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Comparative evaluation of life cycle impact assessment software tools through a wind turbine case study

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ABSTRACT

This paper seeks to analyse the differences between environmental impact assessment software tools by examining the results that they give when applied to a multi-megawatt wind turbine.

Seven different life cycle impact assessment software tools are compared: CML 2001, Eco-indicator 99, Ecopoints 97, EDIP, EPS 2000, IMPACT2002 and TRACI.

In Acidification and Eutrophication two groups are found: one includes the results provided by CML, Ecopoints 97, EDIP, EPS and TRACI and the other those of Eco-indicator 99 and Impact2002. In Abiotic Depletion all the results are similar except those of the EPS method, which gives negative figures. Likewise in Ozone Layer Depletion the results provided by Ecopoints 97 differ from the rest. In Human Toxicity and Ecotoxicity markedly different results are obtained by each of the LCIAs studied.

In some categories major differences are found between the results provided by the 7 LCIAs examined. Which of the impact assessment software tools currently available in LCA software is chosen is therefore a critical issue. The results provided by the different software tools are not always similar, and this needs to be realised and taken into account when using the resulting data in decision-making processes.

1. Introduction

From an environmental viewpoint it is becoming increasingly important to analyse the potential impact of products and actions [1–3]. Life Cycle Assessment (LCA) has become a highly important tool for providing in-depth analyses of this kind, for instance in studies concerned with the replacement of fossil fuels by renewables in electricity production, and a significant option in the process of transition towards a low-emission production economy [4,5]. In the field of energy there are a great many LCA studies that deal with the production and storage of energy. Some of these studies are listed in Table 1. Each study listed uses just one of the various Life Cycle Impact Assessment (LCIA) software tools currently available, but there is seldom any discussion or comparison with other software tools. There are several articles on this topic (see Table 2), but they tend to concentrate on specific case studies and very few of them deal with wind energy.

For example, Brent and Hietkamp [27] evaluate and compare the applicability of the five LCIA procedures that have been used in the South African manufacturing sector for decision and design purposes, on a qualitative and quantitative basis. Cavalett et al. [29] expand the discussion about how, and how much, the environmental performance is affected by the use of different LCIA, illustrated by the case study of the comparison between gasoline and ethanol produced from sugarcane in Brazil. And Dreyer et al. [31] develop a quantitative comparison of the CML 2001 and EDIP97 performed on the characterised indicator scores and on the normalised scores, while some more qualitative points regarding the use of midpoint and endpoint software tools are illustrated by a comparison of the weighted Eco-indicator 99 and EDIP97 results.

Non-specialists and persons with only a passing knowledge of LCA often ask why different results may be obtained when different Life-Cycle Impact Assessment (LCIA) software tools are used, and whether the degree of uncertainty in results is high enough [41] to cast doubt on the scientific arguments put forward.

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Table 1
Some LCA studies about energy production and storing.

Authors	Journal	Methodology	Field
Barba-Gutiérrez, Y. et al. [6]	Environmental Modeling and Assessment	Ecopoint 97	Eco-efficiency
Bravo, Y. et al. [7]	Solar Energy	CML/Eco-indicator 99	Power generation
Chester, M. et al. [8]	Environmental Research Letters	TRACI	Transportation
Coventry, Z.A. et al. [9]	International Conference on Thermal Treatment Technologies and Hazardous Waste Combustors 2012	TRACI	Waste to energy technologies
Desideri, U. et al. [10]	Applied Energy	Eco-indicator 99	Solar power
Dufour, J. et al. [11]	International Journal of Hydrogen Energy	Eco-indicator 95	Hydrogen production
Esteban, B. et al. [12]	Biomass and Bioenergy	CML/EDIP	Bio fuels
Gebreslassie. B.H. et al. [13]	Computers & Chemical Engineering	Eco-indicator 99	Bio fuels
González-García, S. et al. [14]	Science of The Total Environment	CML	Biomass
Hajjaji, N. et al. [15]	Journal of Cleaner Production	CML/Eco-indicator 99	Hydrogen production
Martínez-González, A. et al. [16]	CTyF – Ciencia, Tecnologia y Futuro	IMPACT2002	Fuels
Martinez, E. et al. [17]	International Journal of Life Cycle Assessment	CML	Wind power
Martinez, E. et al. [18]	Renewable Energy	Eco-indicator 99	Wind power
Miller, V.B. et al. [19]	Renewable Energy	TRACI	Hydrokinetic energy
Modahl, I.S. el al. [20]	International Journal of Life Cycle Assessment	EPS	Fossil gas power
Nishimura, A. et al. [21]	Applied Energy	NETS	Solar power
Pawelzik, P.F. and Zhang, Q. [22]	Biomass and Bioenergy	Eco-indicator 95	Bio fuels
Pérez-Fortes, M. et al. [23]	Computer Aided Chemical Engineering	IMPACT2002	Hydrogen and biomass
Talens Peiró, L. et al. [24]	Energy	CML	Bio fuels
Torres, C.M. et al. [25]	Fuel	Eco-indicator 99	Bio fuels
Wang, B. et al. [26]	Computers & Chemical Engineering	Eco-indicator 99	Gasification

The research described here seeks to examine the differences between various environmental impact assessment software tools based on the results obtained when they are applied to a multi-megawatt wind turbine. These environmental impact assessment software tools applied on renewable energies are commonly used to analyze, compare, and make decisions about the merits of such energy sources over the conventional ones. For this reason it is important, from the renewable energy point of view, to know in more detail the possible effect that can be obtained on the final result of the analysis the use of the different environmental impact assessment software tools. In this paper seven different LCIA software tools are compared: CML 2001 [42], developed by the Institute of Environmental Sciences of Leiden University; Eco-indicator 99 (EI99), the first endpoint impact assessment software tool which allowed the environmental load of a product to be expressed in a single score [43]; Ecopoints 97, developed by BUWAL (the Swiss Agency for the Environment), one of the earliest systems for impact assessment with a single score [44]; EDIP, developed by the Centre for the Environmental Design of Industrial Products (EDIP) in the Netherlands as an upgrade and improvement on CML 92 in several respects [45]; EPS 2000 (Environmental Priority Strategies), which is oriented towards sustainable product development [46]; IMPACT2002, which proposes a feasible implementation of a combined midpoint/damage approach, linking all types of life cycle inventory results via 14 midpoint categories [47]; and TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts) for environmental impact factors, developed by the Environmental Protection Agency [48]. Among the different existing LCIA software tools these seven have been chosen as a representative sample of the most used software tools in the scientific literature to date (Tables 1 and 2). Table 3 shows the number of LCA studies using the different software tools in those references. Based on these results, the software tools that appear more than once have been selected, with the exception of Eco-indicator 95, which is not included in the study due to the selection of Eco-indicator 99.

2. Method

A brief outline is given below of each of the LCIA software tools examined, the impact categories included in the study, the environmental impact and effects of recycling wind turbines at the end of their useful lifetimes and a sensitivity analysis for the case in hand to determine the impact of the variations in the parameters used.

Table 2
Comparative studies of LCIA.

Authors	Journal	Methodology	Field
Brent, A.C., Hietkamp, S. [27]	International Journal of Life Cycle Assessment	CML/Eco-indicator 99/EPS	Production
Bovea, M.D. and Gallardo, A. [28]	Materials & Design	EDIP/CML/EPS/Eco-indicator 99/Eco-indicator 95	Eco-design
Cavalett, O. et al. [29]	International Journal of Life Cycle Assessment	CML/IMPACT2002/EDIP/Eco-indicator 99/TRACI	Bio fuels
Carvalho, I.S. et al. [30]	Ships and Offshore Structures	CML/IMPACT2002/Eco-indicator 99	Dismantling activity and recycling.
Dreyer, L.C. et al. [31]	International Journal of Life Cycle Assessment	EDIP/CML/Eco-indicator 99	Production
Fantozzi, F. and Buratti, C. [32]	Biomass and Bioenergy	EPS/EDIP/Eco-indicator 99	Biomass
Knoeri, C. et al. [33]	International Journal of Life Cycle Assessment	Ecoindicator 99/Ecological scarcity 2006	Recycled
Monteiro, H. and Freire, F. [34]	Energy and Buildings	CML/Eco-indicator 99	Building
Pant, R. et al. [35]	Journal of Life Cycle Assessment	CML/IMPACT2002/EDIP	Production
Renou, S. et al. [36]	Journal of Cleaner Production	CML/Eco-Indicator 99/EDIP/EPS/Ecopoints 97	Waste water treatment
Simões, C.L. et al. [37]	Waste Management and Research	Eco-indicator 99/CML/EPS/, Eco-indicator 95/EDIP	Recycled
Valderrama, C. et al. [38]	Journal of Cleaner Production	CML/Eco-indicator 99	Sewage sludge valorisation
Van Caneghem, J. et al. [39]	Journal of Hazardous Materials	CML/Eco-indicator 99/EPS/EDIP and USEtox	Emitted to air
Van Caneghem, J. et al. [40]	Resources, Conservation and Recycling	CML/CExD/EPS/Eco-indicator 99	Production