

Applications of Multivariate Statistics in Life Cycle Assessment

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Introduction

LCA is crucial for achieving the European Green Deal's targets and supporting sustainable development.

Multivariate statistics can offer valuable solutions as LCA tools become more complex. This review evaluates scientific publications combining both, focusing on evaluating the fields of application and potential of multivariate statistics in LCAs.

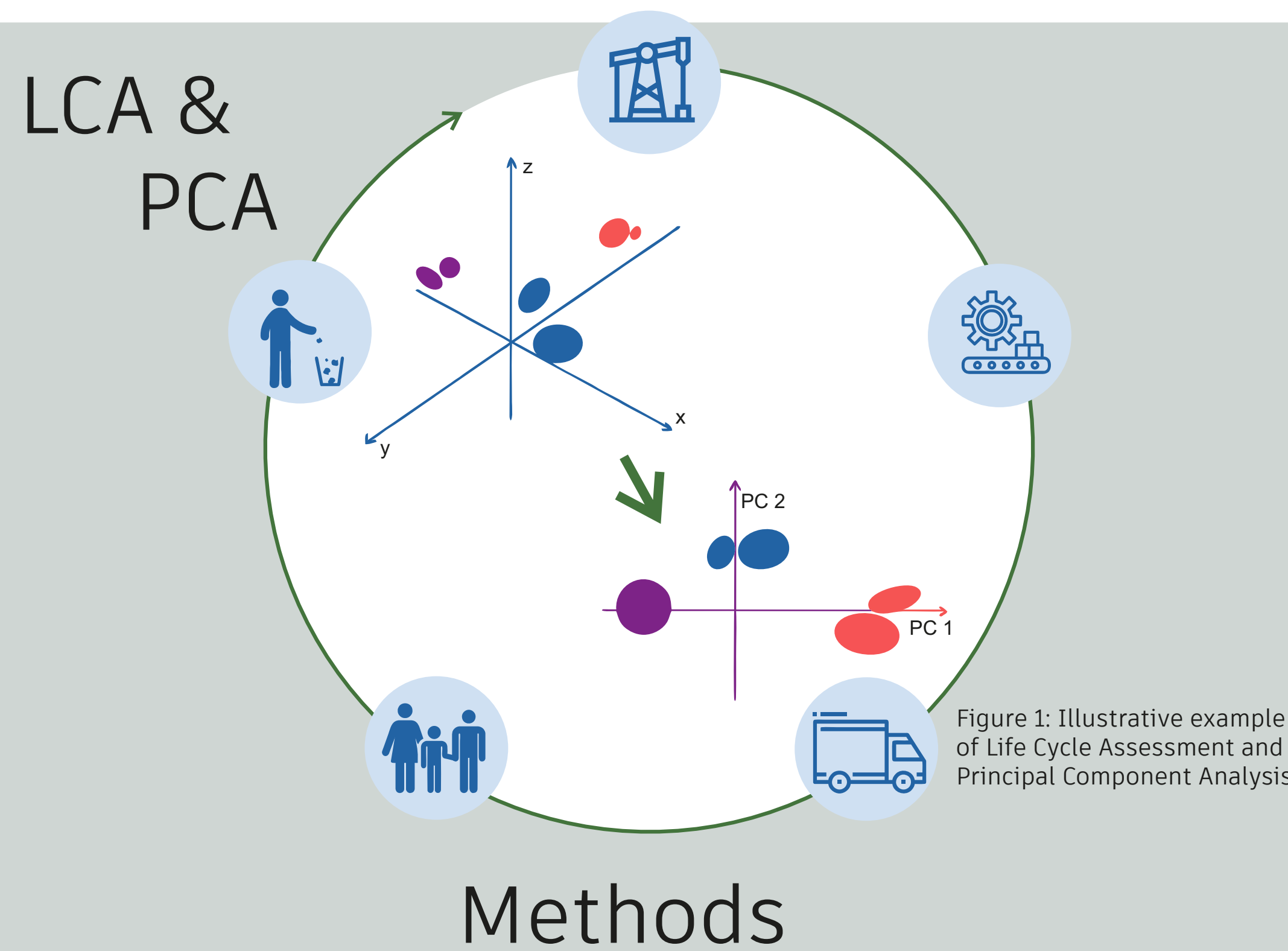


Table 1: Overview of the reviewed studies combining LCA and multivariate methods. Other used statistical methods such as bivariate and univariate are also included

	Study	Topic	Statistical Methods	Data Amount
Agriculture & Food Production	Fraterrigo Garofalo et al. (2023)	Production optimization of omega-3 oil from tuna viscera	MLR, PCA	15 experiments
	González-Quintero et al. (2021)	Environmental impact assessment of dual-purpose farms in Colombia	PCA, HCPA, Kruskal-Wallis & Kruskal-Nemenyi	Data from 1,313 farms
	Michos et al. (2012)	LCA of peach orchard farming systems in Greece	PCA, ANOVA, MC, HCA, Mann-Whitney	16 farming systems
	Chen et al. (2015)	LCA of trout farms in France	PCA with non-parametric bootstrap	24 trout farms
	Bava et al. (2014)	Environmental impact analysis of dairy farms	PCA, CA, PC	28 dairy farms
	Mu et al. (2017)	Environmental performance of specialized dairy farms	MLR, CCA, Outlier detection	55 specialized dairy farms
	Grados & Schrevens (2019)	LCA of potato agricultural in the Central Peruvian Andes	CA, LDA, EFA	Data from 58 potato pilot plots
Material & Elements	Smith et al. (2021)	Chemical element sustainability index for piezoelectric materials	PCA, Trend analysis, Monte Carlo Analysis	59 chemicals
	Rydh & Sun (2005)	Simplification of LCAs at an early stage of product design	LRA, PCA (Sartorius AG, 2023)	data of 214 mechanical design materials
Supply Chain	Genovese et al. (2017)	Reducing redundancies and identifying relationships among indicators in LCA	PCA	LCA calculations on five random samples of 1,000 supply chains
	Pozo et al. (2012)	Dimensionality reduction of environmental metrics for multi-objective optimization	PCA, Pareto solutions	2 supply chain case studies: power plant and 14 recyclable products
Waste Water Treatment	Flores-Alsina et al. (2010)	Incorporating multiple criteria into a common LCA for waste water treatment	Normalisation techniques, HCA, PCA, FA, Discriminant Analyses	12 control strategies at plant level and environmental, legal, technical & economic indicators
	Guo et al. (2023)	Interrelationships between GWP of waste and sludge treatment facilities	PCA, uncertainty analysis	Data from 660 cities
Other	Rowley et al. (2015)	Unsupervised weighting algorithm using PCA for the Choquet integral in two case studies	PCA	135 Australian industry sectors and eight alternative biosolids management options
	Bersimis & Georgakellos (2013)	Assessing environmental performance of beverage packaging (aluminum, glass, and PET) in the Greek market	PC, PCA, consistency test	16 beverage containers and 5 impact categories
	Gutiérrez et al. (2010)	Relationships of impact categories in two LCAs: wastewater treatment plants and cultivation systems, and processing and consumption of mussels.	PC, PCA, Multidimensionale Scaling	7 impact category results from 13 wastewater treatment plants and 10 impact category results from 5 life stages of mussels.
	Basson & Petrie (2007)	Decision-making under uncertainty in LCA while comparing bed combustion and refurbished existing pulverized fuel boilers	Latin Hypercube sampling, PCA	Three scenarios for two power station reactivation cases including financial, social, and environmental aspects

- Literature research via Google Scholar, WTI-AG, and ScienceDirect.
- Systematic categorization based on specific topics of LCA.
- Analysis of statistical methods employed, utilization cases, data availability, and software used.

Results

- 17 scientific articles employing multivariate statistical methods like PCA, MLR, CCA, FA, EFA, LDA, HCA, HCPC, and others to analyze environmental impact were summarized.
- Identified use cases categorized as „Grouping of Products/Systems“, „Reduction of Parameters“, „Evaluation of Parameters“, and „Support for Decision Makers“.
- PCA being the most frequently used statistical method.

Discussion

- Multivariate statistics can provide objective views of similarities between products/systems, reduce redundant information, evaluate parameter significance, and create new evaluation categories or indices.
- Future studies needed to validate these results and explore lower Technology Readiness Levels (TRL).
- Suggested integration for existing LCA software or interfaces between statistical and LCA software.

Conclusion

Multivariate statistical methods are beneficial for addressing LCA challenges like reducing data complexity and identifying non-redundant impact categories and their relationships.

Further research in various sectors and domains is emphasized, particularly: exploring lower TRL, addressing data limitations, potential exploration of uncertainty analysis, time series and spatial analysis and comparison to AI methods.

Table 2: Summary of publications by categories and statistical methods used by topic

Topic	Nr. of studies	PCA	CA	HCA	MLR	(E)FA	HCPA	CCA	LDA
Agriculture and Farming	7	5	2	1	2	1	1	1	1
Materials and Elements	2	2	0	0	0	0	0	0	0
Supply Chain	2	2	0	0	0	0	0	0	0
Wastewater Treatment	2	2	0	1	0	1	0	0	0
Multiple and other Categories	4	4	0	0	0	0	0	0	0
Sum	17	15	2	2	2	1	1	1	1

Abbreviations

Multivariate methods: Principal Component Analysis (PCA), Multiple Linear Regression (MLR), Canonical-Correlation Analysis (CCA), Factor Analysis (FA), Exploratory Factor Analysis (EFA), Linear Discriminant Analysis (LDA), Hierarchical Cluster Analysis (HCA), Hierarchical Clustering on Principal Components (HCPC), other cluster analysis (CA)

Bivariate methods: Pearson Correlation (PC), Spearman Rank Correlations (SRC)

Univariate tools: Analysis of Variance (ANOVA), Linear Regression Analysis (LRA)

Others: Monte Carlo Analysis (MC), Artificial Intelligence (AI)

