Scientific Papers. Series B, Horticulture. Vol. LXV, No. 2, 2021
Print ISSN 2285-5653, CD-ROM ISSN 2285-5661, Online ISSN 2286-1580, ISSN-L 2285-5653

A LITERATURE REVIEW OF LIFE CYCLE COST ANALYSIS TECHNIQUE APPLIED TO FRUIT PRODUCTION

Ana Cornelia BUTCARU[1], Ion CERTAN[1], Ioana Laura CĂTUNEANU[1], Florin STĂNICĂ[2], Liliana BĂDULESCU[1, 2]

[1]Research Center for Studies of Food Quality and Agricultural Products, University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Marasti Blvd, District 1, Bucharest, Romania
[2]Faculty of Horticulture, University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Marasti Blvd, District 1, Bucharest, Romania

Corresponding author email: anabutcaru@gmail.com

Abstract

This research aimed to carry out a literature review of the use of life cycle cost analysis (LCCA) in the fruit production sector by analysing its evolution in the last twenty years period. Life cycle cost analysis (LCCA) was an economic evaluation technique valuable that enabled to estimate of the total cost of owning and operating over a given period. At the same time, it provided additional information to supplement LCA-based decision-making. Articles published in peer-reviewed scientific journals were selected and reviewed. They were refined according to references and organized in several groups. Specific topics were selected such as organic and conventional technologies. Cost-hot spots along product life cycle stages were identified and improvement actions were presented.

Key words*: cost-hot spot; life cycle stages; organic technology.*

INTRODUCTION

Life cycle cost analysing (LCCA) is part of the life cycle evaluation methods, highlighting the overall economic cost of a specific product, service, or system (Davis et al., 2005; Perera et al., 2009). It is defined by the ISO standard, Buildings and Constructed Assets, Service-life Planning, Part 5: Life-cycle Costing as an economic assessment, considering all the significant and relevant cost flows of a specific project (ISO 15686-5:2017; RICS, 2016). LCCA is a method for assessing the total cost of owning and operating a product, facility, or a system over a period of time. The life cycle costs are the sum of the direct, indirect, recurring, nonrecurring, and other related costs incurred or estimated to be incurred during the useful life span (Fuller & Petersen, 1996; Woodward, 1997; Fuller, 2010; Gram & Schroeder, 2012; Bosona et al., 2019; Kambanou & Sakao, 2020).

This method can be a powerful technique that enables to making of the most cost-effective decisions at different life cycle stages. The LCCA should be performed early in the design process, giving the possibility to refine the design to ensure a reduction in life-cycle costs (Fuller & Petersen, 1996; Hunkeler & Rebitzer, 2003; Estevan & Schaefer, 2017; Bosona et al., 2019).

As a method, LCCA precedes the extension of environmentally oriented lifecycle thinking or sustainability (Hunkeler et al., 2008; Kambanou & Sakao, 2020). LCCA was first used in the United States by the Department of Defense in the mid-1960s. They applied LCC in the procurement of military equipment, as they found that acquisition costs only accounted for a small part of the total cost for the weapons systems while operation and support costs comprised as much as 75% (Asiedu & Gu, 1998; UNEP LCA Training Kit, 2013; Estevan & Schaefer, 2017). Since then, LCCA was widely used also in the construction sector and nowadays in green public procurement (Perera et al, 2009; Directorate-General for Environment & ICLEI, 2016; Clement et al., 2016; Bucea-Manea-Țoniș et al., 2021). It becomes essential in sustainable public procurement (SPP) (www.ec.europa.eu). A general appreciation for LCC sustain is important in changing the procurement and budgeting mindset from "the best value for money" to the "best value across the asset life-cycle." Green public procurement is expected to reduce environmental impacts and save resources. Environmental vocabularies for green contract identification were highlighted (Yu et al., 2020). An interesting evolution of the value of green contracts percentage from total contracts was observed. In 2012, Ireland (25%), Netherlands (22%), United Kingdom (19%), Slovakia (17%), Slovenia (10%), Bulgaria (10%), Danmark (9%), Cyprus (9%), Greece (8%), and Hungary (8%) were first top 10 countries (Estevan & Schaefer, 2017). In 2018, France, Switzerland and Ireland had over 35% value of the green contract from all contracts, followed by Sweden, Denmark, Norway, United Kingdom (Yu et al, 2020).

An integrated life cycle evaluation study could combine more methods: Life cycle assessment (ISO 14040:2006; https://eplca.jrc.ec.europa.eu), Life cycle cost analysis, and social Life cycle assessment (the methodology is still underdeveloped) (Swarr et al., 2011; Fiedler et al., 2018).

LCC and LCA are designed to provide answers to different questions. Life Cycle Assessment evaluates the relative environmental performance of alternative production systems for providing the same function. Life Cycle Cost compares the cost-effectiveness of alternative investments or business decisions from the perspective of an economic decision-maker (Norris, 2001; Gluch & Baumann, 2004).

UNEP LCA Training Kit (2013) detailed three approaches for aligning environmental and economic dimensions: defining LCA compatible with LCC, defining LCC compatible with LCA, or a mix of the previous ones. Combined LCA/LCC results help specify eco-efficiency or environmental cost-effectiveness of decisions, as 'cost per unit of environmental improvement'.

Specific instruments were developed for both methods, IT tools and methods (Langdon, 2005), separately or combined.

The objective of this study was to present a review of the Life cycle cost analysis technique applied to fruit production.

LIFE CYCLE COST ANALYSIS TECHNIQUE APPLIED TO FRUIT PRODUCTION

LCC involves methods of financial evaluation that calculate and analyse simple payback, net present value (NPV), and internal rate of return (IRR) (Fuller & Petersen, 1996; Durairaj et al., 2002; Bosona et al., 2019). It implies details about cost categories, bearers, models, and aggregation (UNEP LCA Training Kit, 2013).

For the cost categories, details for economics (cost regarding budget, market, collective, alternative, social, etc.), life cycle stages (R&D, primary production, manufacturing, use, disposal, etc.), and activity types (design, transport, sales, manufacturing, etc.) should be provided.

The cost bearer like producers, supply chain, owner, the user (not the owner), life cycle (all involved), country's society, global society can be evaluated.

Between cost models can be listed steady-state models, comparative static equilibrium models, static optimization models, quasi-dynamic models, dynamic optimization models, dynamic models, system dynamic models, etc.

Net present value, average yearly cost, steady-state cost, annuity, pay-back time, or benefit-cost ratio are used as methods (UNEP LCA Training Kit, 2013).

Very few articles were found on the Life cycle cost analysis method applied to fruit production (selection in Table 1), in accordance with França et al. (2021), Lampridi et al. (2019), de Luca et al. (2017).

Sottile et al. (2020), combined LCA with LCC analyzes and presented the ecological and economic indicators for orchard renewal in Sicily at almond (*Prunus dulcis* L.). Environmental impact categories for modern and traditional almond orchards were evaluated, higher values for global warming and non-renewable energy parameters at the modern one being registered. For the economical evaluation, the best results were registered for modern almond orchids, for all net present values per hectares invested scenario. Interesting results for stakeholders perception evaluation on the relevance of different categories of assessment showed the maximum relevance for LCCA categories (investments, operational costs and rentability) and minimum for LCA for growers. And minimum relevance for LCCA indicators but maximum for LCA for territorial governance.

Pruning to energy is an important topic for several years for renewable energy resources. Bosona et al. (2019) for almond, apple, olive, vineyard, and peach evaluated the economic impact. The life cycle costs varied from 50.06 €/tw.b. (vineyard chips), 54.67 €/tw.b. (vineyard bale), 65.85 €/tw.b. (olive chips), 71.37 €/tw.b. (apple bale), 94.49 €/tw.b. (peach chips) to 108.90 €/tw.b. (almond chips) in a specific scenario of transport (50 km). The operational cost was about 73% of the total life cycle cost while investment cost represented the remaining 27%. Dyjakon et al. (2020) stated that under 25 km distance between plant and farm is the optimum value for profitable activity in the apple orchard.

A harvester for recovering wood biomass from apple orchards was evaluated using LCCA by Nati et al. (2018).

Tamburini et al. (2015) included in their study apple and pear between the dominant five crops in the Emilia Romagna region, Italy, using LCC combined with LCA. Potential environmental impacts due to the agricultural phase for the production of 1 kg of selected crops was evaluated at 9.70×10^{-2} for apple and 3.76×10^{-1} for pear GWP_{100} (kg CO_2 eq.) and at 7.95 €cent/kg to apple respectively 42.96 €cent/kg to pear for total costs of the life cycle. When quantified of externalities costs deriving from fertilizers and pesticides use, integrating LCA with LCC, externalities calculated from fertilizers emissions were 4.23 €cent/kg (apple) and 6.59 €cent/kg (pear) and for pesticides emissions 7.05 €cent/kg (apple) and 4.06 €cent/kg (pear).

Using a photovoltaic irrigation system was assessed in India for the banana crop (Narale et al., 2013) or in Greece (Taousanidis & Gavros, 2016) for olive orchards. Both studies found the LCC for the PV system lower than the diesel one, being a more economical choice.

A comparison between organic and conventional systems combined with the LCA method was made for several fruit species like bergamot, olive, lemon, and orange. At bergamot, the organic system presented a higher performance (NPV of 91,421.60 € ha^{-1}), rather than in a conventional system (71,921.06 € ha^{-1}). IRR was also 28% greater in organic than conventional system. Orange and lemon organically produced had lower LCC costs than conventional ones (Pergola et al., 2013).

More studies on olive crop economical evaluation were made. The profitability of olive cultivation was higher in the organic system mainly due to the subsidies (Mohamad et al., 2014; Stillitano et al., 2018; Iofrida et al., 2020). Hot spots were identified, along with each phase of the production process, in order to suggest management strategies to reduce production costs and to increase production efficiency (Stillitano et al., 2016).

Weeds control in olive orchards was modeled and using reduced herbicide applications in combination with the no-tillage scenario was the less expensive solution, compared with conventional farming system and zero chemical weeding (De Luca et al., 2018a; De Luca et al., 2018b).

Several studies were focused to assess the profitability of fruit crop species, being an important instrument in policy decisions. In Calabria Region, Southern Italy, economical evaluation through LCC methods showed fig crop more suitable than vineyard and olive (Stillitano et al., 2017).

Table 1. LCCA methods applied in the fruit growing sector

Species	Topics	Source
apple	pruning-to-energy, Poland	Dyjakon et al., 2020
almond*	comparison modern with traditional farms, Italy	Sottile et al., 2020
banana	solar PV water pumping system for irrigation, India	Narale et al., 2013
bergamot*	comparison between conventional and organic cropping systems, Italy	Strano et al., 2017
fig	production "Dottato" cultivar, Italy	Stillitano et al., 2017
olive	photovoltaic irrigation system, Greece.	Taousanidis & Gavros, 2016
olive*	weed control, Italy	De Luca et al., 2018a; De Luca et al., 2018b
olive*	comparison between organic and conventional olive systems, Italy	Mohamad et al., 2014; Iofrida et al., 2020
olive	comparison between organic and conventional olive systems, Italy	Stillitano et al., 2018

Species	Topics	Source
olive	economic feasibility assessment of different olive farming investments in order to identify the key elements to optimize their economic performance	Stillitano et al., 2016
almond, apple, olive, vineyard, and peach	pruning-to-energy	Bosona et al., 2019
lemon and orange*	production in organic and conventional farming, Italy	Pergola et al., 2013
tomato, apple, pear, wheat, and chicory*	environmental and economic impacts of the agricultural production of the dominant five crops in the project area, Emilia Romagna region, Italy	Tamburini et al., 2015
fruit waste	review of evaluation methods in LCC	De Menna et al., 2018

*includes LCA method

CONCLUSIONS

Life cycle cost analysis, besides Life cycle assessment and social life cycle assessment, are decision tools. Knowing and applying them lead to sustainable decisions and investments. LCCA is also a powerful instrument to be included in most of the research and technology transfer projects for universities or research institutes.

Combining LCC with LCA increases the knowledge, even if calculating the costs of the effects of environmental degradation are difficult and some are still in discussion on how to be quantified.

Further researches are required in agriculture and especially in fruit growing production for a better understanding of horticultural systems and better investment decision.

An in-depth analysis could allow integrating policy tools into effective packages that will increase the supply of desired environmental and social goods, ensuring at the same time farmers' economic sustainability.

REFERENCES

Asiedu, Y. & Gu, P. (1998). Product life cycle cost analysis: State of the art review. *International Journal of Production Research, 36* (4), 883-908.

Bucea-Manea-Tonis, R., Dourado Martins, O.M., Ilic, D., Belous, M., Bucea-Manea-Tonis, R., Braicu, C. & Simion, V. (2021). Green and Sustainable Public Procurement—An Instrument for Nudging Consumer Behavior. A Case Study on Romanian Green Public Agriculture across Different Sectors of Activity. *Sustainability*, 13, 12, https://doi.org/10.3390/su13010012.

Bosona, T., Gebresenbet, G., Dyjakon, A. (2019). Implementing life cycle cost analysis methodology for evaluating agricultural pruning-to-energy initiatives. *Bioresource Technology Reports*, 6, 54-62, https://doi.org/10.1016/j.biteb.2019.02.006.

Clement, S., Watt, J. & Semple, A. (2016). *The Procura+ manual, a guide to implementing sustainable procurement, 3rd Edition*. D, Freiburg: ICLEI – Local Governments for Sustainability, European Secretariat.

Davis, M., Coony, R., Gould, S. & Daly, A. (2005). A guidelines for Life cycle cost analysis. *Stanford University Land and Buildings*.

De Luca, A.I., Falcone, G., Stillitano, T., Iofrida, N., Strano, A. & Gulisano, G. (2018a). Evaluation of sustainable innovations in olive growing systems: A Life Cycle Sustainability Assessment case study in southern Italy. *Journal of Cleaner Production*, 171, 1187-1202, https://doi.org/10.1016/j.jclepro.2017.10.119.

De Luca, A.I., Iofrida, N., Falcone, G., Stillitano, T. & Gulisano, G. (2018b). Olive growing scenarios of soil management: integrating environmental, economic and social indicators from a life-cycle perspective. *Acta Hortic*. 1199, 209-214, DOI: 10.17660/ActaHortic.2018.1199.34.

De Luca, A.I., Iofrida, N., Leskinen, P., Stillitano, T., Falcone, G., Strano, A. & Gulisano, G. (2017). Life cycle tools combined with multi-criteria and participatory methods for agricultural sustainability: Insights from a systematic and critical review. *Sci. Total Environ.*, 595, 352–370.

De Menna, F., Dietershagen, J, Loubiere, M. & Vittuari, M. (2018). Life cycle costing of food waste: A review of methodological approaches. *Waste Management* 73, 1–13.

Directorate-General for Environment (European Commission) & ICLEI – Local Governments for Sustainability. (2016). *Buying green! A handbook on green public procurement*, 3rd Edition, ISBN: 978-92-79-56848-0, doi: 10.2779/246106, Luxembourg: Publications Office of the European Union.

Dyjakon, A., den Boer, J., Gebresenbet, G., Bosona, T. & Adamczyk, F. (2020). Economic analysis of the collection and transportation of pruned branches from orchards for energy production. *Drewno, 63*(205), DOI: 10.12841/wood.1644-3985.284.01.

Durairaj, S.K., Ong, S.K., Nee, A.Y.C. & Tan, R.B.H. (2002). Evaluation of Life Cycle Cost Analysis methodologies. *Corporate Environmental Strategy, 9* (1), 30-39.

Estevan, H. & Schaefer, B. (2017). *Life Cycle Costing State of the art report*. ICLEI – Local Governments for Sustainability, European Secretariat.

Fiedler, K., Lord, S. & Czarnezki, J.J. (2018). Life Cycle Costing and Food Systems: Concepts, Trends, and Challenges of Impact Valuation. *Mich. J. Envtl. & Admin. L.* 8(1), 1-47.

França, W.T., Barros, M.V., Salvador, R. et al. (2021). Integrating life cycle assessment and life cycle cost: a review of environmental-economic studies. *Int J Life Cycle Assess* 26, 244–274. https://doi.org/10.1007/s11367-020-01857-y.

Fuller, S. (2010). Life-Cycle Cost Analysis (LCCA). *National Institute of Standards and Technology*, https://www.nist.gov.

Gluch, P. & Baumann, H. (2004). The life cycle costing (LCC) approach: a conceptual discussion of its usefulness for environmental decision-making. *Building and Environment*, 39 (5), 571-580, https://doi.org/10.1016/j.buildenv.2003.10.008.

Gram, M. & Schroeder, W.E. (2012). Evaluating the life cycle costs of plant assets, a multidimensional view. *Serbian Journal of Management*, *7* (2), 287–298.

Hunkeler, D., Lichtenvort, K. & Rebitzer, G. (2008). *Environmental Life Cycle Costing*. USA, Boca Raton, FL: CRC Press.

Hunkeler, D.& Rebitzer, G. (2003). Life Cycle Costing - Paving the Road to Sustainable Development? *Int. J. LCA 8* (2), 109–110.

Iofrida, N., Stillitano, T., Falcone, G., Gulisano, G., Nicolò, B. & De Luca, A. (2020). The socio-economic impacts of organic and conventional olive growing in Italy. *New Medit*. 19. 117-131. 10.30682/nm2001h.

ISO (2017) ISO 15686-5-buildings and constructed assets-service-life planning-part 5: life-cycle costing. Nederlands Normalisatie Institut, Delft.

ISO (2008) ISO 15686-5-buildings and constructed assets-service-life planning-part 5: life-cycle costing. Nederlands Normalisatie Institut, Delf.

ISO (2006) ISO 14040: environmental management-life cycle assessment-principles and framework. International Organization for Standardization, Geneva.

Lampridi, M.G., Sørensen, C.G. & Bochtis, D. (2019). Agricultural sustainability: a review of concepts and methods. *Sustainability*, 11, 5120, doi:10.3390/su11185120.

Langdon, D. (2006). Literature review of life cycle costing (LCC) and life cycle assessment (LCA). *Davis Langdon Management Consulting.*

Lichtenvort, K., Rebitzer, G., Huppes, G., Ciroth, A., Seuring, S., Schmidt, W.P., Günther, E., Hoppe, H., Swarr, T. & Hunkeler, D. (2008). History of life cycle costing, its categorization, and its basic framework. *In Environmental Life Cycle Costing; Hunkeler, D., Lichtenvort, K., Rebitzer, G., Eds.; SETAC-CRC*: Pensacola, FL, USA, 1–16.

Kambanou, M.L. & Sakao, T. (2020). Using life cycle costing (LCC) to select circular measures: A discussion and practical approach, *Resources, Conservation and Recycling*, 155, https://doi.org/10.1016/j.resconrec.2019.104650.

Mohamad, R.S., Verrastro, V., Cardone, G., Bteich, M.R., Favia, M., Moretti, M. & Roma, R. (2014). Optimization of organic and conventional olive agricultural practices from a Life Cycle Assessment - and Life Cycle Costing perspectives. *Journal of Cleaner Production*, 70, 78-89, https://doi.org/10.1016/j.jclepro.2014.02.033.

Narale, P.D., Rathore, N.S. & Kothari, S. (2013). Study of solar PV water pumping system for irrigation of horticulture crops. *International Journal of Engineering Science Invention 2* (12), 54-60.

Nati, C., Boschiero, M., Picchi, G., Mastrolonardo, G., Kelderer, M. & Zerbe, S. (2018). Energy performance of a new biomass harvester for recovery of orchard wood wastes as alternative to mulching. *Renewable Energy*, 124, 121-128.

Norris, G.A. (2001). Integrating Life Cycle Cost Analysis and LCA. *Int. J. LCA 6* (2), 118- 120.

Perera, O., Morton, B. & Perfrement, T. (2009). *Life Cycle Costing a question of value*. International Institute for Sustainable Development (IISD). http://www.iisd.org.

Pergola, M., D'Amico, M., Celano, G., Palese, A.M., Scuderi, A., Di Vita, G., Pappalardo, G. & Inglese, P. (2013). Sustainability evaluation of Sicily's lemon and orange production: An energy, economic and environmental analysis. *Journal of Environmental Management*, 128, 674-682, https://doi.org/10.1016/j.jenvman.2013.06.007.

Royal Institution of Chartered Surveyors (RICS) (2016). *Life cycle costing*. UK, Reading, Berks: Columns Design XML Ltd.

Sottile, F., Massaglia, S. & Peano, C. (2020). Ecological and economic indicators for the evaluation of almond (*Prunus dulcis* L.) orchard renewal in Sicily. *Agriculture*, 10, 301. https://doi.org/10.3390/agriculture10070301.

Stillitano, T., Falcone, G., De Luca, A.I., Spada, E., Gulisano, G. & Strano, A. (2018). Long-term feasibility of Mediterranean olive production systems. *Acta Hortic*. 1199, 203-208, DOI: 10.17660/ActaHortic.2018.1199.33

Stillitano, T., Falcone, G., Spada, E., De Luca, A.I., Grillone, N., Strano, A. & Gulisano, G. (2017). An economic sustainability assessment of "Fichi di Cosenza" PDO production compared with other profitable permanent crops. *Acta Hortic.* 1173, 395-400, DOI: 10.17660/ActaHortic.2017.1173.68.

Strano, A., Falcone, G., Nicolò, B.F., Stillitano, T., De Luca, A.I., Nesci, F.S. & Gulisano, G. (2017). Eco-profiles and economic performances of a high-value fruit crop in southern Italy: a case study of bergamot (*Citrus bergamia* Risso), *Agroecology and Sustainable Food Systems, 41:*9-10, 1124-1145, DOI: 10.1080/21683565.2017.1357064.

Stillitano, T., De Luca, A., Falcone, G., Spada, E., Gulisano, G. & Strano, A. (2016). Economic profitability assessment of Mediterranean olive growing systems. *Bulgarian Journal of Agricultural Science*. 22. 517–526.

Swarr, T.E., Hunkeler, D., Klöpffer, W. et al. (2011). Environmental life-cycle costing: a code of practice. *Int. J. Life Cycle Assess.* 16, 389–391. https://doi.org/10.1007/s11367-011-0287-5.

Tamburini, E., Pedrini, P., Marchetti, M.G., Fano, E.A. & Castaldelli, G. (2015). Life Cycle based evaluation of environmental and economic impacts of agricultural productions in the Mediterranean Area. *Sustainability*, 7, 2915-2935. https://doi.org/10.3390/su7032915.

Taousanidis, N. & Gavros, K. (2016). An analysis of photovoltaic irrigation system for olive orchards in Greece. Materials Science and Engineering Conference Series, 161, 012095, doi = 10.1088/1757-899X/161/1/012095.

UNEP LCA Training Kit, Module j – Life cycle costing & eco-efficiency. (2013). https://www.lifecycleinitiative.org/

Woodward, D.G. (1997). Life cycle costing—Theory, information acquisition and application. *International Journal of Project Management, 15*, 6, 335-344, https://doi.org/10.1016/S0263-7863(96)00089-0.

Yu, C., Morotomi, T. & Yu, H. (2020). What influences the adoption of green award criteria in a public contract? An empirical analysis of 2018 European public procurement contract award notices. *Sustainability 12*(3):1261. https://doi.org/10.3390/su12031261.

https://ec.europa.eu/environment/gpp/what_en.htm

https://eplca.jrc.ec.europa.eu