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LIFE CYCLE ASSESSMENT- A TOOL FOR ENVIRONMENTAL SUSTAINABILITY: CRITICAL REVIEW ON LIFECYCLE ASSESSMENT SOFTWARE

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Abstract: Due to improved consciousness about environmental impacts associated with anthropogenic development activities, Environmental Impact Assessment (EIA) became a mandatory exercise for decision-making for a proposed development activity or a project/industry, which carryout as legal practice in more than 100 countries. The major limitation of the current EIA process is that EIA focuses on impacts associated with production/development activity in an area, not providing an impact assessment of the product after it is made and circulated. Various approaches and tools have been developed to overcome this limitation. Life Cycle Assessment (LCA) is one approach and tool that achieved prominence as a tool to assess absolute environmental sustainability. Life cycle assessment gives a holistic impact assessment of a development activity/project/ industry or a product by factual analysis of the product's entire lifecycle in terms of sustainability. There are many LCA approaches such as cradle to gate, cradle to cradle, cradle to grave, gate to gate, and circular economy. LCA as a sustainability indicator and decision-making tool can be utilized for comparison of similar services/activities/designs/products, and also for improved product development, single issues such as carbon footprint or water footprint, product marketing by environmental product declaration or ecolabeling, compliance study for product-specific or sector-specific standards, strategic planning and policymaking, setting environmental regulation, long-term monitoring study, and identification of areas for improvement. More details are required, the completer and more comprehensive the LCA needs to be. Hence the LCA is no longer a manual exercise but done by various LCA software designed and developed for a specific purpose. Life cycle inventory data, life cycle impact assessment, and life cycle assessment software provide users with a vast database and impact assessment related to the proposed activity. The diversity of the software present can be overwhelming for users to decide among the software for LCA Study. This article provides an overview of the different LCA software available according to their features, similarities, differences, advantages, disadvantages, user-friendliness, and features specific to software, if any. The article also provides the feasibility of utilizing LCA for EIA in India.

Keywords: Life cycle assessment, Environmental Impact Assessment, LCA Software

I. INTRODUCTION

Over the years, population explosion, and overexploitation of natural resources, have created a burden on the earth's environment[1],[2]. The global and regional environmental problems call for a coordinated effort by various global organizations to achieve sustainability and minimize the environmental impacts of human actions and development activities[3].

Many tools have been developed to study and analyze impacts associated with anthropogenic activities. Environmental Impact Assessment (EIA) is one such process and management tool that helps to measure the impact of proposed development activity, project, or industry on the environment; it is a formal and legal practice followed in more than 100 countries.

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[1] Yifan Ding, *IMPACTS OF AFFLUENCE AND OVEREXPLOITATION OF NATURAL RESOURCES*, 6 ENVIRON. DEV. 2003
[2] Golam Rasul, *Managing the food, water, and energy nexus for achieving the Sustainable Development Goals in South Asia*, 18 ENVIRON. DEV. 14–25 (2016).
[3] V. Jegatheesan et al., *The need for global coordination in sustainable development*, 17 J. CLEAN. PROD. 637–643 (2009).

Indian constitution was one of the first to recognize the need for environmental conservation[4] apart from that, and the Indian Government published the first EIA Notification under the environment protection act (1986) in 1994 for mandatory EIA study for some developmental activities. The notification in force is EIA Notification 2006, which states that the EIA study is mandatory for eight categories of developmental activities. EIA study allows the authorities to analyze the effects of a project on the environment, and after studying the mitigation measures proposed in the EIA study report, it facilitates them to make environmentally sustainable choices.

Life cycle assessment is an analytical tool that gives a holistic impact assessment of a product or a process throughout its life cycle[5], whereas EIA provides the impact assessment during the production, but it does not provide an assessment for consumption and end-of-life for the product. Therefore, integration of LCA and EIA is done in many European countries to give a better and complete impact assessment of development activity[6]. Using LCA along with EIA will give us a local and global impact. In India, EIA is done by a panel of NABET-certified experts[7], so the scoring of anticipated impacts from the same proposed project in EIA can be different according to different experts; this can affect the overall assessment of a project as they are subjected to biases. The biased assessment will be removed entirely if the software is used for scoring/quantifying and summating impacts. Integration of EIA with Software-based Life cycle assessment will help overcome the limitations of the EIA process. Furthermore, running assessments for different alternatives in terms of location and technology becomes more feasible and less time-consuming in using LCA software.

Businesses and trade have become global by acquiring raw materials, machinery, and labor from various parts of the globe[8]; because of this, every production activity and product that we use has a global impact and not just a localized spatial impact; Life cycle assessment helps in understanding and quantifying this global impact. LCA is a tool that can aid EIA in making it completer and more comprehensive. During the past decades, LCA and LCA-based software use for assessing environmental impact has increased. Figure1 provides the number of annual publications involving LCA software from 1996 to 2021.

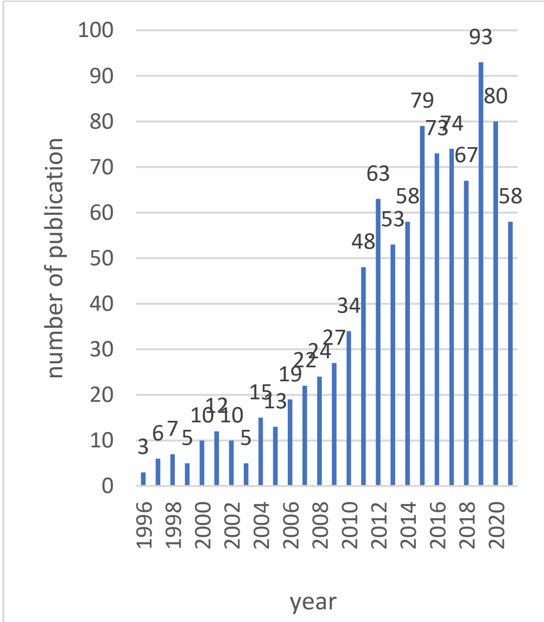

Figure1: Annual number of publications related to LCA and LCA software. (Generated by the researcher)

LCA helps measure the impact of each phase of production or process, starting from raw material extraction through the production process and use of the product to its waste management. [9] It measures the impact of air, soil, and water emissions and different categories like global warming, ozone depletion, acidification of soil and water, Eutrophication, and many more[10]. It has many different approaches like a cradle (raw material extraction) to gate (product formed), cradle (raw material extraction) to grave(disposal) [11], or

[4] Will Banham & Douglas Brew, *A review of the development of environmental impact assessment in India*, 11 PROJ. APPRAIS. 195–202 (1996).

[5] Mary Ann Curran, Life Cycle Assessment Student Handbook (2015)

[6] Pyrène Larrey-Lassalle et al., *An innovative implementation of LCA within the EIA procedure: Lessons learned from two Wastewater Treatment Plant case studies*, 63 ENVIRON. IMPACT ASSESS. REV. 95–106 (2017); Xiaodong Li, Yimin Zhu & Zhihui Zhang, *An LCA-based environmental impact assessment model for construction processes*, 45 BUILD. ENVIRON. 766–775 (2010).

[7] EIA: Environmental Impact Assessment, https://eia.nabet.qci.org.in/ (lApr 29, 2022).

[8] Anders Bjørn et al., *Review of life-cycle based methods for absolute environmental sustainability assessment and their applications*, 15 ENVIRON. RES. LETT. 083001 (2020).

[9] Walter Klöpffer, *Life cycle assessment: From the beginning to the current state*, 4 ENVIRON. SCI. POLLUT. RES. 223–228 (1997).

[10] J. William Owens, *LCA impact assessment categories: Technical feasibility and accuracy*, 1 INT. J. LIFE CYCLE ASSESS. 151–158 (1996).

[11] Suphunnika Ibbotson & Sami Kara, *LCA case study. Part 1: cradle-to-grave environmental footprint analysis of composites and stainless-steel I-beams*, 18 INT. J. LIFE CYCLE ASSESS. 208–217 (2013).

cradle (raw material) to cradle (raw material) [12] depending on the reason one conducts it. Cradle to cradle approach is gaining popularity among scientists and researchers with increasing curiosity about the circular economy concept[13] [14]. LCA is also a tool for comparison, so it can be conducted to determine which raw material or technology has a lesser impact or to identify which phase of the life cycle causes more harm to the environment. A bibliometric analysis was done, and from that, a collaboration network was generated using VOSviewer software; the keywords used were – life cycle assessment and LCA software for Figure 2a and life cycle assessment, SimaPro for Figure 2b. the network illustrates the keywords with maximum co-occurrence in published literature, and the links demonstrate the relationship between the keywords. In Figure 2a, we can see keywords related to different features of LCA like "LCA tool," "life cycle inventory analysis," "life cycle assessment model," "gate life cycle assessment, "etc., and also products and sectors where LCA is employed like "biogas," "bioethanol," "coal," "green roof." Figure 2b shows keywords related to multiple uses of SimaPro software in LCA like "energy balance," "feedstock," "economic analysis," "anaerobic digestion," "comparative study," etc.

Figure 2a: Collaboration network of main keyword co-occurrence for life cycle assessment and LCA software– using VOS viewer software. (Generated by the researcher)

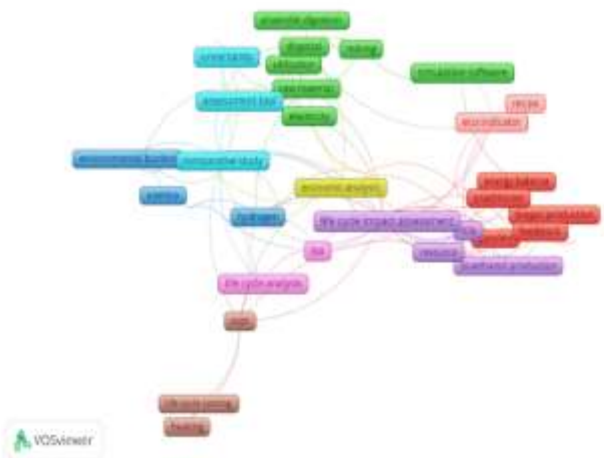

Figure 2b: Collaboration network of main keyword co-occurrence SimaPro software and life cycle assessment– using VOSviewer software. (Generated by the researcher)

Due to the complexity involved, LCA is no longer a manual process; software has been developed and utilized to help with the process. Industry-specific software like POLCAGE 1.0 (possibilistic LCA using GREET and EDIP) developed for comparative LCA of 10 different fuel options for the Philippine automotive transport sector[15]; CAT v1.0 developed for managed forests in the LULUCF sector[16], COMPASS for the packaging industry[17]. Many companies use the generic commercially available software like SimaPro[18] [19], GaBi [20] [21], Umberto[22] [23] [24], OPENLCA [25], ONE CLICK

[12] William McDonough et al., *Peer Reviewed: Applying the Principles of Green Engineering to Cradle-to-Cradle Design*, 37 ENVIRON. SCI. TECHNOL. 434A-441A (2003).
[13] Viktoria Drabe (Née Geng) & Cornelius Herstatt, Why and How Companies Implement Circular Economy Concepts – The Case of Cradle to Cradle Innovations (2016).
[14] Helen Kopnina, *Circular economy and Cradle to Cradle in educational practice*, 15 J. INTEGR. ENVIRON. SCI. 119–134 (2018).
[15] Raymond R Tan, Alvin B Culaba & Michael R.I Purvis, *POLCAGE 1.0—a possibilistic life-cycle assessment model for evaluating alternative transportation fuels*, 19 ENVIRON. MODEL. SOFTW. 907–918 (2004).
[16] Jean-Baptiste Pichancourt et al., *A carbon accounting tool for complex and uncertain greenhouse gas emission life cycles*, 107 ENVIRON. MODEL. SOFTW. 158–174 (2018).
[17] Ricky Speck et al., *Choice of Life Cycle Assessment Software Can Impact Packaging System Decisions: CHOICE OF LCA SOFTWARE CAN IMPACT PACKAGING SYSTEM DECISIONS*, 28 PACKAG. TECHNOL. SCI. 579–588 (2015).
[18] Erwan Saouter & Gert van Hoof, *A database for the life-cycle assessment of procter & gamble laundry detergents*, 7 INT. J. LIFE CYCLE ASSESS. 103–114 (2002).
[19] Md. Shazib Uddin & S. Kumar, *Energy, emissions and environmental impact analysis of wind turbine using life cycle assessment technique*, 69 J. CLEAN. PROD. 153–164 (2014).
[20] Sabrina Spatari et al., *Using GaBi 3 to perform life cycle assessment and life cycle engineering*, 6 INT. J. LIFE CYCLE ASSESS. 81 (2001).
[21] Harshit Khandelwal et al., *Life cycle assessment of municipal solId waste management options for India*, 288 BIORESOUR. TECHNOL. 121515 (2019).
[22] Vikrant Bhakar et al., *Life Cycle Assessment of CRT, LCD and LED Monitors*, 29 PROCEDIA CIRP 432–437 (2015).
[23] Kuldip Singh Sangwan et al., *Measuring Carbon Footprint of an Indian University Using Life Cycle Assessment*, 69 PROCEDIA CIRP 475–480 (2018).
[24] Cassiano Moro Piekarski et al., *Life cycle assessment of medium-density fiberboard (MDF) manufacturing process in Brazil*, 575 SCI. TOTAL ENVIRON. 103–111 (2017).
[25] Joaquín J. Pons et al., *Life cycle assessment of earth-retaining walls: An environmental comparison*, 192 J. CLEAN. PROD. 411–420 (2018).

LCA[26] [27], ECO CHAIN, and MOBIUS[28] [29] for conducting life cycle assessments, which helps them make sustainable choices concerning the environmental impact and also socio-economic impact, reduce their carbon footprint and also factor in their analysis in their marketing strategies[30]. Table1 provides different sectors where LCA is employed.

Study Reference	Work Done	Industry	Software
31	The authors used OpenLCA to analyze the environmental impact of both PLA polymer and ABS plastic. They compared polylactic acid polymers, acrylonitrile butadiene styrene polymers, polyether ether ketone polymers & polyethylene terephthalate polymers. The paper concluded that using polylactic acid over acrylonitrile butadiene styrene will protect the environment from non-biodegradable plastic with more sustainability.	polymer industry	OpenLCA
32	The impact assessment was conducted using the Eco-invent database and OPENLca software to assess the environmental impact of building integrated photovoltaic (BIPV) systems. The authors demonstrated that BIPV systems complement successfully with adaptive shading elements	Solar Energy Materials & Solar Cells	OpenLCA

[26] Bojana Petrovic et al., *Life Cycle Assessment of Building Materials for a Single-family House in Sweden*, 158 ENERGY PROCEDIA 3547–3552 (2019).

[27] Victoria Herrero-Garcia, *Whole-Building Life Cycle Assessment: Comparison of Available Tools*, 4 TECHNOL. DES. 248–252 (2020).

[28] Navneet Khanna et al., *Life cycle assessment of environmentally friendly initiatives for sustainable machining: A short review of current knowledge and a case study*, 32 SUSTAIN. MATER. TECHNOL. e00413 (2022).

[29] Navneet Khanna et al., *Energy Consumption and Lifecycle Assessment Comparison of Cutting FluIds for Drilling Titanium Alloy*, 98 PROCEDIA CIRP 175–180 (2021).

[30] Stefanie Hellweg & Llorenç Milà i Canals, *Emerging approaches, challenges and opportunities in life cycle assessment*, 344 SCIENCE 1109–1113 (2014).

[31] Ganeshan Gujilva Natarajan, R. Kamalakannan & R. Vijayakumar, *Sustainability analysis on polymers using life cycle assessment tool (OPENLCA)*070007 (2020), http://aip.scitation.org/doi/abs/10.1063/5.0034820 (last visited Apr 28, 2022).

[32] P. Jayathissa et al., *Life cycle assessment of dynamic building integrated photovoltaics*, 156 SOL. ENERGY MATER. SOL. CELLS 75–82 (2016).

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33	The goal of the LCA was to assess the environmental impacts of strawberry production in four big strawberry-producing states of the United States: California, Florida, North Carolina, and Oregon. Reliable LCAs for strawberry production can be performed only using datasets specific to a particular location, as production varies significantly according to geographic location. Also, the primary contributor to most environmental burdens was potassium sulfate.	Agriculture	OpenLCA
34	Life cycle assessments (LCAs) of the Vestas' 2-MW Grid Streamer wind turbines were done.	Renewable energy	GaBi
35	A comparative analysis of the environmental impact of different packaging systems used for extended shelf-life milk was done. One liter of extended shelf-life milk was used as the reference unit for the LCA. It was done using Cumulative energy demand and CML2001 as impact assessment methods. The results showed that the multilayer carton system had a lesser environme	Packaging industry	SimaPro

[33] Seyed Mohammad Hossein Tabatabaie & Ganti S. Murthy, *Cradle to farm gate life cycle assessment of strawberry production in the United States*, 127 J. CLEAN. PROD. 548–554 (2016).

[34] Peter Garrett & Klaus Rønde, *Life cycle assessment of wind power: comprehensive results from a state-of-the-art approach*, 18 INT. J. LIFE CYCLE ASSESS. 37–48 (2013).

[35] Massimo Bertolini et al., *Comparative Life Cycle Assessment of Packaging Systems for Extended Shelf Life Milk: Comparative LCA of Packaging Systems for Extended Shelf Life Milk*, 29 PACKAG. TECHNOL. SCI. 525–546 (2016).

	ntal impact.		
36	A life cycle assessment was conducted to compare and analyze three waste treatment technologies - Sanitary Landfill, Incineration, and gasification -pyrolysis.	Solid waste management	SimaPro

This review paper gives an overview of different tools for evaluating the sustainability of anthropogenic activity like traditional EIA, software-based LCA, and Absolute Environmental Sustainability assessment (AESA). The advantages, limitations, features, and relevance of the different tools are observed, and ways to overcome the limitations are also mentioned.

II. CRITERIA FOR EVALUATING DIFFERENT LIFE CYCLE ASSESSMENT SOFTWARE:

LCA is a time-consuming, multifaceted, and data-intensive process; its accuracy and detail vastly rely on the input data and database. The numerous LCA software already present in the market indicates the demand for good LCA software, and their variedness proves the users' different requirements. Selecting software can be overwhelming, so a user should look for the following criteria before committing.

1. Adherence to International Standards- International standardization organization provides the framework for conducting an assessment[37]. [38]According to ISO 14040 and ISO 14044, life cycle assessment has four interlinked phases: -

i. Definition of the study's goal and scope, selecting the functional unit by the users.
ii. Identifying and compiling the inventory data for all the relevant inputs and outputs from and to the environment. Also known as Life Cycle Inventory Analysis (LCI).
iii. Assess the potential environmental impact of the identified inputs and output through Life Cycle Impact Assessment.
iv. Furthermore, the last phase is interpreting and analyzing the impact assessment, which will help the authorities, decision-makers, and users make a more informed judgment.[39]

If the software does not comply with ISO, its results cannot be considered valid. Therefore, one essential requirement is the Life Cycle Assessment according to ISO 14040 and ISO 14044.

2. User-Friendliness and Transparency- The ease of learning and using the software is always a user's top priority. Most developers create a user interface similar to MS Office applications as users are familiar with the background. The compatibility of the application with other applications, an internet homepage, tutorials, and support provided by the developer are all crucial aspects of making software more user-friendly.[40] The ability to export the result to excel, the presence of the Sankey diagram, presentation toolbox make them more user-friendly. Representation of the result in graphical, tabular format or ability to create diagrams benefits in displaying the results better.[41] Users should be able to select the point of calculation and modeling of different outputs. The option of tracing back each result helps find the mistake made. The user interface should be appropriately structured and self-explanatory. A clear structure helps make the modeling process and results transparent and benefits the application.

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[36] A U Zaman, *Comparative study of municipal solId waste treatment technologies using life cycle assessment method*, 7(2), *International Journal of Environmental Science & Technology*, 225-234 (2010).
[37] Matthias Finkbeiner et al., *The New International Standards for Life Cycle Assessment: ISO 14040 and ISO 14044*, 11 INT. J. LIFE CYCLE ASSESS. 80–85 (2006).
[38] ISO 14044:2006(en), Environmental management — Life cycle assessment — Requirements and guIdelines, https://www.iso.org/obp/ui/#iso:std:iso:14044:ed-1:v1:en (last visited Apr 30, 2022).
[39] Mary Ann Curran, *Life Cycle Assessment: a review of the methodology and its application to sustainability*, 2 CURR. OPIN. CHEM. ENG. 273–277 (2013).
[40] N Unger, P Beigl & G Wassermann, *General requirements for LCA software tools*, 7Institute of Waste Management, BOKU–University of Natural Resources and Applied Life Sciences, Vienna Austria. 2004.
[41] CURRAN, Supra note 5.

3. Database- A good quality database means the data should be recent and reliable (from more than one source), and also it should have the original information from where the data is sourced. [42] The database should be stored, structured, and separated from the modeling database. The database should have modeled process chains and the ability to file sub-layers in a process chain so the database can be reused to model other scenarios. Users, particularly students and researchers, are using the database and their own, so the authenticity and reliability of the database are as necessary as the variedness and volume. The geographical source of the data is also a concern associated with life cycle inventory. Local and regional data, i.e., the data's source, can significantly affect an LCA and the final assessment[43]. Sometimes the databases are industry-specific e.g., The data offered by KCL is mainly related to the Finnish pulp and paper industry[44]. One of the most widely used databases is the Ecoinvent database[45]; other widely used databases are EU LCDN, World Food Life Cycle Database[46], and AgriFootprint [47].

The access to the database is always not direct; in many packages, they provide it separately, and one has to buy both. In the case of OpenLCA, the software is free to download along with a few databases, but it also has a paid database. The volume of data differs with each software package.

4. Uncertainty Calculation Analysis, Variability, Sensitivity Analysis- Uncertainty, variability, and sensitivity analysis are often neglected, and because of this practicality of LCA tools for environmental impact assessment get limited. Uncertainty is generally due to choices or in parameters and models; variability is characterized by three types, spatial, temporal, and source and object-related [48], [49] There are many statistical tools available to deal with uncertainty and variability analysis, but two of the most popular and widely used are Monte Carlo simulation and Latin Hypercube simulation[50]. Such analysis is required to help identify the parameters that cause a large spread in the model output. All of this is done to improve the accuracy of the overall model output. For LCA, many input parameters are needed; sensitivity analysis is required due to the uncertainty of these parameters[51]. Different methods like Key issue analysis, Standardized regression coefficients (using Monte Carlo sampling), and Sobol's sensitivity index, for example, are used to analyze uncertainty[52], [53].

5. Impact Assessment- The life cycle impact assessment (LCIA) software tool help in evaluating the potential environmental impact. Every LCIA has different categories according to which they measure the impact. There are several LCIA included in the package of different LCA software with impact categories such as acidification, ecotoxicity, carcinogens, land occupation, and reference units. The selection of LCIA depends on the goal of the LIFE CYCLE ASSESSMENT. Furthermore, the results of an LCA can vary depending on the LCIA selected[54] [55] [56]. Therefore, it is always necessary to define the goal and scope first and gather prior knowledge about the different

[42] Bruce W. Vigon & Allan A. Jensen, *Life cycle assessment: data quality and databases practitioner survey*, 3 J. CLEAN. PROD. 135–141 (1995).
[43] Christopher L. Mutel & Stefanie Hellweg, *Regionalized Life Cycle Assessment: Computational Methodology and Application to Inventory Databases*, 43 ENVIRON. SCI. TECHNOL. 5797–5803 (2009).
[44] Tuomo Nikulainen, *R&D COLLABORATION AND NANOTECHNOLOGY — AN OPPORTUNITY FOR TRADITIONAL INDUSTRIES*, 09 INT. J. INNOV. TECHNOL. MANAG. 1250023 (2012).
[45] Gregor Wernet et al., *The ecoinvent database version 3 (part I): overview and methodology*, 21 INT. J. LIFE CYCLE ASSESS. 1218–1230 (2016).
[46] WFLDB: Food, QUANTIS, https://quantis-intl.com/metrics/databases/wfldb-food/ (last visited Apr 29, 2022).
[47] Thiago Oliveira Rodrigues et al., *LCA—Life Cycle Inventory Analysis and Database*, *in* LIFE CYCLE ENGINEERING AND MANAGEMENT OF PRODUCTS: THEORY AND PRACTICE 71–93 (2021).
[48] Mark Huijbregts, *Uncertainty and variability in environmental life-cycle assessment*, 7 INT. J. LIFE CYCLE ASSESS. 173–173 (2002).
[49] Anna E. Björklund, *Survey of approaches to improve reliability in lca*, 7 INT. J. LIFE CYCLE ASSESS. 64 (2002).
[50] Mark A. J. Huijbregts, *Part II: Dealing with parameter uncertainty and uncertainty due to choices in life cycle assessment*, 3 INT. J. LIFE CYCLE ASSESS. 343–351 (1998).
[51] EVELYNE GROEN ET AL., SENSITIVITY ANALYSIS IN LIFE CYCLE ASSESSMENT (2014).
[52] Evelyne A. Groen et al., *Methods for global sensitivity analysis in life cycle assessment*, 22 INT. J. LIFE CYCLE ASSESS. 1125–1137 (2017).
[53] Wei Wei et al., *How to Conduct a Proper Sensitivity Analysis in Life Cycle Assessment: Taking into Account Correlations within LCI Data and Interactions within the LCA Calculation Model*, 49 ENVIRON. SCI. TECHNOL. 377–385 (2015).
[54] E. Martínez et al., *Comparative evaluation of life cycle impact assessment software tools through a wind turbine case study*, 74 RENEW. ENERGY 237–246 (2015).
[55] Helena Monteiro & Fausto Freire, *Life-cycle assessment of a house with alternative exterior walls: Comparison of three impact assessment methods*, 47 ENERGY BUILD. 572–583 (2012).
[56] Jin Zhou, Victor W. -C. Chang & Anthony G. Fane, *Environmental life cycle assessment of reverse osmosis desalination: The influence of different life cycle impact assessment methods on the characterization results*, 283 DESALINATION 227–236 (2011).

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LCIA categories. Tables 2a and 2b provide four different LCIA from the OpenLca software.

Life Cycle Impact Assessment			
Traci		Recipe Midpoint (H)	
Name	Reference unit	Name	Reference unit
environmental impact – acidification	moles of H^+-Eq	agricultural land occupation – ALOP	m2a
environmental impact – ecotoxicity	kg 2,4-D-Eq	climate change - GWP100	kg CO_2-Eq
environmental impact - eutrophication	kg N	fossil depletion – FDP	kg oil-Eq
environmental impact - global warming	kg CO_2-Eq	freshwater ecotoxicity – FETPinf	kg 1,4-DCB-Eq
environmental impact - ozone depletion	kg CFC-11-Eq	freshwater eutrophication – FEP	kg P-Eq
environmental impact - photochemical oxidation	kg NO_x-Eq	human toxicity – HTPinf	kg 1,4-DCB-Eq
human health – carcinogenic	kg benzene-Eq	ionizing radiation - IRP_HE	kg U235-Eq
human health - non-carcinogenics	kg toluene-Eq	marine ecotoxicity – METPinf	kg 1,4-DCB-Eq
human health - respiratory effects, average	kg PM2.5-Eq	marine eutrophication – MEP	kg N-Eq
		metal depletion – MDP	kg Fe-Eq
		natural land transformation – NLTP	m2
		ozone depletion – ODPinf	kg CFC-11-Eq
		particulate matter formation – PMFP	kg PM10-Eq
		photochemical oxidant formation – POFP	kg NMVOC
		terrestrial acidification - TAP100	kg SO_2-Eq
		terrestrial ecotoxicity – TETPinf	kg 1,4-DCB-Eq
		urban land occupation – ULOP	m2a
		water depletion – WDP	m3

Table 2a. Provides the impact categories of two different LCIA of openLCA software.

IMPACT 2002+ (Endpoint)		eco-indicator 99, (E,E)	
Name	eference unit	Name	eference unit
climate change - climate change	oints	ecosystem quality - acidification & eutrophication	oints
climate change – total	oints	ecosystem quality – ecotoxicity	oints
ecosystem quality - aquatic ecotoxicity	oints	ecosystem quality - land occupation	oints
ecosystem quality - land occupation	oints	ecosystem quality – total	oints
ecosystem quality - terrestrial acidification & nutrification	oints	human health – carcinogenic	oints

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ecosystem quality - terrestrial ecotoxicity	oints	human health - climate change	oints
ecosystem quality – total	oints	human health - ionizing radiation	oints
human health - human toxicity	oints	human health - ozone layer depletion	oints
human health - ionizing radiation	oints	human health - respiratory effects	oints
human health - ozone layer depletion	oints	human health – total	oints
human health - photochemical oxidation	oints	resources - fossil fuels	oints
human health - respiratory effects (inorganics)	oints	resources - mineral extraction	oints
human health – total	oints	resources – total	oints
resources - mineral extraction	oints	total – total	oints
resources - non-renewable energy	oints		
resources – total	oints		

Table 2b. Provides the impact categories of two different LCIA of openLCA software.

These features of life cycle assessment software storing, filtering massive databases, and finally evaluating the impact factor becomes easy. Moreover, the time taken to run these assessments becomes short, so time for decision-making and implementation is also reduced.

An evaluation of widely used, commercially available LCA software is done using these criteria. The evaluation is provided in Table 3.

Features	SimaPro	GaBi	OpenLca	Umberto
Free version	No	No	Yes	No
User-friendliness	Yes	Yes	Yes	Yes
Windows-based/ compatibility	Compatible	Compatible	Compatible	Compatible
International based database	Yes	Yes	Yes	Yes
database	Paid	Paid	Paid and free are both available.	Paid
Uncertainty calculations	Monte Carlo simulation	Monte Carlo simulation	Monte Carlo simulation	Monte Carlo simulation
Software or online	Software	Software	Software	Software
Demo version	Not available	30-day free demo available.	Not available.	14-day free demo version available.
Service and support	Available	Available	Available	Available

Table 3. Gives a comparison between widely used and popular LCA software.

III. ABSOLUTE ENVIRONMENT SUSTAINABILITY ASSESSMENT (AESA)

AESA is another emerging tool developed to measure the sustainability of projects, nations, companies, and individuals; this tool works to estimate whether a specific anthropogenic activity is entirely environmentally

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sustainable[57] [58]. It is different from Traditional EIA and life cycle assessment, As AESA checks environment sustainability by comparing the estimated environment pressure of the activity in question to the environment's carrying capacity. The anthropogenic activity is considered environmentally sustainable if environmental pressure is lesser than the Carrying capacity. With the increase in AESA being used in multiple scientific fields [59], there is a need for a clear understanding of the methodologies and a common framework for AESA (Fang et al., 2015). LCA-based AESA involves quantifying carrying capacity and assigning carrying capacity to an anthropogenic system. LCA-BASED AESA can help evaluate the sustainability of activity in an absolute sense, and if it is found to be not sustainable further calculations of assigned carrying capacity can be done to set future targets [60] [61].

IV. LIMITATIONS OF LCA SOFTWARE

Life cycle assessment software is not fully-proof yet; it lacks many aspects[62]. Since governments and companies often use the life cycle assessment results as a supportive tool for decision making, results should show consistency irrespective of the software. The differences observed in results when compared are often seen due to inconsistency in the database and impact assessment inventory[63], different studies comparing software SimaPro and GaBi [64] showed that for the same set of input and the same methodology, results could vary[65] [66] . The result can differ depending on the software used and the LCIA methodology adopted. There have been cases where the characterization factor used for the same substance was different in two software. Also, it was seen that if the spelling of the substance varied from the closest characterization factor, it could not be matched, which resulted in zero being used as an influential characterization factor, and the substance did not contribute to the environmental impact assessment [67]. Case studies have shown that differences in the value of characterization factors can cause uncertainty [68] while using OpenLCA; it was seen that it lacked data regarding many chemicals, different fuel options, and many more. There is a shortage of characterization factors and also precursor chemicals for analysis [69].

Geographic location and data appropriate for international use are other aspects that need improvement for the regionalization of data happening at the process level, with further information provided at a flow-specific level, e.g., via emission compartments. Gregor Wernet (ecoinvent, Switzerland) presented at the 69th LCA forum, Swiss Federal Institute of Technology, Zurich, 13 September 2018, on the topic "Regionalization in LCA: current status in concepts, software, and databases," gave the example of climate change impacts from electricity generation in India to showcase the significant impacts that geographical disaggregation of inventory data can have [70]. He further explained the need for improvements and more collaboration on LCI-LCIA interfaces to transfer data between inventories and impact assessment methods. Many European LCA TOOLS/SOFTWARE provide databases with data appropriate to international applications.

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However, specific applications like LiMS (Life Cycle Interactive Modelling system) from Chem Systems, EcoManager, and REPAQ provide databases appropriate to the United States[71] [72]. The use of life cycle assessment software is increasing, requiring developers to look into the above-written disadvantages and improve the margin of error. If these discrepancies are corrected, software for evaluating environmental impact assessment will become more feasible in real-life practice and decision-making.

V. PROSPECT

LCA started with assessing different phases of the life cycle of a product and comparing products with each other to see which one has a lesser environmental impact. Now slowly, the objective of conducting life cycle assessment is shifting from assessing environmental impact to checking environmental sustainability. With increased life cycle assessment, software developers must look into the limitations and improve the margin of error. If these discrepancies are corrected, the use of software for evaluating environmental impact assessment will become more feasible in real-life practice and decision-making. Developing a common framework for life cycle assessment, AESA, LCA-AESA, will help broaden the scope of evaluating absolute environmental sustainability and help authorities and policymakers make decisions with future generations in mind.

VI. CONCLUSION

Environmental Impact Assessment and Life Cycle Assessment have evolved a lot over the past decades, it is no longer manual, and there is no one way of assessing environmental impact. Various methods and tools have been developed for lifecycle assessment, and software is also available. This paper explains EIA, LCA, and LCA software, their advantages, and disadvantages, and how integrating them will give better and more holistic results. Although there are limitations in databases, characterization factors, and impact assessment, software-based LCA still makes the process leading up to decision-making efficient and less time-consuming.

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