metrics, etc [10].

SC performance evaluation has traditionally been dominated by indicators such as cost, quality, delivery, and flexibility. In the circumstances of considering sustainability, these indicators are still very important but not necessarily in a dominant role. Also, indicators introduced in this section are relatively rough and only give a general idea of SSC performance evaluation. Detailed indicators are explicated according to different performance evaluation theories in Section 4.

4. Performance evaluation theory and method

Due to the fact that SC combines suppliers, manufacturers, distributors, dealers, and customers with information flow feed forward and material flow feedback, it is largely different from the current enterprise management model as from enterprise operation performance evaluation and analysis.

Based on the basic features and goal of SC management, SC performance evaluation is capable of properly reflecting the overall SC performance as well as of each member enterprise on the SC rather than a single supplier. During the evaluation process, not only performance of a certain member enterprise of SC should be evaluated but also the influences that the certain member enterprise has on the upper or lower SC member enterprises should be evaluated. SC performance evaluation normally includes the following aspects: the overall SC performance, each member enterprise performance, partnership among member enterprises of the SC, and incentive level toward member enterprises.

To fulfill above targets, ordinary enterprise performance evaluation theories are not fully applicable; this section will mainly illustrate several common SC performance theories, and they are using driving factors to evaluate SC performance, key performance indicator, SC balanced scorecard, and SC operations reference model.

4.1. Using driving factors to evaluate SC performance

Sunil Chopra from Northwestern University of America and Peter Meindl from Stanford University proposed the following idea: by deeply studying the cross function driving factors that influence SC performance (facilities, inventory, transportation, information, purchasing, and pricing), SC performance can be improved through responsiveness and efficiency of the SC logistics [11].

http://dx.doi.org/10.5772/63065

4.1.1. Facilities

Facilities refer to the actual location of the SC, storage sites, assembly, or processing sites. Production sites and storage sites are the main two facilities. Decisions about facilities role, location, production capacity, and flexibility have a significant influence on SC performance. For instance, to improve responsiveness, an automotive parts distributor will locate their warehouse close to their customer, although it may lower their efficiency. Or a distributor with high efficiency will decrease their warehouses to maintain efficiency despite that it will influence responsiveness.

Here are some indicators to evaluate facilities performance [11]:

1. Production capacity—the maximum production quantity of a facility.

2. Utilization—the ratio between currently being used production capacity and total production capacity of a facility. Utilization has an impact on unit cost of production and a variety of delay. When utilization is improved, unit cost will be reduced but delay will be more.

3. Theoretical production process time/cycle—production time required for one unit with the circumstances of no delay.

4. Actual average production process time/cycle—the actual average production time for all products in a certain period of time such as a week or a month. Actual production process time/cycle including theoretical time and all the delays.

5. Process time efficiency—the ratio between theoretical time and average production process time.

6. Product variety—the number of products or product series in a production facility. The bigger number, the higher possibility of increasing production cost, and production process time.

7. The top 20% stock keeping unit (SKU) and customer contribution toward production—the value of the top 20% SKU and customer consumption volume should be measured, the result of 80/20 principle (top 20% factors contribute to 80% of the capacity) shows that profit may come from using the top 20% specific procedures to process the top 20% and the other 80% of the products.

8. Processing/adjustment/shutdown/idle time—processing time of a facility/prepare and adjustment time of a facility/time that facilities cannot operate due to damage/idle time because of no product demand.

9. Average production volume—the average yield of each batch of product. A large volume usually comes with a low production cost and high SC inventory.

10. Production service level: ratio between punctually completed orders and the total orders.

4.1.2. Inventory

Inventory consists of raw material inventory, work in progress (WIP), and finished goods. Changing inventory strategy will greatly influence SC efficiency and responsiveness. For example, clothing retailers may own a large amount of stock to quickly respond and satisfy customer demands. However, enormous stock will increase retailer's cost so that efficiency will be decreased, which will have an undesirable influence of responsiveness in return.

Increasing inventory helps SC to improve responsiveness toward customers. A high level of inventory makes an enterprise easier to take advantage of economies of scale, lower cost of production, and transportation, yet by doing so inventory carrying costs will be increased. Managers should review the following inventory indicators that influence SC performance [11].

1. Average inventory—average volume of carrying inventory during a period of time. Average inventory should be measured according to unit, demand days, and monetary value.
2. Overdue inventory products—a great number of stocks owned by an enterprise. This indicator may be used to identify oversupplied products or the reason for high level of inventory (price discount or a low delivery speed).
3. Average replenishment quantities—average quantities of each supplement orders.
4. Average safety inventory—the average quantities of stocks when replenishment arrives. Average replenishment quantities were measured by SKU. Cargo unit and demand days should also be known. Average replenishment quantities were measured by SKU. Cargo unit and demand days should also be known.
5. Seasonal inventory—cycle stocks and safety stocks carried by an enterprise to meet the seasonally changing demand.
6. Fulfillment ratio—ratio between orders were fulfilled on time by inventory and total orders. Fulfillment ratio is determined by the average demands units (per thousand, million) rather than average time to fulfill the order.
7. Out of stock time ratio—ratio between time of a certain product which has no stock and time it has inventory. This ratio can be used to estimate the demand during the period of out of stock.

4.1.3. Transportation

Using a rapid mode of transport will increase responsiveness and transportation cost, but the advantage is stock carrying cost can be decreased. Managers should review the following transportation indicators that influence SC performance [11].

1. Average inbound transportation costs—certain percentage of product sales or sales costs that are put into manufacturing facilities. It is ideal but very difficult to measure this indicator by units that are invested in. Average inbound transportation costs are often included in sales costs. It is beneficial to allocate these costs by a supplier.

http://dx.doi.org/10.5772/63065

2. Average scale of loading stocks to storage—average units or price that finished product put into a storage.

3. Loading costs of inbound transportation of each time—average transportation costs of each purchasing. Together with average scale of loading stocks to storage, larger economies of scale can be created by inbound transportation.

4. Average outbound transportation costs—delivery costs of product sent from manufacturing facilities to customers. This indicator is usually measured by proportion of sales. It is beneficial to allocate these costs by a customer.

5. Average loading scale of outbound transportation—average units or price of each delivery from the manufacturing facilities.

6. Loading costs of outbound transportation of each time—average transportation costs of each delivery. Together with average loading scale of outbound transportation, larger economies of scale can be created by outbound transportation.

7. Transportation mode ratio—ratio between a certain transportation mode and all kinds of transportation mode (per unit, US dollar or RMB). This indicator can be used to estimate excessive use or inadequate use of a certain transportation mode.

4.1.4. Information

Effective information is capable of helping an enterprise improve its responsiveness and efficiency. Information factor may optimize performance of other factors. Usage of information was based on a strategy orientation supported by other factors. Accurate information not only helps an enterprise improve their efficiency by decreasing inventory and transportation costs but also optimizes responsiveness by adjusting supply and demand on the SC. Managers should review the following information indicators that influence SC performance [11].

1. Forecasting period—it refers to a period of future time that the prediction is against. Forecasting period must equal to the lead time of decision-making triggered by forecast.

2. Update frequency—update frequency of each forecast. Forecast updating should be more frequent than decision amendment so that influence toward decision brought up by big changes can be weakened and corrective action can be adopted.

3. Prediction error—deviation between actual demand and forecast value. Prediction error is a measurement and an action toward uncertainty (safety inventory or excessive production capacity).

4. Seasonal factor—the degree to which actual demand is higher or lower than average demand in a season.

5. Planning fluctuation—difference between planning product volume or inventory and the actual ones. These fluctuations can be used to identify shortages and surpluses.

6. Ratio between demand changing and order changing—standard deviation of coming demand and supply orders. If the standard deviation is less than 1, it suggests “bullwhip effect” may exist.

4.1.5. Purchasing

The target of making a decision to purchase is to increase the total profit that is shared by the SC. Purchasing has an influence on sales, service, production cost, transportation cost, and total profit. If a third-party logistics can make more profit than first and second logistics, outsourcing logistics is meaningful. In comparison, if third-party logistics is not able to increase SC profit or it is very risky to outsource logistics, the enterprise should remain the function of SC. Managers should review the following purchasing indicators that influence SC performance [11].

1. Due days—days from which the supplier finished their tasks until they get paid.
2. Average purchasing price—the average price of purchasing a certain product or a service. When calculating average purchasing price, final result should be based on quantity-weighted of each price.
3. Range of purchasing price—it refers to price fluctuation during a period of time. This indicator is used to make sure if purchasing price is related to purchasing quantity.
4. Average purchasing quantity—average quantity of each purchasing. This indicator is used to make sure if the total quantities of purchasing from each region are adequate.
5. Due deliver ratio—ratio between due deliver time and total deliver time.
6. Supply quality—product quality provided by the suppliers.
7. Supply lead time—days from ordering until successful delivery.

4.1.6. Pricing

All the target of pricing decision should be focused on increasing profit for the enterprise. To achieve the target, it is necessary to understand the cost structure of SC activities and values that are created by those activities. For instance, daily low-cost strategy is able to stabilize demand and result in an efficient SC. Some other pricing strategy may reduce SC costs and maintain an even earn market share. Price discrimination is able to attract different customers with different demands. As long as these strategies are conducive to increasing revenue or reducing costs, enterprises should adopt a bit of both.

Managers should review the following pricing indicators. For menu pricing, each indicator should be reviewed respectively according to each section of the menu [11].

1. Profit margin—profit percentage of revenues. Enterprises need to look at various profit margin indicators in order to optimize pricing. Specific indicator dimension including type of profit margin (gross profit margin, net profit margin, etc.), profit scope (cargo unit, product series, department, enterprise, etc.), and type of customers.

http://dx.doi.org/10.5772/63065

2. Sales unpaid days—average time to receive cash after sales.

3. Increment of fixed cost of each ordering—the increment is independent of ordering scale. The increment consists of cost of transformation methods in plant, ordering processes, and transportation costs of delivery scale which is independent of purchasing company.

4. Increment of variable costs per unit—the costs will increase as the ordering scale changes. Costs including cargo pickup costs and variable production costs in manufacturer's plant.

5. Average selling price—the average price of a completed task of SC in a period of time. When calculating average sales price, final result should be based on quantity-weighted of each price.

6. Average ordering quantities—average quantities of each ordering. Average ordering quantities, ordering scale, increment of fixed cost of each ordering, as well as increment of variable costs per unit can help to estimate contribution of a certain completed task of SC.

7. Selling price range—the variation range of the highest and lowest selling price per unit of product within a specific period.

8. Range of sales volume in a period of time—the variation range of the highest and lowest sales volume within a specific period (day/week/month).The purpose of reviewing this indicator is to understand the correlation between sales volume, selling price, and potential chance to adjusting selling price to change in sales volume as time pass.

Driving factors and indicators are summarized in the following **Table 1**

Driving factors of SC	Indicators
Facilities	Production capacity
	Utilization
	Theoretical production process time/cycle
	Actual average production process time/cycle
	Process time efficiency
	Product variety
	The top 20% SKU and customer contribution toward production
	Processing/adjustment/shutdown/idle time
	Average production volume
	Production service level
Inventory	Average inventory
	Overdue inventory products
	Average replenishment quantities
	Average safety inventory
	Seasonal inventory
	Fulfillment ratio
	Out of stock time ratio

Driving factors of SC	Indicators
Transportation	Average inbound transportation costs
	Average scale of loading stocks to storage
	Loading costs of inbound transportation of each time
	Average outbound transportation costs
	Average loading scale of outbound transportation
	Loading costs of outbound transportation of each time
	Transportation mode ratio
Information	Forecasting period
	Update frequency
	Prediction error
	Seasonal factor
	Planning fluctuation
	Ratio between demand changing and order changing
Purchasing	Due days
	Average purchasing price
	Range of purchasing price
	Average purchasing quantity
	Due deliver ratio
	Supply quality
	Supply lead time
Pricing	Profit margin
	Sales unpaid days
	Increment of fixed cost of each ordering
	Increment of variable costs per unit
	Average selling price
	Average ordering quantities
	Selling price range
	Range of sales volume in a period of time

Table 1. Driving factors and indicators of a SC€.

4.2. Key performance indicator

Serve as a monitor of the macro strategy implementation result, key performance indicators (KPI) refer to operational tactical target that are decomposed from macro strategy of an enterprise and have impact on strategy development as well as overall performance of a company [12]. KPI is a popular international tool of measuring company operation performance and managing strategic target, the establishment of which will form a responsibility oriented system management mode. In addition, KPI is quantifiable and is agreed in advance, meanwhile, it is also a significant indicator system that is used to reflect the degree of organization target accomplishment. Briefly, KPI is an effective management tool which can motivate a company to create more value. The specific functions of KPI are as follows [12]:

http://dx.doi.org/10.5772/63065

1. As company strategy target decomposed, senior managers are able to have a clear understanding about the business operating conditions of company's most critical value creation.

2. Changing degree of key performance driving factors can be reflected effectively so that managers can timely diagnose operation problems and take relevant actions.

3. Qualitative and quantitative indicators can be distinguished. A strong impetus will be given to implementing company strategy.

4. Key, important operation behavior can be revealed so that managers can focus on those business that have the greatest driving force toward company performance.

5. Determined by senior managers and agreed by participants who will go through the exam, as a result, an objective foundation for performance management and communication between leader and member is provided.

To fulfill the above functions, choosing KPI should be in line with the following principles: indicators should be easy to understand, explain, and convey. They should be clear rather than ambiguous, instead of random ones. Meanwhile, it is necessary that indicators should be able to control and enforce, not just some decorations. Finally, they should be quantifiable and trustworthy [12].

To deal with the fierce competition, a lot of manufacturing enterprise outsource their logistics operation. As a result, evaluating performance of a logistics service provider is particularly important, which is also a basis of supplier selection. In an organization system, the majority of large manufacturing enterprises have set up SC management department or logistics operation department to be in charge of logistics-related business. In large manufacturing enterprises, line transportation, warehouse management, and regional distribution are the three relatively independent logistics segments. Hence, to evaluate SC performance, KPI can be chosen from the three segments. Summarization of indicators is in **Table 2**.

Category	**Indicators**
KPI of line transportation	Plan execution rate *P*
	Plan remaining rate *R*
	Delivery delay rate *D*
	Accidental freight *A*
	Timely transfer document rate *T*
	Document accuracy *E*
	Service quality S
KPI of warehouse	Correctness of cargo receiving and sending out *C*
	Document accuracy *E*
	Timely transfer document rate *T*

Category	Indicators
	Stock damaged ratio *Q*
	Warehouse quality *W*
	Customer satisfaction *M*
KPI of regional distribution	Fulfilled orders on time rate *F*
	Accidental freight *A*
	Document accuracy *E*
	Timely transfer document rate *T*
	Customer satisfaction *M*

Table 2. Indicators of logistics operation performance.

4.2.1. KPI of line transportation

Focused on the two eternal themes of logistics service security and punctuality, following indicators of line transportation are chosen [12–15].

(1) Plan execution rate *P* (Vehicle arrival rate)—This indicator refers to ratio between program execution time of logistics service provider within response time and program number (Vehicles arrive on time and comply with loading requirement). Response time means the time that vehicles of logistics service provider or company's own supply department need to arrive assigned location and loading cargo after delivery plans were issued by logistics department. Response time of a forwarding station in a whole nation is two days. Program execution rate P1 on the first day must reach 85%, the rest must all be finished on the second day which means accumulated program execution rate on the second day must be 100%. Plans cannot be finished on the day must be recorded in remaining plan table. Plans that cannot be finished in two days must be otherwise recorded and make a special (urgent) plan.

(2) Plan remaining rate *R*

This indicator mainly assesses the plans remaining time of logistics service provider or SC department when they carry out plans. Plans that cannot be finished on the first day can be seen through plan execution rate of the second day, but plans that also cannot be finished on the second day cannot be shown. So plan remaining rate is used for reviewing time and days of remaining plan.

(3) Delivery delay rate *D*

Since the moment cargo has been loaded on the vehicle, logistics service provider or SC department will urge driver to deliver cargo to the destination safety, timely, and completely except for the force majeure (war, earthquake, large collapsed pavements, and mountains covered by snow). Other reasons (traffic jam, broken vehicles, and traffic accidents) cannot be served as exceptions. Ratio between delayed deliver plans and the total plans of a certain month is called delivery delay rate *D*. Punctual delivery ratio will be 1-*D*.

http://dx.doi.org/10.5772/63065

(4) Accidental freight *A*

It can be divided into accident loss ratio and freight accident ratio. Ratio between accident lost value and cargo total value is called accident loss ratio. Freight accident ratio refers to the ratio between accident times and total delivery times.

(5) Timely transfer document rate *T*

This indicator mainly assesses if the following documents are transferred timely by the forwarding station—statistic document, daily plan remaining document, overdue vehicle statistic document, reimbursement, and statistic document of delivery list.

(6) Document accuracy *E*

Documents must be filled in according to required format and should be kept clear and tidy. For those hand-filled documents, handwriting should be clear, neat, and without alterations. After documents are filled in, they should be strictly and carefully checked to eliminate mistakes.

(7) Service quality *S*

This indicator is mainly used to review service awareness and service attitude of logistics service provider or SC department.

4.2.2. KPI of warehouse (transit warehouse)

Warehouse management focuses on customer service, which is mainly about customer satisfaction and warehouse management quality. Six indicators and relevant daily used documents are determined [12-15].

(1) Correctness of cargo receiving and sending out *C*

Total amount of receiving and sending out cargo minus wrong receiving and sending out cargo amount, than compared to the total amount, the proportion of which will be correctness of cargo receiving and sending out.

(2) Document accuracy *E*

This indicator has the same meaning with “Document accuracy *E*” in transportation indicators.

(3) Timely transfer document rate *T*

This indicator mainly assesses if the following documents are timely transferred by transit warehouse: receiving list, product inventory daily report, transit warehouse shipments feedback form, spare and ware out parts daily form, damaged cargo maintenance monthly form, finished product age analysis monthly form, spare and ware out parts monthly form, inventory of advertising materials monthly report, defective products processed monthly report, etc.

(4) Stock damaged ratio Q

Ratio between amount of goods damaged in warehouse and total amount of goods. Because damage occurred in warehouse, warehouse manager should take responsibility for the loss.

(5) Warehouse quality W

It is expressed as the storage environment, fire safety, cargo stacking, and goods identification should comply with certain provisions of the transit warehouse management. Performance of this indicator can be evaluated through onsite inspection. Storage environment refers to inside and outside hygiene of a warehouse, pest control, storage temperature and humidity control, and cargo maintenance in warehouse. Fire safety is determined by whether the firefighting facilities are complete and useful and whether the firefighting measures can be implemented without any potential risks. Cargo stacking and goods identification should be in line with warehouse management rules.

(6) Customer satisfaction M

Customer satisfaction is quantified by number of effective customer complaints. In reality, customer satisfaction consist of four aspects: loading waiting time, service attitude of warehouse management (including guards, warehouse keeper, billing staff, and porters), ability to deal with abnormal situations, and time of repeated complaints.

4.2.3. KPI of regional distribution

Indicators of regional distribution focus on distribution network, promptness of delivery is considered, and five indicators and related documents are determined [12–15].

(1) Fulfilled orders on time rate

On time refers to cargo that were delivered to the destination within the requested time (e.g., 24 hours) after orders were received. Fulfillment refers to the delivered cargo that can meet the requirement of the order in respect to SKU standard and quantity. Delivery time will be counted after logistics supervisor issues delivery list. Cargo must be delivered within requested time (e.g., 200 km within 12 hours, 200 km–400 km within 24 hours, more than 400 km within 36 hours) to the specific department or the customer.

(2) Accidental freight A

This indicator has the same meaning with "Accidental freight A" in transportation indicators.

(3) Document accuracy E

This indicator has the same meaning with "Document accuracy E" in transportation indicators.

(4) Timely transfer document rate T

This indicator mainly assesses if the following documents are transferred on time: second distribution process control report, second distribution daily report, and second distribution summarization report.

(5) Customer satisfaction M

Customer satisfaction is quantified by a number of effective customer complaints. Service awareness and service attitude of carrier are the main concerns.

4.3. SC balanced scorecard

The conception of balanced score card (BSC) was first proposed by Robert S Kaplan and David P Norton in 1992. BSC clearly stress on enterprise vision and motivator to accomplish enterprise strategy. Then, strategy motivators are transferred into specific target and measureable indicators which include external and internal measurement as well as objective and subjective factors. BSC consist of four distinctive aspects: financial aspect, customer aspect, internal business aspect, innovation, and learning aspect (**Figure 1**) [16]. Meanwhile, BSC can be used to decompose target of the whole enterprise into targets of each level of the enterprise.

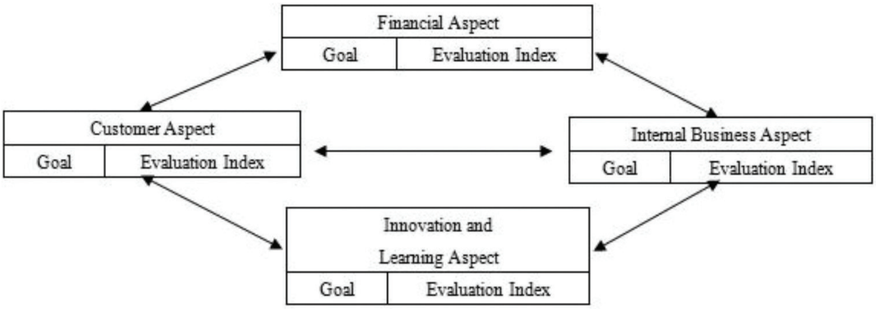


Figure 1. Balanced Scorecard.

BSC can be used not only as a tool of behavior controlling and historical performance estimation but also for clarifying and spreading corporate strategy and individual plan, department plan, and organization plan. These plans can be linked together so that their common goal can be accomplished. BSC emphasizes on integration of financial and nonfinancial measurement, and these indicators must be blended into every management level so that managers can understand their factors that lead to decisions and behaviors. A propagating, communicating, and learning system is constructed rather than a simple traditional controlling system to keep the goals in consistency due to the fact that performance indicators are shared in the management system. Hence, BSC has become a foundation of new strategic management system and become a bridge which correlate long-term strategy and short-term behavior (**Figure 2**) [16].

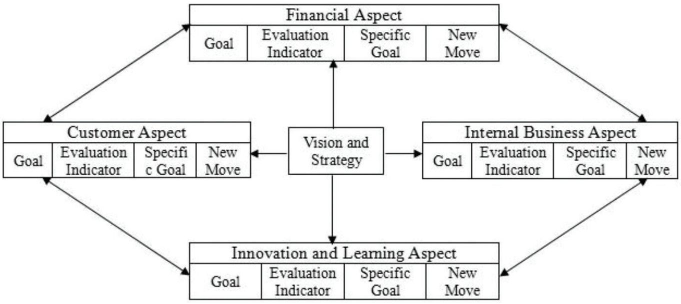


Figure 2. Relations of Balanced Scorecard and Enterprise Vision.

Since 1998, with the condition of new economics which was represented by information technology, BSC has the ability to promote enterprises to expand and grow and has been vigorously applied in strategy management. Before BSC was invented, there was no standard framework or systematic theory about SC performance evaluation methods. Application of BSC exactly covered this shortage. Brewer and Speh were the first ones to explore how to apply BSC in SC performance and proposed a new tool to evaluate SC performance, SC balanced scorecard (SCBSC). Based on SC business processes, SCBSC start from enterprise strategy and can be used to evaluate enterprise operation performance comprehensively by linking performance indicators and enterprise strategy together. As a result, core competitiveness of the enterprise is fostered. Framework of SC performance was connected to the four dimensions of BSC by Brewer and Speh so that basic structure of SCBSC was defined (**Figure 3**) [17].

Figure 3 shows that, Brewer and Speh set up a connection framework between SCM and BSC. SC performance management including four aspects: (1) goal of SC management, (2) customer profit, (3) financial benefits, (4)SC improvement. There is a one-to-one correspondence between chain performance management and 4 aspects of BSC [17]. For example, the ability of a SC to fulfill its goal can be revealed from its inner operation. Emergence of SCBSC is a breakthrough in SC performance evaluation. Beforehand, BSC and SCM were seen as two separate management tool. Employees are incented to work correctly under the background of SC concept when managers aware that evaluation process of BSC can be adopted into SC performance evaluation [17].

Thus, advantages of SCBSC can be further indicated as follows [17]:

1. SC itself is a combination of multi departments or multi organizations. Its executive performance must be reached by the members working together from inside and outside of an organization. The causal relationship of 4 aspects of BSC makes a clear description about how an effective cooperation can be reached by members from different organizations and how multi-functional operations can be coordinate to achieve their mutual goal.

http://dx.doi.org/10.5772/63065

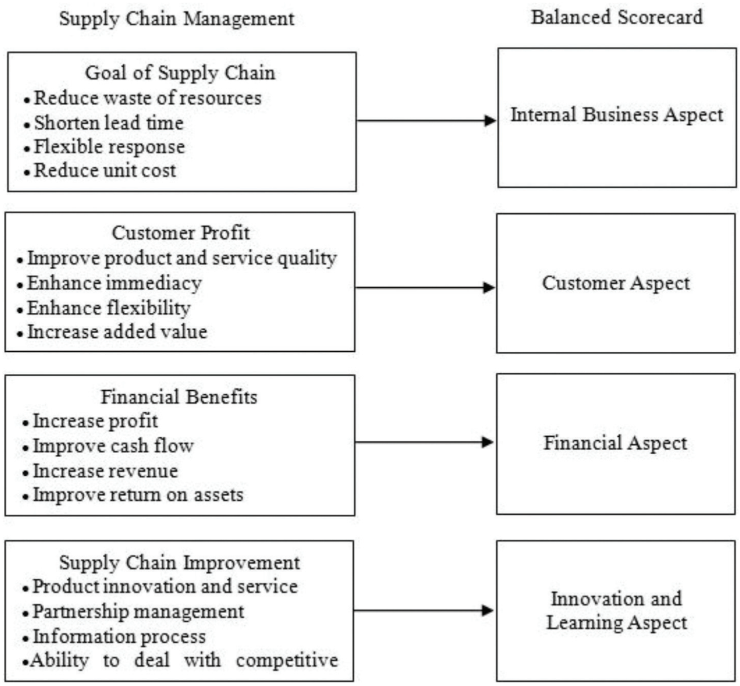


Figure 3. Connection between SC Management and BSC.

2. The "balanced" conception of BSC advocates that performance evaluation of an enterprise and its partners on SC should be conducted simultaneously, which is the same from management goal of SC performance evaluation.

3. Indicators and final goal of BSC can be special designed to fit different SCs which can still connect with enterprise strategy, so BSC can be used in a very flexible way.

4. Different member from different management level such as supervisors and staff can have a clearly understand about their operation goal from BSC rather than consider it as a reward or punishment tool.

Some indicators of the 4 aspects were proposed to reflect goals and tasks of different SCBSC angles. These indicators are not comprehensive even deficient for some specific SCs. Most of the indicators are rarely used in BSC, instead, they are more maneuverability in the diagnosis level.

4.3.1. Internal business aspect

An outstanding process decision of an organization will generate outstanding customer performance, which means optimizing internal business process is very crucial for an enterprise. Combining internal business process, finance, and customer goal, SC should focus on two kinds of brand new internal business process operation [17]:(1) to rationalize existing relationship of each member in each process and shorten operation process cycle while reducing cost. α(12)Forecast and respond to customer demand. SC operation should not be confined to a short-term point of view but should develop market and make product innovation so that customers can be attracted.

(1) Product improvement and innovation process evaluation [16–19]

In a traditional SC, R&D is considered to be some kind of a subsidiary or a support to a business rather than a fundamental factor to determine pricing. The existing problem is that, on the one hand, the input–output relationship is ambiguous, on the other hand, there is insufficient attention paid to product innovation and product development and design are neglected. However, serving as a long-term influence factor to SC value, R&D is necessarily to be evaluated. Indicators including ratio between new product sales and total sales, time that need to develop new product and percentage of first time designed product that can meet all the requirements of customers.

(2) Operation process evaluation [16–19]

Operation process is a short-cycle process, which contains all the contents starting from receiving customer orders and ending at putting the product on sale or offering service. Detailed evaluation indicators consist of efficiency of SC effective leading time, flexibility of SC production time, target cost reaching rate, SC operation quality, and perfect order completion rate.

4.3.2. Customer aspect

One of the main goals of SC management is to provide its customer persistent and stable profit. Therefore, one core of SC management is customer management, which means fully understanding customer demand and evaluating to what extent the customer demand has been satisfied. Customers are mainly concerned with four aspects [17]: time, quality, function, and service cost. The total circulation time of SC order fulfillment can measure the time that SC needs to meet the customer demand. Quality has always been a critical competition mean; however it is no longer a necessary strategic competition advantage but a compulsive existence. Function and service costs are significant factors to maintain customers and attract new customers. In addition to these aspects, customers are very sensitive to their product cost. During transaction process, product price is only part of cost, transaction cost that happened when dealing with suppliers is also part of cost. When chosen, these indicators mainly reflect customer demand. Indicators are not only those that reveal customer value or customer feedback but also can be those that reveal some specific aspects such as service quality, flexibility, and cost.

(1) Total circulation time of SC order fulfillment [16–19]

This indicator evaluates overall respond time to customer orders of a SC, which includes ordering and receiving time, time of placing material to production, time of goods from production until ready to be delivered, time of goods delivered and customer signing receipts, and time of customer confirming that goods have been received.

(2) Customer maintenance rate [16–19]

Persistent profit of a SC comes from the core customer. If a SC wants to remain or increase market share, the most convenient thing to do is to maintain existing customers, try to manage relationship with customers and satisfy customers as much as possible. Customers should be allowed to participate in production design and development so that they will become a lasting profit source. In addition to keeping existing customers, customer loyalty should be analyzed during SC management. Of course, if an enterprise wants to gain more profit, constantly strategy of expanding customer scope should be made on the basis of existing customers.

(3) Customer acceptance to SC respond flexibility [19]

This indicator is used to evaluate the acceptance degree of SC customization and respond flexibility.

(4) Customer sales growth and profit [16–19]

It is shown as SC product annual customer sales increment and profit rate. These kind of indicators mainly reflect performance of three aspects of downstream of the SC: (1)annual sales growth year by year, (2)if profit of service provided to special customer will increase as partnership enhanced, (3)if service accepted base is increasing. Expanding sales and attracting new customers are both new profit increase points.

4.3.3. Financial Aspect

Although SC evaluation is process-oriented and focus on nonfinancial indicators, financial still is the center of SCBSC, which means final success of a SC should also be a financial one. Achieving operation goal by greatly lower cost and increase marginal income ratio so that cash flow is optimized and more profit will be gained, at the same time, a higher capital recovery ratio will be gained. Improved performance in the other three aspects can guarantee a long-term benefit in the financial aspect, hence, optimizing this aspect of a SC is still a priority.

(1) Capital return rate of a SC

Divide customer profit by the average used assets of the SC during a period of time, and capital return rate can be calculated, which reflects degree of value-added of the asset.

(2) SC profitability

This indicator shows profitability of a SC and is an important indicator in evaluating financial performance. By measuring the ratio between net profit and total income, SC profit can be effectively calculated so that overall performance of a SC will be promoted to improve. Therefore, evaluating this indicator will help an enterprise to have a clear understanding about finance contribution rate of the SC.

(3) Cash turnover ratio

Cash turnover ratio is a key indicator which links all the processes of a SC. It mainly evaluates cash flow condition of all the processes including raw material, labor, WIP, finished goods, and profit gained of the SC.

(4) SC total inventory cost

In a SC, inventory cost includes raw material cost, WIP cost, finished product cost as well as in-transit inventory cost [2]. Nowadays, due to the more and more demanding customer requirements, inventory management becomes more and more important to lower SC cost.

(5) SC inventory days

SC inventory days indicate the days that capital are occupied as inventory in SC operation.

4.3.4. Innovation and learning aspect

There are mainly three sources for innovation and growth: talents, system, and organization procedure [2]. In these three aspects, the goal of BSC is to reveal the gap between existing talents, systems, procedures, and the required ability to accomplish breaking performance [2]. SC's sustainable competitiveness is directly correlated with SC's future development ability. In the evaluation model, finance evaluation, customer evaluation, and inner business process evaluation are mainly to analyze current competitiveness of the SC, but the goal of success is changing constantly, and SC performance must be capable of indicating sustainable competitiveness. A SC has to make continuous improvement and innovation, explore and integrate internal and external resources of the SC while improving existing procedures, product/service quality, and new product develop ability due to the increasingly tough global competition. SC improvement and innovation are a dynamic process. Each SC needs to pay attention to potential threats and opportunities in external market at any time and redefine core value. This includes redesigning products and its processes through SC integration, effective regulation on interorganizational activities as well as continuous improvement in SC information process management, and SC partners can all share precise information that are needed for decision-making. The following indicators are chosen.

(1) Profit growth rate

Profit growth rate indicates development potential of an enterprise. Difference between profit of current period and previous period divided by profit of previous period is profit growth rate.

(2) Information sharing degree

It is believed by most scholars that "bullwhip effect" can be avoided by information sharing from upstream and downstream so that SC performance can be improved [2, 11–12]. Sales, forecast data, and technology data are shared by members of dynamic alliance to prevent information distortion, improve customer feedback efficiency so that supply and demand can be connected, coordinated, and be quickly responded.

(3) New product research and development cycle

http://dx.doi.org/10.5772/63065

This indicator consists of two aspects, one is the ability of replacing product and the other one is the ability of innovating processes. The ability of replacing product includes new product quantity, product technology reservation, and patent application. The ability of innovating processes is understanding about individual demand tendency of customer of the SC and on the basis of which to adjust processes. This innovation include not only restructuring process but also selecting the superior member and eliminating the inferior member.

4.4. The SC operations reference model

In 1996, in order to help enterprises to implement a more effective SC and to transit from function management to process management, two consulting companies from Boston, America, Pittiglio Rabin Todd & McGrath (PRTM) and AMR Research (AMR) led to the establishment of SC Council (SCC), and illustrated the SC operations reference model (SCOR) in the very year. This model integrated well-known business process reengineering (BPR), benchmarking and process measurement, and a multifunctional SC performance evaluation system was constructed. Currently, SCOR model has been released in eight editions, which are the first standard SC operation reference models that can served as diagnose tool of SC and covers all the industries.

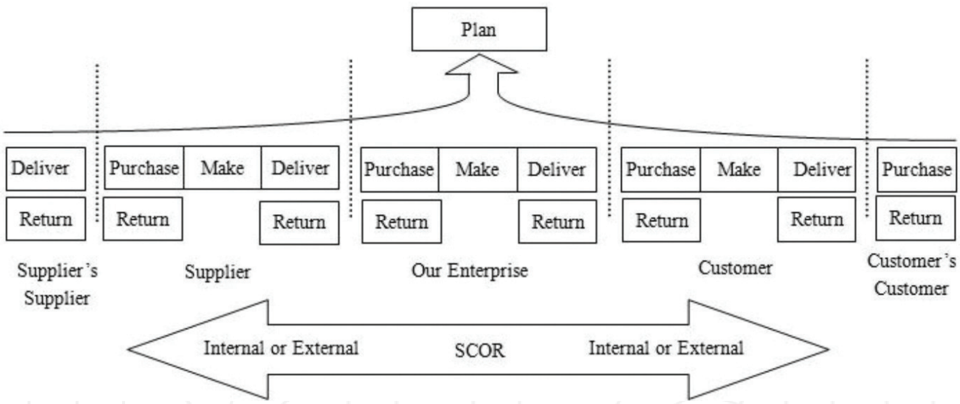


Figure 4. SC Operations Reference-Model.

SCOR has the ability to help a SC enterprise to understand current situation and future anticipation, quantify operational performance among peers, and set up internal goal. There are mainly four indicators in SCOR [20]: (1)reliability of SC, (2)flexibility and reaction, (3)cost, (4)capital. The first two indicators evaluate performance in customer service and the last two evaluate inner performance of an enterprise. In SCOR, all processes in the entire SC are considered and each member of the alliance will be evaluated systematically rather than a certain enterprise is evaluated, which makes the SC become more transparent with a higher performance. Framework of SCOR is founded on five management processes: plan, purchase, manufacture, deliver, and return [11] (**Figure 4**).

SCOR can be classified into three layers according to its detailed degree of definition [15]: top layer, configuration layer, and process unit layer. Each layer can be used to analyze the operation of integrated SC. After the first three layers, there are the fourth layer, the fifth layer, and the sixth layer [11]. They are more detailed and specific that belonging to different enterprises, so definition of these layers are not included in SCOR [11].

4.4.1. First layer of SCOR (top layer)

SC are divided into five processes by the first layer: plan, source, make, deliver, and return, where return include return of raw materials and return of products [11]. Raw materials will be returned to the suppliers. Return of product means returned goods are received and dealt with (**Figure 5**).

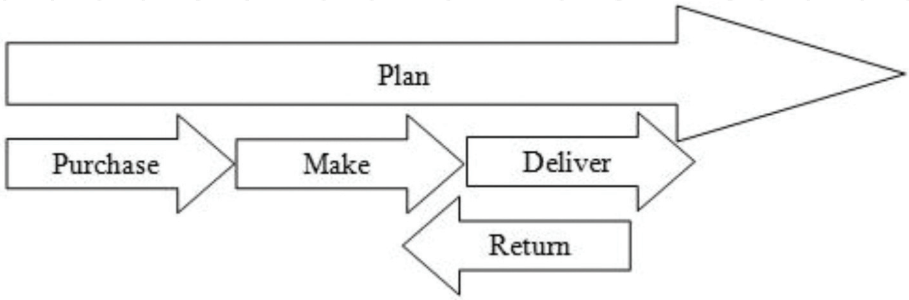


Figure 5. Basic Process of First Layer of SCOR.

Basic strategy decision can be made according to the following indicators after first layer analysis of SCOR [20–23].

(1) Delivery performance—on (ahead of) time order complete/plan finish rate.

(2) Delivery speed—delivered rate within 24 hours after finished goods warehouse receiving orders.

(3) Order complete performance—production flexibility, capital turnover period, capital turnover rate, lead time of order completion, SC respond time, inventory days of supply, all orders fulfillment rate, value-added productivity, and warranty and after-sales costs.

4.4.2. Second layer of SCOR (configuration layer)

The second layer consists of 30 possible core process scopes of SC [22]. An enterprise can choose the standard process unit of this layer to construct their SC. Every product or product model will own their own SC. Detailed configuration of the layer processes of SCOR is showed in **Figure 6** [11].

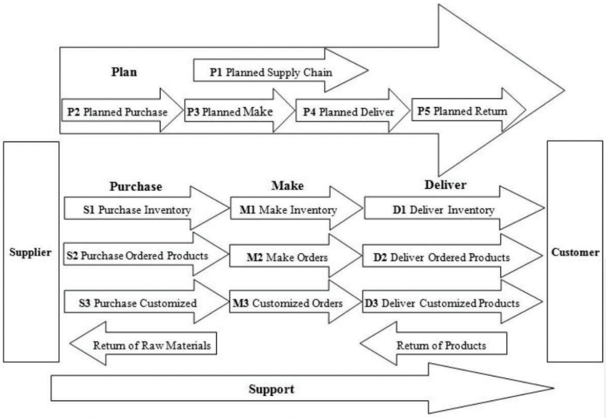


Figure 6. Configuration Layer Process of SCOR.

4.4.3. Third layer of SCOR (process decomposition layer)

The third layer of SCOR is process decomposition layer, which shows the details of process unit classified in the second layer and offers information that is needed by an enterprise to make a successful plan and set up other SC improvement goals [11]. Planning content of this layer include process definition, goals evaluation, best implementation, and necessary software ability to achieve best function [23]. Operation strategies should be adjusted on this layer.

4.4.4. Fourth layer of SCOR (implementation layer) [20–23]

The fourth layer and its following layers are all implementation layers which do not belong to the scope of SCOR. When special requirements for SC improvement are raised, every definition of the fourth layer is based on enterprises' own situation, the particularity makes it impossible and unnecessary to define the special units in industry standards. In implementation layers, process units decomposed from the third layer will be decomposed again by each enterprise based on their current SC management so that competition advantages will be gained and business process changes can be adapted to.

4.5. Analytic hierarchy process

Analytic hierarch process (AHP) was proposed by American operational research expert, T. L. Saaty in the 1970s, which is a multiobjective decision-making method combines qualitative analysis and quantitative analysis [24]. The main idea of AHP is through analysis of factors related to complex system and their mutual relations, simplifies the system into an orderly hierarchical structure so that factors can be incorporated into different layers [24–25]. Then, judgment matrix will be built in each layer and relative weight of each layer will be gained. Finally, global weight against overall goal of each factors that belong to different layers will be calculated so that basis for decision-making and selection will be provided [24–25]. Since AHP was introduced, due to its feature of dealing with decision-makings in combination of qualitative and quantitative analysis, it has been paid a lot of attentions and has been rapidly and widely used in various fields of social economy areas such as energy systems analysis, urban planning, economic management, and research evaluation. However, AHP also has some limitations [26]: (1) it relies on experience of people to a large extent, so it can at most exclude severe inconsistency of thinking process rather than the possibility of existence of serious one-sidedness of decision-makers. (2)Comparison process and judgment process of AHP are rather rough that cannot be used to deal with highly precise problems. As a result, AHP can be mostly regarded as a semiquantitative (or a combination of qualitative and quantitative) approach [26].Weakness of AHP have been improved and perfected by many scholars, and some new theories and methods have been formed such as group decision, fuzzy decision theory, and feedback control theory, which have become new research hotspots in recent years.

4.6. Analytic network process

Analytic network process (ANP) was proposed in 1996 also by T. L. Saaty, professor of University of Pittsburgh of United States [27]. ANP is a new decision-making method developed from AHP, which allows the coexistence of indicators that can quantify or are difficult to quantify [28]. Correlations or feedbacks of factors within clusters or among different clusters are also take into consideration [28]. Therefore, ANP is better than AHP in decision problem reflection and description. A system will be divided into two parts, one is control hierarchy which consists of problem goal and decision criteria where decision criteria are considered to be independent of each other [29]. Control hierarchy is a typical AHP structure and weight of each criteria can be gained by traditional calculation of AHP method [29]. The other part is network hierarchy, which consist of element groups that are subjected to control hierarchy.

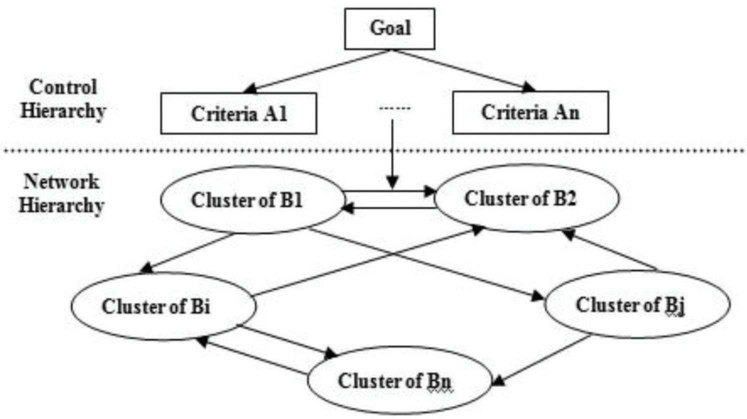


Figure 7. Basic ANP Structure.

Network consists of elements that interact and multiinfluence each other [29]. Basic ANP structure is shown in **Figure 7**.

4.7. Fuzzy comprehensive evaluation method

Theoretic basis of fuzzy comprehensive evaluation is fuzzy mathematics. Fuzzy mathematics is a new science proposed in 1965 by American cybernetician L. A. Zadeh, which had a quick development in the last 50 years.

In the natural sciences or social sciences, there are many definitions that are not very strict or are fuzzy. Fuzzy feature mainly refers to the ambiguity of transitions among different objectives [30]. For instance, pollution category of environment quality can be described as "slight pollution, medium pollution, and heavy pollution," a certain ecology situation to survival or adaptability of a certain crop can be described as "favorable, relatively favorable, less favorable, and unfavorable," and these concepts are normally very fuzzy. To deal with these "fuzzy" concept data, fuzzy set theory came into being.

According to requirements of set theory, one object correspond to one set, either it belongs to the set, or it does not belong to the set, and only one or the other. Such a set theory itself is unable to deal with specific fuzzy concepts [30]. Due to this fact, in 1965, American automatic control Professor Zadeh first proposed the concept of fuzzy sets and created the theory of fuzzy mathematics. Currently, fuzzy mathematics have been broadly used in various areas.

Comprehensive evaluation is an overall evaluation of an object that are subjected to several factors, and this kind of problems are all frequently happening in daily life or in scientific work. Product quality assessment, scientific achievement evaluation, and certain crop adaptability all belong to comprehensive evaluation. Inevitably, there will be ambiguity and subjectivity when evaluating objects from many aspects, and using fuzzy mathematics method to conduct comprehensive evaluation will make the evaluation result to remain with the greatest objectivity so that a relatively ideal evaluation result can be acquired [31]. This is where the existing meaning of fuzzy comprehensive evaluation model lies.

Mathematical model of fuzzy comprehensive evaluation can be divided into one layer model and multilayer model, which can be applied to different types of objectives respectively [31].

Evaluation indicators refer to the ones that fuzzy comprehensive evaluation are based on, which are also contained by the objectives. These indicators are various attributes or properties of objectives that are also known as parameters or quality indicators. Because they are capable of revealing the quality of objectives comprehensively, objective situation can be evaluated based on these indicators.

If evaluation objective contains one-layer structured indicators, which means the objective consists of several indicators, quality evaluation can be done based on these indicators [31]. Under these circumstances, it would be appropriate to use one-layer model to evaluate the objectives.

If an evaluation objective contains multilayer structured indicators, which means objective itself is a main factor that contains several subfactors, each subfactor also contains several indicators, etc [30]. Under these circumstances, it would be appropriate to use multilayer model to evaluate the objectives. When it comes to this situation, each subfactor should be evaluated first based on the indicators that subfactors contain and then the main factor will be evaluated according to the subfactors evaluation result so that overall evaluation result of the objective can be reached.

Complicated casual relationships always existed in SC performance evaluation indicator system [32]. Both qualitative and quantitative indicators make performance evaluation has a fuzzy and uncertain feature [32]. Fuzzy comprehensive evaluation offers a power tool to evaluate this uncertainty and provides scientific basis for rational evaluation decisions.

4.8. Gray relational analysis

Gray system theory is a new mathematic theory which integrates system analysis, modeling, forecasting, decision-making, and control in whole and can be used to solve problems in the condition of insufficient data, incomplete sample, and imprecise information [33]. This ability to deal with incomplete information can fit realistic requirements in a better way and is more effective in an incomplete information environment [33]. Gray relational analysis (GRA) has the ability to develop a part of the information that is already known and to extract useful information, and then it will have a correct understanding about the overall system and control it effectively. Different from traditional statistical methods, it is not necessary for sample data to comply with statistical rules such as normal distribution and T distribution while using GRA [24]. Another significant advantage of this method is that it is able to get satisfactory results through vast changing factors [33]. For reasons mentioned above, GRA is considered to be the best approach in decision-making in modern business environment.

4.9. Markov chains theory [34–35]

Markov chain was named after A.A. Markov, and it is a random process in discrete time which has Markov features in mathematics. In this process, given the current knowledge or information, forecast in the past (the historical time before now) is irrelevant to future (future state after now).

Markov forecast method is the one that predicts the probability of events. Based on the theory of Markov state transition, it predicts changes in every moment (or period) in future based on current situation of an event, which has been widely used in the economic field.

In the condition of SC, each operation strategy of each node enterprise can be adjusted, operation behaviors of enterprises are random, changing trends of which only related to a current state that means SC performance has nothing to do with past performance before the current time. Therefore, Markov chain theory can be used to do research on changing trends of SC performance and forecast the pros and cons of overall SC performance in a future moment.

http://dx.doi.org/10.5772/63065

4.10. Rough set theory [36–38]

In early 1980s, a Polish mathematician Z. Pawlak proposed a data analysis method based on indistinguishable relationship, rough set theory. Rough set theory studies on expression, learning, and summarization of incomplete and uncertain knowledge and data, essence of which is symbol-based machine learning.

Research objective of rough set theory is an objective set (observations and cases) described by multiattributes set (features, symptoms, and characters). Every objective and its attributes have a value to serve as its descriptive symbol. Objective, attribute, and descriptive symbol are the three basic elements of a decision problem. This form of expression can also be seen as a two-dimensional table, the row corresponding to objects, the column corresponding to attributes of objectives. Each row contains descriptive symbols of its corresponding objectives as well as information of objective membership category. Typically, the available information about the object is not necessarily enough to divide its membership category. In other words, this inaccuracy results in distinguishing the capability of objects. Given an equivalence relation between objects, formed by which, leads to unclear relationship of approximate space. Up approximation and down approximation formed by unclear classes are used to describe rough set theory. These approximations correspond to possible maximum objective set and possible minimum objective set that surely belong to a given class respectively. The difference between down approximation and up approximation is a boundary set which contains all the objectives that cannot be exactly determined whether they belong to the given class. Approximation accuracy and quality can be determined by this kind of processing. Rough set method can deal with significant classification problems, all redundant objects, or attribute inaccurate subsets can be approximately classified in a good way so that acceptable quality classification can be reached. In addition, it can also be used in the form of a decision planning set to show all the important relationships among most of the attributes and particular classifications.

4.11. Artificial neural network (ANN) [39–41]

Study work of McCulloch and Walter Pitts in 1940s is considered to be the beginning of modern artificial neural network research. They proposed the first mathematical model of artificial neuron which was used to describe human brain's working principles. Artificial neural network is a smart network constructed artificially based on the understanding of human brain and neural network, which is able to fulfill certain functions. It is an information processing system constructed on the basis of imitation of brain neural network structure and its function. Therefore, research foundation of artificial neural network is understanding about human brain and brain's neural network.

Through research on human brain's neural network, its basic feature can be noticed:

1. Human brain consists of large amount of neurons and neuron connections.
2. Signal transfer strength is determined by neuron connection strength.
3. Neuron connection strength can be changed according to the training of that network received.

4. Signals can bring provocative influences or restraining influences.
5. The cumulative signal effect of a neuron received determines the state of the neuron.
6. Whether cells will be activated rely on the "threshold" of the neuron.

Therefore, here is the basic construction of artificial neural network:

1. Neuron is a unit with multi-input (multiple of dendrites of one neuron connected to other neurons via synapses) and single output (one neuron has only one axon as an output channel) unit.
2. Only when a neuron has a feature of nonlinear input/output characteristics and when the cumulative effect of the received signal in the cell exceeds a threshold, the cell will be activated, then it will send signal to other neurons through the axons.
3. Neurons have plasticity. Signal input strength that cells received from different neurons is adjusted by a corresponding synaptic connection strength.

Artificial neural network is capable of conducting associative inference, parallel processing rapidly, identifying self-adaptively, and simulating human thinking. After scientific training and learning, it is able to find out nonlinear relationship between input and output of a system, so it can be used for intelligent reasoning and forecasts. SC performance evaluation system is a complex evaluation system that comprise a plurality of indicators as well as input and output. Indicators maybe obscure and uncertain. In addition, nonlinear correlation among indicators may exist. To deal with such a complex evaluation system, artificial neural network has been used more and more to construct SC performance evaluation system.

5. An evaluation model of SC performances using 5DBSC and LM-BP neural network algorithm

5.1. Introduction

A SC is a system of organizations, people, activities, information, and resources involved in moving a product or a service from suppliers to customers. SC activities transform natural resources, raw materials, and components into various finished products that are delivered to end customers. A highly efficient SC would bring great benefits to an enterprise such as integrated resources, reduced logistics costs, improved logistics efficiency, and high quality of overall level of services. In contrast, an inefficient SC will bring additional transaction costs, information management costs, and resource waste costs and reduce the production capacity of the all enterprises on the chain. So the evaluation of a SC is very important for an enterprise to survive in a competitive market in the business environment of the globalization. Therefore, it is important to research various methods, performance indicator systems, and technology for evaluating, monitoring, predicting, and optimizing the performance of a SC. A typical procedure of the performance evaluation of a SC is to use the established evaluation performance indicators, employ a numerical method, follow a given procedure to carry out quantitatively or qualitatively comparative analysis to provide the objective and accurate evaluation of a SC performance in a selected operation period.

Various research work has been carried out in proposing the performance indicator systems [42–44] and methods [45–47] for SC performance evaluations. But there is no widely accepted indicator systems that can be applied in practical SC performance evaluation due to the fact that the indicators in the different systems have been defined without a common understanding of the meanings and the relationships between them that are nonlinear and very complicated. The methods proposed for applying an indicator system are also difficult to effectively apply for practical SC performance evaluation.

The study of bionics bridges the functions, biological structures, and organizational principles found in nature with our modern technologies. The output of bionics study includes not only physical products but also various computations, social and business management methods that can be applied in different areas. People have learned from the biological system behaviors and structures to design and develop a number of different kinds of natural-inspired optimization algorithms that have been widely used in both theoretical study and practical applications [48–50]. Though there have been various efforts in applying the natural-inspired algorithms to evaluate the SC performance of a selected historical period, these efforts are either an isolated effort or limited to develop their methods/models for predicting and optimizing SC performance [51–55]. As far as the authors are aware, they have not been applied in practical SC management. So it is necessary to propose and develop a model that can be used not only for evaluating but also for predicting and optimizing SC performance. In this section, the existing performance indicator systems and methods will be first discussed and evaluated in Section 5.2; various natural-inspired algorithms will be reviewed and their applications for SC performance evaluation will be discussed in Section 5.3; based on the work in Sections 5.2 and 5.3, 5DBSC and LM-BP neural network and its application in SC performance evaluation will be presented in Section 5.4 and 5.5, respectively; then, a model will be proposed using LM-BP neural network and 5DBSC for SC evaluation in Section 5.6 and a case study of SC performance evaluation of an automotive company in Changchun, Jilin, China will be discussed using the proposed model in Section 5.7.

5.2. Indicator systems and methods for SC performance evaluation

The performance evaluation is an important part of SCM. It uses a set of defined indictors for objectively or subjectively measuring their performance. The traditional indicator systems and methods were normally developed for evaluating the performance of a single enterprise [42, 56–57]. They cannot be applied to evaluate the performance of the whole SC and enterprise cooperation situations. That would eventually lead to the losses of competitive advantages of a SC as a whole.

There have been efforts made for proposing and developing various indicator systems for SC performance evaluation. Beamon proposed a method that involves the quantitative and qualitative indicators to evaluate the SC performance. The indicators included resources, output, and flexibility, in short ROF [42]. Chen Ke proposed an integrated '3+1' method for the performance evaluation of a SC. This method consists of four submethods. They are for extracting the key indicators, analyzing factor correlation, discovering impacting-routine, and mining hidden patterns, respectively [43]. Bolch classified the performance evaluation into three parts [44]. The first part is the internal performance evaluation, and the main indicators include asset management, productivity, quality, customer service, and cost management; the second part is the external performance evaluation, and the main indicators include baseline assessment and the customer adaptations; the third part is the comprehensive performance evaluation, and the main indicators include the response time and the total cost of a SC, the ratio of on-shelf and inventory, standby time, the available days of inventory and cash-return time.

Meanwhile, the efforts have also been made to propose and develop methods for performance evaluation. Return on investment (ROI) was proposed by Dupont Company in the US and an early method for SC performance evaluation [58]. KPI is a performance evaluation method for selecting the key indicators for measuring, sampling, calculating, and analyzing. It is a tool that can be used to decompose an enterprise's strategy into operatable futuristic target [45]. KPI method is based on the assumption that people involved would take all necessary actions in order to achieve the predefined aim. SC Operations Reference (SCOR)was jointly proposed and developed by the two the US companies, PRTM and AMR. SCOR mainly consists of three layers and four components [20]. Among the three layers, the first one is the description layer. This layer describes the five fundamental business processes: planning, material acquisition, manufacturing, delivery, and reverse material-flow. The second one is the provision layer. This layer provides the enterprise own-selected key business processes. The third one is business process decomposing layer for analyzing the details of the business processes selected in the second layer. The four components include the fundamental description of the features of business processes, the general definitions of the business processes, the best practices, and choice of the software. There are 11 indicators: delivery, order fulfillment (including the customer satisfaction), order finished rate, SC response time, production flexibility, the total cost of SCM, value-added productivity, guaranteed costs, cash flow cycle, the stock turnover rate, and asset turnover days. In 1992, Kaplan and Norton first proposed Balanced Scorecard (BSC) [16]. There are four layers of the indicators: (1) accounting layer, (2) customer layer, (3) internal business process layer, and (4) learning and development layer. The characteristics of BSC are simple, straight forward, and clear in layer classification.

Benchmarking was proposed and developed by American Xerox Co. It is used for analyzing the enterprise's current situation. In benchmarking, the best practices learned from the enterprises in the same or the other industrial sectors are used as the evaluation standard to learn their the successful experiences and to catch up and surpass the successful enterprises [47]. In benchmarking method, the whole SC is considered as the integrated unit to learn the wealth of experience and success factors of the other whole SC in order to optimize and integrate their own SC.

In addition, AHP has been applied to the performance evaluation [24]. With AHP, some qualitative parameters can be expressed as the quantitative ones. AHP is a multiobjective decision method that combines both quantitative and qualitative analysis methods. The main disadvantages of AHP are that the decision-makers' subjective opinions are overstressed, and the subjective bias is relatively big.

Among the above performance evacuation methods, BSC is widely adopted because of its simplicity, clear objective definition, and comprehensiveness. The central principle of BSC is its capability of achieving the balance between the various performance indicators. The main tasks of BSC are clarifying the strategy and reaching agreement, effectively communicating the tactics between the enterprises, linking the departmental and individual aims and annual budget, linking tactics, long-term aims and annual budget, identifying and linking tactic plans, carrying out the periodic and systematic evaluation, and postreview for learning and modifying the tactics. The four layers of the conventional BSC serve the enterprises' long-term strategy and tactics. In every layer, objectives, evaluation items, objective values, and action plans are analyzed, as shown in **Figure 8**.

There are different models of BSC. Wong applied BSC to study the performance from material flow performance, production flexibility, order indicator, and cash turnover time [60]. Akkermans et al. thought that there is a flaw of cause and effect relationships and time delay in BSC, and its variables can be either causes or results and their relationships are not linear [61]. In addition, the performance indicators in BSC do not cover the indicators that are directly related to suppliers' performance. To avoid this problem, the 5DBSC has been proposed [17]. In 5DBSC, there are five different aspects of indicators. Among them 3 are qualitative and 11 are quantitative. Performance indicators of 5DBSC are more inclusive and cover the two indicators for supplier evaluation. So in this case study, 5DBSC will be used to build the performance evaluation model of a SC. The details of the 5DBSC will be discussed in Section 5.4.

Though there have been claimed applications of the performance indicator systems and methods as discussed above, there are still quite a few issues that hinder their applications:

1. It is difficult to obtain all indicator data from every partner enterprises on the chain.
2. There are no widely accepted methods for mathematically modelling all qualitative indicators so that the indicators can be properly considered.
3. The relationships between these indicators are very complicated. Some of them are interrelated. So it is impossible to have a closed form expression to include all these 14 indicators for SC performance evaluation.
4. There are limited further developments of the methods for using these indicators for SC performance evaluation, which prevent the people in industry from applying 5DBSC. Even when 5DBSC is applied, the results are different for each times they apply.
5. Even though there are numerical methods available for processing these indicators, they are mainly used for the evaluation of the history data. They are not for predicting, simulation, and optimization purposes.

From the above discussion, it can be seen that it is important to develop new models for the people in industry to apply them for SC performance evaluation after selecting a set of the performance indicator systems. The SC performance evaluation can be expressed as:

Figure 8. BSC (source [59]).

$$[A][P_i]=[S_p] \tag{1}$$

where A is a $m \times n$ transformation matrix for mapping the n performance indicators into m SC performance evaluation index, P_i is a $n \times 1$ performance indicator vector for expressing n indicators of a selected performance system and Sp is a $m \times 1$ performance evaluation vector for expressing m performance evaluation indices. So one of the main task of SC performance evaluation is to determine A.

As discussed above, the main limitation of the current method is that it is difficult to build a closed form of matrix A in Eq. 1. However, a considerable amount of efforts have been made in applying the natural-inspired methods or algorithms for various science, engineering, and business management applications. These methods can be used to build a model for SC performance evaluation.

5.3. Natural-inspired algorithms and their applications to SCM performance evaluation [62]

5.3.1. Natural-inspired algorithms

There are a number of natural-inspired algorithms that can be used for engineering and business system analysis and optimization: Ant colony optimization (ACO) is a metaheuristic algorithm for a wide range of combinatorial optimization problems [63–64]; Bees algorithm (BA) is inspired from the food foraging behavior of honey bees and a population-based optimization algorithm for many combinatorial optimization problems[65]; Genetic algorithm (GA) generates solutions to search, optimization, and machine-learning problems via applying techniques inspired by biological evolution and GA has been widely adopted to solve complex problems, especially in the areas of scheduling, global optimization, and control engineering [66]; Firefly algorithm (FA) is inspired by the firefly's biochemical and social aspects that fireflies produce luminescent flashes as a signal system to communicate with other fireflies, especially to prey attractions [67]. If the SC performance evaluation can be expressed as a combinatorial optimization problem, then both ACO-based and BA-based algorithms can be used for SC performance evaluation including history data analysis, prediction, and optimi-

http://dx.doi.org/10.5772/63065

zation. Similarly, GA can also be used in the various optimization problems in SC performance evaluation.

ANN are information-processing paradigms inspired by the way biological neural systems process data. In most cases an ANN is an adaptive system that changes its structure based on external or internal information that flows through the network. In more practical terms neural networks are nonlinear statistical data modelling or decision-making tools. They can be used to model complex relationships between inputs and outputs or to find patterns in data. There have been a significant number of publications about ANN and its applications [68–70]. The application areas of ANNs include system identification and control (vehicle control and process control), game-playing and decision-making (back gammon and chess, racing), pattern recognition (radar systems, face identification, and object recognition), sequence recognition (gesture, speech, and handwritten text recognition), medical diagnosis, financial applications, data mining (or knowledge discovery in databases), visualization, and e-mail spam filtering. But as far as the authors are aware, there are very limited efforts in applying ANN in SC management. However, the previous applications of ANN provide the solid knowledge background for proposing and developing ANN-based algorithms for SCM performance analysis and optimizations.

Besides the algorithms discussed above, some other algorithms have also been reported. Evolution programming algorithm (PA) was proposed by Fogel [71]. PA is different from GA in that the evolution in GA is only between 'father' and 'son' generations, but in PA, it is stressed that the evolution can be among the same group of the creatures. Particle swarm algorithm (PSA) was proposed by J Kennedy in 1995 [72]. It mimics the food hunting behaviors of bird flock. The main characteristic of PSA is that the searching is based on the searching speed but not on the gradient information. PSA has been applied in functional optimizations, neural network training, industrial system optimization, control, etc. Immune algorithm (IA) is based on the inspiration of the biological immune system [73]. IA can be used to tackle complex problems and produce a reasonable manufacturing schedule within an acceptable time.

5.3.2. Applications of natural-inspired algorithms to SC performance evaluation

(1) The applications of genetic algorithm

Zhang et al. applied the genetic algorithm to selectively analyze the eight different aspects of the performances of a SC, including the efficiency, satisfaction, cooperation, supply, dispatching, cost, and profit. Their work was valued in the area of the complexity simplification [74]. Li carried out the study in the area of Eigenvalues selection and optimizing support vector machines (SVM, also support vector networks) in order to reduce the performance indicator number when evaluating a SC [51]. Yu proposed the SC optimization model with soft time windows-SC network (STW-SCN) and hard time window-SC network (HTW-SCN) [75].Then, GA was used to find the solution of the model. Gabbert applied GA to study the complicated transportation scheduling problem of a rail-network [76]. Liu Cheng (2006) studied the routine optimum problem of the logistics with STW-SCN [77].The transportation segment of a SC was optimized, and hence, the performance was improved.

In the performance evaluation of a SC, GA application is different from that of a neural network. In a neural network, the evaluation model is directly established, but GA is mainly used for data processing and jointly applied with the other system models. GA plays an important role in efficient data processing for the evaluation of a SC.

(2) Applications of neural network

Pawlak studied a kind of neural network with simplified parameters by combining the data mining theory of rough sets and the intelligent optimization method [78]. Shi investigated the domain, condition, and decision features of rough set theory and applied these concepts into the performance evaluation of a SC including performance indicator simplification, redundant indicator removal. He used BP network for training, and this case study has shown that the predicted result was fitted well to the practical data and the error was about 10.36% [52]. Xi investigated the application of the modified fuzzy neural network to the performance evaluation of a SC. In his study, the middle layer was divided into fuzzy layer and reasoning layer. The main achievement of his study was that the people's bias and the randomness of the evaluation process have been minimized to achieve the relatively objective results [53]. Zheng proposed a dynamic evaluation method of a SC by combining the rough set reduction technique and the learning capability of a BP neural network. His method was first implemented based on the reduced number of the performance indicators and BP neural network to learn from and train samples. The trained neural network was used for the evaluation [26]. The advantage of this method is that the data processing task is small, and hence, the complexity of BP neural network structure is simplified and the computation is reduced. However, this method's reliability is not as high as expected when also carried out as a study of evaluating the performance of the materials SC in Beijing using BP neural network [54].

(3) Applications of other algorithms

PSA is mainly applied in the areas of material scheduling, transportation, and inventory management. It is applied to optimize the results of a neural network. Xu applied the particle swarm optimization algorithm to find the solution of the collaborative optimum model of a multilayer SC from the perspective of production scheduling and group dispatching [42].The application of Ant colony algorithm (ACA) to SCM has been focused on the scheduling and the vehicle routine optimization [79]. Li defined an ecological chain by combining SC, industry chain and value chain, and established logistic grow model for enterprises, enterprise group Lotka-Volterra predation model, and enterprise symbiosis model [80–81].

In summary, the neural network has been used in the performance evaluation of a SC. The corresponding theories, applications, and the required computer programming have been studied. The other algorithms have been tried in the SC management, but as far as the authors are aware, there have been no direct applications to the performance evaluation of a SC. The feature of GA makes it be widely applied in the data processing in the performance evaluation of a SC, but cannot be used as an independent method. The particle swarm optimum algorithm and ACA can be used for routine scheduling in the transportation and production stages of a SC, but their applications are limited in the performance evaluation of a SC. However, they can be jointly applied with neural networks in the performance evaluation of a SC. This can be the focus of the future researches.

In a neural network, an algorithm is required for updating weight and thresholds for training the network. Back propagation (BP) algorithm was initially developed to achieve the training and then various BP-related algorithms have been developed. Compared with the existing BP algorithms, the computation amount in LMBP algorithm is increased for each iteration, but the iteration times are considerably reduced, and hence, the convergence speed is increased. LMBP is the fastest neural network training algorithm for those networks with intermediate number of parameters, even for the cases that require the large amount of computations [82–83]. For the case of SCM performance evaluation, it is impossible to have a closed form mathematical performance objective function, so it requires iterative searching. It is often that the searching does not converge when the other BP algorithms are used, which can lead to the failure of generating a reliable evaluation. In addition, to establish a reliable and meaningful model for SC performance evaluation, a large amount of historical data should be collected and used. This demands the high search speed of the algorithm. So LMBP is a better algorithm compared with the other BP algorithms. Therefore, in this case study, LMBP is selected as the natural-inspired algorithm for evaluating SC performance and will be discussed in Section 5 in details.

5.4. 5 DBSC

A 5DBSC was proposed by Zheng for the SC performance evaluation [26]. The 5DBSC includes the four groups of the indicators adopted in the conventional BSC plus a new supplier dimension. The supplier dimension includes the on time delivery and flexibility. The indicator structure of 5DBSC is shown in **Figure 9**, and the indicator system of 5DBSC is listed in **Table 3**.

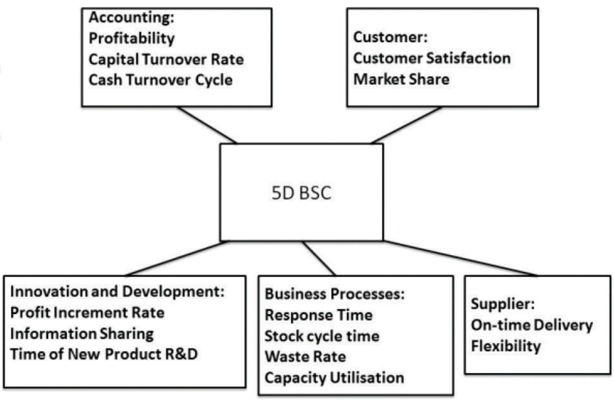


Figure 9. The indicator system of a 5D-BSC.

Indicator Groups	Indicators	Nature of indicators	Meaning of indicators
Accounting	Profitability (F_1)	Quantitative	Profit level of a SC
	Capital turnover rate (F_2)	Quantitative	Management efficiency of the net capital of a SC
	Cash turnover time (F_3)	Quantitative	Cash flow payback period
Customer	Customer Satisfaction (C_1)	Qualitative	Customers' awareness and acceptability
	Market Share (C_2)	Quantitative	Size of the customer community
Business processes	SCRT (SC response time) (P_1)	Quantitative	Required time from all enterprises on the chain finding the changes of the market requirements to absorbing these changes and adjusting their plans to meet these changes.
	Stock turnover rate (P_2)	Quantitative	Amount of cash in the stock account
	Waste rate (P_3)	Quantitative	The quality control and production technology
	Capacity utilization (P_4)	Qualitative	Facility application level
Innovation and development	Profit increment rate (D_1)	Quantitative	Development capability of an enterprise
	Information Sharing (D_2)	Qualitative	Level of the information integration Dependent on the partners strategic relationships
	Period of a new product R&D (D_3)	Quantitative	How fast a chain to respond to the market changes. Different from each products and enterprises, so it is difficult to determine its value.
Suppliers	On time delivery rate (S_1)	Quantitative	Delivery's capability of a supplier
	Flexibility (S_2)	Qualitative	SC's capability of dealing with the special business environment and meeting the customers' special requirements or unexpected requirements.

Table 3. The indicators of 5D BSC.

5.5. LMBP network algorithm and its application in SC performance evaluation

A LMBP feed-forward neural network is a neural network with LMBP algorithm for the network training (**Figure 10**).

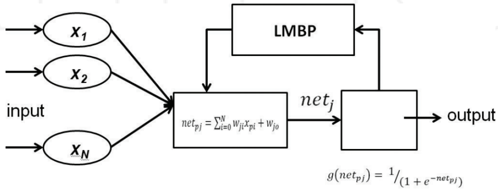


Figure 10. LMBP neural network.

In the prediction context, multilayer FNN training consists of providing input–output examples to the network and minimizing the objective function (i.e., error function) using either a first-order or a second-order optimization method. This so-called "supervised training" can be formulated as minimizing an error function of neuron weights. The error function is the sum of the nonlinear least squares between the observed and the predicted outputs, defined by Eq. 2 as follows:

$$E = \frac{1}{2} \sum_{p=1}^{N} \sum_{k=1}^{M} \left(y_{pk} - \hat{y}_{pk} \right), \tag{2}$$

where N is the number of the patterns and M the total output units, y represents the targeted output and $\hat{y}$ the model predicted output.

In the BP training, minimization of E is attempted using the steepest descent method and computing the gradient of the error function by applying the chain rule on the hidden layers of the FNN [84]. Consider a typical multilayer FNN whose hidden layer contains M neurons. The network is based on Eq. 3 and Eq. 4 [62]:

$$net_{pj} = \sum_{i=0}^{N} w_{ji} x_{pi} + w_{jo} \tag{3}$$

$$g\left(net_{pj}\right) = 1 \Big/ \left(1 + e^{-net_{pj}}\right) \tag{4}$$

where net_{pj} is the weighted inputs into the jth hidden unit, N the total number of input nodes, w_{ji} the weight from input unit i to the hidden unit j, x_{pi} a value of the ith input for pattern p, w_{jo} the threshold (or bias) for neuron j, and $g(net_{pj})$ the$j$th neuron's log-sigmoid activation function to simulate biological neuron's nonlinear characteristic. Note that the input units do not perform operation on the information but simply pass it onto the hidden nodes.

The output unit receives a net input of

$$net_{pk} = \sum_{j=0}^{M} W_{kj} g(net_{pj}) + W_{ko} \tag{5}$$

$$\hat{y}_{pk} = g\left(net_{pk}\right) \tag{6}$$

where M is the number of hidden units, W_{kj} represents the weight connecting the hidden node j to the output k, W_{ko} is the threshold value for neuron k, and $\hat{y}_{pk}$ the kth predicted output.

Recall that the ultimate goal of the network training is to find the set of weights W_{ji} connecting the input units i to the hidden units j and W_{kj} connecting the hidden units j to output k, that minimize the objective function (Eq. 2). Since Eq. 2 is not an explicit function of the weight in the hidden layer, the first partial derivatives of E are evaluated with respect to the weights using the chain rule, and the weights are moved in the steepest-descent direction. This can be represented mathematically as

$$\Delta W_{kj} = -\eta \,{\partial E}\big/{\partial W_{kj}} \tag{7}$$

where η is the learning rate which simply scales the step size. The usual approach in BP training consists in choosing η according to the relation $0 < \eta < 1$. From Eq. 7 it is straightforward that BP can suffer from the inherent slowness and the local search nature of first-order optimization method [62].

However, second-order nonlinear optimization techniques are usually faster and more reliable than any BP variants [85]. So LMBP was developed for multilayer FNN training. The LMBP uses the approximate Hessian matrix (second derivatives of E) in the weight update procedure as follows:

$$\Delta W_{kj} = -\left[H + \mu I\right]^{-1} J^T e \tag{8}$$

where e is the residual error vector, μ a variable small scalar which controls the learning process, $J = \nabla E$ is the Jacobian matrix, and $H = J^T J$ denotes the approximate Hessian matrix usually written as $\nabla E \cong 2 J^T J$. In practice, LMBP is faster and can be used to find better optima for a variety of problems than do the other usual methods [62].

After processing all of the layers, the activated result, y, of the output layer, compared with the target value $\hat{y}$, and the resulted error will be propagated backward to the network's weight to minimize the overall error.

The standard LMBP training process can be described in the pseudo-code as follows:

1. Initialise the weights and parameter μ ($\mu = 0.01$ is normally appropriate).

2. Compute the sum of the squared errors over all inputs, $E(w) = e^T e$, where W= [consists of all weights of the network, e is the error vector comprising the error for all the training nodes.

3. Solve Eq. 5 to obtain the increment of weight $\Delta w = -[J^T J + \mu I]^{-1} J^T e$, where J is the Jacobian matrix, μ is the learning rate which is to be updated using the decay rate, β depending on the outcome. In particular, μ is multiplied by β ($0<\beta<1$).

4. Recomputed the sum of squared errors $E(w)$.

Using $w + \Delta w \Delta w$ as the trial W, and judge

IF trial $E(w)$< in step 2 then

$w = w + \Delta w$; $\mu = \mu \cdot \beta$ ($\beta = 0.1$); go back to step 2

ELSE

$\mu = \mu/\beta$; go back to step 4

END IF

5.6. A model for performance evaluation of a SC

In this section, a model for performance evaluation of a SC is proposed. This model is based on 5DBSC and LMPB neural network as shown in **Figure 11**.

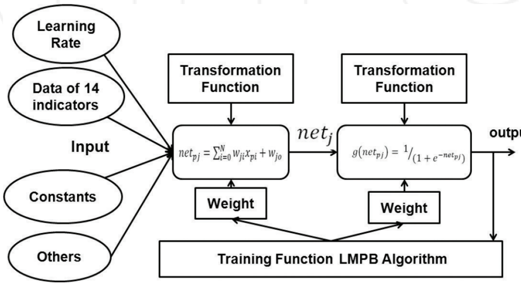


Figure 11. LMBP neural network for evaluating the performance of a SC.

The procedure of proposed model is shown in **Figure 12**. There are three stages in the model: Stage 1—data preparation, Stage 2–training neural network using LMBP algorithm, and Stage 3—postprocessing and application.

In Stage 1, there are three tasks (1) collect the data of the 14 indicators of 5DBSC for a period, (2) applying a technique for data preprocessing, here the main work is to normalize the collected data of the 14 indicators and (3) variable data selection.

In Stage 2, the task is to follow the steps and apply equations in Section 4 to train the neural network as shown in **Figure 11**.

In Stage 3, there are two tasks: (1) postprocess the outcome, mainly record the weights, and thresholds of the trained neural network and (2) apply the model to evaluate, analyse, and optimize the performance of a SC.

5.7. Case study—result analysis

Matlab and its neural network tool box have been used to implement the proposed model in Section 6. An automotive company in Changchun, Jilin Province, China, was selected as the case study to demonstrate the proposed model. Considering the confidential issues, the real name of the company is not used. So in this case study, this company is called Company Y. To

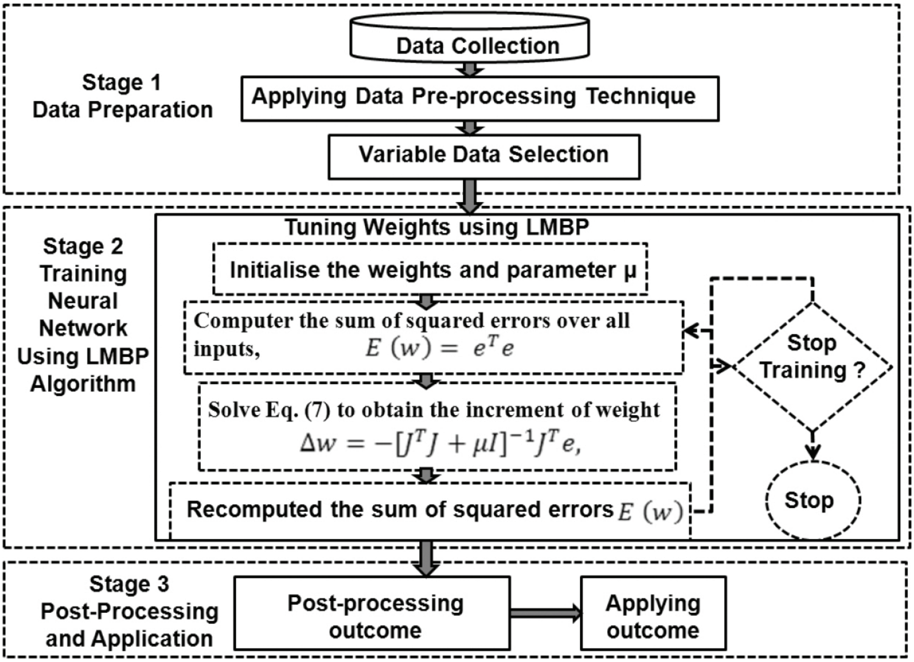


Figure 12. Procedure of the proposed model.

express the performance of a SC, a performance index system is used. There are four levels of performances: poor, reasonable, good, and excellent. These four levels are represented using a four-element vector(1 0 0 0)、(0 10 0)、(0 01 0)、(0 0 0 1), respectively. The advantage of using a four-element vector over a single digit is that four-element vector can be used to express the performance between those four levels. This is especially useful for SC performance prediction and optimization.

5.7.1. Data Preparation

1) Data collection

Table 2 lists the collected data of the 14 indicators of 5DBSC of Company Y for 12 months from January to December 2012.

2) Data preprocessing

The indicators in **Table 4** have different dimensions. They should be preprocessed to be dimensionless before they can be input into LMBP network. The dimensionless process is typically to normalize the indicators' values. It is a process to remove the effects of dimensions through mathematical transformation. The range of normalized indicators' value should be [0, 1]. The normal dimensionless process method includes linear function normalization, logarithmic function normalization, and inverse cotangent function normalization. In this case study, the linear function normalization is adopted for dimensionless processing. There are two types of indicators: the benefit type and cost type. The benefit type means that the bigger the value of the indicators, the better. In contrast, the cost type means that the smaller the value of the indicators, the better. Among these 14 indicators, C_1, C_2, F_1, P_4, D_1, D_2, S_1, and S_2 belong to the benefit type of indicators. The others belong to the cost type of indicators. The formula of the linear function normalization is either $y_i = (x_i - x_{min}) / (x_{max} - x_{min})$ for the benefit type of indicators and $y_i = (x_{max} - x_i) / (x_{max} - x_{min})$ for the cost type of indicators, where $x_i$is the original value of the indicators before the normalization, $y_i$is the value after normalization, x_{max} and $x_{min}$are the maximum and minimum values, respectively. To determine x_{max} and x_{min}, these 14 indicators should also be classified into two different kinds: qualitative and quantitative. C_1, P_4, D_2, and S_2 are the qualitative indicators. The others are the quantitative indicators. For those qualitative types of indicators, they have to be digitized for the further processing. In this paper, 0, 1, 2, 3, and 4 are used to express poor, reasonable, good, and excellent performance of these four qualitative indicators. So their $x_{max}$and x_{min} are 4 and 0, respectively. For those quantitative type of indicators, the $x_{max}$and are determined based on the company's experiences and their meanings. The values of them are listed in **Table 5**. Then, normalized data are calculated and listed in **Table 6**.

	Customer dimension		Accounting dimension			Internal business process dimension				Innovation and development dimension			Supplier dimension		SC performance
	C_1	C_2	F_1	F_2	F_3	P_1	P_2	P_3	P_4	D_1	D_2	D_3	S_1	S_2	
Jan.	4	1.54%	0.444	0.263	120	90	0.25	0	4	0.000	3	200	1	2	reasonable
Feb.	4	1.29%	0.426	0.225	130	91	0.10	0	4	–0.171	3	200	1	3	poor
Mar.	3	1.59%	0.520	0.328	130	88	0.30	0	4	0.660	3	120	1	3	good
Apr.	4	1.64%	0.507	0.310	120	89	0.30	0	4	–0.069	4	140	1	3	good
May	4	1.29%	0.561	0.248	120	90	0.15	0	4	–0.160	4	200	1	4	reasonable
Jun.	3	1.18%	0.414	0.216	120	92	0.10	0	4	–0.281	4	200	1	4	poor
Jul.	3	1.40%	0.426	0.247	110	90	0.25	0	4	0.157	3	120	1	3	reasonable
Aug.	4	1.39%	0.459	0.275	110	90	0.25	0	4	0.136	3	130	1	4	good
Sep.	3	1.44%	0.468	0.295	110	90	0.20	0	4	0.088	4	130	1	4	good
Oct.	4	1.20%	0.419	0.215	120	92	0.15	0	4	–0.324	4	180	1	4	poor
Nov.	4	1.62%	0.500	0.289	120	88	0.30	0	4	0.489	4	120	1	4	excellent
Dec.	4	1.64%	0.509	0.322	120	90	0.25	0	4	0.095	4	120	1	4	excellent

Table 4. The original data of the supply chain of Y Company in 12 months (2012).

C_2	F_1	F_2	F_3	P_1	P_2	P_3	D_1	D_3	S_1
(0, 2%)	(0, 1)	(0, 1)	(100,150)	(85,95)	(0, 1)	(0, 1)	(0, 1)	(100,210)	(0, 1)

Table 5. The values of x_{max} and x_{min} of the quantitative indicators.

	C_1	C_2	F_1	F_2	F_3	P_1	P_2	P_3	P_4	D_1	D_2	D_3	S_1	S_2	**SCM performance**
Jan.	1.00	0.77	0.44	0.26	0.60	0.50	0.25	1.00	1.00	0.00	0.75	0.08	1.00	0.50	(0 1 0 0)
Feb.	1.00	0.65	0.43	0.23	0.40	0.40	0.10	1.00	1.00	–0.17	0.75	0.08	1.00	0.75	(1 0 0 0)
Mar.	0.75	0.80	0.52	0.33	0.40	0.70	0.30	1.00	1.00	0.66	0.75	0.75	1.00	0.75	(0 0 1 0)
Apr.	1.00	0.82	0.51	0.31	0.60	0.60	0.30	1.00	1.00	–0.07	1.00	0.58	1.00	0.75	(0 0 1 0)
May.	1.00	0.65	0.56	0.25	0.60	0.50	0.15	1.00	1.00	–0.16	1.00	0.08	1.00	1.00	(0 1 0 0)
June.	0.75	0.59	0.41	0.22	0.60	0.30	0.10	1.00	1.00	–0.28	1.00	0.08	1.00	1.00	(1 0 0 0)
July.	0.75	0.70	0.43	0.25	0.80	0.50	0.25	1.00	1.00	0.16	0.75	0.75	1.00	0.75	(0 1 0 0)
Aus.	1.00	0.70	0.46	0.28	0.80	0.50	0.25	1.00	1.00	0.14	0.75	0.67	1.00	1.00	(0 0 1 0)
Sep.	0.75	0.72	0.47	0.30	0.80	0.50	0.20	1.00	1.00	0.09	1.00	0.67	1.00	1.00	(0 0 1 0)
Oct.	1.00	0.60	0.42	0.22	0.60	0.30	0.15	1.00	1.00	–0.32	1.00	0.25	1.00	1.00	(1 0 0 0)
Nov.	1.00	0.81	0.50	0.29	0.60	0.70	0.30	1.00	1.00	0.49	1.00	0.75	1.00	1.00	(0 0 0 1)
Dec.	1.00	0.82	0.51	0.32	0.60	0.50	0.25	1.00	1.00	0.10	1.00	0.75	1.00	1.00	(0 0 0 1)

Table 6. The processed data of Company Y's supply chain in 12 months.

5.7.2. Determination of the number of nodes in hidden layer

The determination of the number of hidden layers and their nodes are the focuses of a LMBP network analysis. According to universal approximation theory, as long as there are enough nerve cells in the hidden layer, a LMBP network can be used to approximate any functions. It only requires the two hidden layers when learning noncontinuous functions. In practical applications, it is normal to test the case with one hidden layer, then to see if it is required to use the two hidden layers. In this case study, one hidden layer is chosen for the test.

The node numbers of the input and output layers are determined by the sample characteristics, sample number, and sample's experimental objective number. The sample data are represented with the SC performance indicators and four-dimensional data used for the four levels of the SC performance in 12 months. So there are 14 nodes in the input layer and 4 nodes in the output layer. The number of nodes in the hidden layer has the significant impact on the structure and characteristics of a network. The unnecessary high number of nodes in the hidden layer would reduce the learning and reasoning efficiency, but the low number of the nodes would lead to the nonconvergence of learning. The trial-and-error method is currently widely used [46].

http://dx.doi.org/10.5772/63065

In this case study, the initials have been set to zero, then to try to adjust the node numbers of the LMBP network for comparing the errors. The results of running our Matlab program have been listed in **Table 7**. From the table, it can be seen that the value of MSE is the minimum at 5.13E-09 when the node number of hidden layer is 18.

Nodal No. in Hidden Layer	8	10	12	14	16	**18**	20	22	24	26
Epoch	12	4	4	3	4	**3**	3	4	4	5
MSE(10^{-6})	3.57	0.346	0.467	2.40	0.155	**0.005**	7.69	4.09	1.99	98

Table 7. The impact of the node number of the hidden layer on the LMBP network.

5.7.3. The determination of transformation functions

The transformation functions in the neural cells include logarithmic function (Logsig), tangent function (Tansig), and linear function (Purelin). Purelin is a transformation function that is inputted through input layer to calculate the outputs of the output layer. This function can be used to transfer the inputs of the neural cells to the outputs through the adjusting the threshold. Tansig is a hyperbolic tangent S-type transfer function. It can be used for mapping the neurons' outputs into [–1,1]. Logsig is a logarithmic S-type transfer function. It is used for mapping the neurons' outputs into [0,1]. These three functions are differentiable and suitable to train a LMBP algorithm neural network. K.M. Hornik thought that as long as there are enough nodes in the hidden layer, employing S-type functions in the hidden layer of a three-layer network, and employing linear functions in the output layer, the neural network can approximate any functions with any errors at considerably high probability [86]. But it is not easy to meet the preconditions.

In this case study, numerous trial experiments have been repeated. From the experimental results, it has been found that the errors of our neural network are minimal if Purelin functions are employed for both from the input layer to the hidden layer and from the hidden layer to the output layer. The results have been listed in **Table 8**.

	t–t	t–1	t–p	p–t	p–1	p–p	1–t	1–1	1–p
Epoch	11	9	4	22	8	**3**	11	18	4
MSE	4.89E-04	4.50E-04	1.13E-04	9.72E-04	5.20E-04	**5.13E-09**	2.04E-04	7.24E-04	2.94E-06

**t* is for Tansig function, *p* is for Purelin function, and *l* is for Logsig function.

Table 8. The error comparison analysis when employing the different transformation.

The BP neural network toolbox of Matlab 7.6 provides the LMBP training functions, it is called Trainlm. The format of trainlm function is as [*w*, *b*, *te*, *tr*]=trainlm[*w*, *b*, '*f*', *x*, *t*, *tp*], where: *p* is the input vector matrix, *t* is the target vector, *w* is the new weight, *b* is the new threshold vector, *f* is the transformation functions between the layers of the network, *te* is the actual network training times, *tr* is error squared sum vector of the network, and *tp* is the optional parameters. In our program, *tp* is set as the maximum training time.

The learning speed predetermines the rates of modification of the weight and the threshold. When the learning speed is low, the weight of a network is relatively quick to converge, but the learning time can be long. It is normal to set the learning speed to 0.01. In this case study, the training parameters have been set as follows: net.trainParam.show = 5; net.trainParam.lr = 0.01; net.trainParam.mc = 0.9; net.trainParam.epochs = 1000 and net.trainParam.goal = 1e-3.

5.7.4. *Analysis of the training results*

The last column of **Table 4** is used for representing the performance evaluation of Company Y for 12 months in 2012. They can be rearranged as

$$To = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \tag{10}$$

As discussed above, the parameters of Company Y's LMBP neural network are the node number of the input layer is 14, that of the hidden layer is 18, that of the output layer is 4, the transformation function is purelin, training function is trainlm, the iteration number is 3, and the criterion mean square error (MSE) was e-03. So the program should be compiled as net = newff(P, T_0, 3, {'purelin', 'purelin'}, 'trainlm', 'MSE'), where P is a 12 by 14 matrix of 14 indicators in the period of 12 months.

The results of the LMBP network program for the case study are as follows: when the LMBP network reached the stable condition, MSE was 5.13E–09 and the fitness of the network training, R was approximately 1. The results of performance evaluation of company's SC for the 12 months in 2012 are

$$Tc = \begin{bmatrix} -0.0001 & \mathbf{0.9999} & -0.0001 & -0.0001 & -0.0001 & \mathbf{0.9999} & -0.0001 & -0.0001 & -0.0001 & \mathbf{0.9999} & -0.0001 & -0.0001 \\ \mathbf{1.0000} & -0.0000 & -0.0000 & -0.0000 & \mathbf{1.0000} & -0.0000 & \mathbf{1.0000} & -0.0000 & -0.0000 & -0.0000 & -0.0000 & -0.0000 \\ 0.0000 & 0.0000 & \mathbf{1.0000} & \mathbf{1.0000} & 0.0000 & 0.0000 & 0.0000 & \mathbf{1.0000} & \mathbf{1.0000} & 0.0000 & 0.0001 & 0.0001 \\ 0.0001 & 0.0001 & 0.0001 & 0.0001 & 0.0001 & 0.0001 & 0.0001 & 0.0001 & 0.0001 & 0.0001 & \mathbf{1.0001} & \mathbf{1.0001} \end{bmatrix} \tag{11}$$

where each column stands for performance index vector for one month.

The difference between To and Tc is

$$dT = 10^{-3} \begin{bmatrix} 0.065 & 0.070 & 0.092 & 0.088 & 0.081 & 0.070 & 0.074 & 0.089 & 0.086 & 0.081 & 0.104 & 0.105 \\ 0.005 & 0.003 & 0.011 & 0.008 & 0.003 & 0.002 & 0.008 & 0.007 & 0.007 & 0.002 & 0.010 & 0.008 \\ -0.031 & -0.032 & -0.046 & -0.046 & -0.038 & -0.032 & -0.038 & -0.043 & -0.042 & -0.036 & -0.052 & -0.051 \\ -0.083 & -0.082 & -0.127 & -0.121 & -0.093 & -0.078 & -0.102 & -0.113 & -0.111 & -0.089 & -0.138 & -0.133 \end{bmatrix} \tag{12}$$

From *dT*, it can be seen that the model using 5DBSC and LMBP neural network for SC performance evaluation is accurate. The maximum error is less than 0.02%, well lower than 10% accepted in SC performance evaluation. That means that the model is accurate, valid, and efficient.

5.7.5. Optimizing the SC performance of Company Y

From **Table 4**, it can be seen that the SC performance of Company Y for the period of February, June, and October, 2012 was evaluated as poor (1 0 0 0). In this section, the data in these three months will be used as an example to demonstrate how the developed model can be used to optimize SC performance of these months.

The method adopted in this case study is to use an excellent performance month as the benchmark month. It can be seen that the performance was evaluated as excellent for November and December. So one simple way is to adjust the poor performance's14 indicators toward excellent performance's 14 indicators, respectively. In this case study, a linear equation is adopted for adjusting data and expressed as Eq. 9.

$$x_{ap} = x_{ip} + \lambda(x_{ep} - x_{ip}) \tag{9}$$

where x_{ap} is the adjusted indicator, x_{ip} is the poor month's indicator, x_{ep} is the excellent month's indicator, and λ is the adjusting factor with the value range from 0 to 1. **Table 7** lists the numerical results that shows how the performance is improved when February's data is adjusted toward November's data. From the **Table 9**, it can be found that

When λ = 0, that means that the data of 14 indicators are not changed, so the performance vector remains the same and the performance is classified as poor.

When λ = 0.25, that means that the data of 14 indicators are changed 25% toward those values of the excellent month's 14 indicator, the performance vector is changed to [0.75 0 0 0.25], which means that the performance is improved 25%, similarly. When λ = 0.5 and 0.75, the performance is improved 50% and 75%, respectively. The same results have been achieved when all three poor months' indicators are adjusted toward those of the two excellent months' indicators. The reason behind it is that the new model is developed using the linear transformation functions for both from the input layer to the hidden layer and from the hidden layer to the output layer. This is the main advantage of the proposed model over the other models. Again, this proves that the new model is valid and reliable and can be used to optimize SC performance.

It should be pointed out that, in this example, the values of all the 14 indicators are adjusted toward the excellent month's values at the same rate. Though this does not affect the validity and reliability of the new model, it would be very difficult or practically impossible to implement this kind of indicator changes.

Further work should be carried out to establish a cost model that should include the costs for any changes of any of 14 indicators and the benefits gained from the changes.

The optimization function of the model not only provides the people a tool to improve the performance of a SC but also guides the people to improve the ways they mange the SC activities. In this numerical example, to achieve a 75% performance improvement, one of the changes of the indicators is SC response time (SCRT) (P_1)should be reduced from 91 days to 88.75 days. That means that Company Y should collaborate with its partners to make efforts to achieve this target. The same analysis can be done for the other indicators.

λ	C_1	C_2	F_1	F_2	F_3	P_1	P_2	P_3	P_4	D_1	D_2	D_3	S_1	S_2	New Performance
0	1	.645	.426	.225	.4	.4	.1	1	1	–.171	.75	.083	1	.75	[1 0 0 0]
.25	1	.686	.445	.241	.45	.475	.15	1	1	–.006	.813	.25	1	.813	[0.75 0 0 0.25]
.5	1	.728	.463	.257	.5	.55	.2	1	1	.159	.875	.417	1	.875	[0.5 0 0 0.5]
.75	1	.769	.482	.273	.55	.625	.25	1	1	.324	.938	.583	1	.938	[0.25 0 0 0.75]

Table 9. Performance improvement when February's data is adjusted toward November's data.

5.8. Discussion

In this case study, the existing performance indicator systems and methods have been discussed and evaluated, various natural-inspired algorithms have been reviewed, and their applications for SC performance evaluation has also been discussed. Then, a model has been proposed and developed using 5 dimensional balanced scorecard (5DBSC) and Levenberg–Marquardt Back-propagation (LMBP) neural networkfor SC performance evaluation.

A program has been written using Matlab tool box to implement the model based on the practical values of the 14 indicators of 5DBSC of a given previous period. This model can be used to evaluate, predict, and optimize the performance of a SC. The analysis results of a case study company show that the proposed model is valid, reliable, and effective. The convergence speed is faster than the previous work.

However, it should be pointed out that the focus of this paper is placed on the proposition of the new model. The development of the model was only based on a relatively short period of 12 months of Company Y. To make the model more reliable and with higher practical values, more data should be collected over longer period for training the network.

To apply the proposed model for optimizing SC performances and hence guiding companies to improve their SC management, cost model should be built as a conditional function to make sure any changes in SC management are cost effective.

Author details

Xuemei Fan[1] and Shujun Zhang[2*]

*Address all correspondence to: szhang@glos.ac.uk

http://dx.doi.org/10.5772/63065

1 School of Management, Jilin University, Changchun Jilin, China

2 School of Computing and Technology, The University of Gloucestershire, Chetenham, UK

References

[1] Lindu Zhao, SC and logistics management. *China Machine Press*, 2007.

[2] Daoping Wang, Ceng Yang, Supply chain management. Peking University Press, 2012.

[3] Seuring, S. and Müller, M. From a literature review to a conceptual framework for sustainable supply chain management. *Journal of Cleaner Production*, 2008, Vol. 16 (15): 1699–1710.

[4] Carter, C.R. and Rogers, D. A framework of sustainable supply chain management: moving toward new theory. *International Journal of Physical Distribution and Logistics Management*, 2008, Vol. 38 (5): 360–387.

[5] Elkington, J. (1998), Partnerships from cannibals with forks: the triple bottom line of 21st-century business, *Environmental Quality Management*, Vol. 6 No. 1, pp. 37–51.

[6] Fahimnia, B., Reisi, M., Paksoy, T. and Özceylan, E. The implications of carbon pricing in Australia: an industrial logistics planning case study, *Transportation Research Part D: Transport and Environment*, 2013, Vol. 18 January, pp. 78–85.

[7] Carroll, A.B. and Shabana, K.M. The business case for corporate social responsibility: a review of concepts, research and practice, *International Journal of Management Reviews*, 2010, Vol. 12 No. 1, pp. 85–105.

[8] Mohsen V., Soosay, C., Fahimnia, B., and Sarkis, J. Framing sustainability performance of supplychains with multidimensional indicators. *Supply Chain Management: An International Journal*, 2014, Vol. 19(3): 242–257.

[9] Frost, S. and Burnett, M., Case study: the Apple iPodin China, *Corporate Social Responsibility and Environmental Management*, 2007, Vol. 14 No. 2, pp. 103–113.

[10] Philip Beske-Janssen Matthew Phillip Johnson Stefan Schaltegger, 20 years of performance measurement unsustainable supply chain management—what has been achieved? *Supply Chain Management: An International Journal*, (2015), Vol.20 Iss 6 pp. 664–680.

[11] Sunil Chopra, Peter Meindl, Supply chain management: strategy, planning and operation, 2012.

[12] Gengzhong Feng and Weihua Liu, Logistics and supply chain management. *China Renmin University Press*, 2010.

[13] Tatsiana Haponava and Saad Al-Jibouri, Establishing influence of design process performance on end-project goals in construction using process-based mode, *Benchmarking: An International Journal*, 2010, 17(5).

[14] William P.Anthony and Pamela L. Perrewe, Strategic Human Resource Management (Second Edition), 2000.

[15] Richard L.Daft, Theory and design of organizations (Tenth Edition), 2010.

[16] Kaplan R S and Norton D P. The Balanced Scorecard: measures that drive performance, *Harvard Business Review*, 1992, Jan–Feb, 71–80.

[17] Brewer P.C and Speh T. W. Using the balanced scorecard to measure supply chain performance, *Journal of Business Logistics*, 2000, 21(1):75–93.

[18] Kaplan, R.S and Norton D.P. The strategy focused organization: how balanced scorecard companies thrive in the new competitive environment, *Boston: Harvard Business School Press*, 2001.

[19] Rajat Bhagwat and Milind Kumar Sharma, Performance measurement of supply chain management: a balanced scorecard approach, *Computers & Industrial Engineering*, 2007, 53(1): 43–62.

[20] Stewart G. Supply-chain operations reference model (SCOR): the first cross-industry framework for integrated supply-chain management. *Logistics Information Management*, 1997, 10, 62–67.

[21] Martin Christopher. Logistics and supply chain management (4th edition), 2012.

[22] C.N. Verdouw, A .J.M. Beulens, J.H. Trienekens, and J. Wolfert, Process modelling in demand-driven supply chains: a reference model for the fruit industry, *Computers and Electronics in Agriculture*, 2010, 73(2):174–187.

[23] http://www.supply-chain.org 2010, accessed on 12-12-2015.

[24] Saaty, T and Joyce J. *Conflict Resolution: The Analytic Hierarchy Process*. New York: Praeger. 1989.

[25] Sevkli, M., Koh, S.C., Zaim, S., Demirbag, M. and Tatoglu, E., Hybrid analytical hierarchy process model for supplier selection, *Industrial Management & Data Systems*, 2008, 108 (1):122–142.

[26] Zheng P. *Study of methods for evaluating the performance of dynamic supply chains*, Dissertation, Hunan University, 2008.

[27] Saaty, T, Decision making with dependence and feedback, 1996.

[28] Saaty, T., Decision making in complex environment: The analytic hierarchy process (AHP) for decision making and the analytic network process (ANP) for decision making with dependence and feedback. www.Superdecisions.com/,2003.

[29] Saaty, T. L. and Vargas, L. G, Diagnosis with dependent symptoms: Bayes Theorem and the analytic network process, *Operations Research*, 1998, 46 (4):491–502.

[30] Zadeh L. A. Fuzzy sets information control, 1965.

[31] Zuzeng Peng and Weiyu Sun, Fuzzy mathematics and its application, Wuhan University Press, 2003.

[32] Jinyin Liu and Mengda Wu, Fuzzy theory and its application, National University of Defense Technology Press, 2000.

[33] Julong Deng and Hong Guo, Grey forecast theory and its application, 1997.

[34] YanruHao, Theory of Markov chain, market share analysis and forecast, 2000.

[35] J.A. Whittaker and J. H. Poore, Markov analysis of software specification, ACM *Transactions on Software Engineering and Methodology*, 1993, 2 (1): 93–106.

[36] Pawlak Z., Rough set theoretical aspects of reasoning about data, 1991.

[37] Lijun Xiong and Longfei Xu, Rough set theory and its application development, *Journal of Jinan University (Natural Science Version)*, 2003,24(3):70–75.

[38] Pawlak, Z. Rough sets decision algorithms and Bays' theory. *European Journal of Operational Research*, 2002,136(1):181–189.

[39] H.D. Landahl, W.S. Mcculloch, and W. Pitts, A statistical consequence of the logical calculus of nervous nets. *Bulletin of Mathematical Biology*, 1943, 5(4):135–137.

[40] Warren McCulloch and Walter Pitts. A logical calculus of the ideas Immanent in nervous activity, 1986.

[41] Zongli Jiang. Introduction of artificial neural network, 2001.

[42] Beamon B.M. Measuring supply chain performance. *International Journal of operations and Production Management*, 1999, 19, 275–292.

[43] Chen K. *Research and Practice of the models of supply chain performance in manufacturing industry*, PhD thesis, Tianjin University, 2009.

[44] Bolch, G., Greine, S., Meer, H.D, et al. *Queuing Networks and Markov Chains Modeling and Performance Evaluation with Computer Science Applications*, 2nd Edition. A John Wiley&Sons, Inc., 2006.

[45] Yi, K G. KPI assessment: study of implication, workflow and counter measures. *Technological Economy*, 2005, 1, 48–49.

[46] Chai N, Hu Y C. The performance evaluation of public organizations based on fuzzy AHP (analytic hierarchy process). *Technological Economy*, 2005, 12, 93–95.

[47] Boxwell, R. *Benchmarking for Competitive Advantage*. New York: McGraw-Hill. 1994.

[48] Vincent, J F V and Bogatyrev, N. et al. Biomimetics: its practice and theory. *J. R. Soc. Interface* 2006, 3, 471–482.

[49] Ren L. Progress in the bionic study on anti-adhesion and resistance reduction of terrainmachines. *Science in China Series E: Technological Sciences*, 2009, 52, 273–284.

[50] Richardson, P. *Fitness for the future: applying biomimetics to business strategy*, PhD Thesis, Bath University, 2010.

[51] Li, Y. Application of GA and SVM to the performance evaluation of supply chain. *Journal of Computer Engineering and Application*, 2010, 46, 246–248.

[52] Shi, C. D., Chen, J. H., and Hu, J., Study of supply chain performances using rough sets and neural network, *Computer Engineering and Application*, 2007, 43, 203–245.

[53] Xi, Y. F., Wang C, and Nie X X. Study of the evaluation methods of supply chain performances using fuzzy neural network, *Information Journal*, 2007, 9, 77–79.

[54] Wen, P. N., Zhang, Z. Y., and Luo B. Prediction and analysis of material flow in Beijing using BP neural network, *Technology and Methods*, 2009, 6, 91–93.

[55] Wu, X Z, Zhou H, and Liang C H. Optimisation of multi-layer supply chains using particle swarm optimisation algorithm, *Computer integrated manufacturing systems*, 2010, 16, 127–132.

[56] Zhao, X. and Dian, J., Analysis of the current situations of methods for evaluating supply chain performance. *Business Research*, 2005, 2, 60–62.

[57] Lummus, R.R. and Vokurka, R.J., Strategic supply chain planning. *Production and Inventory Management Journal*,1998, 39, 49–58.

[58] Farris, P.W., Bendle, N. T., Pfeifer, P. E., and Reibstein D. J. *Marketing Metrics: The Definitive Guide to Measuring Marketing Performance.* Upper Saddle River, New Jersey: Pearson Education, Inc, 2010|accessdate= requires |url= (help).

[59] Kaplan, R. S. and Norton, D. P. Using the balanced scorecard as a strategic management system. *Harvard Business Review*, 2007, July ,75–85.

[60] Wong, W. P. A review on benchmarking of supply chain performance measures. *Benchmarking*, 2008, 15, 25–51.

[61] Akkermans, H. and Orschot, K.V. Developing a balanced scorecard with system dynamics. *Proceedings of 20th International System Dynamics Conference*, July 28–August 1, 2002, Palermo, Italy, 2002.

[62] Fan, X., Zhang, S., Hapeshi, K., and Yang, Y., Evaluation of the performances of supply chains using 5DBSC LM-BP neural network bionic algorithm, *Journal of Bionics Engineering*, 2013, Vol.10, pp. 383–395.

[63] Dorigo, M. *Optimization, learning and natural algorithms*. PhD Thesis, Politecnico di Milano, Italy, 1992 (In Italian).

[64] Martens, D., Backer, M. De, Haesen, R., Vanthienen, J., Snoeck, M., and Baesens, B., Classification with ant colony optimization. *IEEE Transactions on Evolutionary Computation*, 2007, 11,651–665.

[65] Seeley, T D. *The Wisdom of the hive: the social physiology of honey bee colonies*, Harvard University Press, Cambridge, 1996.

[66] Cha, S. H. and Tappert, C. C. A genetic algorithm for constructing compact binary decision trees. *Journal of Pattern Recognition Research*, 2009, 4, 1–13.

[67] Yang, X. S., Firefly algorithms for multimodal optimization. Stochastic algorithms: foundations and applications, *Lecture Notes in Computer Sciences*, 2009, 5792, 169–178.

[68] Fukushima, K., Neocognitron: A self-organizing neural network model for a mechanism of pattern recognition unaffected by shift in position. *Biological Cybernetics*, 1980, 36, 93–202.

[69] Hinton, G. E., Osindero, S. and Teh, Y. A fast learning algorithm for deep belief nets. *Neural Computation*, 2006, 18, 1527–1554.

[70] Mcculloch, W. and Pitts, W., A logical calculus of the ideas immanent in nervous activity. *Bulletin of Mathematical Biophysics*, 1943, 5, 115–133.

[71] Fogel, L. J., Evolutionary programming in perspective: the top-down view. In *Computational Intelligence: Imitating Life*, 1994—Piscataway, NJ: IEEE Press, 135–146.

[72] Shi, Y. H. and Eberhart, R. C. Empirical study of particle swarm optimization. *Proceedings of the 1999 Congress on Evolutionary Computation*, 06–09 July, 1999, Washington DC, USA.

[73] Zandieh, M., Ghomi, F. and Husseini, M., An immune algorithm approach to hybrid flow shops scheduling with sequence-dependent setup times, *Applied Mathematics and Computation*, 2006, 189, 111–127.

[74] Zhang, F. M., Cao, Q. K., and Fang Q. Y., A comparative inquiry into supply chain performance. *The Proceedings of International Conference on Management Science & Engineering*, 10–12 Sept, Long Beach, USA, 2008.

[75] Yu, J. M., *GA and its application to design of supply network*. Dissertation, South China University of Science and Technology South China University of Technology, 2011.

[76] Gabbert, P. S. A system for learning routes and schedules with genetic algorithms. In: ICGA 1991,1991:430–436.

[77] Liu, C., *Modelling and theoretical design of the optimisation of supply networks*, Dissertation, Changsha Central South University, 2006.

[78] Pawlak, Z., Rough sets decision algorithms and Bays' theory. *European Journal of Operational Research*, 2002, 136, 181–189.

[79] Liu, Y. Z. and Xuan, H. Y. ACA and its application to vehicle routine problems, *Information and Control*, 2004, 33, 249–252.

[80] Li, J. J. *Study of theory of ecological chain of enterprises*, Dissertation, Jilin University, 2011.

[81] Sabelis, M. W., Odiekmann, O., and Jansen, V. A. A. Metapopulation persistence despite local extinction: predator-prey patch models of the Lotka-Volterra type, *Biological Journal of the Linnean Society*, 1991, 42, 267–283.

[82] Li, X. F. and Liu, G. Z.The modification and application of artificial neural network BP algorithm. *Journal of Sichuan University (Engineering Edition)*, 2000, 32, 105–109.

[83] Huang, J. Y. and H J Z. BP network and its application in SCM performance evaluation. *Shang Management Science*, 2006, 6, 75–57.

[84] Rumelhart, D. E., Hinton, G. E., and Williams, R. J. (8 October 1986). Learning representations by back-propagating errors. *Nature*, 1986, 323, 533–536.

[85] Masters T. *Advanced Algorithms for Neural Networks: a C11 Sourcebook*, Wiley, New York, USA, 1995.

[86] Hornik, K. M., Stinch, M., and White, H. Multilayer feedforward networks are universal approximators. *Neural Networks*, 1989, 2,359–366.

Chapter 8

Modeling Sustainable Supply Chain Management as a Complex Adaptive System: The Emergence of Cooperation

Aida Huerta Barrientos and Idalia Flores de la Mota

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/62534

Abstract

The aim of this chapter is to characterize sustainable supply chain management as a complex adaptive system (CAS) and develop an evolutionary game theory-based model to understand how cooperation emerges from interactions among companies to adopt sustainable management practices. We consider two interacting populations 1 and 2, each one with heterogeneous companies belonging to the same supply chain. One population is expected to behave cooperatively in adopting sustainable management practices while the other is expected to behave uncooperatively. The mathematical model we propose is game-dynamical replicator equations for multiple populations in the prisoner ´s dilemma (PD) game and we implement it using NetLogo software. The proportion of cooperative companies in each population that adopt sustainable management practices evolves positively over time as companies only imitate the adoption of sustainable management practices in their own population and in the populations of their partners when the benefit obtained by cooperating is maximum. The spatial patterns observed help us to clarify the preconditions for the emergence of cooperation among companies in managing material, information and capital flows in a sustainable way. Finally, our simulation results show that the sustainable management of supply chains needs to be studied as CASs, in order to take into account the social side of sustainability.

Keywords: Sustainable supply chain management, complex adaptive systems, cooperation, modeling and simulation, evolutionary game

1. Introduction

The 2030 Agenda for Sustainable Development of the United Nations [1] is an action plan for people, planet and prosperity that consists of 17 sustainable development goals, namely: 1) no poverty, 2) zero hunger, 3) good health and well-being, 4) inclusive and equitable quality education, 5) gender equality, 6) clean water and sanitation, 7) affordable and clean energy, 8) sustainable economic growth, full and productive employment and decent work for all, 9) building resilient infrastructure, 10) reducing inequality, 11) making cities sustainable, 12) ensuring sustainable consumption and production patterns, 13) taking urgent action to combat climate change, 14) conservation and sustainably use marine resources, 15) protecting, restoring and encouraging the sustainable use of land ecosystems, 16) promoting peace and inclusive societies for sustainable development, and, last but not least, 17) strengthening the means of implementing and revitalizing the Global Partnership for Sustainable Development. Furthermore, in recent years, consumers and legislation have been pressing companies to address the issue of sustainable development in their operations, converting this into an important and challenging task in the new business world [2, 3].

The integration of sustainability into supply chains is a critical next step in achieving sustainable development, as supply chains consider the product from the moment when the raw materials are first processed until the product is delivered to the end-user. In this sense, sustainability must ensure issues and flows that extend beyond the core of supply chain management (SCM) [4]. SCM has traditionally been used to describe the planning and control of materials, information flows, and the logistics activities within a company as well as externally among companies [5]. However, the growing interest in SCM has led to numerous definitions being developed to describe it and to some characteristics of sustainability being incorporated into it, for example, the concept of sustainable supply chain management (SSCM). In the last ten years, a number of literature reviews have been published on SSCM [6–8], decision-support tools for SSCM [9, 10], SSCM practices [11, 12] and sustainable supply chain planning [13]. Interesting results are showed in Ref. 6 where a total of 12 definitions for SSCM were identified and its analysis showed that the characteristics of SCM that are most commonly addressed in the definitions were coordination focus and flow focus, while the sustainability characteristics that were explicitly addressed were the three dimensions of the triple bottom line of economic, environmental and social considerations, the stakeholders' focus and the long-term focus of business sustainability. From the systemic perspective, we propose that SSCM is a complex system made up by large numbers of adaptive companies at multiple scales that have adopted sustainable management practices and whose sustainability objectives are based on the three aspects of sustainable development: economic, environmental and social aspects. In this sense, the cooperative management of material, information and capital flows derived from customer and stakeholders' requirements emerges from the interaction among companies that acquire multiple sustainable strategies they need to survive in the greater macro environment.

SSCM research has mainly been qualitative, based on conceptual frameworks and empirical ones, using case studies and surveys [14]. A review of recent SSCM modeling shows that researchers have used deterministic approaches and integrated some environmental and sustainability aspects, while neglecting stochastic modeling techniques such as: considering social factors [14], equilibrium models and multi-criteria decision making. All these approaches lead to three main analytical subjects: an analytical hierarchy but without taking into account the social side of sustainability [15], an analytical network process and a life cycle analysis [16]. A hybrid methodology for the modeling and optimization of decision problems in SSCM is presented in Ref. 17. SSCM modeling is a young research area that needs more modeling-based research in order to fully integrate SSCM into business practice. To understand the complex dynamics of SSCM, it is not feasible to apply traditional modeling approaches because they do not take social aspects into account and cannot explain the emergence of cooperation and the dynamic evolution of modern supply chains. So, it is necessary to adopt the complex adaptive system (CAS) approach to achieve a new way of thinking in SCCM research.

CASs are systems where complex behavior emerges as a whole pattern in different scales and as the result of the non-linear interaction of large numbers of simple components, and the system is able to cooperate, adapt, learn and evolve, improving its performance over time. In addition, CASs demonstrate their resilience, their ability to experience external shock and respond to them by recovery and adaptation. In this sense, modern SCM is a collectively self-sustaining structure of functions and obligations that lives in a socio-economic-environmental world, exchanges signals, and survives or dies. CASs are distinguished by the extensive use of computer simulation as a research tool. Several scholars have studied supply chain problems based on a CAS approach and obtained results from their research [18–21]. In this chapter we present a study concerning the modeling of SSCM as a CAS. The aim of this chapter is to develop an evolutionary game theory-based model of SSCM to understand how cooperation emerges from interactions among companies in a supply chain in order to adopt sustainable management practices, taking into account the social side of sustainability. We propose game-dynamical replicator equations for multiple populations in the PD game for the mathematical model and implement it using NetLogo software. We find that sustainable management of supply chains based on a CAS approach really appreciates the interactions among companies in supply chains and the complex dynamics that they create, which can enhance the resilience of the SSCM as a whole when responding to the complex environment.

This chapter is organized as follows. We begin by reviewing the characteristics of a resilient SSCM in Section 2. The top-down and bottom-up modeling approaches and decision making in SSCM are presented in Section 3. We develop and implement the game-dynamical replicator equations for multiple populations in the PD game as the simulation model of SSCM using NetLogo software and then we analyze how cooperation emerges from interactions among companies in a supply chain to adopt sustainable management practices, in Section 4. Based on the simulation results, some proposals for sustainable, adaptive and cooperative management of supply chains are outlined in Section 5 and we give our conclusions in Section 6.

2. Toward a resilient SSCM

From the systemic perspective, the best ways for the SSCM to face future global challenges characterized by unpredictable socio-ecological-economic situations are by having the flexibility, through its systemic resilience, to adapt to new situations, absorb shocks and recover quickly.

2.1. Systemic resilience

In the past few years, resilience has been used significantly for governing and managing a transition toward sustainability [22]. As suggested by Walker and Salt [23], the key to ensuring a sustainable and resilient supply of the essential ecosystem services on which humanity depends on is by enhancing the resilience of socio-ecological systems, instead of optimizing isolated components of the system. So, in SSCM, diverse components such as companies, suppliers, stakeholders and consumers provide different options for responding to change and dealing with the uncertainty and the unforeseen caused by interactions with its complex environment, but the SSCM needs to respond in a coordinated and collaborative way. According to Carpenter et al. [24], systemic resilience has three defining characteristics that, when applied to SSCM, are as follows:

1. The amount of change a SSCM can experience and still remain within the same domain of attraction.
2. The degree to which SSCM is capable of self-organization.
3. The degree to which SSCM can build the capacity to learn and to adapt.

A SSCM is a network of many actors such as consumers, providers, producers, etc. that interact in parallel through the interchange of material, information and capital flows. From their interactions arise global patterns of self-organization that to some degree will enable the SSCM to be resilient due to the structure. It is important to note that the degree of self-organization of the SSCM´s companies is variable, unpredictable and an individual understanding of each particular consumer, provider or producer would not have been made it possible to predict it.

One tool for enhancing the resilience of SSCM could be adaptive management, increasing the collective capacity of stakeholders and companies of a SC to learn and adapt in a sustainable development context. The diversity of the components in the SSCM also permits them to compensate for the loss or failure of others by redundancy in their material, information and capital flows. Participation through the active engagement of all the relevant stakeholders of SC is considered fundamental for building the relationships needed to improve socio-ecological-economic resilience. As suggested in Ref. 25, collaboration, as a requirement for implementing sustainable management approaches, may contribute to inter-organizational dynamics by strengthening the knowledge absorption capacity, structuring solutions, and motivating activity around a commonly defined goal such as the sustainability of supply chains.

http://dx.doi.org/10.5772/62534

2.2. Modularization

The complexity of a SSCM is derived from the interchange of material, information and capital flows among companies that have adopted sustainable management practices in a complex environment. If there are a lot of strong interactions as a result of globalization and technological change, then the SSCM becomes vulnerable due to the presence of undesired cascade and side-effects. This means that the SSCM would not be able to recover well from disruptions and, in consequence, will not be sufficiently resilient to survive. In order to avoid a catastrophic situation and, following recommendations for a well-designed system, the SSCM needs to be designed in a hierarchical way of functional modules or units, taking into account dynamic and adaptive decoupling strategies between these modules to minimize the level of connectivity in order to prevent a cascade effect. Additionally, the interactions among companies could be modified as much as necessary to let new outcomes emerge such as, for example, cooperation among companies. In order to reduce the impact of dysfunctional links on the hierarchical structure of the SSCM, redundant interactions among companies and stakeholders with a lower level of connectivity need to be implemented. This means that one strategy to be implemented by the SSCM in order to survive being resilient is for it to operate in a modular way with a low level of connection between modules. In the next section, we present the top-down and bottom-up modeling approaches and decision making in SSCM to understand how the emergence of resilience of a SSCM from interrelations among companies can be modeled.

3. Top-down versus bottom-up decision making and modeling approaches

On the one hand, when studying CASs, it is necessary to develop models that represent the real system through abstractions of the aspects of interest based on macro and micro perspectives. For this, we start to develop a system model from a top-down perspective that considers the system as a whole at macro level. Then, when the bottom is reached, the bottom-up deduction is used but guided by the top-down view, at micro level. On the other hand, the decision-making process in the SSCM has been traditionally based on the top-down approach. It means that leader companies exert their command and control power in a centralized way but limiting the adaptation of local companies and canceling the collective intelligence of the SSCM. This traditional decision-making process is not sufficient for modern SSCM, which is characterized by unpredictable situations that demand the adaptation and learning of local companies.

3.1. Top-down approach

In order to model a real CAS, it is necessary to observe the system structures at macro level. The top-down approach is a holistic perspective provided by synthetic microanalysis, in which experiments are performed to find natural emergent properties and delineate macroscopic phenomena with systemic concepts [26]. It represents the first approximation to the real system. Top-down decision making (see **Figure 1**) works very well in SSCMs that are simple and deterministic, not complex. In this case, the SSCM can be considered predictable, with low variability and centralized control, so its performance can be enhanced. At macro level, the decision time is more important than the consensus between the constituent parts. A SSCM that is controlled from the top-down is vulnerable due to the concentration of power that makes it easily corruptible [27] in the exchange of information, material and capital. So, the top-down approach needs to be complemented by the bottom-up approach in order to enhance the resilience in a SSCM for increasing the collective capacity of companies and stakeholders to learn and adapt in a sustainable development context.

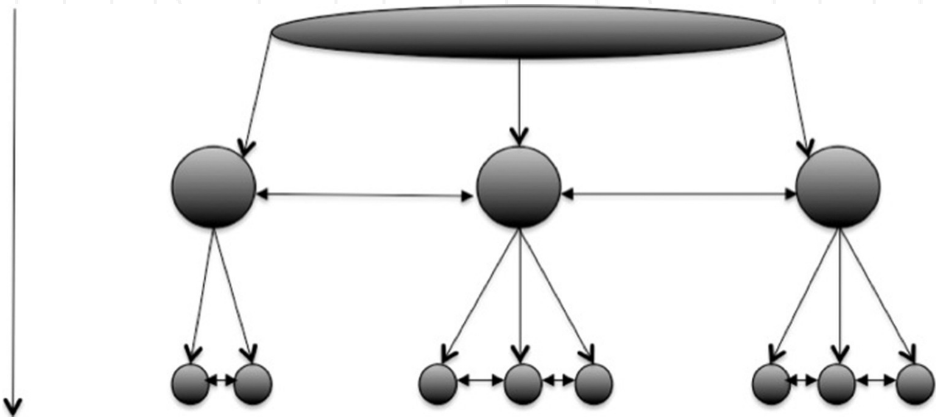


Figure 1. Diagram of the top-down approach, the flow of information, materials and capital is represented by arrows.

3.2. Bottom-up approach

Once the system structures have been observed based on the top-down perspective and the bottom has been reached, we need to analyze them in terms of the laws of their constituent parts combined with suitable idealization and approximation [26] at the micro level. The bottom-up approach is a deductive perspective, in which experiments are performed to find natural emergent properties at certain levels as a result of the interactions between the constituent parts.

Bottom-up decision making (see **Figure 2**) works very well in SSCM with coordination mechanisms that support flexibility, local adaptations, creativity and diversity. In this case, the power is decentralized, and both the companies and stakeholders in the SSCM are empowered and self-organized according to their interrelations, based on their own sustainability objectives, enabling the sustainable collective intelligence to be more resilient.

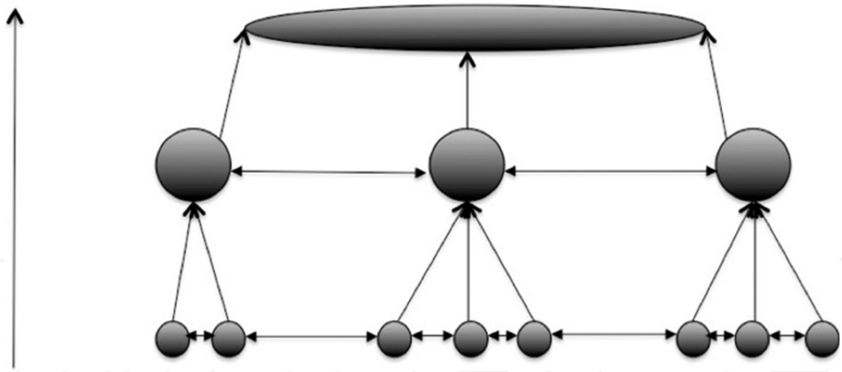


Figure 2. Diagram of bottom-up approach, the flow of information, materials and capital is represented by arrows.

3.3. Synthetic microanalysis

Synthetic microanalysis (see **Figure 3**) still combines the top-down and bottom-up perspectives, uniting without reducing. Based on synthetic microanalysis, system and constituents' views, each confirmed by experiments, we are able to find out about the approximations, idealizations, and possible contingent factors required for connecting them [26]. The main purpose of synthetic microanalysis is to use the net of macro concepts to obtain the feedback of the micro information relevant to the explanation of system's emergent properties.

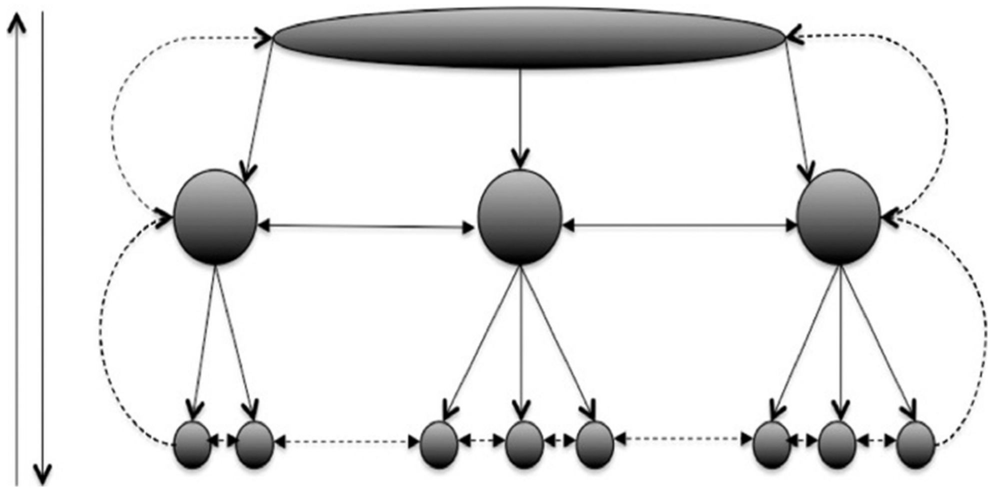


Figure 3. Diagram of synthetic microanalysis.

In the next section, we propose game-dynamical replicator equations for multiple populations in the PD game as the SSCM model, using the bottom-up approach. Then we implement it in a computer using NetLogo software. From the computer simulation results, we analyze how cooperation emerges from interactions among companies in a supply chain for the adoption of sustainable management practices that could, in some sense, favor the resilience of the SSCM.

4. Modeling and simulation of SSCM as a CAS at the level of companies

By modeling the SSCM as a CAS, we can study its ability to reorganize its constituent adaptive companies at multiple scales so that it can face the problems posed by its macro environment. In a world of selfish companies, from their interactions, cooperation could emerge as a way of achieving sustainability in their management. We observe that, in the literature, in order to gain a better understanding of factors promoting cooperation among individuals, biologists, economists, social scientists, mathematicians and physicists have intensively studied game theoretical problems such as Prisioner´s dilema game, snowdrift game, and public goods game [28].

Game theory was developed by John von Neumann in 1928 and discussed in Ref. 29 as a theory of "games of strategy" to provide a new approach to a number of economic questions. Game theory assumes that a fraction of people known as cooperators interacts with another fraction known as non-cooperators. Therefore, a large amount of research has focused on how cooperation can be supported by mechanisms such as repeated interactions; reputation; clusters of cooperative individuals; costly punishment; success-driven migration [30, 31]. But, the problem of cooperation among groups with different preferences such as the SSCM (e.g. suppliers, manufacturers and retailers with different sustainable goals in the three dimensions: economic, environmental and social) is a young research area that needs attention.

For example, in a SSCM, suppliers and manufacturers appear to practice different sustainable management but they interact with each other on a daily basis interchanging material, information and capital flows, not necessarily in a sustainable way. In this sense, it is important to see whether it is possible to identify preconditions for cooperation among companies that belong to the same supply chain, in order to adopt sustainable management practices without being controlled by a central authority. To answer this research question, we model cooperation in an evolutionary game-theoretical way. Evolutionary game theory goes back to John Maynard Smith [32, 33] who adopted the methods proposed by von Neumann to the context of biological natural selection. Evolutionary game theory studies the strategies of populations of agents who repeatedly engage in strategic interactions. The evolution of behavior of populations is represented by the so-called replicator dynamic introduced by Taylor and Jonker [34, 35]. In this situation, when two populations characterized by the "strategies" or "behaviors" i and j states interact with each other, game theory formalizes the

http://dx.doi.org/10.5772/62534

result according to payoffs P_{ij}, and the structure of the payoff matrix (P_{ij}) determines the kind of game [36].

According to Helbing and Lozano [36], the replicator equation is as follows:

$$\frac{dp(i,t)}{dt} = p(i,t)\left[\sum_j P_{ij}\, p(j,t) - \sum_{j,l} p(l,t) P_{lj}\, p(j,t)\right] \quad (1)$$

where the relative frequency of behavior i of populations is represented by $p(i, t)$, which increases when the expected success $F_i = \sum_j P_{ij}\, p(j, t)$ exceeds the average, $\sum_i F_i\, p(i, t)$.

4.1. The model

In this study, we consider the PD game that is an abstract formulation of some very common and very interesting situations [30], in which what is best for each company individually leads to mutual defection, when every company would have been better off with mutual cooperation. We propose game-dynamical replicator equations for multiple populations to describe the evolution in time of the proportions $p(t)$ and $q(t)$ of cooperative companies in populations 1 and 2 of the same supply chain. In the model, we assume that companies in population 1 prefer to adopt sustainable management practices in their operations while companies in population 2 operate based on unsustainable management practices, but the companies of populations 1 and 2 interact in a daily basis interchanging material, information and capital flows. Our study is carried out for 2*2 game, which contains four payoffs: T (temptation) to behave noncooperative, R (reward) for mutual cooperation, P (punishment) for mutual noncooperative behavior and S (Sucker´s payoff) for a cooperative individual meeting an uncooperative one.

According to Helbing et al [37], the game-dynamical replicator equations for two populations are as follows:

$$\frac{dp(t)}{dt} = p(t)\left[1 - p(t)\right] F\left(p(t), q(t)\right) \quad (2)$$

$$\frac{dq(t)}{dt} = q(t)\left[1 - q(t)\right] G\left(p(t), q(t)\right) \quad (3)$$

where the functions $F(p(t), q(t))$ and $G(p(t), q(t))$ reflect the interactions among companies in and out of populations 1 and 2, respectively.

In this study, the model was developed using agent-based modeling methodology and implemented using NetLogo software. This software is still the most widely used agent-based modeling language [38]. The agents represent the companies and they are grouped in two populations according to whether or not they prefer to adopt sustainable management practices. We propose six parameters in the model: the number of groups of companies in the supply chain (NG), the number of companies in each group (NC), the cost (C) and the benefit (B) of cooperation in adopting sustainable management practices. Companies only derive benefit if other companies in their group cooperate, and companies always pay the cost of cooperating with others in adopting sustainable management practices because they need to implement them in their daily operations. The probability of one company that has adopted sustainable management meeting another company in the same situation (P_a) and the probability of one company that has adopted sustainable management in their operations meeting another company that has not adopted it yet (P_b), as showed in **Table 1**.

Parameter	Minimum	Maximum
Groups of companies in the supply chain (NG)	10	50
Companies in each group (NC)	10	20
Cost (C) of cooperation in adopting sustainable management practices	1	5
Benefit (B) of cooperation in adopting sustainable management practices	1	10
Probability of one company that has adopted sustainable management meeting another company in the same situation (P_a)	50%	100%
Probability of one company that has adopted sustainable management in their operations meeting another company that has not yet adopted it (P_b)	50%	100%

Table 1. Parameters for simulating the interaction among companies in adopting sustainable management practices

We ran the computer simulation in NetLogo software in 50 steps considering the variation of the six parameters, NG, NC, C, B, P_A and P_B listed in **Table 1**, to find out under what conditions cooperation in adopting sustainable management practices emerges in a supply chain, given that companies are self-interested. We proposed four simulation scenarios so we ran each one in 50 time steps. In this sense, the simulation run finishes when the 50 time steps are achieved. The computer simulation results are presented and analyzed in Sections 4.2 and 4.3.

4.2. Results

In the first simulation scenario, we fixed the B, C, P_a and P_b parameters in their minimum values while the NG and NC parameters varied between their minimum and maximum values. The evolution of dynamics in the timeline is showed in **Figures 4** and **5**.

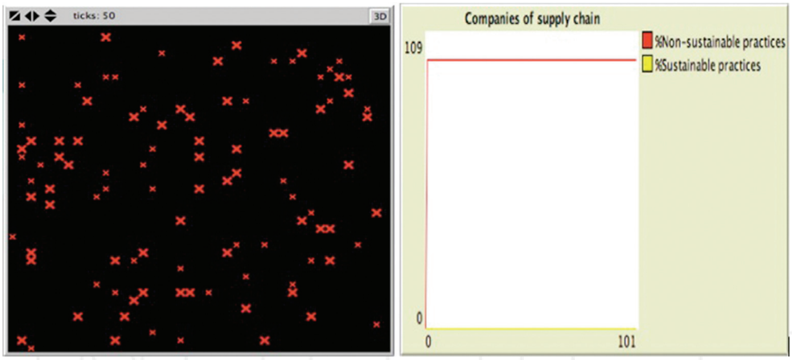


Figure 4. Snapshot of the computer simulation, showing the representative dynamics of the interactions among the companies in a supply chain in respect of adopting sustainable management practices updated on a 20 X 20 lattice for NG and NC minimum (100 companies).

In **Figure 4**, we observe that the effect of 10 groups and 10 companies in each group on the interactions between the companies that have adopted sustainable practices and those that have not yet adopted them is that in the long term all the companies decide not to adopt sustainable practices. In this case, the cost and benefit of cooperation in adopting sustainable practices remains unchanged, at its minimum value.

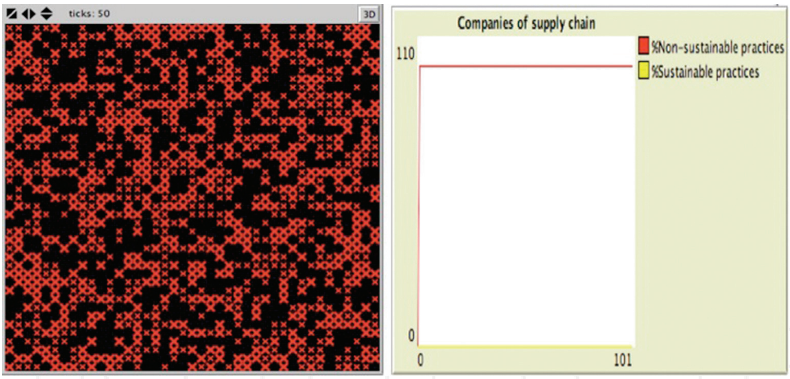


Figure 5. Snapshot of the computer simulation, showing the representative dynamics of interactions among companies in supply chain in respect of adopting sustainable management practices updated on a 20 X 20 lattice for NG and NC minimum (100 companies).

In **Figure 5**, we observe that the effect of 50 groups and 20 companies in each group on the interactions between the companies that have adopted sustainable practices and those that have not yet adopted them is that in the long term all the companies decide not to adopt sustainable practices, as in the case showed in **Figure 4**. In this case, the cost and benefit of cooperation in adopting sustainable practices remain unchanged, at its minimum value.

In the second simulation scenario, we fixed the B, C, NG and NC parameters at their minimum value while the P_a and P_b parameters were varied to its maximum value. The evolution of dynamics in the timeline is showed in **Figures 6** and **7**.

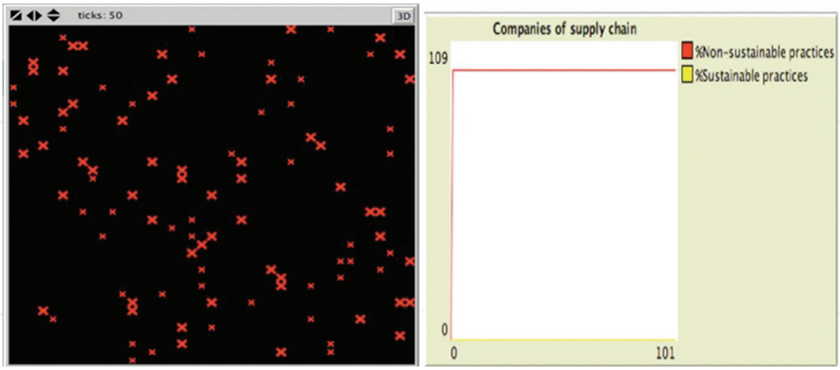


Figure 6. Snapshot of the computer simulation, showing the representative dynamics of the interactions among the companies in a supply chain in respect of adopting sustainable management practices updating on a 20 X 20 lattice for P_a maximum and P_b minimum (100 companies).

In **Figure 6**, we observe that the effect of the probabilities of one company that has adopted sustainable management meeting another company in the same situation (50%) or meeting another that has not adopted it (50%) on the interactions between all the companies is that, in the long term, all the companies decide not to adopt sustainable practices. In this case, the cost and benefit of cooperation in adopting sustainable practices as well as the size of groups of companies remain unchanged, at its minimum value.

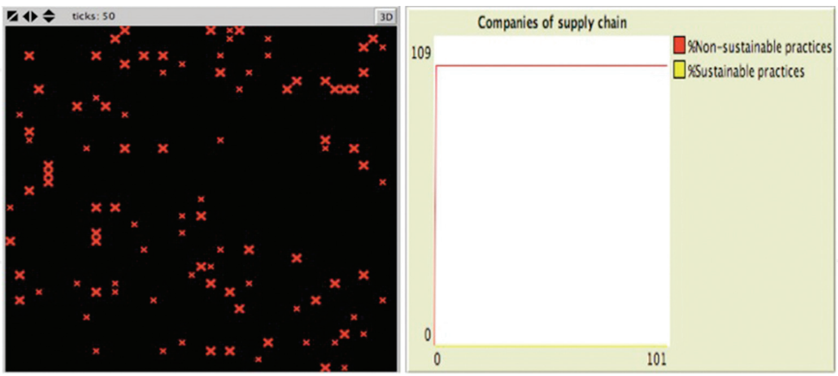


Figure 7. Snapshot of the computer simulation, showing the representative dynamics of interactions among companies in supply chain in respect of adopting sustainable management practices updating on a 20 X 20 lattice for P_a minimum and P_b maximum (100 companies).

http://dx.doi.org/10.5772/62534

In **Figure 7**, we observe that the effect of the probabilities of one company that has adopted sustainable management meeting another company in the same situation (100%) or meeting another that has not adopted it (100%) on the interactions between all the companies is that in the long term all the companies decide not to adopt sustainable practices. In this case, the cost and benefit of cooperation in adopting sustainable practices as well as the size of groups of companies remain unchanged, at its minimum value as showed in **Figure 6**.

In the third simulation scenario, we fixed the C, NG, NC, P_a and P_b parameters at their minimum values while the B parameter was set up to its maximum value. The evolution of dynamics in the timeline is showed in **Figure 8**.

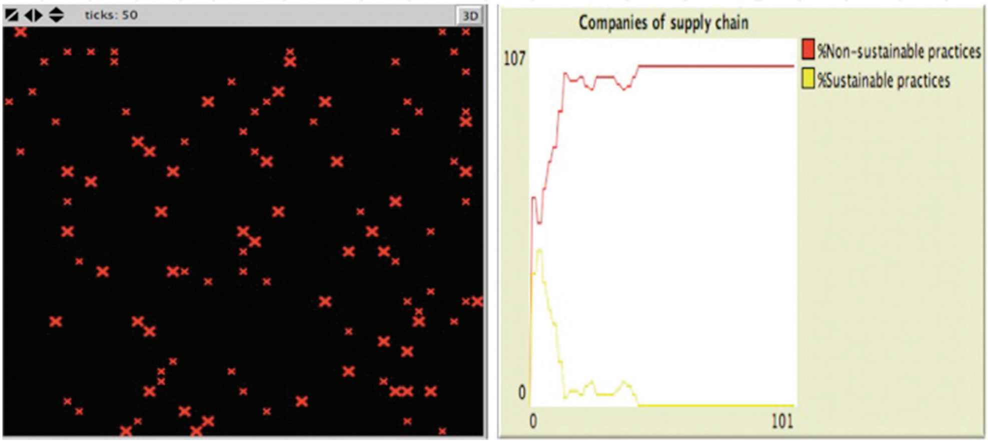


Figure 8. Snapshot of the computer simulation, showing the representative dynamics of interactions among companies in supply chain in respect of adopting sustainable management practices updating on a 20 X 20 lattice for B maximum value and C, NG, NC, P_a and P_b parameters in its minimum value (100 companies).

In **Figure 8**, we observe that the effect of the benefits of adopting sustainable practices at their maximum value on the interactions between all the companies is that in the short term all the companies decide to adopt sustainable practices but in the long term they decide to cancel the adoption of the said practices. In this case, the cost, the size of groups, and the probabilities of interacting with other companies in the same situation remain unchanged, at their minimum value.

Finally, in the fourth simulation scenario we fixed the C, NG, NC and P_b parameters at their minimum value, while the B and P_a parameters were set up at their maximum value. The evolution of dynamics in the timeline is showed in **Figure 9**.

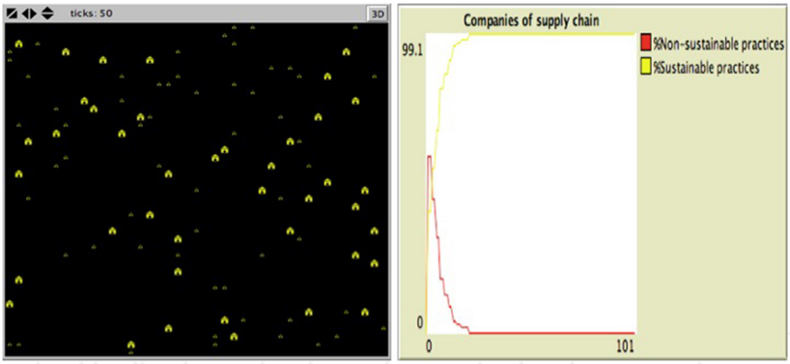


Figure 9. Snapshot of the computer simulation, showing the representative dynamics of interactions among companies in supply chain in respect of adopting sustainable management practices updating on a 20 X 20 lattice for B and P_a parameters in its maximum value while C, NG, NC and P_b parameters in its minimum value (100 companies).

In **Figure 9**, we observe that the effect in adopting sustainable practices at its maximum value and the probability of companies that have adopted sustainable practices meeting another company in the same situation at 100% on the interactions between all the companies is that in the short term, in fact immediately they start to interact, all the companies decide to adopt sustainable practices. In the long term, they do not change their decision. In this case, the cost, the size of groups and the probabilities of interacting with other companies in the same situation remain unchanged, at their minimum value.

4.3. The challenge of cooperation among companies in adopting sustainable management practices

From the simulation results, we observe that the proportion of cooperative companies of each population adopting sustainable management practices evolves positively in time as companies imitate the adoption of sustainable management practices in their own population and in the populations of their partners just when the benefits are maximum, as showed in the fourth scenario. In this sense, two preconditions are necessary for companies in a supply chain to cooperate in adopting sustainable management practices, as follows:

1. Interaction with companies that have adopted these kinds of practices in their operations and management.

2. Explicit knowledge of the benefits of operating in a sustainable way.

For the first point, companies are responsible for looking for partners that have a good reputation for practicing sustainable management in a supply chain, technology can help them. This precondition operates in the bottom-up decision-making approach. For the second point, associations, institutions as well as governments need to enhance the benefits of adopting sustainable management practices in order to be attractive for companies. This precondition operates in the top-down decision-making approach. It is clear that companies will not adopt sustainable practices by just interacting with companies that operate in a sustainable way, by

http://dx.doi.org/10.5772/62534

incrementing the size of a group of partners or by dismissing the cost of sustainable operation, as showed in the first, second and third scenarios. Based on our results, in the next section we give some proposals for the sustainable, adaptive and cooperative management of supply chains.

5. How to manage supply chains in sustainable, adaptive and cooperative way: some proposals

The sustainable management of a supply chain requires companies that are able to adapt to new interactions with others companies, maximizing the benefits of managing the material, information and capital flows in a sustainable way. Here, we propose some actions that, from our simulation results, we consider could enhance the sustainable management of supply chains:

1. Improving resilience in SSCM.
2. Building a reputation among companies in promoting sustainable management practices.
3. Balancing top-down and bottom-up decision making in supply chains.
4. Using information systems (ISs) to compensate best sustainable management practices.
5. Giving people cooperative and adaptive management skills.

5.1. Improving resilience in SSCM

Stakeholders and companies must increase their ability to learn to adapt in a sustainable development context. The cooperation and participation through the active engagement of all relevant stakeholders of SC are considered fundamental to building the relationships needed to improve socio-ecological-economic resilience through interactions that maximize the benefit for companies in terms of sustainability. On the one hand, if a SSCM is controlled from the top-down, then it will become vulnerable and, in consequence, the concentration of power in companies will make them easily corruptible. On the other hand, as our simulation results show, cooperation in the sustainable management of material, information and capital flows emerges from the bottom-up as a result of self-organization among companies that perceive the benefits of interacting with companies that have adopted sustainability practices. In this case, the structure of the SSCM is adjusted by the emergent interrelations enabling the SSCM to face an unpredictable environment.

5.2. Building a reputation in SSCM to promote the adoption of sustainable management practices

The companies in a SC need to build its reputation of their own business based on multiple sustainability criteria in the three aspects of sustainable development, i.e., economic, environmental and social aspects. Green innovations [39] as well as reputation can advantage the formation of new interactions between companies that have adopted sustainable management practices in their business and other companies that have not yet adopted such practices. On the one hand, based on our simulation results, we observed that companies only imitate the adoption of sustainable management practices in their own population and in the populations of their partners when the benefits are maximum and when they interact with others that have adopted these practices. On the other hand, indirect reciprocity [40] *give and you shall receive* is built on reputation and can sustain high levels of cooperation [41] for adopting sustainable practices. In this sense we propose that building a reputation for practicing sustainability principles can be a path for other companies to follow. So, government and institutions need to recognize and increase the benefits for prestigious companies in adopting the best sustainability principles and practices as their strategy, in order to contribute to their motivation for maintaining their reputation as contributors for local and global sustainable development.

5.3. Top-down and bottom-up decision making in SSCM

As discussed in Section 3, the top-down approach needs to be complemented by the bottom-up approach in order to enhance the resilience in a SSCM for increasing the collective capacity of companies and stakeholders to learn and adapt in a sustainable development context.

5.4. Using information systems to compensate best sustainable management practices

As was demonstrated in our simulation results, the cooperation of companies in the adoption of sustainable management practices is a function of the benefits perceived by them. In this direction, a system of benefits supported by the IS needs to be developed.

It is important for administrators in the supply chain to understand the importance of sustainability, and how objectives can be brought into line to achieve these goals by using information technologies (ITs). They also need to know the difference between using ISs and ITs and how they can be adapted to achieve sustainability.

Using what is known as green IT and green IS has these main differences:

1. An IT transmits, processes, or stores information.
2. An IS is an integrated and cooperating set of software using ITs to support individual, group, organizational, or societal goals.

Green IT is mainly focused on energy efficiency and equipment utilization. It addresses issues such as

1. Designing energy efficient chips and disk drives.
2. Replacing personal computers with energy efficient thin clients.
3. Use of virtualization software to run multiple operating systems on one server.
4. Reducing the energy consumption of data centers.
5. Using renewable energy sources to power data centers.

http://dx.doi.org/10.5772/62534

6. Reducing electronic waste from obsolete computing equipment.

7. Promoting telecommuting and remote computer administration to reduce transportation emissions.

According to Watson et al [42], the use of IS refers to *the design and implementation of ISs that contribute to sustainable business processes*. This helps an organization to

1. Reduce transportation costs with a fleet management system and dynamic routing of vehicles to avoid traffic congestion and minimize energy consumption.

2. Support team work and meetings when employees are distributed throughout the world, and thus reduce the impact of air travel. IS can move remote working beyond telecommuting to include systems that support collaboration, group document management, cooperative knowledge management, and so forth.

3. Track environmental information (such as toxicity, energy used, water used, etc.) about the creation of products, their components, and the fulfillment of services.

4. Monitor a firm's operational emissions and waste products to manage them more effectively.

5. Provides information to consumers so that they can make green choices more conveniently and effectively.

Green IS has a greater potential than green IT because it tackles a much larger problem. It can make entire systems more sustainable compared to reducing the energy required to operate ITs.

Other authors give a definition of IS and again they focus the importance of it. For example, in the Melville's [43] study, it can be seen that: We thus define IS for environmental sustainability as IS-enabled organizational practices and processes that improve environmental and economic performance. We launch a new discourse on IS innovation for environmental sustainability by drawing upon the uniqueness of IS scholarship, which incorporates both behavioral science (search for truth) and design science (search for utility in designed artifacts) (Hevner et al. [44]). Finally, it is important to mention that IS is used in different ways depending on how the problem is framed. For example, if the problem is framed in economic terms, then IS may be viewed as a means by which energy productivity (quotient of output and amount of energy used) is increased. If the problem is viewed in ecological terms, then IS might be framed in terms of how online social networking reduces greenhouse gas emissions or how data centers increase greenhouse gas emissions. Another implication of complexity is the need for research methodologies that account for uncertainty and feedback, such as system dynamics by Sterman [45]. Altogether, the environmental sustainability research context is distinctive in scope, complexity, and urgency, requiring IS researchers to extend epistemological horizons [43].

5.5. Giving people cooperative and adaptive management skills

Problems involving ISs and environmental sustainability involve human behavior and the broader social, organizational, and environmental contexts. Review of the IS and operation literature and examination of other business literature reveal three classes of sustainability phenomena: (1) how cognitive states about sustainability (beliefs, opportunities, etc.) emerge; (2) actions of organizations and individuals regarding sustainability practices and processes; and (3) environmental and financial performance outcomes. Taken together, the three classes of phenomena comprise micro and macro issues. Coleman's [46] model of micro–macro relations provides the foundation for a conceptual framework, developed by Melville [43]. This framework called Belief–Action–Outcome (BAO) is summarized in **Figure 10**, and is explained in **Table 2**.

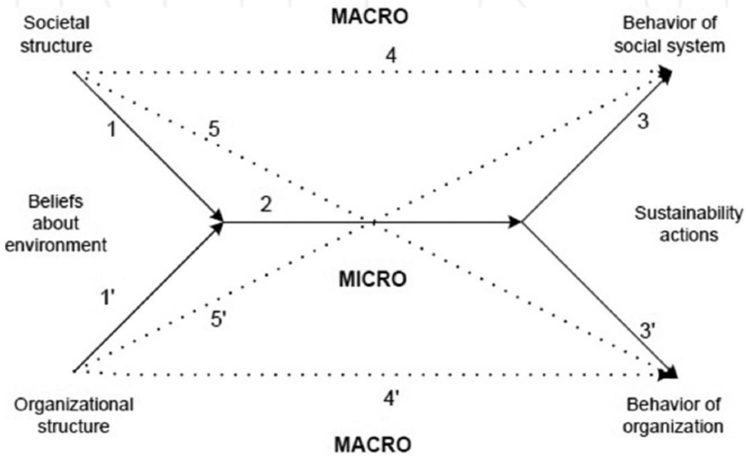


Figure 10. BAO framework for IS research and sustainability. Source: Ref. 43.

	Belief formations	Action formation	Outcome
Description	How psychic states (beliefs, desires, opportunities, etc.) about the natural environment are formed.	How psychic states about the natural environment translate to actions.	How sustainability actions affect social and organizational systems. How macro states affect behavior of society and organizations.
Analysis level	Macro–micro	Micro–micro	Micro–macro (links 3 and 3'). Macro–macro (How societal structure affects the behavior of social systems-link 4, how organizational structure affects the behavior of organzation-link 4', how societal structure affects the

http://dx.doi.org/10.5772/62534

	Belief formations	Action formation	Outcome
			behavior of organzation – link 5, and how organziational structure affects the behavior of social systems- link 5’).
Constructs	**Societal structure:** Cultural or normative patterns that define expectations of agents about each other’s behavior and that organize enduring interrelationships .† **Organizational structure:** Ways in which an organization divides its labor into distinct tasks and achieves coordination among them.‡ **Psychic state:** Beliefs, desires, opportunities, etc.	**Action:** Something done by an individual, such as adoption of an information system to improve organizational recycling or facilitate ride sharing.	**Behavior of society:** Functioning of society and natural environment (includes performance). Behavior of organization: Functioning of organization (includes performance).
Example studies	Integrated assessment using a designed information system changed individual beliefs about risks of climate change (Schlumpf et al. 2001).	Belief that reducing greenhouse gas emissions is critical to sustainability leads to adoption of social networking site encouraging energy conservation (Bottrill 2007).	IT investment in services and most manufacturing sectors increases electricity demand, with implications for greenhouse gas emissions (Cho et al. 2007).
Example theories	Contingency theory. Information processing theory. Media richness theory.	Game theory. Social cognitive theory. Technology acceptance model. Theory of planned behavior. Theory of reasoned action.	Absorptive capacity. Dynamic capability theory. Production theory. Resource-based theory. Systems’ theory.

† Adapted from 47
‡ See 48

Table 2. BAO framework terminology. Source: Ref. 43

Finally, the framework is consistent with the study of dynamic change processes as well as static cross-sectional analysis. For example, the adoption of an environmental management system (EMS) incorporating an online social network with the goal of engaging employees, improving environmental performance, and reducing costs might be viewed as an organizational change process involving belief formation (links 1, 1'), sustainability actions (link 2), and environmental (link 3) and organizational performance (link 3') outcomes. In contrast, a survey of organizational use of IS for sustainability and perceived environmental performance impacts might focus entirely on the macro–macro (link 5') [43].

6. Conclusions

Being able to visualize the sustainable supply chain as a complex adaptive system helps us to avoid making mistakes, such as over-simplifying the problem, and to treat it as a deterministic case. This approach allows us to consider all the seemingly insoluble problems as they arise. Thinking of a supply chain that is sustainable requires a lot of effort in terms of not only theory and a change of paradigms but also as a practical undertaking, because as Pagell and Shevchenko [49] point out we need to avoid having supply chains that are merely less unsustainable while, at the same time, not being truly sustainable. In this study, we proposed game-dynamical replicator equations for multiple populations to describe the evolution in time of the proportions $p(t)$ and $q(t)$ of cooperative companies in populations 1 and 2 of the same supply chain. In the model, we assumed that companies in population 1 prefer to adopt sustainable management practices in their operations while companies in population 2 operate based on unsustainable management practices, but the companies of populations 1 and 2 interact in a daily basis interchanging material, information and capital flows. From our simulation results, we observed that the total success of cooperation depends on the payoffs resulting from interactions with companies that have adopted sustainable management. We suggest that government and institutions need to recognize and increase the benefits for prestigious companies in adopting the best sustainability principles and practices as their strategy, in order to contribute to their motivation for maintaining their reputation as contributors for local and global sustainable development. We conclude that sustainable management of supply chains needs to be studied as CASs, in order to take into account the social side of sustainability. Finally, the combined use of game theory and simulation by agents using an approach of complex adaptive systems led us to have a series of opportune activities that can be improved and broadened as they are put into practice by different businesses with a commitment to sustainability. In the words of Pagell and Shevchenko "If we continue to conduct research that mainly focuses on how variations on existing practices impact the ability of unsustainable supply chains to become less unsustainable, then we will miss a critical opportunity to lead future practice and the development of a new supply chain model.

Author details

Aida Huerta Barrientos* and Idalia Flores de la Mota

*Address all correspondence to: aida.huerta@comunidad.unam.mx

Department of Operations Research, Faculty of Engineering, National Autonomous Mexico University, Mexico City, Mexico

References

[1] United Nations. Transforming our world: The 2030 Agenda for Sustainable Development (Resolution A/RES/70/1). 2015

[2] Amaeshi KM, Osuji OK, Nmodim P. Corporate social responsibility in supply chains of global brands: A boundaryless responsibility? Clarifications exceptions and implications. Journal of Business Ethics. 2008; 81; 223–234.

[3] Quariguasi J, Bloemhof-Ruwaard J. Designing and evaluating sustainable logistics networks. International Journal of Production Economics. 2008; 111; 195–208.

[4] Linto J, Klassen R, Jayaraman V. Sustainable supply chains: An introduction. Journal of Operations Management 2007; 25; 1075–1082.

[5] Cooper MC, Lambert DM, Pagh JD. Supply chain management: More than a new name for logistics. International Journal of Logistics Management 1997; 8; 1–13.

[6] Ahi P, Searcy C. A comparative literature analysis of definitions for green and sustainable supply chain management. Journal of Cleaner Production 2013; 52; 329–341.

[7] Carter RC, Rogers DS. A framework of sustainable supply chain management: Moving towards new theory. International Journal of Physical Distribution & Logistics Management 2008; 135; 360–387.

[8] Seuring S, Muller M. From a literature review to a conceptual framework for sustainable supply chain management. Journal of Cleaner Production 2008; 16; 1699–1710.

[9] Wu Z, Pagell M. Balancing priorities: Decision-making in sustainable supply chain management. Journal of Operations Management 2011; 29; 577–590.

[10] Taticchi P, Garengo P, Nudurupati S, Tonelli F, Pasqualino R. A review of decision-support tools and performance measurement and sustainable supply chain management. International Journal of Production Research 2015; 53; 6473–6494.

[11] Beske P, Land A, Seuring S. Sustainable supply chain management practices and dynamic capabilities in the food industry: A critical analysis of the literature. International Journal of Production Economics. 2014; 152; 131–143.

[12] Dües CM, Tan KH, Lim M. Green as the new Lean: How to use Lean practices as a catalyst to greening your supply chain. Journal of Cleaner Production 2013; 40; 93–100.

[13] Boukherroub T, Ruiz A, Guinet A, Fondrevelle J. An integrated approach for sustainable supply chain planning. Computers & Operations Research 2015; 54; 180–194.

[14] Brandenburg M, Rebs T. Sustainable supply chain management: A modelling perspective. Annals of Operations Research 2015; 229; 213–252.

[15] Seuring S. A review of modelling approaches for sustainable supply chain management. Decision Support Systems 2013; 54; 1513–1520.

[16] Brandenburg M, Govindan K, Sarkis J, Seuring S. Quantitative models for sustainable chain management: Developments and directions. European Journal of Operational Research 2014; 233; 299–312.

[17] Sitek P, Wikarek J. A hybrid framework for the modelling and optimisation of decision problems in sustainable supply chain management. International Journal of Production Research 2015; 53; 6611–6628.

[18] Choi T, Dooley K, Rungtusanatham M. Supply networks and complex adaptive systems: Control versus emergence. Journal of Operations Management 2001; 19; 351–366.

[19] Dunne J, Brose U, Williams R. Modeling food-web dynamics: Complexity-stability implications. 2004. Santa Fe Institute (SFI) working paper 2004-07-021.

[20] Bettencourta L, Cintrón-Arias A, Kaiser D, Castillo-Chávez C. The power of a good idea: Quantitative modelling of the spread of ideas from epidemiological models. Physica A 2006; 364; 513–536.

[21] Kimbrough S, Wu D, Zhong F. Computers play the beer game: Can artificial agents manage supply chains. Decision Support Systems 2002; 33; 323–333.

[22] Schianetz K, Kavanagh L. Sustainability indicators for tourism destinations: A complex adaptive systems approach using systemic indicator systems. Journal of Sustainable Tourism 2008; 16; 601–628.

[23] Walker B, Salt D. Resilience thinking: Sustaining ecosystems and people in a changing world. Washington, DC: Island Press. 2006. 192.

[24] Carpenter S, Walker B, Anderies JM, Abel N. From metaphor to measurement: Resilience of what to what? Ecosystems 2001; 4; 765–781.

[25] Hoof B, Thiell M. Collaboration capacity for sustainable supply chain management: Small and medium-sized enterprises in Mexico. Journal of Cleaner Production 2014; 67; 239–248.

[26] Auyang S. Foundations of complex-system. Theories in economics, evolutionary biology, and statistical physics. Cambridge: Cambridge University Press. 1999.

[27] Helbing D. The automation of society is next: How to survive the digital revolution. Version 1.0. 2015. DOI: 10.13140/RG.2.1.2681.1603.

[28] Helbing D, Jihansson A. Evolutionary dynamics of populations with conflicting interactions: Classification and analytical treatment considering asymmetry and power. Physical Review 2010; 81.

[29] von Neuman J, Morgenstern O. Theory of games and economic behaviour. Princeton: Princeton University. 1944.

[30] Axelrod R. The evolution of cooperation. New York: Basic Books, Inc., Publishers. 1984.

[31] Helbing D. Social Self-Organization, Understanding Complex Systems. Berlin: Springer-Verlag. 2012. DOI: 10.1007/978-3-642-24004-1_10.

[32] Maynard J. Game theory and the evolution of fighting. In On Evolution. Edinburgh: Edinburgh University Press. 1972.

[33] Maynard J, Price G. The logic of animal conflict. Nature 1973; 246; 15–18.

[34] Taylor P, Jonker L. Evolutionarily stable strategies and game dynamics. Mathematical Biosciences 1978; 40; 145–156.

[35] Schuster P, Sigmund K. Replicator dynamics. Journal of Theoretical Biology 1983; 100; 533–538.

[36] Helbing D, Lozano S. Phase transitions to cooperation in the prisoner´s dilemma. Physical Review E 2010; 81.

[37] Helbing D, Johansson A. Cooperation, norms, and revolutions: A unified game-theoretical approach. PLoS One 2010; 5. DOI: 10.1371/journal.pone.0012530.

[38] Wilensky U, Rand W. An introduction to agent-based modeling: Modeling natural, social, and engineered complex systems with NetLogo. Cambridge: MIT Press. 2015.

[39] Nair A, Yan T, Ro Y, Oke A, Chiles T, Lee S. How environmental innovations emerge and proliferate in supply networks: A complex adaptive systems perspective. Journal of Supply Chain Management 2016; 52.

[40] Alezander RD. The Biology of Moral Systems. New York: de Gruyter, 1987.

[41] Milinski M, Semmann D, Krambeck H. Reputation helps solve the ‘tragedy of the commons’. Nature 2002; 415; 424–426.

[42] Watson R (Ed.), Boudreau MC, Chen A, Huber M. Green IS. Building sustainable business practices. In Watson RT (Ed.), Information Systems: A Global Text, 2008, Athens, GA: Global Text Project, pp. 1–17.

[43] Melville N. Information systems innovation for environmental sustainability. MIS Quarterly. 2010; 34; No. 1; 1–21.

[44] Hevner A, March S, Park J. Design science in information systems research. MIS Quarterly. 2004; 28; No. 1; 75–105.

[45] Sterman JD. System dynamics modeling: tools for learning in a complex world. California Management Review. 2001; 43; No. 4, 8–28.

[46] Coleman JS. Foundations of Social Theory (2nd ed.). Cambridge, MA: Harvard University Press. 1994.

[47] Lopez J, Scott J. Social Structure. Buckingham, England: Open University Press. 2000.

[48] Mintzberg H. The Structuring of Organizations. Englewood Cliffs, NJ: Prentice–Hall. 1979.

[49] Pagell M, Shevchenko A. Why Research in Sustainable Supply Chain Management Should Have no Future. Journal of Supply Chain Management. 2014; 50;No.1, 44–55.

Chapter 9

Energy Chains Optimization for Selection of Sustainable Energy Supply

Srđan Vasković, Petar Gvero, Vlado Medaković and
Velid Halilović

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/62537

Abstract

The notion of energy chain concept has been defined as the trajectory of energy transformations from the fuel source or energy sources to useful energy form to end users. Production of fuels, heat and electricity from different sources is defined by the appropriate energy supply chain. Every single energy supply chain can be uniquely defined by several sustainability criteria. These criteria are: total energy efficiency of production, total exergy efficiency of overall chain, the coefficient of exergy quality for different products at energy chains, economy of production, investment and environmental criteria. Optimal energy supply chain can be chosen by using multicriteria optimization which fulfils the above-mentioned sustainability criteria. This selected energy chain is close to ideal solution. The ideal energy supply chain is formed from the set of energy production ways which are defined from the perspective of sustainability criteria and which have connection with the current status of technologies, economic, environmental parameters, etc. The concept of optimization in practice is usually based on economics until recently, often neglecting all the other consequences of such a decision. Therefore, multicriteria decision making (MCDM) improves the opportunities in assessing the optimal variant of energy chain for defined ranking criteria. Before the optimization process, it is necessary to create a mathematical model for calculation of optimization criteria. Also, for each specific case of energy production, it is necessary to develop appropriate mathematical formulas to describe the energy chain. Numerical verification, all mathematical calculations and modelling have been applied and confirmed on wood biomass supply chain for energy production in this case. The reason for this is complexity of supply chains in the bioenergy and representation of renewable energy sources. For total ranking of energy chain for production of fuel or energy and selection of optimum variant, the multicriteria optimization and VIKOR method were applied. The significance of energy production from renewable energy sources is particularly expressed nowadays. Basically, the most significant part in the process of energy production from energy sources is the supply chain, final conversion of energy in useful form at the energy plant and the distribution process to end users. Due to the fact that there are various opportunities for the composition of energy chains of fuel supply and different ways of energy production, it is necessary to try to make a unique mathematical approach for this problem. With the proposed sustainability criteria and developed mathematical model, it is possible to unify the overall problem of energy supply chains' optimization. The proposed developed method can be used for the optimization of any kind of energy supply chains (electricity, heat, fuels or their mix). All of these are enabled by proper selection criteria for the description of overall energy transformations in energy chains and quality evaluation of the energy produced. The developed approach and mathematical model have a very practical application in the selection of optimal variant of energy production and of course in designing new energy chains.

Keywords: energy supply chains, optimization, exergy, mathematical modelling, optimization criteria, biomass, bioenergy, renewable energy

1. Introduction

The process of energy and fuel production is closely related to sustainability. The use of fossil fuels causes harmful influences to the environment, while, on the other hand, the reserves of fossil fuels are limited. With the development of human civilizations, the needs for energy grow, which causes an accelerated consumption of fossil fuel reserves. The decrease of fossil fuel reserves and their harmful influences to the environment have forced the mankind to take the direction of the more intensive use of renewable energy sources as well. Observed from a thermodynamic aspect, for the analysis of an energy production process, it is necessary to evaluate the process both in terms of quantity and quality. For that reason, energy and exergy efficiencies of an energy production process were defined, and they have to be taken into account. The energy production chains can be defined in different ways, and in most cases the logistics of the fuel supply has a significant role. The selection of optimal variant of energy production presents a process that has to take into account a set of the most significant factors and criteria, which can be adequately used for the description of energy production chains. From the set of different energy production chains described by optimization criteria, it is possible to select the variant of energy production which is optimal for some particular case, based on the current state of development of energy production technology, economic and ecological parameters. The optimal variant of energy production selected in this way is not completely sustainable, but it presents a way and a path by which we get closer to a sustainable energy chain of energy production. It is obviously the best approach method for optimization of energy chains in the multicriteria decision making, which solves the selection problem of an optimal energy production. In this text, there is a description of multicriteria optimization application and the VIKOR method for the selection of optimal and sustainable energy supply process.

http://dx.doi.org/10.5772/62537

2. Concept of multicriteria decision making

Not long ago, the concept of optimization was based mostly on the economic criteria, while the other consequences of such a solution were often neglected.. It was thought that the increase in financial profit not only leads to the progress and general welfare of the society, but also to the satisfaction of all human needs. The accompanying effects of this concept, such as the deterioration of quality of water and air, and the pollution of environment in general, bad social influences, etc., undoubtedly indicate a wrong basis of such a model. Because of that, a new, still dominating, concept has been created, of the so-called sustainable development, that is, of such a development which is in harmony with the environment, corresponding to modern technical standards, economically and socially acceptable from the viewpoint of social disturbances that it may cause. So, such an approach enables the fulfilment of the present generation's needs, without disturbing the opportunity of other generations to meet their needs too. There is no unique and generally accepted definition of the notion of sustainable development. The most often stated definition of sustainable development is the one given by the United Nations World Commission on Environment and Development (the so-called Brundtland Commission) in its report with the title "Our Common Future". The definition is: "Sustainable development is the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs too." For that reason, the need for searching an optimal solution in many criteria has been created, thus initiating the appearance of a new branch in the field of optimization, that is, of optimal decision making—multicriteria optimization—as a tool for assistance in the process of multicriteria decision making (MCDM). In the United States, multicriteria analysis is also often called MCDM, and in Europe, it is called multicriteria decision aid (MCDA) [1]. MCDM is a complex process of finding a solution, and it occurs at a few phases and a few levels of decision making. There are different methods of MCDM, and most of them belong to the category of discrete methods. In discrete methods, the problem of decision making is defined through finite number of options. In this paper, the MCDM methods are divided into [2]:

- Basic methods—The simplest forms of the MCDM method, and it is difficult to apply them in solving the optimization of energy chains due to the inadequacy of their simple preferential models.
- One-criterion approach—The methods where all the criteria are reduced to one criterion for comparison. The following methods belong to this group: MAUT, TOPSIS, SMART, AHP, etc. These methods belong to the American school of MCDM.
- Outranking methods—The methods where the alternatives are compared, and the preferences of one in relation to the other are identified. They include: NAIDE, ELECTRE, PROMETHEE, etc. These methods belong to the European school of MCDM.
- Target method, or the referent point method—This method identifies the options closest to the ideal one and the furthest from the anti-ideal point. These methods include the target and compromise programming, the VIKOR method.

- Fuzzy set theory—This uses the approach of imprecise and insecure information. It is used as a means which can be applied to any MCDM methodology, and not exclusively as a specific MCDM methodology.

The application of multicriteria optimization and decision making may have a significant role in the selection of technological, economical, more efficient and ecological criteria, and of many other criteria of acceptable solutions. This method also provides a good opportunity of application in the selection of optimal variants of energy production from biomass and the quality analysis of energy chains. Energy production from biomass is, by its nature, multidimensional and complex, with many available sources of biomass, technical possibilities and a diverse set of interested parties which have a multitude of opposed opinions. To develop and run a successful option of biomass utilization for energy purposes, there are many requirements which should be taken into account and met. Scott and associates have provided an overview of those academic papers which try to deal with the problems occurring within the bioenergy sector, by using the MCDM. These methods are especially appropriate for bioenergy production, if its multidimensional nature is taken into account as well, but they can also be equally relevant for other energy conversion technologies. The related articles which occur in international journals from 2000 to 2010 have been collected and analysed in such a way that the answers to the following two questions can be given: (1) which methods are the most popular ones? (2) what problems attract the highest attention? The overview discovers that the optimization methods are the most popular ones among the methods where the selection has been made within a small number of alternatives, and, as such, used in 44% of analysed papers, and among the methods where the selection has been made within many alternatives, they have been used in 28% of papers. The most popular application area of MCDM is in the selection of technologies, with 27% of analysed papers, while the application of MCDM to the decision-making policy participates with 18% [3].

3. Reasons for the application of multicriteria optimization in the selection of optimal energy supply chain

Generally, multicriteria optimization presents the finding of the variant (in our case, of an energy chain, a defined way of energy production), which will, in many ways, meet the required solution closest to the ideal one. The multicriteria optimization method occurred exactly from the striving towards a sustainable concept of the development of mankind. Because of that, the chosen methodology for the selection of optimal variant of energy production from biomass is good enough for the solving of this problem. The reason for that is more than simple. Biomass presents a renewable energy source and is an important part in the chain of sustainability. In the overviewed literature, a few papers have been found in which the VIKOR optimization method has been used. However, the real reason why this method is potentially good in solving the problem of selection of an optimal chain of the energy production from biomass is the possibility of different criterion weights definition and weights in decision-making strategies. Besides that, for all the obtained solutions, it is possible to check

http://dx.doi.org/10.5772/62537

their stability mathematically as well, that is, whether they will be good enough if some parameters are given a greater importance in the optimization than others. Of course, the forming of the criterion matrix gives a systematic overview of all characteristics of the observed energy chains, among which the best option has been selected. In this way, the universal concept is formed, which can give many answers on the design, installation and exploitation of the systems for energy production from biomass in a much more comprehensive sense.

4. Definition criteria for evaluation of biomass supply chain and approach to the optimal variant of energy production

The energy chains modelling should be based on modularity. It practically means that it is necessary to do a mathematical modelling of every energy chain element as an independent entity which will present a mathematical model for itself, as an elementary part of the energy chain. In literature, many studies have focused on techno-economic assessment to evaluate the economic feasibility of forest biomass utilization for the generation of heat [4], power [5], combined heat and power [6], and biofuel, heat and power [7]. The previous studies have compared alternative process technologies that use forest biomass to produce electricity [8] and alternative products that can be generated from a specific forest biomass base [9, 10]. Also, it is possible to minimize the cumulative fossil energy demand or the consumption of certain types of critical resources (e.g., labour, materials) associated with the unit of biofuel products, in order to achieve the maximum utilization of available resources [11]. For the most economic objectives, we often try to optimize the total quantity, that is, maximize total profit or minimize total cost. However, for environmental criteria, the “environmental impact per functional unit” is more critical [12]. This is because, for example, one may care more about the carbon footprint of producing one gallon of biomass-derived gasoline, rather than the annual total CO_2 emission of the entire biofuel supply chain. Therefore, the environmental impact evaluated based on functional unit is, in fact, the indicator of how “green” the supply chain is. All these studies did not find the optimal design of the forest biomass supply chain under analysis. Especially for conditions of optimization, this includes several different criteria such as technical, logistics, energetic, economic or environmental factors. This is a good direction for the development of the criteria for optimization of energy chains. The approach to the modelling of all elements is based on the analysis from the aspect of consumed energy in every element of the chain. The calculation of other criteria comes down to the calculation of production costs, CO_2 emission and investment cost per installed power of all energy consumers in the chain. Almost all the important elements of an energy chain for biofuel and energy production can be defined by the criteria $f_{1j}, f_{2j}, f_{3j}, f_{4j}, f_{5j}, f_{6j}$. The calculation of all the criteria functions is different for each of the chain variants (a_1, a_2, a_3 … a_n). But we have similar approach to the analysis of a single element of the chain. Well-defined criteria describe the overall energy chain based on biomass completely. For this reason, it is necessary to properly select the set of criteria which would have given a better assessment of the value chain of biomass energy. The following criteria must be defined:

- energy efficiency of observed chain; criteria function noted as f_{1j};
- exergy efficiency of chain; criteria function noted as f_{2j};
- the coefficient of exergy quality for different products at energy chains f_{3j};
- specific investment cost per total installed power of all machines and plants in the energy chain, €/kW; criteria function, f_{4j};
- production cost of energy chain per 1 kWh of the lower heating value of produced biofuels or energy, €/kWh; criteria function, f_{5j};
- CO_2 emission in the total chain due to the fossil fuels consumption for 1 kWh of the lower heating value of produced biofuel or energy, kg/kWh; criteria function, f_{6j}.

As we know, lower calorific value (or lower heating value, LHV) of a fuel portion is defined as the amount of heat evolved when a unit weight (or volume in the case of gaseous fuels) of the fuel is completely burnt and one part of that heat is used for water evaporation with the combustion products [13]. That is the main reason why we defined the previous criteria with lower heat value of fuels. It is the useful heat energy given in combustion process from chemical energy stored in all fuels and of course in biomass. The mentioned criteria are different for differently defined initial conditions of a problem. Solution to the problem of selecting the optimum variant of fuels and energy production consists of:

- Mathematical model for calculation of optimization criteria;
- Mathematical method for the selection of optimum variant of energy chain.

The significance of energy chains analysis from the aspect of invested energy is very important. In the literature, we can find the so-called EROEI factor (energy returned on energy invested), which presents the quotient of utilizable energy from a certain fuel (or from a way of energy production) and the energy consumed to convert the fuel or energy to a useful form [14]. To be able to evaluate the total energy consumption in an energy chain for fuel production at all, it is necessary to calculate all the consumed energies to the primary energy form. Primary energy is the content of energy in fuel related to lower heating value and weight of fuel. In that way, the total summation of all the consumed energy amounts in the energy chain of fuel/energy production is enabled. The principle of calculation of primary energy is defined by Equation 1 (see Figure 1):

$$LHV_{fuel} = \frac{\text{Output energy or work}}{\mu_1 \cdot \mu_2 \cdots \mu_n} \tag{1}$$

where LHV_{fuel} (kWh) is the primary energy related to lower heating value of fuel, $\mu_{1 \ldots} \mu_n$ are different coefficients of energy transformation. For example, overall energy efficiency for conventional power plants with pulverized coal firing has efficiencies as follows: 39–47%—steam turbine coal-fired power plant [15].

4.1. Function of energy efficiency for energy chain f_{1j}

Energy efficiency for the *q*th element of chain and *j*th energy chain of production is the ratio between the obtained energy and the energy consumed in the process of energy production in dimensionless unit, kWh/kWh. The value which is the ratio between the lower calorific value of the fuel consumption or any kind of energy (expressed in the form of primary energy, see Equation 1) and lower heating value of biomass processed in every single operation is important in the first part of the energy chain defined for biomass fuel production depending on the energy plant [16]. This approach to calculating efficiency involves the productivity of machines and equipment for processing of biomass, as well as defined energy and fuel consumption from certain processes (elements) in the energy supply chain [17]. All consumed energy is defined as primary energy in LHV fuel (see Figure 2).

Total energy efficiency factor of the energy chain including power plants, transmission losses in the network, as well as all levels of energy transformation is defined by

$$f_{1j} = \left(1 - \sum_{k=1}^{q} \frac{e_{ckj}}{e_{pkj}}\right) \cdot \mu_{bj} \cdot \mu_{ej} \cdot \mu_{tj} \cdot \mu_{gj} \cdot \mu_{dj} \cdots \mu_{end,usej}, \quad (2)$$

where e_{cqj} is the primary energy consumed in one element of the bioenergy chain, expressed in kWh; e_{pqj} is lower heating value of processed biomass in one element of the chain, expressed

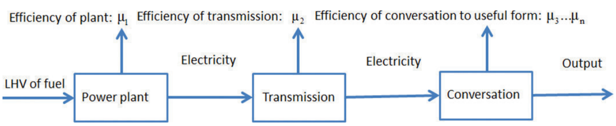


Figure 1. Principle of calculation of primary energy.

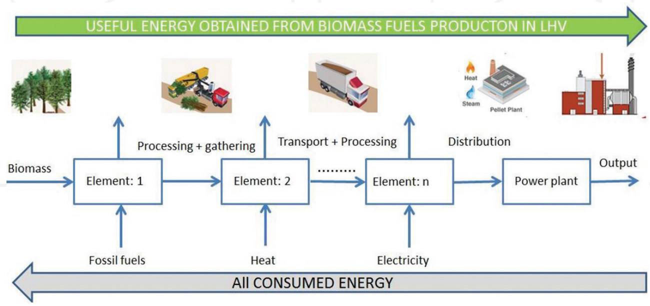


Figure 2. Part of supply chain for biofuels production up to power plant.

in kWh; *k* is the counter of elements in the energy chain; and *q* is the total number of elements in the energy chain; $\mu_{bj} \cdot \mu_{ej} \cdot \mu_{tj} \cdot \mu_{gj} \cdot \mu_{dj} \cdots \mu_{end,usej}$ are the factors of energy efficiencies for boilers, heat exchangers, turbines, generators, distribution, end users, etc. [15].

4.2. Function of exergy efficiency for overall energy chain f_{2j}

Different ways of formulating exergy efficiency (effectiveness, or rational efficiency) for various energy systems are given by Cornelissen [18]. The exergy performance of the system can be evaluated by means of the exergy efficiency. Two expressions of the exergy efficiency are often used in literature, the simple and the rational exergy efficiency [19, 20]. Their mathematical expressions are given in Equation 3.

$$\mu_{exsimple} = \frac{E_{xout}}{E_{xin}}, \mu_{exrat} = \frac{E_{xdes,out}}{E_{xin}}, E_{xin} = E_{xout} + I \quad (3)$$

where $\mu_{exsimple}$ is simple exergy efficiency, E_{xout} is total exergy output, E_{xin} is total exergy input, μ_{exrat} is rational exergy efficiency, $E_{xdes,out}$ is desired output exergy. The irreversibility of the process or exergy loss, *I*, is defined as the difference between desired exergy outputs E_{Xout} and the required exergy inputs E_{Xin} to it [20]. When we talk about the exergy efficiency of the entire bioenergy chain (from the source of biomass to the end user), then the individual exergy efficiency of single chain elements must be taken into account (see Figure 2). The total exergy efficiency of the energy chain is

$$f_{2j} = \left(1 - \sum_{k=1}^{q} \frac{e_{xckj}}{e_{xpkj}}\right) \cdot \mu_{exbj} \cdot \mu_{exej} \cdot \mu_{extj} \cdot \mu_{exgj} \cdot \mu_{exdj} \cdots \mu_{ex,end,usej}' \quad (4)$$

where e_{xckj} is exergy consumed in one element of chain, expressed in kWh; e_{xpkj} is exergy stored in the produced fuel, in kWh; *k* is the counter of elements in energy chain; *q* is the total number of elements in the energy chain; $\mu_{exbj} \cdot \mu_{exej} \cdot \mu_{extj} \cdot \mu_{exgj} \cdot \mu_{exdj} \cdots \mu_{ex,end,usej}$ are factors of exergy efficiencies for boilers, heat exchangers, turbines, generators, distribution, end users, etc. For more information about energy and exergy efficiencies of selected processes, see [21]. Energy and exergy analyses for three different cogeneration systems (steam cogeneration, gas-turbine cogeneration and diesel-engine cogeneration were performed by Kaushik [22]. It should be noted that the first part of the supply chain relates to the production of fuels from biomass; exergetic efficiency of this part of the chain is approximately equal to the energy efficiency. The main reason for this is a constant chemical exergy of biomass. There are cases when it comes to the occurrence of chemical exergy destruction, such as pyrolysis and gasification of biomass. Then it is needed to calculate the exergy efficiency of these processes.

4.3. The coefficient of exergy quality for different products at energy chains f_{3j}

Various forms of energy have different qualities. There are different basic energy forms: kinetic energy, potential energy, thermal energy, chemical energy, electrical energy, electromagnetic energy, sound energy and nuclear energy. It is said that energy can be "useful" if it can be entirely transformed by an ideal system (i.e., without losses) into any other type of energy. Useful energy, otherwise known as exergy, only represents a part of energy. Electrical and mechanical energies are "high quality" forms of energy; their exergy index is 100%, since exergy is equal to energy. Table 1 provides an overview of the coefficients of exergy quality for different energy forms:

Coefficients f_{3j}	Electricity	Fuel	Heat
	$E_j = 1$ kWh	$F_j = 1\text{kWh} \cdot \mu_{exp}$	$H_j = 1\ \text{kWh} \cdot \left(1 - \frac{T_0}{T}\right)$

Table 1. Coefficients of exergy quality.

where μ_{exp} is exergy efficiency for the production of electricity from different types of fuels from defined technology [21]; T_0 is environment temperature (K); T is temperature of heat reservoir (K); E_j, F_j and H_j are coefficients of exergy quality for electricity, fuel and heat, respectively. Also, we can define the combined coefficient of exergy quality as

$$f_{3j} = E_j \cdot e_j + F_j \cdot f_j + H_j \cdot h_j, \tag{5}$$

where $e_j + f_j + h_j = 1$, e_j, f_j, h_j are percentages of simultaneous production of electricity, fuel and heat at the energy chain.

The main difference between the quality factor of energy form (q) and coefficient of exergy quality (f_{3j}) is only that exergy quality factor takes into account the degree of conversion of chemical exergy into electricity. This factor provides a comparison of fuel and electricity.

4.4. Function of specific investment cost for energy chain f_{4j}

Engineers and investors typically interpreted and measured the performance of energy systems based on economic value such as investment and production costs. The most widely used economic performance metrics for comparing the economic value energy systems are net present value, total life cycle cost, rate of return, benefit–cost ratio and payback period. The economic principles and applications of these techniques are discussed in numerous standard engineering economics analyses and engineering economy texts [23, 24]. For energy chains, there are more elements included in their composition. Specific investment cost in the energy chain is the ratio between the total investment cost and the total installed power of all the elements in the chain:

$$f_{4j} = \frac{\sum_{k=1}^{q} I_{kj}}{\sum_{k=1}^{q} P_{kj}}, \tag{6}$$

where $\sum_{k=1}^{q} I_{kj}$ is the sum of all investment in the elements of energy chain [€]; $\sum_{k=1}^{q} P_{kj}$ is the sum of all installed power in the energy chain (kW, MW); q is the number of elements in the energy chain; k is the counter for the number of elements in the energy chain; j is the number of energy chains. If in the energy chain there are elements whose function cannot be expressed in units of €/ kW, it is necessary to bring these elements in similar correlations. For example, if the storage for biomass exists, then I_{kj} is certain value of investment in storage and P_{kj} (installed power) is equal to zero.

4.5. Function of specific production cost for energy chain f_{5j}

Investments are defined as the sum of all incurred expenses until plant operation reaches readiness, while operating costs occur during operation and depend on capacity utilization [25]. The production costs (operating and maintenance) were calculated by dividing the total annual costs as a fixed and variable, with the net generating capacity and net annual generation respectively, electricity and district heat or fuels. For electricity-generating technologies, including combined heat and power generation, the denominators are electric capacity and electricity generation. For heat-only technologies, the denominators are heat-generating capacity and heat generation. Often, the reference documents do not distinguish between fixed and variable production costs. Then the total production costs are expressed, typically in €/MWh or €/kWh. Function of total production costs f_{5j} for bioenergy plants is

$$f_{5j} = \frac{\left(\sum_{k=1}^{q}\left(Op_{kj} + Mp_{kj}\right) + Cr_j\right) \cdot t}{Ep\left(fuel / heat / electricity\right)_j \cdot t}, \left[€ / kWh, € / MWh\right], \tag{7}$$

where $(Op_{kj} + Mp_{kj})$ is the sum of all operating and maintenance costs in all elements of energy chain per year (€/h); Cr_j is the cost of biomass raw material (€/h); $Ep(fuel/heat/electricity)_j$ is the productivity of different energy forms per chain (kWh/year, MWh/h). Operating and maintenance costs also include labour costs per kWh of energy produced.

4.6. Function of specific CO_2 emission for energy chain f_{6j}

A trend in GHG emissions from fossil fuel combustion illustrates the need for all countries to increase the use of more sustainable energy in future. The emission of GHG of particular species is often monitored because of the adverse environmental consequences that can cause photochemical smog, acid rain, global warming and ozone depletion. The details of, and standard methods used to measure, global warming potentials (GWPs) are defined by the IPCC [26]. For measurement of an energy system's environmental performance, the results are expressed through a mass of carbon dioxide equivalent emission per unit of desired output (e.g., kg-CO_2-eq./kWh elec.). The following equation can be used for the estimation of greenhouse gas emissions from the combustion of each type of fuel per energy chain [27]:

$$f_{6j} = \frac{\left(\sum_{k=1}^{q} \frac{m_{kj} \cdot ec_{kj} \cdot e_{fkj}}{3.6}\right) \cdot t}{Ep\left(fuel / heat / electricity\right)_j \cdot t}, \tag{8}$$

where m_{kj} is the quantity of fuel type consumption in one element of energy chain (kg/h); ec_{kj} is the energy content factor of the fuel according to each fuel (kWh/kg); e_{fkj} is the emission factor for each gas type (in our case CO_2) for different fuel types according to each fuel (kWh/kg) [28];Ep(fuel/heat/electricity)$_j$ is productivity of different energy forms for each chain per hour (kWh/h, MWh/h).

5. Mathematical model for the selection of optimum variant of energy chain for energy production from wood biomass

In this paper, for the actual problem of selection optimum variant of energy chain, VIKOR optimization method is applied as a proposal and as an adequate method for the solution of multicriteria optimization related to the selection of optimal energy chain of production. This method aims to collect all the most important factors which describe energy supply chains from biomass and make the selection of optimal supply chain. The VIKOR method (multicriteria compromise ranking) has been developed for the determination of a multicriteria optimal solution. The VIKOR method has been developed on such a methodological basis that a decision-maker is suggested as the alternative (or solution) to present a compromise between wishes and opportunities, the different interests of the decision-making participants. The VIKOR method has been developed for a multicriteria optimization of complex systems. It is focused on ranking and selection of the best solution from the given set of alternatives, with conflicting criteria [29]. The VIKOR method requires the values of all the criteria functions for all the alternatives in the form of a matrix to be familiar. Because of that, at the beginning of the optimization process, a general form of the problem has been set (evaluation matrix) for the specific case. The matrix of criterion functions for all variants of the production of fuels or energy from biomass is of $6 \times n$ dimensions (6 criteria and n alternatives of energy production from biomass), obtained from the calculation of different cases of energy chains' composition:

$$F = \begin{matrix} & a_1 & a_2 & a_3 & \dots & a_n \\ \begin{matrix} f_1 \\ f_2 \\ f_3 \\ f_4 \\ f_5 \\ f_6 \end{matrix} & \multicolumn{5}{c}{\begin{bmatrix} f_{11} & f_{12} & f_{13} & \dots & f_{1n} \\ f_{21} & f_{22} & f_{23} & \dots & f_{2n} \\ f_{31} & f_{32} & f_{33} & \dots & f_{3n} \\ f_{41} & f_{42} & f_{43} & \dots & f_{4n} \\ f_{51} & f_{52} & f_{53} & \dots & f_{5n} \\ f_{61} & f_{62} & f_{63} & & f_{6n} \end{bmatrix}} \end{matrix} \quad (9)$$

where $\{a_1, a_2, a_3 \dots a_n\}$, $j = n$ are a finite set of possible alternatives for the n energy chains of production; $\{f_1, f_2, f_3, f_4, f_5, f_6\}$, $i = 6$ are a finite set of criterion functions for five defined and adopted criteria on the basis of which the chains of energy production from biomass are analysed; $\{f_{11}, f_{12} \dots f_{6n}\}$ are the set of all the criterion functions' values in matrix F. An ideal solution is determined on the basis of the criterion functions' values from the equation [29]:

$$f_i = \underset{j}{\text{ext}}\, f_{ij},\; i = 1, 2, \dots, 6. \quad (10)$$

The operator ext denotes a maximum if the function f_i describes a benefit or profit, and a minimum if f_i describes damages or costs or other variables which are of interest to optimize (minimization or maximization criterion functions). This is the best way to define an ideal solution for energy production from different energy chains based on biomass. The criterion functions within the matrix F are commonly not expressed in the same measurement units (i.e., the belonging criterion space is heterogeneous). For that reason, in order to perform use of multicriteria optimization, it is necessary to convert all the criterion functions into dimensionless functions whose values will be in the interval [0, 1]. This process is called the normalization of dimensional units in the area of multicriteria mathematics. Firstly, the best values of criterion functions are determined. In our case, those are the maximum values of first three criterion functions (energy and exergy efficiency, the coefficient of exergy quality for different products at energy chains) and minimum values of the other three criterion functions (minimization of CO_2 emission per 1 kWh energy produced, production cost per 1 kWh energy produced and specific investment cost per kilowatt installed in the production chain). Then we have mathematically [29]

$$\begin{aligned} &\max f_1\left(f_{1j}\right) = f_1^*, \quad \max f_2\left(f_{2j}\right) = f_2^*, \quad \max f_3\left(f_{3j}\right) = f_3^*, \\ &\min f_4\left(f_{4j}\right) = f_4^*, \quad \min f_5\left(f_{5j}\right) = f_5^*, \quad \min f_6\left(f_{6j}\right) = f_6^*. \end{aligned} \quad (11)$$

In the same way, the worst values of the criterion functions can be determined, which are obtained by the same criterion functions [29]:

http://dx.doi.org/10.5772/62537

$$\begin{aligned} &\min f_1\left(f_{1j}\right)=f_1^-, \quad \min f_2\left(f_{2j}\right)=f_2^-, \quad \min f_3\left(f_{3j}\right)=f_3^- \\ &\max f_4\left(f_{4j}\right)=f_4^-, \quad \max f_5\left(f_{5j}\right)=f_5^-, \quad \max f_6\left(f_{6j}\right)=f_6^-. \end{aligned} \tag{12}$$

Then all the elements of the matrix *f* are converted in the value domain [0, 1]. This is achieved by the following formula [29]:

$$d_{ij}=\frac{f^{*}-f_{ij}}{f_i^{*}-f_i^{-}}, \text{ and a matrix is formed, in the form } D=\left[d_{ij}\right], \text{ for } i=1,...6 \text{ and } j=1,\ldots n. \tag{13}$$

Considering the difference $f_i^{*}-f_i^{-}$ in the expression for d_{ij} it is necessary for all elements of the matrix *D* to be of the values in the interval (0, 1). The values of criterion functions are obtained by maximization or minimization of criterion functions. The criterion weights for the specific problem related to ranking variants of energy chains, for the six main criteria defined are mutually equal. The reason for this is very simple, because we strive for the minimal CO_2 emission quantities, production cost and specific investment cost per totally installed power in the energy chain. Also, at the same time, the aim is maximization of energy efficiency and exergy efficiency and quality of energy forms. All criteria functions have equal weight and importance. Due to that, it will be valid that the criterion weights are

$$w_1=w_2=w_3=w_4=w_5=w_6=w_j=\frac{1}{6}. \tag{14}$$

After that, the values of the elements of matrices S_j and R_j were calculated. Considering the equality of the criterion weights, they are obtained as [29]:

$$\begin{aligned} &S_{j=1\ldots n}=w_j\cdot\sum_{i=1}^{6}d_{ij}=\frac{1}{6}\cdot\sum_{i=1}^{6}d_{ij}=\left[\frac{1}{6}\cdot\sum_{i=1}^{6}d_{i1},\frac{1}{6}\cdot\sum_{i=1}^{6}d_{i2},\frac{1}{6}\cdot\sum_{i=1}^{6}d_{ij},\ldots\frac{1}{6}\cdot\sum_{i=1}^{6}d_{in}\right], \\ &R_{j=1\ldots n}=w_j\times\max_i\left[d_{ij}\right]=\left[\frac{d_{i1}\max}{6},\frac{d_{i2}\max}{6},\frac{d_{ij}\max}{6},\ldots\frac{d_{in}\max}{6}\right]. \end{aligned} \tag{15}$$

In this way, the problem is reduced from a multicriteria space to a two-criterion problem. The values of minimal and maximal elements are determined from the matrices S_j and R_j [29].

$$S^{*}=\min_j S_j,\ S^{-}=\max_j S_j,\ R^{*}=\min_j R_j,\ R^{-}=\max_j R_j. \tag{16}$$

The decision strategy weight will be taken as $\upsilon = 0, 6.$ This is valid for the criterion number m = 6 [29]. For the other case and number criterion m [29], we have

$$\upsilon = \begin{cases} 0.5, & m \leq 4 \\ 0.6, & 5 \leq m \leq 10. \\ 0.7, & m \geq 10 \end{cases} \tag{17}$$

On the basis of that, it is possible to calculate the value of the matrix q_j pursuant to the equation [29]:

$$q_j = \upsilon \cdot \frac{\left(S_j - S^*\right)}{S^- - S^*} + \left(1 - \upsilon\right)\frac{R_j - R^*}{R^- - R^*}. \tag{18}$$

A certain value of q_j corresponds to every chain in the following matrix [29]:

$$\begin{matrix} & CH_1 & CH_2 & CH_j & CH_n \\ Q_j = [& q_1; & q_2; & q_j; & q_n] \end{matrix} \; Q^* = \min_j Q_j \tag{19}$$

The optimum variant of production is defined by the minimal value. The ranking of alternatives is formed from the lowest value of q_j to the highest value of q_j, which is from the best to the worst variant. In our case, the alternatives are the mentioned energy chains for fuels and energy production from biomass [29].

5.1. Acceptable advantage and stability of the selected variant of optimal energy chain on the basis of the VIKOR method

In the cases when values of criterion weights are different and some criteria are given a greater importance in relation to the others, the stability of the obtained optimal solution should be checked on the basis of the VIKOR method. The alternative (a') is suggested as a compromise solution, which is the highest ranked value on the Q measure (matrix). Then, two conditions have to be met:

(1) *Acceptable advantage*

$$Q(a'') - -Q(a') \geq DQ \tag{20}$$

where a'' is the second-position alternative on the rank list (Q); DQ = 1/(m− 1) advantage threshold, where m is the number of alternatives (energy chains).

(2) *Acceptable stability*

The alternative *a′* should also be ranked as the best in *S* and/or *R* rank (matrix). In that case, the solution has been selected correctly [29].

6. Enclosure of specific mathematical functions for elements in wood biomass supply chain

For the production of biofuel from wood biomass, it is necessary to engage different types of mechanization, plants for converting biomass to useful fuel, human and other resources. Due to the fact that the energy chains for biofuel production were analysed from the energy aspect in this paper, in the text that follows, mathematical descriptions will be given for the particular elements of an energy chain pursuant to the previously adopted concept for the calculation of functions for the elements in supply chain [16].

6.1. Biomass collection machines in a supply chain

Biomass collection machines are the first elements in a chain from which the entire biomass supply process starts. Different operations in wood biomass collection require different machines, whose selection for use practically depends on the application conditions. In the structure of the analysed energy chains discussed in this paper, the following machines were used: chainsaw, tractor, truck, hydraulic crane, mobile chipper and forwarder. For all the production machines whose fuel consumption is expressed in litres per hour (l/h) and the labour productivity in volume unit per hour (m^3/h), the following relations were adopted to Equations 2–8 [16]:

$$f_{1j} = \frac{\sum_{q=1}^{n_1} \frac{\rho_{Fjq} \cdot Fc_{jq} \cdot t_{jq}}{1\,000} \cdot Hv_{jq}}{\sum_{q=1}^{n_1} \frac{ehv_{0jq}(100 - w_{jq}) - (2.44 w_{jq})}{100} \cdot \rho_{0jq} \cdot \frac{10^4}{\left(100 - w_{jq}\right) \cdot \left(100 + \alpha_{vjq}\right)} \cdot Pr_{jq} \cdot t_{jq} \cdot \left(SVF\right)_{jq}} \tag{21}$$

$$f_{5j} = \frac{\sum_{q=1}^{n_1} Fc_{jq} \cdot t_{jq} \cdot c_{jq}}{\sum_{q=1}^{n_1} \frac{ehv_{0jq}(100 - w_{jq}) - (2.44 w_{jq})}{100} \cdot \rho_{0jq} \cdot \frac{10^4}{\left(100 - w_{jq}\right) \cdot \left(100 + \alpha_{vjq}\right)} \cdot Pr_{jq} \cdot t_{jq} \cdot \left(SVF\right)_{jq}} \tag{22}$$

$$f_{6j} = \frac{\left(\rho_{Fjq} \cdot Hv_{jq} \cdot \frac{e_{Fjq}}{10^6}\right) \cdot \sum_{q=1}^{n_1} Fc_{jq} \cdot t_{jq}}{\sum_{q=1}^{n_1} \frac{ehv_{0jq}(100 - w_{jq}) - (2.44 w_{jq})}{100} \cdot \rho_{0jq} \cdot \frac{10^4}{\left(100 - w_{jq}\right) \cdot \left(100 + \alpha_{vjq}\right)} \cdot Pr_{jq} \cdot t_{jq} \cdot \left(SVF\right)_{jq}} \tag{23}$$

$$f_{4j} = \frac{\sum_{q=1}^{n_1} I_{Mjq}}{\sum_{q=1}^{n_1} P_{Mjq}} \tag{24}$$

where $q = 1 \dots n_1$ is the number of machines included in the work; Fc_{jq} is specific fuel consumption of the observed working machine, l/h; Pr_{jq} is productivity of the working machine, m^3/h; t_{jq} is working time of machine, h; Hv_{jq} is lower heating value of fuel (gasoline or oil, depending on the fuel type the machine uses), MJ/kg; $w_{jq} \geq 30\%$ wood moisture, %; $\rho 0_{jq}$ is wood density, kg/m^3; α_{vjq} is the percentage of wood swelling, %; $(SVF)_{jq}$ is fulfilment factor of volume ($0 \dots 1$); c_{jq} is the price of a litre of fuel (gasoline or oil); ρ_{Fjq} is the density of fuel at atmospheric conditions, kg/m^3; e_{Fjq} is coefficient of CO_2 emission for different fuels in kilograms of CO_2 per gigajoule of the fuel heating value, kg CO_2/GJ; I_{Mjq} is the cost price of a new working machine, €; P_{Mjq} is the maximal power of working machine in kilowatts, in which $j = 1, 2 \dots n$.

It must be mentioned that the previously written equations are valid only for the working machines whose productivity is expressed in working hours [16]. Calculation defined criteria for trucks:

$$f_{1j} = \frac{\sum_{q=1}^{n_1} \frac{\rho_{Fjq} \cdot Ftc_{jq} \cdot l_{jq}}{1\,000} \cdot Hv_{jq}}{\sum_{q=1}^{n_1} \frac{ehv_{0jq}\left(100 - w_{jq}\right) - \left(2.44 w_{jq}\right)}{100} \cdot M_{tjq} \cdot 1000} \tag{25}$$

$$f_{5j} = \frac{\sum_{q=1}^{n_1} Ftc_{jq} \cdot l_{jq} \cdot c_{jq}}{\sum_{q=1}^{n_1} \frac{ehv_{0jq}\left(100 - w_{jq}\right) - \left(2.44 w_{jq}\right)}{100} \cdot M_{tjq} \cdot 1000} \tag{26}$$

$$f_{6j} = \frac{\left(\rho_{Fjq} \cdot Hv_{jq} \cdot \frac{e_{Fjq}}{10^6}\right) \cdot \sum_{q=1}^{n_1} Ftc_{jq} \cdot l_{jq} \cdot c_{jq}}{\sum_{q=1}^{n_1} \frac{ehv_{0jq}\left(100 - w_{jq}\right) - \left(2.44 w_{jq}\right)}{100} \cdot M_{tjq} \cdot 1000} \tag{27}$$

where Ftc_{jq} is specific fuel consumption in trucks, l/km; l_{jq} is transportation distance, km; M_{tjq} is maximal truck load, t. It must be emphasized that the load of a truck for wood chips is different from the load of a truck for timber transportation. The fuel consumption of machines which take part in the wood biomass supply chain is mostly expressed in litres per hour. Also, the working productivity of particular machines is given in the volume amount of biomass processed, attracted, collected or loaded by the machine in a time interval. In order to obtain some proper units of fuel consumption and productivity of different machines for wood biomass collecting, it is necessary to perform different measurements and explorations in the exploitation conditions [17].

6.2. Biomass collection machines in a supply chain

Mechanical wood processing implies the type of processing at which, in the first place, the shape and dimensions of wood are changed by using mechanical means (saws, knives, etc.). The residues which emanates in sawmills presents a significant amount of wood biomass for the production of solid biofuels. Besides the main products in sawmills, such as planks and lumbers, different forms of semi products, namely, the emanated wood residues, from processing are less important. The energy in primary wood processing is collectively consumed per volume unit of a final product. Thus, we have the following mathematical functions (f_{1j}, f_{5j}, f_{6j}, f_{4j}) for a sawmill [16]:

$$f_{1j} = r \cdot \frac{\frac{1}{\eta c_{el}} \cdot \left(\sum_{q=1}^{n_1} Fp_{jq} \cdot t_{jq} \cdot Ec_{jq} \right)}{\frac{1}{3.6} \cdot \left(\sum_{q=1}^{n_1} \frac{ehv_{0jq}(100 - w_{jq}) - (2.44\, w_{jq})}{100} \cdot \rho_{0jq} \cdot \frac{10^4}{(100 - w_{jq}) \cdot (100 + \alpha_{vjq})} \cdot Fp_{jq} \cdot t_{jq} \cdot (SVF)_{jq} \right)} \tag{28}$$

$$f_{5j} = r \cdot \frac{\frac{1}{\eta c_{el}} \cdot \left(\sum_{q=1}^{n_1} Fp_{jq} \cdot t_{jq} \cdot Ec_{jq} \cdot Ce_{jq} \right)}{\frac{1}{3.6} \cdot \left(\sum_{q=1}^{n_1} \frac{ehv_{0jq}(100 - w_{jq}) - (2.44\, w_{jq})}{100} \cdot \rho_{0jq} \cdot \frac{10^4}{(100 - w_{jq}) \cdot (100 + \alpha_{vjq})} \cdot Fp_{jq} \cdot t_{jq} \cdot (SVF)_{jq} \right)} \tag{29}$$

$$f_{6j} = r \cdot \frac{e_{Fj} \cdot \frac{\sum_{q=1}^{n_1} Fp_{jq} \cdot t_{jq} \cdot Ec_{jq}}{\eta c_{el}} \cdot \frac{3.6}{10^3}}{\frac{1}{3.6} \cdot \sum_{q=1}^{n_1} \left(\frac{ehv_{0jq}(100 - w_{jq}) - (2.44\, w_{jq})}{100} \cdot \rho_{0jq} \cdot \frac{10^4}{(100 - w_{jq}) \cdot (100 + \alpha_{vjq})} \cdot Fp_{jq} \cdot t_{jq} \cdot (SVF)_{jq} \right)} \tag{30}$$

where $q = 1 \ldots n_1$ is the number of sawmills; Fp_{jq} is productivity (sawmill capacity), m^3/h; Ec_{ijq} is specific consumption of electricity per cubic metre processed, kWh/m^3 (20–30 kWh/m^3 soft and hard wood) [30]; t_{ijq} is the working time of machine, h; ηc_{el} is the factor of efficiency of electricity production from a thermal power station (coal as a fuel, assumption); r is the factor of wood residue in primary processing, in the interval from 0.25 to 0.35 (soft and hard wood without bark) [30]; $w_{jq} \geq 30\%$ wood moisture, %; $\rho 0_{jq}$ is wood density, kg/m^3; α_{vjq} is percentage of wood swelling, %; $(SVF)_{jq} = 1$ is fulfilment factor of volume (timber); Ce_{jq} is the price of a kWh of electricity; e_{Fij} is coefficient of CO_2 emission for coal in kilograms of CO_2 per gigajoule of the fuel heating value, kg CO_2/GJ. It must be mentioned that it has been assumed that the sawmill consumes the electricity produced in a thermal power station. The factor ηc_{el}=0, 36 takes into account all the energy losses from the thermal power station to the motor which drives the system for woodcutting. The factor of loss includes the losses in boiler, turbine, generator and electric supply network [15]. It must be emphasized that all energy losses are reduced to the primary energy form (heating value). In such a way, the opportunity of a simple summation of heating values equivalent to certain forms of energy consumption is obtained, regardless of thermal energy or electricity in question. Considering Equation 24, it has been previously defined. In this case, the power of motor P_{Mjq} which drives the cutting system is taken for the sawmill, while the price of a plant for primary processing is taken as the cost price I_{Mjq}.

6.3. Plant for production of wood chips, drying, briquetting and pelleting

For the wood chips, briquettes or pellets production process, it is, as first, necessary to chop the initial wood residue to a certain granulation, and then dry it. If a wood chip is produced, then the production line ends with machines for rough chopping of wood to certain granulation. If we want to produce a wood briquette or pellet after rough chopping, the obtained wood chips are dried in rotary dryers, and then are additionally fine-chopped, to be briquetted or pelleted later. The mathematical functions (f_{1j}, f_{5j}, f_{6j}, f_{4j}) by which the production of wood chips, briquettes and pellets within a plant have been described are related to electricity consumption due to the mechanical work of chopping of wood residue. Thus, we have the following relations [16]:

$$f_{1j} = \frac{\frac{1}{\eta c_{el}}\left(\sum_{q=1}^{n_1} Pc_{jq} \cdot \eta_t \cdot t_{jq}\right)}{\frac{1}{3.6}\left(\sum_{q=1}^{n_1} \frac{ehv_{0jq}\left(100 - w_{jq}\right) - \left(2.44 w_{jq}\right)}{100} \cdot Fpc_{jq} \cdot t_{jq} \cdot 1\,000\right)} \quad (31)$$

$$f_{5j} = \frac{\sum_{q=1}^{n_1} Pc_{jq} \cdot \eta_t \cdot t_{jq} \cdot Ce_{jq}}{\frac{1}{3.6} \cdot \left(\sum_{q=1}^{n_1} \frac{ehv_{0jq}(100 - w_{jq}) - (2.44 w_{jq})}{100} \cdot Fpc_{jq} \cdot t_{jq} \cdot 1\,000\right)} \quad (32)$$

$$f_{6j} = \frac{\frac{e_{Fjq} \cdot 3.6}{\eta c_{el} \cdot 10^3} \cdot \left(\sum_{q=1}^{n_1} Pc_{jq} \cdot \eta_t \cdot t_{jq}\right)}{\frac{1}{3.6} \cdot \sum_{q=1}^{n_1}\left(\frac{ehv_{0jq}(100 - w_{jq}) - (2.44 w_{jq})}{100} \cdot Fpc_{jq} \cdot t_{jq} \cdot 1\,000\right)} \quad (33)$$

It will be emphasized again that the electricity for driving a plant has been produced from a thermal power station. Of course, that should not be a case. If it is assumed, for example, that the drive of a plant has used the electricity obtained from a hydroelectric power station, then the CO_2 emission factor is equal to zero for the plant. In Equations 31–33, we have the following values introduced: $q = 1 \ldots n_1$ is the number of plants; Pc_{jq} is the electrical power of the plant, kW; η_t is the simultaneity factor of the operation of all electric motors in the plant (0.7–0.95), which depends on whether the plant has an installed electric power compensation system or not; t_{jq} is the working time of machine in hours, h; Fpc_{jq} is the output productivity of the plant, t/h; Ce_{jq} is the price of 1 kWh of electricity; ηc_{el}=0, 36 takes into account all the energy losses from the thermal power station to the electricity user in a factory; e_{Fjq} is the coefficient of CO_2 emission for coal in kilograms of CO_2 per gigajoule of the fuel heating value, kg CO_2/GJ. In the case of wood chips production plants, pelleting and briquetting plants, the total installed electric power in the plant is taken as P_{Mjq}, while the price of the plant installation is taken as the cost price I_{Mjq}.

The output moisture value of wet wood chips can vary significantly depending on the input moisture of wood to be chopped, and is usually in the interval from 30 to 50%. In pellets and briquettes, there is a prescribed moisture value, between 9 and 12%. It can be concluded that the differences in wood chips, pellets and briquettes in production plants are seen only in the installed power of a plant, productivity, and in the electric power compensation factor.The mathematical functions (f_{1j}, f_{5j}, f_{6j}, f_{4j}) which describe the drying of chopped material before briquetting or pelleting process are the following ones [16]:

$$f_{1j} = \frac{\frac{1}{3.6 \cdot \eta_b \cdot \eta_d}\left(\sum_{q=1}^{n_1}\left(\frac{w_{1jq} - w_{jq}}{100 - w_{jq}}\right) \cdot M_{jq} \cdot t_{jq} \cdot L_e\right)}{\frac{1}{3.6}\left(\sum_{q=1}^{n_1}\frac{ehv_{0jq}(100 - w_{jq}) - (2.44 w_{jq})}{100} \cdot M_{jq} \cdot t_{jq} \cdot \left(\frac{100 - w_{1jq}}{100 - w_{jq}}\right)\right)} \tag{34}$$

$$f_{5j} = \frac{\frac{1}{3.6 \cdot \eta_d}\left(\sum_{q=1}^{n_1}\left(\frac{w_{1jq} - w_{jq}}{100 - w_{jq}}\right) \cdot M_{jq} \cdot t_{jq} \cdot L_e\right) \cdot Ch_{jq}}{\frac{1}{3.6}\left(\sum_{q=1}^{n_1}\frac{ehv_{0jq}(100 - w_{jq}) - (2.44 w_{jq})}{100} \cdot M_{jq} \cdot t_{jq} \cdot \left(\frac{100 - w_{1jq}}{100 - w_{jq}}\right)\right)} \tag{35}$$

$$f_{6j} = \frac{\frac{e_{Fjq}}{\eta_b \cdot \eta_d \cdot 10^3}\left(\sum_{q=1}^{n_1}\left(\frac{w_{1jq} - w_{jq}}{100 - w_{jq}}\right) M_{jq} \cdot t_{jq} \cdot L_e\right)}{\frac{1}{3.6}\left(\sum_{q=1}^{n_1}\frac{ehv_{0jq}(100 - w_{jq}) - (2.44 w_{jq})}{100} \cdot M_{jq} \cdot t_{jq} \cdot \left(\frac{100 - w_{1jq}}{100 - w_{jq}}\right)\right)} \tag{36}$$

In pelleting and briquetting plants, multipass rotary dryers are used. Due to the complexity of the mathematical model of the rotary dryer for sawdust drying, this paper presents a simplified approach to the calculation of the thermal energy needed for drying chopped wood residue. It is assumed that for the evaporation of every kilogram of water from a wet material, it is necessary to invest the amount of heat equal to the latent heat of evaporation, increased by the coefficient of losses in the dryer. Also, the reduction of heat energy consumed for drying to primary energy has been done through the coefficients of losses in the boiler which supplies the dryer. We have the following parameters used in Equations 34–36: $q = 1 \ldots n_1$ is the number of dryers; M_{jq} is the input capacity of raw materials, m^3/h; t_{jq} is the dryer operation time, h; w_{1jq} is the moisture of the material at the entrance of the dryer (0 … 1); w_{jq} is the moisture of the material at the exit of the dryer (0 … 1); L_e=2.44 is the latent heat of evaporation for water [31], MJ/kg; $\eta_b \approx 0.9$ is boiler efficiency [15]; η_d is rotary dryer efficiency, usually within the limits from 0.4 to 0.6 [32]; Ch_{jq} is the price of 1 kWh of thermal energy, €/kWh; e_{Fjq} is the coefficient of CO_2 emission for different fuels, in kilograms of CO_2 per gigajoule of the fuel heating value, kg CO_2/GJ. If wood biomass is used in the boiler for drying heat production, then the CO_2 emission is equal to zero. In this paper, the data from a real pellet production plant ″Enterprise for making of wood packaging and production of eco-briquettes—pellets EU PAL factory Pale, Bosnia and Herzegovina″ has been used for defining particular mathematical functions and logistic concept.

7. Model testing results in the case of the selection of optimal chain of energy and fuel supply from biomass

For the analysis and selection of an optimal chain of the production of electricity, fuel and thermal energy, three energy chains have been taken into account: CHP (combined heat and power) facility with the ORC process, pellet production and hot water boiler. All the facilities and processes are real, and the necessary data used for calculation are real and present the current state in the use of biomass for energy purposes in the Republic of Srpska and Bosnia and Herzegovina. As a fuel supply chain for the CHP facility with the ORC process and hot water boiler, the chain of wood chips obtained by means of a mobile chipper has been used. Table 1 presents the optimization criteria calculated with the help of a model made using MathCAD software for the analysed energy production chains. For the input of data which describe the real state of solid fuels production (wood chips and pellet), the data from sawmills and companies in Republic of Srpska/Bosnia & Herzegovina have been used. The companies are as follows: "Company for making of wood packaging and production of eco briquettes–pellets, EU PAL L.L.C. Pale", sawmill "GOD" L.L.C. Han Pijesak, sawmill "MTK OMORIKA" L.L.C. Han Pijesak, company for transportation of timbering and assortments "KINGDOM" L.L.C. Han Pijesak, City heating plant in Prijedor. For an average fuel consumption and the specification of wood mechanization included in the production of wood fuels, the results from study [17] have been used. The production of pellet is determined by a chain consisting of saw, tractor, lifter, truck, fork lift, dryer and facility for pelleting. In the pellet production chain, there are two transportations: the transportation of timbers (60 km) and the transportation of

http://dx.doi.org/10.5772/62537

wood residue to the pellet facility (30 km). The total distance is 90 km of transportation to the final product. The production of wood chips by mobile wood chipper is determined by the chain which consists of saw, skidder, mobile chipper and truck for the transportation of wood chips. The work of skidder in the forest is predicted on a short distance of 1 km. The transportation of wood chips is performed with a truck with the total truck body volume of 60 m^3 at the distance of 90 km. Other data related to the biomass fuel supply chain are: the price of a litre of gas/oil of 1€, the price of wood residue from the sawmill—0.0563 €/kWh, drying of wood residue from 50 to 12% for pellet production, wage of 12–15 €/day for workers and wage of 25 €/day for a truck driver. For the calculation of parameters from f_{1j} to f_{6j} which are related to the production of pellet and wood chips by means of a mobile chipper, the formulae (1) and (21–36) have been used.

Energy chain: production of heat and electricity, production of pellets, heat generation			
Description of energy chains	CHP with ORC process	Process of production of wood pellets	Hot water boiler
Moisture content in wood fuel	50%	50%	50%
Solid wood fuels:	Wood chips from mobile chipper, fir	Sawmill wood residue, fir	Wood chips from mobile chipper, fir
Energy and exergy efficiency of wood chips produced by mobile chipper	$f_2 = f_1 = 0.97$		$f_2 = f_1 = 0.97$
Criteria for the selection of optimal energy chain obtained from the model developed in Mathcad software			
Overall energy efficiency of chain	0.743	0.684	0.807
Overall exergy efficiency of chain	0.223	0.684	0.155
Coefficient of exergy quality	0.385	0.122	0.287
Total specific investment cost per total installed power in the energy chain, EUR/kW	3.149×10^3	5.263×10^3	1.235×10^4
Total specific production cost, EUR/kWh	0.044	22.37×10^{-3}	0.054
Total specific emissions of CO_2, kg/kWh	0.015	51.695×10^{-3}	0.018

Table 2. Basic parameters and results of model testing at the selection of optimal variant of the energy chain.

The data on the analysed technologies for the ORC process and hot water boiler have been taken from the documentation for the installation of these systems in the City District Heating Plant from Prijedor (Bosnia and Herzegovina) [33].

General information about CHP plant with ORC process, option 1:

$P_n = 5140$ kW, nominal power of thermo-oil boiler

$P_e = 1000 - 50 = 950$ kW, installed electric power of plant reduced by own consumption

$P_t = 4095 - 400 = 3695$ kW, installed heat power of plant reduced by own consumption for drying fuel

$T = 353$ K, outlet temperature of water from CHP process to district heating grid

$T_0 = 273$ K, reference temperature of environment

$m_f = 2200$ kg/h, fuel consumption

$H_d = 9929$ kJ/kg, lower heating value of fuel for moisture content 43%

$I_M = 4083674.99$ €, total investment cost for plant

$P_M = 5095$ kW, total installed power of CHP plant

General information about wood pellet plant, option 2:

$\eta_{Cel} = 0.36$, the efficiency of electrical power generation from thermal power plants to the consumption

$F_{PC} = 2$ t/h, pellet plant productivity

$P_C = 500$ kW, total installed electrical power in pellet plant taken from real factory, EU Pale DOO

$eh_{V0} = 19.49$ MJ/kg, lower heating value of dry wood, fir

$w = 12\%$, moisture content

$\rho_0 = 450$ kg/m^3, density of dry wood, fir

$\alpha_v = 8\%$, the percentage of swelling for fir

$\eta_t = 0.8$, factor of simultaneity work of all electric drives in plant

$Ce = 0.09$ €/kWh, price of 1 kWh of industrial electrical energy

$e_f = 100$ kg CO_2/GJ, specific emission coefficient of CO_2 for stone coal

$I_M = 650{,}000$ €, total investment in pellet plant

$P_M = 1946$ kW, total installed power in pellet plant, heat + electrical power

General information about the hot water boiler, option 3:

$P_t = 10{,}000$ kW, output thermal power from heating plant

$T = 383$ K, outlet temperature of water from boiler

$T_0 = 273$ K, reference temperature of environment

$m_f = 5570$ kg/h, fuel consumption

$H_d = 7500$ kJ/kg, lower heating value of fuel for moisture content 50%

$I_M = 6{,}855{,}949$ €, total investment in boiler

$P_M = 10{,}000$ kW, thermal power of boiler

http://dx.doi.org/10.5772/62537

The calculation of criteria for the optimization of tested energy chains has been performed with the help of the formulae (2)–(6). For the selection of the optimal variant of energy chain, formulas (9)–(19) have been used. The check of stability and acceptability of the solution has been performed with the help of Equation 20.

Due to the optimization model at the comparison of incomplete energy chains and different qualities of energy production, the combined production of thermal energy and electricity in the facility with the ORC process has been obtained (the blue column in Table 2). This solution has both the necessary stability of the solution and the sufficient advantage in relation to the second-ranked variant. It is interesting to notice that pellet production is the second-ranked variant. It can be concluded from that that, under the conditions of testing with model, the advantage is given to pellet production in relation to heat production. However, for a complete valorization of the process, it is also necessary to take the process of pellet transportation into account. In that case, much clearer situation is obtained on this advantage of fuel production in relation to heat production. This case of model testing serves for the quality evaluation of different forms of energy (electricity, thermal energy and fuel). In that set, there are different and incomplete energy chains. Such analysis and optimization process are obtained by the factor of exergy quality (see Table 1 and Equation 5). Electricity has the highest factor of exergy quality, and it is equal to the number 1. All other values of this factor for heat and fuel are smaller than the number 1. In the analysed optimization process, at the selection of an optimal variant of energy chain, in the third case of the model testing, the factor of exergy quality for wood pellet fuel is equal to the exergy efficiency of electricity production in the ORC process, and is 0.122. Generally, if there had been several energy chains which produce electricity, either averaged values of this factor from several different technologies to be compared or the factor with the smallest value of transformation of fuel into electricity could be taken as a valid factor of exergy quality. The factor of exergy quality enables the reduction of energy production process per cumulative kilowatt hour of thermal energy and electricity. This effect has a large application in the evaluation of the production cost and specific emission of CO_2 reduced per cumulative kilowatt hour of thermal energy and electricity produced, 1 kWht+e. A conclusion can be made from this on the great significance of exergy-economic analysis of energy processes. All the data for the analysed technologies have been disclosed by the district heating plant in Prijedor.

8. Conclusions and discussion

Developed mathematical model described in this paper defines adequate universal criteria, which describe biomass energy chains and which are adapted to the process of multicriteria optimization. These criteria are related to total energy efficiency of a production chain, total exergy efficiency of a production chain, factor of exergy quality of different energy forms, total production cost per 1 kWh of energy produced, total investment cost per total installed power in an energy chain, total emission of fossil fuels consumed for the production of 1 kWh of fuel, heat or electricity. This approach combines the most significant specific criteria for the description of the entire chain of energy production and gives the possibility to compare the energy chains as well as selection of the optimal variant for the production of fuels and/or different forms of energy from biomass. The optimal variant is obtained on the basis of multicriteria optimization, by using the adapted VIKOR method. The verification of the developed mathematical method has been done on the application of energy and fuel supply from biomass. In the calculation part, three energy chains have been used for the verification of the concept, whose criteria for optimization are provided in Table 1. These energy chains are the ORC process with combined production of thermal energy and electricity, the process of wood pellet production (solid fuel) and the process of thermal energy production by means of a hot water boiler, for district heating purposes. All three variants of energy chains produce different energy forms which have a different quality of output products. For that reason, such energy chains have been selected to demonstrate the universality of the model application to the analyses of other energy and fuel production processes as well. It should be noted that the exergy quality factor of produced energy allows comparison of different energy forms. The proposed criteria for optimization are closely related to technical–technological, thermodynamic, economic and ecological characteristics which describe energy chains. Of course, the physical basis of the proposed criteria for the optimization of energy chains is based on the concept of sustainability. Depending on the initial data on the basis of which the criteria for the optimization of energy chains are calculated, these criteria, at the same time, give the information on the current state of development at which the applied technologies and the ways of energy production are. From the set of different chains of energy production described with the suggested optimization criteria, it is possible to select the variant of energy production which is optimal. The selected optimal variant is, at the same time, the one closest to the sustainable way of production of energy and/or fuels in the observed set of defined energy chains. The developed mathematical model and the suggested concept have a large practical application in the selection of an optimal variant of production of biofuels and/or production of energy from biomass in defined real conditions. Besides that, the model can also be used in the process of designing and establishing of energy production chains, both from biomass and from some other sources. From the aspect of energy chains of energy production, the model is very universal and can be equally applied to any other energy supply chains.

Author details

Srđan Vasković[1*], Petar Gvero[2*], Vlado Medaković[1] and Velid Halilović[3]

*Address all correspondence to: srdjan_vaskovic@yahoo.com and gvero.petar@gmail.com

1 University of East Sarajevo, Faculty of Mechanical Engineering, East Sarajevo

2 University of Banja Luka, Faculty of Mechanical Engineering, Banja Luka

3 University of Sarajevo, Faculty of Forestry Engineering, Sarajevo, Bosnia and Herzegovina

References

[1] Vučijak B., 2007. Multicriteria optimization in space management, scientific contributions. Space, 33, 108–117.

[2] Mutikanga H.E., 2012. Water loss management: tools and methods for developing countries. Thesis, Delft University, Netherlands.

[3] Scott A., Ho W., Dey P.K., 2012. A review of multi-criteria decision-making methods for bioenergy systems. Energy, 42(1), 146–156.

[4] Chau J., Sowlati T., Sokhansanj S., Preto F., Melin S., Bi X., 2009. Techno-economic analysis of wood biomass boilers for the greenhouse. Applied Energy, 86(3), 365–371. doi: 10.1016/j.apenergy.2008.05.010.

[5] Kumar A., Flynn P., Sokhansanj S., 2008. Biopower generation from mountain pine infested wood in Canada: an economical opportunity for greenhouse gas mitigation. Renewable Energy, 33(6), 1354–1363. doi: 10.1016/j.renene.2007.07.008.

[6] Danon G., Furtula M., Mandić M., 2012. Possibilities of implementation of CHP (combined heat and power) in the wood industry in Serbia. Energy, 48(1), 169–176. doi: 10.1016/j.energy.2012.02.073.

[7] Ng K.S., Sadhukhan J., 2011. Techno-economic performance analysis of bio-oil based fischer-tropsch and CHP synthesis platform. Biomass and Bioenergy, 35(7), 3218–3234. doi: 10.1016/j.biombioe.2011.04.037.

[8] Bridgwater A.V., Toft A.J., Brammer J.G., 2002. A techno-economic comparison of power production by biomass fast pyrolysis with gasification and combustion. Renewable and Sustainable Energy Reviews, 6(3), 181–246. doi: 10.1016/S1364-0321(01)00010-7.

[9] Kumar A., 2009. A conceptual comparison of bioenergy options for using mountain pine beetle infested wood in western Canada. Bioresource Technology, 100(1), 387–399. doi: 10.1016/j.biortech.2008.04.077.

[10] Sarkar S., Kumar A., Sultana A., 2011. Biofuels and biochemicals production from forest biomass in western Canada. Energy, 36(10), 6251–6262. doi: 10.1016/j.energy.2011.07.024.

[11] Althaus H.J., Bauer C., Doka G., Dones R., Frischknecht R., Hellweg S., Humbert S., Jungbluth N., Köllner T., Loerincik Y., Margni M., Nemecek T., 2010. Implementation of Life Cycle Impact Assessment Methods, St. Gallen, Swiss Centre for Life Cycle Inventories.

[12] Yue D., Kim M.A., You F., 2013. Design of sustainable product systems and supply chains with life cycle optimization based on functional unit: general modeling frame-

work, mixed-integer nonlinear programming algorithms and case study on hydrocarbon biofuels. ACS Sustainable Chemistry & Engineering, 1, 1003–1014.

[13] Librenti E., Ceotto E., Candello M., 2010. Biomass Characteristics and Energy Contents of Dedicated Lignocellulose Crops, Biomass and Waste 3, 7–8.

[14] Hall C., 2011. Introduction to special issue on new studies in EROI (Energy Return on Investment), Sustainability, 3(10), 1773–1777.

[15] Honorio L., Bartaire J., Bauerschmidt R., Ohman T., Tihany Z., Zeinhofer H., Scowcroft J., Vasco de Janerio K.H., Meier H., Offermann D., Lnagnickel U., 2003. Efficiency in electricity generation, Report drafted by Eurelectric ”Preservation of resources“, working groups “Upstream”, Subgroup in collaboration with VGB.

[16] Vasković S., Halilović V., Gvero P., MedakovićV., MusićJ., 2015. Multi-criteria optimization concept for the selection of optimal solid fuels supply chain from wood biomass. Croatian Journal of Forest Engineering, 36(1), 123–129.

[17] Krajnc N., 2011. Wood Energy Technologies, Partnership Programmes—TCDC/TCC–TCP/YUG/3201 (D), Belgrade.

[18] Cornelissen R.L., 1997. Thermodynamics and sustainable development: the use of exergy analysis and the reduction of irreversibility. PhD thesis, University of Twente, The Netherlands.

[19] Torío H., Angelotti A., Schmidt D., 2009. Exergy analysis of renewable energy-based climatisation systems for buildings: a critical view. Energy and Buildings, 41, 248–271.

[20] Kotas T.J., 1985. The Exergy Method of Thermal Plant Analysis, Tiptree, Essex, Anchor Brendon Ltd.

[21] Acar B., 2008. An analysis on the utilization of energy and exergy in Turkey. Master thesis, Graduate School of Natural and Applied Sciences of Middle East Technical University.

[22] Kaushik S.C., Reddy V.S., Tyagi S.K., 2011. Energy and exergy analyses of thermal power plants: a review. Renewable and Sustainable Energy Reviews, 15, 1857–1872.

[23] Park C.S., Contemporary Engineering Economics, Fourth Edition, Prentice-Hall, 2007, New Jersey, USA, ISBN: 0131876287, 9780131876286.

[24] White J.A., Case K.E., Pratt D.B., 2009. Principles of Engineering Economic Analysis, Fourth Edition, John Wiley & Sons, Hoboken, New Jersey, USA.

[25] Geldermann J., Rentz O., 2004. The reference installation approach for the techno-economic assessment of emission abatement options and the determination of BAT according to IPPC-directive. Journal of Cleaner Production, 12, 389–402.

[26] IPCC Third Assessment Report: Climate Change, 2001. Technical report, Intergovernmental Panel on Climate Change, PUBLISHED BY THE PRESS SYNDICATE OF THE

UNIVERSITY OF CAMBRIDGE, The Pitt Building, Trumpington Street, Cambridge, United Kingdom, ISBN 0521 80767 0.

[27] NGA Factors, 2014. Australian National Greenhouse Accounts, Australian Government, Published by the Department of the Environment, Commonwealth of Australia, ISSN: 2202-333X.

[28] Herold A., 2003. Comparison of CO2 Emission Factors for Fuels Used in Greenhouse Gas Inventories and Consequences for Monitoring and Reporting under the EC Emissions Trading Scheme, ETC/ACC Technical Paper 2003/10, European Topic Centre on Air Pollution and Climate Change Mitigation, The Netherlands.

[29] Opricović S., 1998. Multicriteria Systems Optimization in Construction, Civil Engineering, University of Belgrade, Belgrade.

[30] Danon G., Bajić V., Isajev V., BajićS., Orešćanin S., Rončević S., 2003. Residues from wood biomass processing and possibilites for energy crops and forest, Chapter 2, in Energy Potential and Characteristics of Biomass Residues and Technologies for Application in Serbia, Belgrade, Faculty of Forestry, Public Company, Srbijašume, Institute for Poplars, pp. 25–26.

[31] Perrot P., 1998. A to Z of Thermodynamics, Published in the United States by Oxford University Press, Inc., New York, ISBN 0-19-856552-6.

[32] Devki Energy Consultancy Pvt. Ltd., 2006. Best Practice Manual “Drayers,”Indian Renewable Energy Development Agency, Vadodara, Ivory Terrace, New Delhi, India, 405 p.

[33] Grontmij A.B., 2014. Final Report: Heating Plant Prijedor–Feasibility Study, Contract Number EBDR C27868/SWME-2013-09-02, Financed by the Swedish Agency for International Development (Sida), Stockholm, Sweden., Enova Sarajevo d.o.o., Sarajevo.

INTECH

Chapter 10

Support International Business Expansion with Sequential Reviews

Rui Fernandes and Carlos Pinho

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/62987

Abstract

This chapter is about the multinational company's decision on whether to enter new foreign markets using direct investment, exporting, or developing a local partner for distribution, with the possibility of scaling the investment under different demand levels. The perception of the host market demand does not remain the same during the investment period due to additional information and economic or political reasons. Therefore, the influence of uncertainty can be addressed by recombining a trinomial lattice model with changing uncertainty, to value investments with several interacting options. Overall, in this chapter we enhance the knowledge associated with exploring foreign markets subject to different demand uncertainties, valuing the flexibility of sequential options.

Keywords: multinational corporations, international business, investments, demand uncertainty, real options

1. Introduction

The recent global financial and sovereign debt crisis stressed the impact of globalization in the world business environment. In this scenario, international transactions and foreign investment continue to be key drivers of globalization and, in the aftermath of the crisis, the impact of the latter has become even more relevant.

The technology has shortened the distance between countries [1, 2]; consequently, it became easier for companies to expand on new foreign markets (FMs), and globalization became an important factor for the world's economy. Hence, competition among multinational companies (MNCs) and also countries is growing. Therefore, it is important for small, middle-sized, and big companies to constantly find new ways to stand out, and expanding on the global market is one way to grow fast since MNCs reach out to new customers' acquisition.

A fundamental problem in new foreign market approach is how the market should be served, considering the inherent costs of doing business abroad, the investment time, and the decision risk frame. There are many reasons, such as limited home market, cost advantages, scale economies, product differentiation, or brand reputation, to support business enlargement into FMs. Despite the possible advantages, there are always doubts regarding the entry mode (EM) choice, related investment scale and time, the demand uncertainty, and consequent risk that the MNCs wish to afford.

The foreign market demand variation is challenging, as there is not always known process (linear or not) and the volatility does not remain the same during the investment period. Volatility tends to decline over time when many investment projects are scaled, as new information and knowledge is gathered. Then, after gathering information about FM and MNC's own activity development over time, more reliable estimation of the investment's expected value and its volatility can be made. Therefore, FM demand volatility is often time changing and declining [3]. The valuation method used for investment return evaluation should also take this into account.

Research on FM direct investment has focused considerable attention on the moment of market entry and EM choice, but less on the dynamics of investment in the postentry phase [4]. In this chapter, we alternatively provide a sequential approach to the traditional evaluation using a discounted cash flow technique, to support the choice of the EM (own company, direct exporting, local distributors, or joint ventures). In fact, managerial decisions related to the projects are usually not taken continuously but rather at certain time periods (milestones). The decisions and subsequent options are made mostly at specific time points when new information from own experience and markets is gathered and analyzed. As a result, an investment can be considered as a staged investment or like a sequence of options.

The setting when an MNC seeks to sell its products in a new FM is that the revenues are uncertain during time. In entering the FM, the MNC can decide to invest immediately, in its own sales operation, or eventually invest later, using better market knowledge. An investment decision in FMs is subject to several different host market volatilities over time (modeling period), which requires adjusting the exercise dates, values, and risk frame to support such decision nodes. As such, any contribution that addresses the market challenges that early internationalizing MNCs face is of key importance, when they compete in constantly changing FM.

The purpose of this research is to find a solution to the following research questions (RQs), while deriving some hypotheses (HPs) that need to be tested:

RQ(1): New information and time experience will decrease the demand volatility level in the host market, what is the impact on the subsequent investment decisions?

HP(1): Testing different host market volatilities for each investment period.

RQ(2): Scaling the investment will decrease the risk and the costs of an abandonment option in postentry phases, more steps means less risk and valuable options?

HP(2): Scaling investment, that is, testing different investment values during the analysis period using a sequential approach.

MNCs must meet the challenge of establishing direct investment under high levels of uncertainty in the host market. A common procedure is to start a foreign subsidiary with little capital and enlarge it later on with additional investments. In this chapter, we study the influence of different perceived levels of uncertainty, by using a sequential approach, to explain the scale of investment in new FM. In spite of a large amount of literature about foreign direct investment, these sequences have to be supported in a dynamic quantified model.

This chapter is organized as follows. Sections 2 and 3 describe the background theory and the reasoning for sequential investments, respectively. Section 4 explores the entry mode theory. Section 5 presents the formulation of the model, with generic sets. Section 6 describes model application, and presents and discusses the results. Finally, the chapter concludes in Section 7 with some final remarks, limitations, and a discussion on future research.

2. Sequential investments

Most of the theories on foreign direct investment center on the decision to initially enter an FM [5–8], but pay less attention to investment decisions after market entry. Since subsequent investment decisions are often substantial [9], the postentry phase and strategic positioning deserve greater attention [10].

Some analyses of international investment recognize the need to investigate the time dimension, but postpone it to future research [11, 12]. Other studies observe sequences of investment, but do not intend to explain their timing [13, 14]. Studies on the timing of investment are limited to international entries [15–17]. The knowledge gap between the initial setup and final operation of an MNC may result from a dynamic deficit of the established theories of internationalization [18].

In a learning process that starts at entry, investors perceive different levels of uncertainty and tend to shift their reasoning for investment over time as new information is gathered; however, most of the times it is based only on market experience. The quantification of the investment returns indicated that economic models highlight the importance of uncertainty to the flow of foreign direct investment [19, 20], as market experience does not fully explain subsequent investment decisions under environmental uncertainty. Uncertainty is a key factor influencing a firm's rate and scale of investment [21–24]. According to the results of these studies, under uncertain environments, investors tend to wait, that is, keep their decisions open instead of investing right away. It has been suggested that international investors react to uncertainty by maintaining flexibility (investment or not) as well [25–27].

3. The Uppsala model

There are many steps for MNC internationalization and several factors that need to be considered, such as transports, communication, contracts, and hired personnel, but one of the most important factors is to find the right location. These factors can be a challenge when the distance and the business differences between home market and FM are big. The lack of knowledge might post barriers of entry on the FM for MNC. To be able to face these internationalization challenges, time, money, and information are important MNC resources [28]. The information flow between the MNC and the host market is an important challenge for MNCs, since the language, business rules, traditions, and industrial setup mostly differ from the home market. In the internationalization process, MNCs can explore their new FM in a more effective way when they improve knowledge about the host market [29, 30] to support the right decisions. Businesses have to first develop on a local, regional, or national level before taking the next step to expand on a new FM. The Uppsala model, developed by Johanson and Vahlne [30], explains the internationalization process using a step frame.

The Uppsala establishment chain model is one of the most frequently cited models in the internationalization of MNCs [31–33]. Based on the concept of postentry phase, it proposes that the progressive acquisition of market experience is the major factor which influences the growth of an MNC. The distance is a key factor in this model, which means that differences in the business environment, language, and habits could be obstacles for MNCs that are planning to expand on FMs. Another key factor is the knowledge about the FM. With detailed knowledge, the uncertainty could decrease; for this reason, MNCs usually decide to do business with geographically close countries instead of long-distance countries and markets. Based on this model, it is assumed that many MNCs, at least in the beginning, use for instance intermediates, such as agents or others, to be able to sell abroad within a limited level of committed resources [30].

MNCs have to first develop on a home market level before taking the next step to expand on FMs. The Uppsala model suggests that MNCs could generate knowledge by exploring the FMs on their own. The more knowledge MNCs collect about an FM by own experience, the better they will manage future uncertainties and risks [30].

According to the Uppsala model, MNCs face four challenges while exploring FMs. These four challenges are as follows: (1) market knowledge, (2) market commitment, (3) commitment decision, and (4) current activities. Market knowledge and market commitment have an impact on implementation of activities and investment decisions. The model therefore suggests that an MNC should invest in one or a few close markets to be able to, later on, and step by step, after having gathered relevant information and experience, expand to other long-distance markets. The model is categorized into two types of knowledge: objective knowledge, which can be transferred from one market to another; and the experiential knowledge, which is the type of hands-on knowledge an MNC learns by doing business abroad. When the MNC has gained relevant knowledge about a specific foreign market, it can decide how to enlarge commitment and establish a plan for further resources allocation [29, 30].

Despite the reasonability of the model, some critical views can be discussed. The step-by-step functionality of the model has been highly criticized. Studies have shown that it is possible to achieve internationalization faster as MNCs tend to overlook some steps that are described in the model [34]. Theoretical assumptions of perfect information, symmetry in risk aversion, and rational decision making may not occur in real circumstances [35] and decision makers can be affected. It is important, however, to support the decisions and options taken on a quantitative approach to understand the impact of a smooth investment versus a fast investment, highlighting the positive impact of decreasing the value of abandonment options during an internationalization process timeframe.

4. Entry modes

Exporting is seen as the first step for entering an international market since it works as a platform for future international expansions [35, 36, 37]. Exporting means the least change for the company. Most often MNCs begin with indirect exporting, which means working through intermediaries, like agents. This means less investment to commit and fast "new" market acquisition. Direct exporting is usually the second step and it means that the company handles their own exports [29]. The risk is higher with this strategy, but the possible future return is also higher. There are different ways to handle the direct exporting. One way is to setup an export department in the home country of the company, which carries out all the export activities. The company could also settle an international foreign sales representative office to handle sales and distribution tasks abroad [38].

Joint venturing is another way of entering a market with proved advantages [39]. This method means joining a foreign company to market the products or services (market acquisition). There are four types of joint ventures: licensing, contract manufacturing, management contracting, and joint ownership. When a company joins with foreign investors to start a local business, they join ownership. This ownership is owned and controlled by both parties, on a uniform basis. An MNC can either buy a local existing firm or two companies can start a whole new business idea. Some countries demand companies to joint ownership as an entry mode because of certain political reasons [38, 40].

Direct investment is about entering the FM by developing foreign-based subsidiaries. When using this kind of entry mode, an MNC can strengthen its image since it creates job opportunities, and it can also strengthen the relation with the government, customers, local suppliers, and distributors. It is adequate for a push strategy, when training and communication are the key factors. Responsibilities, currencies, and legal changes are additional risks that a firm has to deal with when operating through direct investment [38, 41].

5. The model

Let us consider an MNC that has recently decided to expand its operation abroad. Following the initial decision to expand activity by direct exporting, investors must make subsequent decisions to commit additional capital and resources. These decisions are made under host market demand uncertainty, and such decisions are often irreversible once the capital is invested and resources are committed. We assume that the initial and following investments are at least partly irreversible because the subsidiary's activities require specific assets (normally locally located) such as service tools or store facilities, and there are initial installation costs, such as licensing and other legal requirements. Although our research does not specifically focus on FM location choice, we introduce the tax rate in the model formulation to support several alternatives regarding FM location. Tax issues are relevant as different countries have different rules and apply different tax rates.

Despite these daunting aspects of such decisions, the investor is free to choose the timing of additional investment, which can bring a change in the EM—sequential approach from one stage to another—and also an increase in investment at a particular stage. The opportunity to add capital to such expanding operation at a later stage, eventually through a foreign subsidiary or a branch, can be considered as a "call option"—buy additional returns [42]. Under high demand uncertainty, the investor may have retained part of the investment and created a tradeoff purposely to possibly invest more at a later moment, when the uncertainty level has decreased or proves to be constant. Or, perhaps the investor recognizes ex-post that the initial investment was a precondition for a larger investment, even though this expanded financial commitment was not originally intended [43]. Thus, the level of uncertainty at entry and the amount of the initial investment are not causal determinants for subsequent investment decisions.

In the model formulation, we will use the Uppsala theory that explains two important patterns in the internationalization of the firm [44]. First, firms investing in FMs follow an establishment chain, which means that investments are partial and broken down into small steps. At a first moment, there is no regular export activity, so companies start approaching independent foreign sales agents. When the firm acquires additional knowledge and experience about the host market, it often decides to establish a local partnership, preparing conditions for a further step creating its own sales structure [45].

We will quantify the impact of future additional alternatives to support changes in the investment value to be committed versus an initial option on one of the available entry modes.

To support the model formulation, we assume that the demand in the FM to be explored is uncertain, depending on the market size and potential growth opportunities [46, 47]. We include factors such as operating revenues and costs in the model to support the expansion alternatives [48].

Generally, we consider a situation in which an MNC "X" of established portfolio $P = \sum p_i$, located in origin country (C_0), has decided to sell its products in an FM, $f \in F$, a market in which "X" has no sales experience. Among the options available for selling in *f*, we find the following five factors as potentially profitable: (a) direct exporting (DE), (b) using local distributors (DELD), (c) establishing a own company (OC) in the form of a subsidiary (SUB) or (d) a representative office/branch (BRA) to support the sales operation, and (e) eventually a participation in a joint venture (JV).

The main source of uncertainty affecting the investment decision is the market demand D_f. As a consequence of MNC's unfamiliarity with the host country, the investor perceives a significantly higher degree of uncertainty than in a domestic environment [49]. It is possible that the investor consciously reacts to uncertainty by limiting the capital at entry and waits for an increase in the demand to support the decision to commit capital [43].

We assume that the demand is a stochastic variable, denoted by "D_f." To simplify the model formulation, we also assume that the decision to invest in an FM is mainly affected by profit advantages (simplification also defended by Hamada [50]; however, we stress on the importance of firm-specific competitive advantages in FM strategy through proper market positioning such as the degree of product differentiation. Hymer's [51] theory highlights the reasons that justify the existence of an MNC based on the inclusion of firm-specific advantages such as better access to raw material and intangible assets such as trade names, patents, and superior management.).

The problem resolution will be performed according to each hypothesis and research question already discussed in Section 1.

We now list the sets and indices to support a general application for different EMs and business realities:

- $F=\{1, 2, .., l\}$: foreign countries (=FMs), each country is represented by $f \in F$, where l represents the total number of available locations: $|F|=l$.
- $R_f \subset F$: R_f is a subset of F that represents the profit tax rate inside each FM $f \in F$ and is represented by $r_f \in R_f$.
- r_0: it represents the profit tax rate on the origin country C_0.
- $\tilde{\lambda} = \{\text{DE}, \text{DELD}, \text{SUB}, \text{BRA}, \text{JV}\}$: alternative foreign EM, represented by λ, where $|\tilde{\lambda}| = 5$.

To facilitate the formulation of the model, we introduce the following notation:

- $K_f(\lambda)$ represents the present value of investment scaled by $n \in N$, where N refers to the number of steps (nodes), for each EM $\lambda \in \tilde{\lambda}$ and FM $f \in F$.
- $\phi_f(\lambda)$ represents the operating costs to run the business after investment, for each EM $\lambda \in \tilde{\lambda}$ and FM $f \in F$.
- c_v represents the unit product variable cost.
- $p_{vf(\lambda)}$ is the unit product selling price for each EM $\lambda \in \tilde{\lambda}$ and FM $f \in F$.
- c_{DELD} represents the coparticipation on sales value, applied to a local distributor.
- tp represents the unit transfer price.
- ρ is the discounted rate.

- χ is the participation (%) on a JV company, where $\chi \geq 50\%$.
- $N = \{0, 1, \ldots, n, n+1, .., n+q\}$: the number of nodes used in the simulation tree.

As Pindyck[52] shows, there is a numerical solution to find an optimal strategy of incremental investment under uncertainty. Let $K_f(\lambda)$ be the capital invested in market $f \in F$ and D_f the demand for a good in market $f \in F$ that is produced using $K_f(\lambda)$. The value of the investment object $\mathrm{ROI}_f(\lambda)$:

$$ROI_f(\lambda) = C\left[K_f(\lambda), D_f\right] + V\left[K_f(\lambda), D_f\right] \quad (1)$$

Eq. (1) consists of two parts: the value C of the capital already invested and the value V of the option to invest more capital, scaled using $\eta \in H$. Deconstructing the capital into marginal units of investment, the equation reads

$$ROI_f(\lambda) = \int_0^n \Delta C\left(v, D_f\right) dv + \int_n^{n+1} \Delta V\left(v, D_f\right) dv + \ldots + \int_{n+q-1}^{n+q} \Delta V\left(v, D_f\right) dv \quad (2)$$

The investor raises the stock of capital until the value of a marginal unit of capital invested equals its costs plus the opportunity cost of the irreversible decision to exercise the related growth option:

$$\Delta C\left[K_f(\lambda)^*, D_f\right] = s + \Delta V\left[K_f(\lambda)^*, D_f\right] \quad (3)$$

where $K_f(\lambda)^*$ stands for the optimal capital.

The simulations done, assuming a stochastically evolving demand and using dynamic programming, suggest that even in environments of moderate levels of uncertainty, the investors tend to wait for demand to increase before they decide to add capital.

To proceed with the modeling and support the return on investment (ROI) calculation $\mathrm{ROI}_f(\lambda)$, we assume the following formulas for each profit function, $\pi_{(f)}(\lambda)D_f : \lambda \in \hat{\lambda}$:

http://dx.doi.org/10.5772/62987

$$\begin{cases} \pi_{(f)}(DE)D_f = D_f\left(p_{vf(DE)} - c_v\right)(1-r_o) - \phi_{f(DE)}(1-r_o) - \rho K_{f(DE)}e^{\rho}, \\ \pi_{(f)}(DELD)D_f = D_f\left(p_{vf(DELD)} - c_v - c_{DELD}\right)(1-r_o) - \phi_{f(DELD)}(1-r_o) - \rho K_{f(DELD)}e^{\rho}, \\ \pi_{(f)}(SUB)D_f = D_f\left[\left(p_{vf(SUB)} - tp\right)(1-r_f) + (tp - c_v)(1-r_o)\right] - \phi_{f(SUB)}(1-r_f) - \rho K_{f(SUB)}e^{\rho} \\ \pi_{(f)}(BRA)D_f = D_f\left[\left(p_{vf(BRA)} - tp\right)(1-r_f) + (tp - c_v)(1-r_o)\right] - \phi_{f(BRA)}(1-r_f) - \rho K_{f(BRA)}e^{\rho}, \\ \pi_{(f)}(JV)D_f = D_f\left[\left(p_{vf(JV)} - tp\right)(1-r_f)\chi + (tp - c_v)(1-r_o)\right] - \phi_{f(JV)}(1-r_f)\chi - \rho K_{f(JV)}e^{\rho} \end{cases}, f \in F \quad (4)$$

The return on investment algorithm we propose is based on the following steps:

1. Calculate the jump sizes (moves up, down, and middle). These are u, d, and m.
2. Calculate the transition probabilities of various host market demand movements p_u, p_d, and p_m.
3. Build the options tree.
4. Calculate the payoff of the ROI at maturity, based on the profit function—$\pi_{(f)}(\lambda)D_f$—for each EM $\lambda \in \hat{\lambda}$, at the last node $\in N$;

   Calculate ROI at each node $\in N$ based on (or terminal condition of our ROI at maturity, that is, the end (or leaf) nodes) the following equation:

$$ROI_f(\lambda)_{n,j} = e^{-r\Delta t}\left[p_u ROI_f(\lambda)_{n+1,j+1} + p_m ROI_f(\lambda)_{n+1,j} + p_d ROI_f(\lambda)_{n+1,j-1}\right] \quad (5)$$

   where n represents the time position and j is the space position.

5. The output is the return on investment $\mathrm{ROI}_f(\lambda)$.

We can calculate the ROI value at interior nodes of the tree by considering it as a weighting of the ROI value at the future nodes, discounted by one time step.

6. Simulation

We tested the application of the model for an MNC with a plant located in Portugal and the possibility to expand its distribution to an FM by selling directly or exporting, or selling through a subsidiary or a distribution center established in a foreign country, Netherlands (NL). The parameters used are adapted from actual figures to ensure the required confidentiality; however, such assumptions will not affect the results as we maintain the same proportion between parameters. In NL, the corporate tax rate is 20% up to EUR 200,000 and 25% above EUR 200,000, for resident and nonresident MNCs. In Portugal, the tax rate is 25%, with exceptions only for activities not connected with agricultural, industrial, or commercial scope. After the combined analysis of the nature and materiality of the linked transactions, as well as the functions performed and risks assumed by the parties involved in the same corporation, documented policy for setting TP in intragroup transactions adopted the "Principle of Full Competition."

Although case studies inevitably lose representativeness, the power of the case study just lies in its capacity to provide insights and resonance for the reader and it is not true to claim that case studies lack generalizability [53] because case studies can be used like experiments to test a theory.

In the case study, we use a manufacturing company, and the application will mainly point out target, for international expansion, and the expected turnover, however not ignoring operating costs in the model. Dawson [54] stressed the difference in retailing companies' internalization strategy—establish their stores in the foreign markets, just in order to promote the sales growth; and manufactures extend their business outside the home countries, just in search for the cost efficiency, such differentiation will be ignored to enlarge the scope of the model application.

We proceed with two sets of the model. First, the relevance of the market demand uncertainty and the tendency of expected returns over time to test hypothesis 1. The level of international experience that the investor has accumulated prior and following the entry is a variable that drops out in a relation with the increased knowledge of the market. Therefore, hypothesis 1 is also tested.

Figures 1 and **2** are used to test hypothesis 1, specifically, to explore the relation between ROI and FM demand volatility levels for a given number of investment periods.

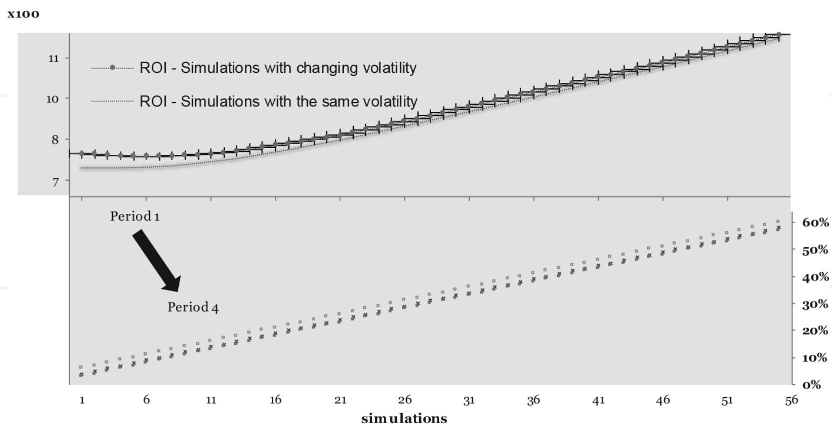


Figure 1. Hypothesis 1: ROI (investment scaled in four periods) and increasing FM demand volatility levels for investment periods.

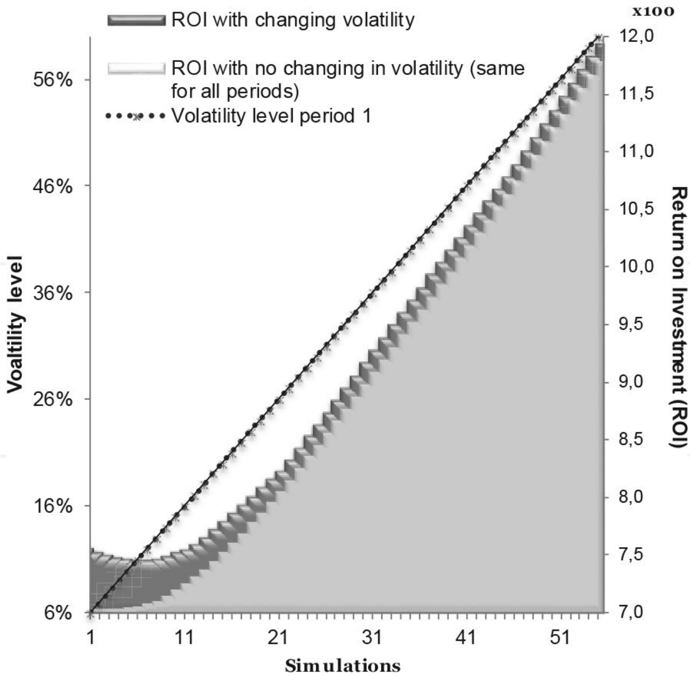


Figure 2. Hypothesis 1: testing the ROI with FM demand volatility level increasing in period 1.

Figures 1 and 2 demonstrate how FM demand volatility changes affect the investment decisions. The higher the volatility, the stronger the ROI, applied for all the periods in which an investment can be scaled. When volatility changes along investment timeframe, assuming that the volatility decreases with market additional information and relevant knowledge along the decision milestones, the return on investment increases, meaning that a flexible investment plan, with different decision points, can be more attractive when compared with an inflexible one [55]. The impact of changing the volatility levels in different periods versus a fixed volatility level (traditional approach) for all the periods is more intensive for low uncertainty levels.

Second, the panel is divided into different phases after entry. Comparing the return on investment of the early phase with those of the latest phases suggests an increasing or decreasing relevance of the sequential approach and enables testing hypothesis 2. Since investors are believed to perceive uncertainty less intensely over time, hypothesis 1 presumes that the negative impact of volatility will be stronger in the first years after entry than in later years. Therefore, it is expected that the investor's international experience will have a positive impact on the investment rate (e.g., reinforcing the equity participation on a JV).

Figure 3 is used to test hypothesis 2, specifically, to explore the relation between ROI and FM demand volatility levels for a different number of investment periods.

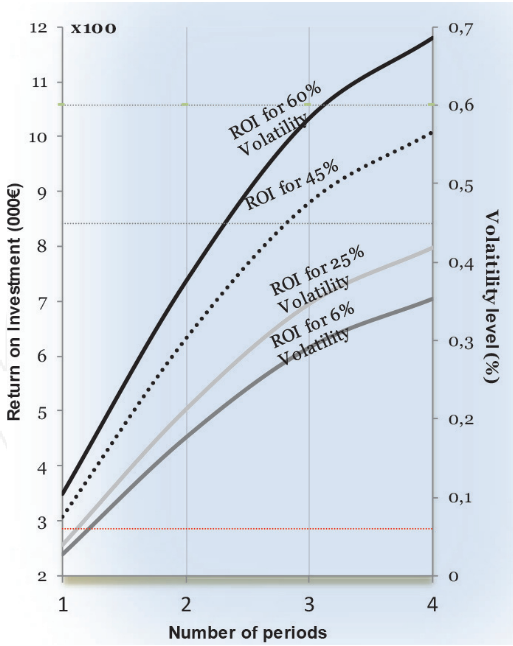


Figure 3. Hypothesis 2: testing FM demand volatility level evolution and ROI for sequential investments.

When the number of periods for investment increases, for the same FM demand volatility level, the ROI is more interesting. These results highlight the importance of flexible decisions on exit options. When companies invest in one single period there is no opportunity to adapt the investment level further, as the knowledge from the market increases. Based on the risk or uncertainty analysis, the MNCs can tailor their own market-entry scenarios. In this situation, a failure of market entry to an FM would not endanger the survival of the whole MNC. It has been generally accepted that step-by-step investments and advancements, as an example, not to build a factory at all, increase knowledge, as an appropriate way to decrease risks (e.g., study presented in [55]. With this simulation, we illustrate an investment scenario involving an interim state that offers either the chance to further invest if things go well or the chance to recoup some investment if not. The results do not consider that entry barriers in the FM can go up. First, rivals could get entrenched by a delay in the entry of an MNC; second, costs will tend to rise as time elapses—the required investment in a single stage can be different from the investment value in several stages. We also recognize that the financial availability of an MNC can vary over time. These facts do not enable the results applicability because the model allows the incorporation of premium costs in the profit function to count with project financing scheme, also as the consideration of a penalty factor for available FM market demand.

Figures 4 and **5** are also used to test hypothesis 2, specifically, to explore the relation between ROI and FM demand volatility levels, considering that demand changes can be either positive or negative along the investment periods.

http://dx.doi.org/10.5772/62987

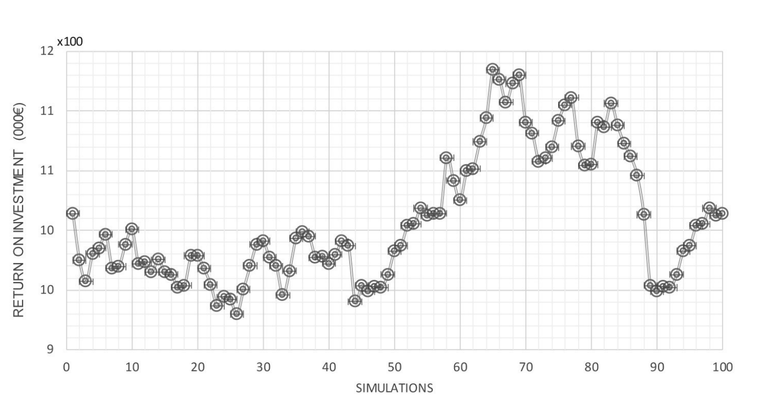


Figure 4. Relation between ROI and foreign market demand volatility levels.

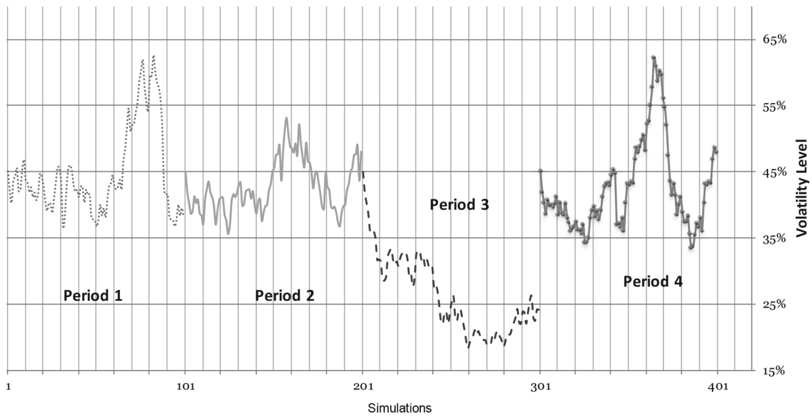


Figure 5. Hypothesis 2: FM demand volatility for different investment periods.

It has been conceptually and empirically validated that sequential investments reduce risk [43, 46, 47]. The previous graphical output indicates that ROI has a consistence positive trend with increase in volatility; however, demand volatility changes can be either positive or negative, and the speed of change within a period is another issue. In Figure 4, the data consider changes in FM demand volatility level for different investment periods and also consider changes inside each investment period. The output of the figure points that when volatility level is higher, the ROI is more interesting; however, the simulations done, using geometric Brownian motion to model the demand, show different possible behaviors in demand over time, which gives a possible range for ROI between EUR 950,000 to EUR 1,150,000.

Finally, we add **Figure 6** to explore the relation between ROI considering different investment values along project timeframe.

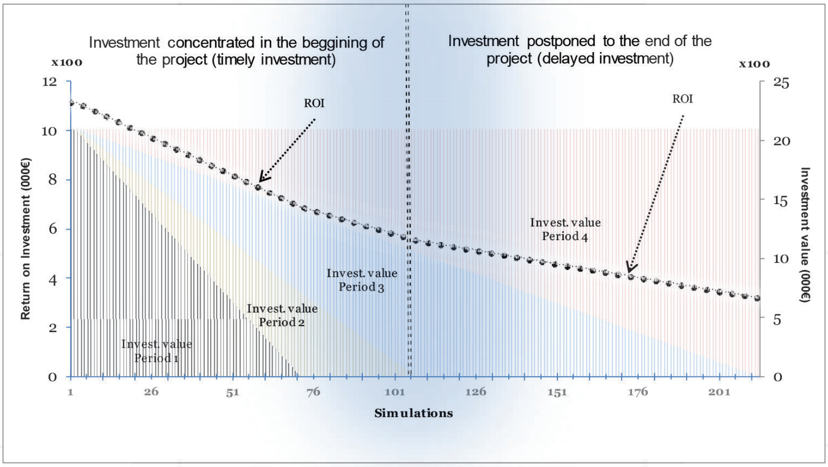


Figure 6. Hypothesis 2: testing ROI for sequential investments with different values.

In Figure 6, we tested the impact of different investment values over time, with different intensities for each period under analysis. In the simulations undertaken, we stated that if MNCs concentrate the investment value in the earlier stages, the ROI is more attractive. These results can be understood as there is a premium for MNCs with the capacity to make/implement decisions faster. In foreign direct investment, there is a gap between the initial entry and the final operation of MNCs; we can identify such gaps with decision points (investment periods) so that a faster MNC can benefit from earlier returns on investment. This analysis is particularly important when a company decides to change the entry mode or increase investment in an existing EM (for instance increasing the equity of a JV or enlarging investment in a new OC).

7. Conclusions

This chapter presents a trinomial tree for investment decision valuation with changing FM demand volatility over investment timeframe. The volatility changes are explored with changing transition probabilities while the space of the trinomial tree is regular, however, with a different number of time steps.

The model of ROI in a new FM is based on growth options acquired by investors in a learning process that starts at the entry to the host country. Later, the investors may exercise the growth option by scaling the investment, depending on the perceived levels of uncertainty and the tendency of the expected payback. The higher the tendency, the higher is the attractiveness of subsequent investment and the higher the uncertainty, and the higher the subsequent returns on investment [57]. Balancing the marginal ROI value of an additional investment unit of

http://dx.doi.org/10.5772/62987

capital helps to reproduce these decisions and explain the sequence of investment in new foreign markets under different forms—with different investment values.

Traditional models of internationalization, for example, the Uppsala approach, have considered such investment sequences in general, but we used a real option theory as it aims at optimal investment decisions. Modeling real investment behavior, however, must take into account that investors make their decisions regarding the uncertainty they subjectively perceive rather than the uncertainty we can objectively measure using any traditional process. The perception of uncertainty is likely to be higher in the first steps of the investment and peak off in the following. The level of uncertainty perception and its receding effect may be stronger in foreign than in domestic environments. Previous models have mainly analyzed overall investment value and paid less attention to the treatment of uncertainty. Comparing an early and a late phase after entry, the model stresses the influence of uncertainty on the investment rate.

As the perception of uncertainty recedes, internationalizing firms seem to change their reasoning for ROI based on option values toward common net present values.

Author details

Rui Fernandes[1*] and Carlos Pinho[2]

*Address all correspondence to: rfernandes.ar@amorim.com

1 Polytechnic Institute of Porto, Porto, Portugal

2 Research Unit in Governance, Competitiveness and Public Policies, Aveiro University, Aveiro, Portugal

References

[1] Laine A, Kock, S. A process model of internationalization—new times demands new patterns. In: IMP 2000; 2000; UK.

[2] Schortgen F. Beyond strategy, timing and liability of foreignness—an analytical extension of business internationalization analysis: the case of China. International Business: Research, Teaching and Practice. 2012;6(1):27–59.

[3] Haahtela T. Increasing uncertainty in cash flow simulation-based volatility estimation for real options: actual increase in volatility or symptom of excess unresolved ambiguity uncertainty. Lecture Notes in Management Science. 2012;4:145–153.

[4] Görg H. Analysing foreign market entry—the choice between greenfield investment and acquisitions. Journal of Economic Studies. 2000;27(3):165–181.

[5] Buckley P, Casson M. The future of the multinational enterprise. London: Macmillan; 1976.

[6] Cieślik A, Ryan M. Productivity differences and foreign market entry in an oligopolistic industry. Open Economies Review. 2012;23(3):531–557.

[7] Dunning J. Explaining the international direct investment position of countries: towards a dynamic or development approach. Review of World Economics. 1981;117(1):30–64.

[8] Müller T. Analyzing modes of foreign entry: greenfield investment versus acquisition. Review of International Economics. 2007;15(1):93–111.

[9] Li J, Li Y, Rugman A. Real options theory and international investment strategy: past, present and future. Handbook of Research on International Strategic Management. 2012;18:342–359.

[10] Xie Y, Zhao H, Xie Q, Arnold M. On the determinants of post-entry strategic positioning of foreign firms in a host market: a "strategy tripod" perspective. International Business Review. 2011;20(4):477–490.

[11] Gatignon H, Anderson E. The multinational corporation's degree of control over foreign subsidiaries: an empirical test of a transaction cost explanation. Journal of Law, Economics, and Organization. 1988;4(2):305–336.

[12] Mudambi R, Mudambi S. Diversification and market entry choices in the context of foreign direct investment. International Business Review. 2002;11(1):35–55.

[13] Camino D, Cazorla L. Foreign market entry decisions by small and medium-sized enterprises: an evolutionary approach. International Journal of Management. 1998;15(1):123–130.

[14] Erramilli M, Srivastava R, Kim S. Internationalization theory and Korean multinationals. Asia Pacific Journal of Management. 1999;16(1):29–45.

[15] Chang S, Rosenzweig P. The choice of entry mode in sequential foreign direct investment. Strategic Management Journal. 2001;22(8):747–776.

[16] Delios A, Henisz W. Political hazards, experience, and sequential entry strategies: the international expansion of Japanese firms, 1980–1988. Strategic Management Journal. 2003;24(11):1153–1164.

[17] Janet Y, Min J, Gerald Y. Foreign market entry timing revisited: trade-off between market share performance and firm survival. Journal of International Marketing. 2012;20(3):50–64.

[18] Fisch J. Internalization and internationalization under competing real options. Journal of International Management. 2008;14(2):108–123.

[19] Chen Y, Funke M. Option value, policy uncertainty and the foreign direct investment decision. University of Dundee; 2003 [Paper No. 139].

[20] Cherian J, Perotti E. Option pricing and foreign investment under political risk. Journal of International Economics. 2001;55(2):359–377.

[21] Bloom N, Bond S, van Reenen J. Uncertainty and company investment dynamics: empirical evidence for UK firms. Center for Economic Policy Research; 2003 [Paper No. 4025].

[22] Kalckreuth U. Exploring the role of uncertainty for corporate investment decisions in Germany. Swiss Journal of Economics and Statistics. 2003;139(2):173–206.

[23] Kogut B. Joint ventures and the option to expand and acquire. Management Science. 1991;37(1):19–33.

[24] Vassolo R, Anand J, Folta T. Non-additivity in portfolios of exploration activities: a real options-based analysis of equity alliances in biotechnology. Strategic Management Journal. 2004;25(11):1045–1061.

[25] Li J, Li Y. Flexibility versus commitment: MNEs' ownership strategy in China. Journal of International Business Studies. 2010;41(9):1550–1571.

[26] Rivoli R, Salorio E . Foreign direct investment and investment under Uncertainty. Journal of International Business Studies. 1996;27(2):335–357.

[27] Santangelo G, Meyer K. Extending the internationalization process model: increases and decreases of MNE commitment in emerging economies. Journal of International Business Studies. 2011;42(7):894–909.

[28] Melin L. Internationalization as strategy process. Strategic Management Journal. 1992;13(S2):99–118.

[29] Daoud D, Högfeldt V. Expanding into new markets—is Lebanon a potential market for Swedish fashion companies? [Degree of Master in Fashion Management]. Borås: The Swedish School of Textiles; 2012.

[30] Johanson J, Vahlne J . The internationalization process of the firm: a model of knowledge development and increasing foreign market commitments. Journal of International Business Studies. 1977;8(1):23–32.

[31] Andersen O . On the internationalization process of firms: a critical analysis. Journal of International Business Studies. 1993;24(2):209–231.

[32] Langhoff T. The influence of cultural differences on internationalization processes of firms: an introduction to a semiotic and intercultural perspective. In: Björkman I,

Forsgren M, editors. The nature of the international firm. Copenhagen: Copenhagen Business School Press; 1997.

[33] Oviatt B, McDougall P. A framework for understanding accelerated international entrepreneurship. Wright, R. Research in Global Strategic Management. 1999;7:23-40.

[34] Chetty S, Campbell H. Paths to internationalization among small and medium-sized firms: a global versus regional approach. European Journal of Marketing. 2003;37(5–6): 796–820.

[35] Bazerman M. Judgment in managerial decision making. 5th ed. New York: John Wiley & Sons; 2001.

[36] Kogut B, Chang S. Platform investments and volatile exchange rates: direct investment in the U.S. by Japanese electronic companies. The review of Economics and Statistics. 1996;78(2):221–231.

[37] Gohary H, Edwards D, Eid R, Huang J. Choice of export entry mode by developing economies SMEs: an empirical investigation of Egyptian SMEs. Journal of Economic and Administrative Sciences. 2013;29(2):113–133.

[38] Kotler P, Armstrong G. Principles of marketing. 12th ed. New Jersey: Pearson Education; 2007.

[39] Talay B, Dalgic O, Dalgic T. Shareholder value creation in international joint ventures: the case of the US automotive industry. Strategic Management Review. 2010;4(1):1–17.

[40] Rajshekhar J, Deligonul S, Dixit A, Cavusgil T. International market reentry: a review and research framework. International Business Review. 2011;20(4):377–393.

[41] Dutta N, Roy S. Foreign direct investment, financial development and political risks. The Journal of Developing Areas. 2011;44(2):303–327.

[42] Fisch, H. Real call options to enlarge foreign subsidiaries—the moderating effect of irreversibility on the influence of economic volatility and political instability on subsequent FDI. Journal of World Business. 2011;46(4):405–544.

[43] Bowman E, Hurry D. Strategy through the option lens: an integrated view of resource investments and the incremental-choice process. Academy of Management Review. 1993;18(4):760–782.

[44] Johanson J, Vahlne J. The mechanism of internationalization. International Marketing Review. 1990;7(4):11–24.

[45] Li J, Frydrychowska M. The international expansion of a multinational company [Master Thesis]. Mälardalen University, School of Sustainable Development of Society and Technology; 2008.

[46] Folta T, Miller K. Real options in equity partnerships. Strategic Management Journal. 2002;23(1):77–88.

[47] McGrath R . A real options logic for initiating technology positioning investments. Academy of Management Review. 1997;22(4):974–996.

[48] Brouthers K, Brouthers L, Werner S. Real options, international entry mode choice, and performance. Journal of Management Studies. 2008;45(5):936–960.

[49] Rob R, Vettas N. Foreign direct investment and exports with growing demand. University of Pennsylvania Working Paper; 2003.

[50] Hamada K. Outsourcing versus in-house production: the case of product differentiation with cost uncertainty. Seoul Journal of Economics. 2010;23(4):439–459.

[51] Hymer S. The international operations of national firms: a study of direct foreign investment. MIT Press. Cambridge; 1976.

[52] Pindyck RS. Irreversible investment, capacity choice, and the value of the firm. American Economic Review. 1988;78(5): 969985.

[53] Fisher C. Researching and writing a dissertation for business students. Financial Times/ Prentice Hall, Pearson Education Limited. London; 2004.

[54] Dawson J. Scoping and conceptualizing retailer internationalization. Journal of Economic Geography. 2007;7(4):373–397.

[55] Fernandes R, Gouveia B, Pinho C. Flexible business plans in dynamic markets: a strategic approach. Journal of Policy and Organisational Management. 2011;2(1):10–15.

[56] Schmidli C. Foreign direct investment decision-making processes of Swiss small and medium enterprises in China [dissertation]. Switzerland: University of St. Gallen; 2008.

[57] Fisch, H. Investment in new foreign subsidiaries under receding perception of uncertainty. Journal of International Business Studies. 2008;39(3):370–386.

INTECH

INTECH