UDC 502.12:330
Orginal Scientific Paper
https://doi.org/10.62598/JVA.10.2.5.10

Received: October 15, 2024
Accepted for publishing: November 5, 2024

SUPPLY CHAIN OPTIMIZATION FOR ENVIRONMENTAL SUSTAINABILITY

Pupavac, Drago, *Polytechnic of Rijeka, Croatia, drago.pupavac@veleri.hr*

Abstract: *This work aims to investigate the possibilities of optimizing supply chains for ecological sustainability. In the tripartite components of sustainability (economy, society, environment), economic issues are currently dominating. A model of supply chains for a sustainable future should equally embrace all three components. The purpose of the work is to promote environmental sustainability. The research results are based on the mathematical method of dynamic programming. The main finding of this paper points to the conclusion that the optimization of supply chains from the point of view of total (economic and ecological) costs is the first and most important step towards greener and ecologically sustainable supply chains.*

Keywords: *sustainability, supply chains, economic costs, environmental costs, dynamic programming*

1. Introduction

Despite significant progress and numerous examples of good practice, the concept of sustainable development, which includes improving economic and social well-being while protecting the environment, may not have achieved the desired global sustainability. Global supply chain has a large effect on the environment. From sourcing raw materials to create products, to how finished products are transported to their final distributor, the supply chain can utilize many valuable, non-renewable resources during each step of the way. Environmental crises are distinguished by rapid and largely unexpected changes in environmental quality that are difficult if not impossible to reverse (Taylor, 2009). With the Covid-19 crises, disruption in global supply chains, inflation, war in Ukraine and energetic crises it's very hard to think about environmental crises. Business world has focused, mainly on economic sustainability.

The impact of the supply chain on the environment is primarily negative. The typical consumer company's supply chain creates far greater social and environmental costs than its own operations, accounting for more than 80 percent of greenhouse-gas emissions and more than 90 percent of the impact on air, land, water, biodiversity, and geological resources (Bové & Swartz, 2016). Consumer companies can thus reduce those costs significantly by focusing on their supply chains. Accordingly, the main hypothesis of this work is: The incorporation of environmental sustainability into supply chains is a critical step toward achieving sustainable development. The methods of analysis and synthesis, comparative method, and the dynamic programming method were used to prove the hypothesis.

2. Literature review

2.1. Supply chains

McKinsey & Company (2022) defined supply chain as interconnected journey that raw materials, components, and goods take before their assembly and sale to customers. A supply chain consist of all stages involved, directly or indirectly, in fulfilling a customer request. A typical supply chain consists of: customers, retailers, wholesalers/distributors, manufactures and component/raw material suppliers. Success in the supply chain is measured in terms of supply chain profitability. The higher the supply chain profitability, the more successful the supply chain (Chopra & Meindl, 2001). For many companies, sustainability is gaining a new dimension. Sustainability has become increasingly important not just from economic but also from ecological and social perspective. While traditional supply chain management focuses on operational speed, cost, and reliability, sustainable supply chain management incorporates the goals of environmental and societal values. This includes dealing with global issues like climate change, water security, deforestation, human rights, fair labor practices, and corruption. The notion of supply chain optimization has grown in popularity in recent years, as firms strive to improve their operational efficiency and cost-effectiveness. However, this optimization must not be at the expense of the environment. Instead, environmental sustainability and supply chain optimization must be studied concurrently to secure a long-term, sustainable future. As the world strives to solve serious environmental challenges, the concept of a low-carbon economy that prioritizes low energy consumption, low pollution and sustainable development is gaining support (Liao, 2023). The supply chain management industry is facing one of its biggest challenges. It is imperative that all links of the supply chain, i.e. the complete supply network, be economically, socially and ecologically sustainable. Sustainable supply chain management is becoming increasingly important for businesses of all sizes and industries (Seuring, 2013). Meeting environmental and social requirements at all levels of the supply chain guarantees that the minimum sustainability performance is met.

2.2 Sustanibility

The concept of sustainability, although widely accepted, is often interpreted in different ways. For example, Andrew Dobson (2000) listed more than three hundred definitions. The most common use of this concept, however, is related to sustainable development, which is defined as development that meets the needs of the present generation without compromising the ability of future generations to meet their needs (World Commission Environment and Development, 1987). Since then, the concept of sustainability has developed in two directions. The first includes three types of sustainability; ecological, economic, and social, which must be in harmony with each other (Crane & Matten, 2010). Another distinguishes between strong and weak sustainability (Kuhlman & Farringotn, 2010). The distinction between strong and weak sustainability is one of the basic reasons why there are many different definitions of sustainable development today and why the discussion about what this concept encompasses is still ongoing in the scientific and professional public. The incorporation of sustainability into supply chains is a critical step toward achieving sustainable development, as supply chains consider the product from the time raw materials are first processed until it is delivered to the end user.

2.2.1. Economic Sustainability

Economic sustainability, sometimes known as the "profit" pillar, is correlated with economic development, growth, productivity, profitability, and the stability of prices and markets (Elkington, 1994; Kuhlman and Farrington, 2010). This pillar in business relates to a company's short- and long-term profitability, which may be assessed using metrics like revenues and market capitalization (Zarra, et al, 2019). Many companies believe that consumers do not care about how they deal with their suppliers and employees, they only being concerned with price. These firms argue that they must find the lowest-cost supplier and relentlessly cut labor costs to remain competitive in the global market arena. However, not all firms accept this rationale. Many managers believe that the implementation of sustainable practices in their business can bring benefits to their firms in terms of revenue effects. Figure 1 depicts the impact of sustainable supply chain methods on customers, as well as the pricing, sales, and revenue implications that arise.

Figure 1. Economic Benefits of Supply Chain Sustainable Practices

Source: Author prepared according: Mefford, R. (2011). The Economic Value of a Sustainable Supply Chain, Business and Society Review. Volume 116, Issue 1, pp. 111, http://dx.doi.org/10.1111/j.1467-8594.2011.00379.

Economic sustainability refers to a company's ability to compete fairly in a given industry. It includes respect for copyright, prevention of counterfeit goods (OECD-EUIPO, 2016), and avoidance of anti-competitive practices (Yang and Ji, 2016).

2.2.2. Environmental Sustainability

Environmental sustainability, the most researched pillar of sustainability, focuses on how we use raw materials to meet human needs and the environmental damage that this causes. Environmental sustainability is the „planet" pilar (Elkington, 1994; Kuhlman and Farrington, 2010). Environmental sustainability promotes recycling, resource reuse, and environmental damage mitigation. The survival of the economy is closely linked to environmental sustainability. Namely, numerous business ventures depend on resources such as clean water, clean air, arable land, and a stable climate. Coca-Cola, as the world leader in the production of soft drinks, recognized the necessity of water protection as a critical factor for the success of its business in the future. To this end, it has developed cooperation with the world organization for nature protection - World Wildlife Fund (The Economist, 2008) for the protection of seven main river basins of drinking water. At the moment, many "green" businesses are not profitable, and the external costs that numerous business ventures make to the ecological system have not been converted into internal costs, which puts polluters in an even more favorable position. Thus, market relations do not solve the issue of balance between production and consumption on the one hand and nature on the other, but act as an accelerator of the destruction of nature and its resources (Strahinja, 2006).

2.2.3. Social Sustainability

Social sustainability has a critical importance for human life. Social sustainability lacks a broadly accepted definition (Cope, Keman, Sanders & Ward, 2022). Social responsibility can be defined as ability of local community to create a life from itself for itself. It is a „people" pilar. Sociial sustainability is a complex concept that include topics such as (Şebnem Yılmaz Balaman): health and social equity, human rights, labor rights, practices and decent working conditions, social responsibility and justice, community development and well-being, product responsibility, community resilience, and cultural competence. The objective of social sustainability is to secure people's socio-cultural and spiritual needs equitably (Popovic, Kraslawski, Avramenko, 2013). Every individual has varied demands, which vary depending on the current state of society (Assefa & Frostell, 2007). Social sustainability might be considered one of the most essential characteristics of sustainability, as the purpose of sustainable development is to make the environment, both societal and natural, a better place for humans.

2.3. Environmental Sustainability and Supply Chains

Companies face pressure to improve *environmental sustainability* in *supply chain*. The "greening" of a supply chain is the management process by which manufacturers, buyers, and retailers reduce their environmental impact throughout the value chain. It involves all stages, including product design, material selection, manufacturing process, transportation of goods, and the recycling and disposal of used goods. Environmental goals that can "green" a company's supply chain include: 1) reducing energy, water, and natural resource consumption, 2) increasing clean and renewable energy use, 3) decreasing waste production and pollution emissions and 4) improving waste byproducts treatment. Green supply chain involves assessing the whole environmental impact of products and services over their entire life span (Handfield, 2005). The concept of a green supply chain is linked to the larger concept of a "sustainable economy." Practitioners suggest that the major goal of environmental sustainability in supply chains should be to enhance organizations' environmental performance while maintaining productivity (Parajuli et al., 2019).

3. Matherial and methods

Let's say (Pupavac, Krpan, Marsanić, 2021) that for a product to be manufactured and delivered on the demand location within the supply chain, certain production and logistic activities need to be done and which can be classified in five phases (I-V): x_1 (procurement of raw materials), x_2 (production), x_3 (warehousing and land transport), $x_{4,}$ (maritime transport), x_5 (distribution), and for which within the global logistic system it is possible to engage 27 different participants: f_1, f_2, f_3...,f_{23}. (cf. Table 1).

Table 1. Production phases within the supply chain and potential supply chain participants

Phases of logistic process	Potential supply chain participants	Costs of each phase within the supply chain (in 000 €)		
1	2	3		
		Economic	Environmental	Total
I. Delivery of raw materials Incoterms EXW - Ex Works	f_1– Russia	11	(35×0.03)=1.05	12.05
	f_2 – Finland	12	(25×0.03)=**0.75**	12.75
	f_3 – Egypt	14	(40×0.03)=1.20	15.20
	f_4 – Bulgaria	14	(30×0,03)=0,9	14.90
	f_5 – Moldavia	**10**	(35×0,03)=1,05	**11.05**
	f_6 – Belarus	11	(45×0,03)=1,35	12.35
II. Production	f_7 – Czech	32	(32×0.03)=0.96	32.96
	f_8 – Romania	22	(40×0.03)=1.2	23.20
	f_9 – Poland	26	(25×0.03)=**0.75**	26.75
	f_{10} – Slovakia	24	(30×0.03)=0.9	24.90
	f_{11} – Serbia	**20**	(50×0,03)=1,5	**21.50**

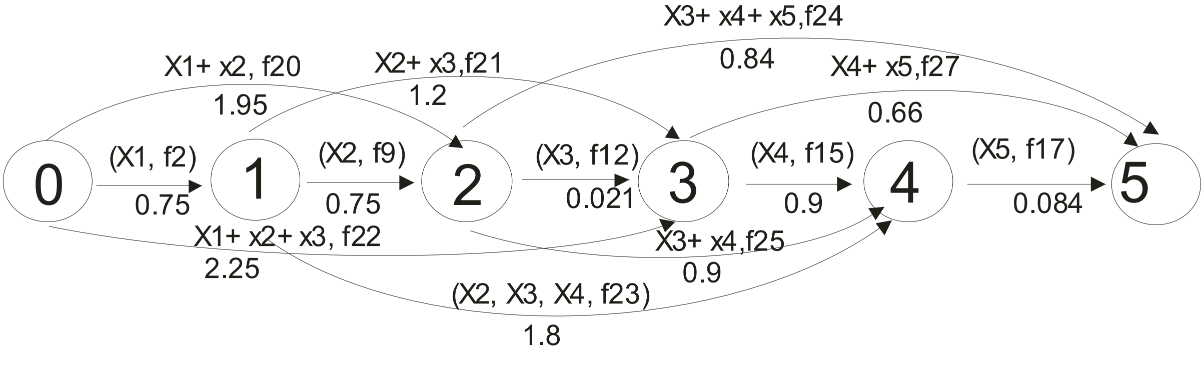
Phases of logistic process	Potential supply chain participants	Costs of each phase within the supply chain (in 000 €)		
III. Warehousing and land carriage (railway operator, road transport operator)	f_{12} – national railway operator f_{13} – ABC Logistics	**8** 9	(0.7×0.03)=**0.021** (4.5×0.03)=0.135	**8.021** 9.135
IV. Sea shipping (ship operators)	f_{14} - Global Alliance f_{15} - Grand Alliance f_{16} - Maersk-Sealand	**7** 8 10	(31.2×0.03)=0.936 (30.0×0.03)=**0.9** (33.0×0.03)=0.99	**7.936** 8.90 10.99
V. Distribution (distributors in North America)	f_{17} – East Coast f_{18} – West Coast f_{19} – Canada	12 **11** 14	(2.8×0.03)=**0.084** (3.1×0.03)=0.093 (3.5×0.03)=0.105	12.084 **11.093** 14.105
I., II.	f_{20} – Austria	30	(65×0.03)=1.95	31.95
II., III.	f_{21} – Switzerland	36	(40×0.03)=1,2	37.20
I., II., III.	F_{22} – GB	42	(75×0.03)=2.25	44.25
II., III., IV.	F_{23} – Croatia	40	(60×0.03)=1.8	41.80
III., IV., V.	f_{24} – Germany	28	(28×0.03)=0.84	28.84
III., IV.	f_{25} – Italy	22	(30×0.03)=0.9	22.90
IV., V	f_{26} – USA f_{27} – USA	20 **18**	(25×0.03)=0.75 (22×0.03)=**0.66**	20.75 **18.66**

The assumption is that the supply chain produces and delivers 100 tons of goods per month. Economic and environmental costs are arbitrarily estimated. Economic costs are the cost price of each stage within the supply chain. Environmental costs refer to pollution of rivers, air, environment, waste, and are expressed in monetary units in such a way that their cost is estimated at 30 EUR/t CO_2. The ecological costs of transport were estimated in such a way that the CO_2 emission of truck transport is 150 g-CO_2/tkm, sea transport 39 g-CO_2/tkm and rail transport 20 g-CO_2/tkm (Niwa, 2009).

4. Results and discussion

Based on the data from table 1, it is evident that in order to design an optimal network from an economic, environmental or total cost aspect, it is not necessary to consider all potential participants, but only some of them. Once non-competitive potential supply chain participants have been eliminated, it is possible to approach the design of the appropriate supply chain network and solve the problem posed.
The following shows the supply chain network from a environmental aspect (cf. figure 2).

Figure 2. Logistic network of potential qualified global supply chain participants from environmental aspect



Above every branch of the logistic network (cf. *Figure 2*) a logistic chain phase is entered as well as potential participants for carrying out a certain activity within the global logistic chain and under the branches of the logistic network costs for carrying out a certain phase within the logistic chain are entered.

In the following, the problem of the shortest path in the network is solved from an environmental aspect by applying the dynamic programming method. Other problems (from economic and total costs aspects) were solved according to the same principle, and the description of their solution is omitted. By applying the recursive expression the following is obtained

f(0) = 0 i f(1) = 0.75, and then

$$f(2) = \min \begin{cases} f(0) + c(x1 + x2, f20 = 0 + 1.95 \\ f(1) + c(x2, f9 = 0.75 + 0.75 \end{cases} \} = 1.50$$

$$f(3) = \min \begin{cases} f(0) + c(x1 + x2 + x3, f22 = 0 + 2.25 \\ f(1) + c(x2 + x3, f21 = 0.75 + 1.2 \quad \} = 1.521 \\ f(2) + c(x3, f12) = 1.5 + 0.021 \end{cases}$$

$$f(4) = \min \begin{cases} f(0) + \infty = 0 + \infty = \infty \\ f(1) + c(x2 + x3 + x4, f23) = 0.75 + 1.80 \} = 2.40 \\ f(2) + c(x3 + x4, f25) = 1.50 + 0.90 \\ f(3) + c(x4, f15) = 1.521 + 0.90 \end{cases}$$

and finally

$$f(5) = \min \begin{cases} f(0) + \infty = 0 + \infty = \infty \\ f(1) + \infty = 10 + \infty = \infty \\ f(2) + c(x3 + x4 + x5, f24 = 1.5 + 0.84\} = 2.181 \\ f(3) + c(x4 + x5, f27) = 1.521 + 0.66 \\ f(4) + c(x5, f17) = 2.40 + 0.084 \end{cases}$$

which means that the length of the shortest path is p*, i.e. the minimum value of the function of the target z* = d(p*) = 2.181, and in this example we have optimum ways p* = (0,1,2,3,5). If the managers choose this solution they will have a cost of supply chain from 66 810 €. The optimal supply chain formed from an economic aspect will have a cost in the amount of 56,000€. We can conclude that a supply chain which is optimized from a environmental aspect has a higher cost for 22,87 % than a supply chain which is optimized from an economic aspect. An overview of other optimal solutions from different aspects is given in table 2.

Table 2. Overview of optimal solutions

Optimization by aspects	Optimal way on network	Supply chain participants	Economic costs (000 €)	Environmental costs (000 €)	Min total costs (000 €)
Economic	0,1,2,3,4,5 0,2,3,4,5 0,2,3,5	f5,f11,f12,f14,f18 f20,f12,f14,f18 f20,f12,27	56 56 56	4.497 3.000 2.631	60.497 59.000 58.631
Environmental	0,1,3,5	f2,f9,f12,f27	64	2.181	66.810
Total costs	0,2,3,4,5	f20,f12,f14,f18	56	3.000	59.000

Based on the data from table 2, we can see that we have not optimal solutions which do not include environmental costs. The optimal solution from the environmental aspect is higher 13.95 % than the best solution from the economic aspect which includes potential environmental cost. It seems reasonable to choose the best solution from the total costs aspect which is also one of the three optimal solutions from the economic aspect. This solution will have slightly higher environmental costs than in the optimal solution, but it is a sure way towards their reduction and elimination.

5. CONCLUSION

Environmental sustainability and supply chain optimization are two concepts that must go hand in hand. By integrating sustainability into supply chain optimization, businesses can reduce their environmental impact, improve their reputation, and ensure long-term sustainability. A growing number of multinational firms have made the commitment in recent years to only do business with suppliers who uphold social and environmental criteria. The most problem arises at first-tier suppliers. Lower-tier suppliers nearly always have worse business practices, which exposes businesses to more substantial financial, social, and environmental risk. The findings of this scientific discussion confirmed the possibility of developing more optimal supply chains in terms of environmental costs. The difference in economic (total) costs in the resulting supply chains is negligible. Optimizing supply chains from the standpoint of economic costs yields significantly better results only if potential environomenat costs are ignored. Supply chain managers must set goals that intentionally create productive tension between economic and environmental criteria and move the supply chains toward a sustainable future.

6. References

1. Aisen, A., & Veiga, F. J. (2013). How does political instability affect economic growth? *European Journal of Political Economy*, 29 151–167.
2. Boriçi, Y.K., and Osmani, E. (2015) Foreign Direct Investment and Economic Growth in Albania. Economics, 3, 27–32.
3. Botrić, V.,and Škuflić, L. (2006) Main Determinants of Foreign Direct Investment in the Southeast European Countries. *Transition Stud Rev* 13, 359–377 https://doi.org/10.1007/s11300-006-0110-3
4. Clemens, W. C. (2010). Ethnic peace, ethnic conflict: Complexity theory on why the Baltic is not the Balkans. *Communist and Post-Communist Studies*, 43(3), 245–261.
5. Demekas, D.G.; Horváth, B.; Ribakova, E.; Wu, Y. (2005) Foreign Direct Investment in Southeastern Europe: How (and how much) can policies help?
6. Demeti, A., and Rebi, E. (2014) Foreign direct investments (FDI) and Productivity in Albania. Interdisciplinary Journal of Research and Development, 1, 7–14.
7. Dickey, D. A., and W. A. Fuller. (1979) Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association* 74: 427–31
8. Eren, M., & Zhuang, H. (2015). Mergers and acquisitions versus greenfield investment, absorptive capacity, and economic growth: Evidence from 12 new member states of the European Union. *Eastern European Economics*, 53(2), 99–123. https://doi.org/10.1080/00128775.2015.1033240

9. Falk, M. (2015). The relationship between FDI through backward linkages and technological innovations of local firms: Evidence for emerging economies. *Eastern European Economics*, 53(5), 424–438. https://doi.org/10.1080/00128775.2015.1065507
10. Granger, C. W. (1988). Causality, cointegration, and control. *Journal of Economic Dynamics and Control*, *12*(2-3), 551-559.
11. Golitsis, P., Avdiu, K., and Szamosi, L.T. (2018) Remittances and FDI Effects on Economic Growth: A VECM and GIRFs for the Case of Albania. Journal of East-West Business, 24, 188–211.
12. Hobbs, S., Paparas, D., and AboElsoud, M.E. (2021) Does Foreign Direct Investment and Trade Promote Economic Growth? Evidence from Albania. Economies, 9(1), 1. https://doi.org/10.3390/economies9010001
13. Hysa, E., and Hodo, L. (2016) Foreign direct investment and economic growth in Albania: A co-integration analysis. International Economics, 234–244.
14. Jakšić, S., Erjavec, N., & Cota, B. (2018). The role of foreign direct investment and labor productivity in explaining croatian regional export dynamics. *Central European Journal of Operations Research, 27*(3), 835–849. https://doi.org/10.1007/s10100-018-0583-2.
15. Janicki, H.P., and Wunnava, P.V. (2004) Determinants of foreign direct investment: empirical evidence from EU accession candidates. Applied Economics, 36(5), 505–509.
16. Johansen, S. (1988) Statistical analysis of cointegration vectors. *Journal of Economic Dynamics and Control* 12: 231–54.
17. Jong-A-Pin, R. (2009). On the measurement of political instability and its impact on economic growth. *European Journal of Political Economy*, 25(1), 15–29.
18. Mateev, M. (2008) Corporate governance problem and its implications for transition economies. Corporate Ownership & Control, 5(3-3), 335–348.
19. Nath, H. K. (2009). Trade, foreign direct investment, and growth: Evidence from transition economies. *Comparative Economic Studies*, 51(1), 20–50.
20. Sapienza, E. (2010) Foreign Direct Investment and growth in Central, Eastern and Southern Europe. Investigación Económica, 69, 99–138.
21. Segal, M. R. (2004). Machine learning benchmarks and random forest regression.
22. Sherstinsky, A. (2020). Fundamentals of recurrent neural network (RNN) and long short-term memory (LSTM) network. *Physica D: Nonlinear Phenomena*, *404*, 132306.
23. Welfe, W. (2013). The models of the Middle and East European Countries. In: Macroeconometric Models. Advanced Studies in Theoretical and Applied Econometrics, vol 47. Springer, Berlin, Heidelberg, 123–190. https://doi.org/10.1007/978-3-642-34468-8_9
24. Weyerstrass, K. (2008). Economic policies on Slovenia's road to the euro area. *Economic Systems*, 32(1), 92–102. https://doi.org/10.1016/j.ecosys.2007.09.003
25. Weyerstrass, K., Haber, G., & Neck, R. (2001). SLOPOL1: A macroeconomic model for Slovenia. *International Advances of Economic Resources*, 7(1), 20–37.