MONOGRAFIE, STUDIA, ROZPRAWY

M114

Magdalena Rybaczewska-Błażejowska

ECO-INNOVATION AND ECO-EFFICIENCY IN THE FRAME OF LIFE CYCLE ASSESSMENT

Politechnika Świętokrzyska
Kielce 2019

MONOGRAFIE, STUDIA, ROZPRAWY

M114

Magdalena Rybaczewska-Błażejowska

ECO-INNOVATION AND ECO-EFFICIENCY IN THE FRAME OF LIFE CYCLE ASSESSMENT

Kielce 2019

MONOGRAFIE, STUDIA, ROZPRAWY NR M114

Redaktor Naukowy
dr hab. Wacław GIERULSKI, prof. PŚk

Recenzenci
dr hab. inż. Waldemar BOJAR, prof. UPT w Bydgoszczy
Prof. Dr. Dr. h.c. Michael SCHMIDT
dr hab. Andrzej WASIAK, prof. PB

Redakcja
Aneta STARZYK

Projekt okładki
Tadeusz UBERMAN

PL ISSN 1897-2691
PL ISBN 978-83-65719-55-3

Wydawnictwo Politechniki Świętokrzyskiej
25-314 Kielce, al. Tysiąclecia Państwa Polskiego 7
tel./fax 41 34 24 581
e-mail: wydawca@tu.kielce.pl
www.wydawnictwo.tu.kielce.pl

Contents

Preface

Environmental degradation and resource scarcity, amongst the many problems related to socio-economic development, are of great importance. The negative impacts of anthropopressure, including the growing consumption of natural resources, emission of air, water and soil pollutants, and waste production, have intensified in the twentieth century as a result of industrialisation and growing consumption. In addition, these impacts do not form simple, linear connections, but a complicated networks, often having economic and social consequences. There arises a challenge of decoupling environmental pressure from economic growth.

Initially, environmental protection relied on corrective measures, implemented locally and focused on end-of-pipe technologies. In recent years, due to the growing problem of natural resources depletion, the approach towards environmental protection has changed radically. Currently, preventive measures, which focus on techniques related to environmental management, are at the forefront of environmental protection. One of such techniques is life cycle assessment. It enables a comprehensive analysis of potential environmental impacts, including the use of natural resources, throughout the entire life cycle of a product system, from the extraction of raw materials across production, delivery and use, up to end-of-life treatment, at both operational and strategic levels.

Due to the fact that life cycle assessment assesses and aggregates environmental impacts into one consistent framework, it can be applied in the frame of eco-innovation and eco-efficiency. Eco-innovation, an indispensable element of future economic growth, is related to the creation of new products and production processes that, within a life cycle perspective, reduces the pressure on the environment, particularly regarding the extraction of natural resources. Eco-efficiency is strongly correlated with eco-innovation, since it addresses the relationship between the environmental and economic performance of a product system and therefore can be applied in comparative analyses of technologies, sectors or economies. In addition, eco-efficiency at the meso- and macro-level is stimulated by eco-innovation at the micro-level and thus these two concepts are very closely intertwined. The eco-innovation studies known from the scientific literature are usually of a general nature covering the drivers, characteristics and

effects of eco-innovation of individual countries. The opposite is true when it comes to eco-efficiency. In this respect, studies known from the scientific literature are usually of a detailed nature and concern a selected group of technologies, products or enterprises. Both, eco-innovation and eco-efficiency are relatively young research fields and, as many authors argue, they are still in their infancy.

This monograph presents author's own approaches to eco-innovation measurement at the micro-level, concerning an individual enterprise, and eco-efficiency assessment at the meso- and macro-level, concerning regions and sectors. The discussion on methodological approaches to eco-efficiency and eco-innovation is preceded by 3 chapters. Chapter 1, entitled *Life cycle assessment as a measuring technique*, provides a general introduction to life cycle assessment and includes a discussion of its structure and possible areas of application. Chapter 2, entitled *The essence of eco-innovation*, provides the scientific background to the study on eco-innovation and thus outlines the existing definitions of eco-innovation, its distinct features, classification and measurement related to the findings of past research. Chapter 3, entitled *The essence of eco-efficiency*, provides the scientific background to the study on eco-efficiency and thus explores the main characteristics of eco-efficiency, typology of the eco-efficiency indicators and the advancement in eco-efficiency quantification.

Chapter 4, entitled *A novel methodology of eco-innovation measurement*, provides the justification of the methodology formulation and presents the methodology itself, its attributes and the applicability. It proves that the proposed methodology for eco-innovation measurement allows the identification and prioritisation of environmental impacts of products and the accompanying production processes from a life cycle and the supply chain perspective. Chapter 5, entitled *A novel methodology of eco-efficiency assessment*, provides the most up-to-date review of the joint application of life cycle assessment and data envelopment analysis to eco-efficiency assessment, formulates author's own approach to eco-efficiency assessment and demonstrates its potential areas of applicability. It proves that the proposed methodology for eco-efficiency assessment allows the direct and indirect environmental impacts of regions and sectors to be quantified from a life cycle perspective, including upstream and downstream processes. I strongly believe that the presented approaches, both based on life cycle assessment, provide transparent benchmarks for assessing environmental performance, which, in turn, will contribute to the transformation of enterprises towards circular business models and development of regions and sectors that are resource responsible. I wish you pleasant reading.

References

Acero, A.P., Rodriguez, C., Ciroth, A., 2015. *LCIA methods: Impact assessment methods in Life Cycle Assessment and their impact categories*. https://www.openlca.org/wp-content/uploads/2015/11/LCIA-METHODS-v.1.5.4.pdf.

Alkaya, E., Demirer, G.N., 2015. *Reducing water and energy consumption in chemical industry by sustainable production approach: a pilot study for polyethylene terephthalate production.* Journal of Cleaner Production 99, 119-128.

Angelo, F.D., Jabbour, Ch.J.Ch., Galina, S.V., 2012. *Environmental innovation: in search of meaning*. World Journal of Entrepreneurship. Management and Sustainable Development 8 (2/3), 113-121.

Arundel, A., Kemp, R., 2009. *Measuring eco-innovation.* http://collections.unu.edu/eserv/UNU:324/wp2009-017.pdf.

Asif, F.M.A., Bianchi, C., Rashid, A., Nicolescu, C.M., 2012. *Performance analysis of the closed loop supply chain.* Journal of Remanufacturing 2 (4), 1-21.

Avadí, Á., Vázquez-Rowe, I., Fréon, P., 2014. *Eco-efficiency assessment of the Peruvian anchoveta steel and wooden fleets using the LCA+DEA framework*. Journal of Cleaner Production 70, 118-131.

Azad, M.A.S., Ancev, T., 2014. *Measuring environmental efficiency of agricultural water use: a Luenberger environmental indicator.* Journal of Environmental Management 145, 314-320.

Aziz, N.A., Wahab, D.A., Ramli, R., Azhari, C.H., 2016. *Modelling and optimisation of upgradability in the design of multiple life cycle products: a critical review.* Journal of Cleaner Production 112, 282-290.

Bakker, C., Wang, F., Huisman, J., Hollander, M., 2014. *Products that go round: exploring products life extension through design.* Journal of Cleaner Production 69, 10-16.

Banker, R.D, Charnes, A., Cooper, W.W., 1984. *Some models for estimating technical and scale inefficiencies in data envelopment analysis*. Management Science 30 (9), 1078-92.

Banker, R.D., Charnes, A., Cooper, W.W., Swarts, J., Thomas, D., 1989. *An introduction to data envelopment analysis with some of its models and their uses.* Research in governmental and non-profit accounting 5, 125-163.

Baran, J., Ryszko, A., 2013. *Opracowywanie i wdrażanie ekoinnowacji technicznych a ekoprojektowanie – integracja procesów i wskazówki metodyczne ich realizacji.* [*Development and implementation of technological eco-innovations and eco-design – integration of processes and methodological guidelines for their implementation*] in: Innowacje w Zarządzaniu i Inżynierii Produkcji. Oficyna Wydawnicza Polskiego Towarzystwa Zarządzania Produkcją. Opole.

Barański, A., Gworek, B., Bojanowicz-Bablok, A., 2011. *Ocena cyklu życia: Teoria i praktyka [Life cycle assessment: Theory and practice]*. Wydawnictwo Instytutu Ochrony Środowiska. Warszawa.

Barba-Gutiérrez, Y., Adenso-Díaz, B., Lozano, S., 2009. *Eco-efficiency of electric and electronic appliances: a data envelopment analysis (DEA).* Environmental Modeling & Assessment 14 (4), 439-447.

Berg, S., 2010. *Water Utility Benchmarking: Measurement, Methodologies, and Performance Incentives*. IWA Publishing. London.

Cainelli, G., De Marchi, V., Grandinetti, R., 2015. *Does the development of environmental innovation require different resources? Evidence from Spanish manufacturing firms.* Journal of Cleaner Production 94, 211-220.

Castellacci, F., Lie, C.M., 2017. *A taxonomy of green innovators: empirical evidence from South Korea.* Journal of Cleaner Production 143, 1036-1047.

Charnes, A., Cooper, W.W., Rhodes, E., 1978. *Measuring the efficiency of decision making units*. European Journal of Operational Research 2 (6), 429-444.

Cheng, C., Shiu, E., 2012. *Validation of a proposal instrument for measuring eco-innovation: an implementation perspective.* Technovation 32, 329-344.

Christiansen, K., de Beaufort-Langeveld, A., van den Berg, N., Haydock, R., ten Houten, M., Kotaji, S., Oerlemans, E., Schmidt, W.P., Weidenhaup, A., White R., 1997. *Simplifying LCA: Just a cut? Final report SETAC-Europe LCA screening and streamlining working group.* SETAC Europe. Brussels.

Ciroth, A., 2007. *ICT for environment in life cycle applications openLCA – A new open source software for life cycle assessment.* The International Journal of Life Cycle Assessment 12 (4), 209-210.

Cluzel, F., 2012. *Eco-design Implementation for Complex Industrial System: from Scenario-based LCA to the Definition of an Eco-innovative R&D Projects Portfolio.* PhD Thesis. Ecole Centrale Paris. Paris.

Cooper, W., Seiford, L., Tone, K., 2006. *Introduction to Data Envelopment Analysis and its uses. With DEA-Solver Software And References*. Springer Publishing. New York.

Crabbé, A., Jacobs, R., Van Hoof, V., Bergmans, A., Van Acker, K., 2013. *Transition towards sustainable material innovation: evidence and evaluation of Flemish case.* Journal of Cleaner Production 56, 63-72.

Cristóbal, J., Limleamthong, P., Manfredi, S., Guillén-Gosálbez, G., 2016. *Methodology for combined use of data envelopment analysis and life cycle assessment applied to food waste management.* Journal of Cleaner Production 135, 158-168.

CSO, SOK (Statistical Office in Katowice). 2016. *Wstępne szacunki produktu krajowego brutto według województw w 2014 r. [Preliminary accounting results of gross domestic product by voivodships in 2014]*. Warsaw: CSO, SOK, Zakład Wydawnictw Statystycznych.

CSO, 2015a. *Powierzchnia i ludność w przekroju terytorialnym w 2015 r. [Area and population in the territorial profile in 2015]*. Warsaw: CSO, Zakład Wydawnictw Statystycznych.

CSO, 2015b. *Gospodarka materiałowa w 2014 r. [Materials management in 2014]*. Warsaw: CSO, Zakład Wydawnictw Statystycznych.

CSO, 2015c. *Ochrona środowiska 2015. [Environment 2015]*. Warsaw: CSO, Zakład Wydawnictw Statystycznych.

CSO, 2015d. *Rocznik statystyczny województw [Statistical yearbook of the regions – Poland]*. Warsaw: CSO, Zakład Wydawnictw Statystycznych.

CSO, 2015e. *Zużycie paliw i nośników energii w 2014 r. [Consumption of fuels and energy carriers in 2014]*. Warsaw: CSO, Zakład Wydawnictw Statystycznych.

CSO, 2015f. *Rocznik statystyczny przemysłu. [Statistical yearbook of industry – Poland]*. Warsaw: CSO, Zakład Wydawnictw Statystycznych.

Dalhammar, C., 2015. *Industry attitudes towards ecodesign standards for improved resource efficiency.* Journal of Cleaner Production 123, 155-166.

Díaz-García C., González-Moreno Á., Sáez-Martínez F., 2015. *Eco-innovation: insights from a literature review*. Innovation 17:1, 6-23.

Dikeman, N., 2018. *What is cleantech?* http://www.cleantech.org/what-is-cleantech/.

Dong, Y., Wang, X., Jin, J., Qiao, Y., Shi, L., 2014. *Effects of eco-innovation typology on its performance: Empirical evidence from China.* Journal of Engineering and Technology Management 34, 78-98.

Doran, J., Ryan, G., 2016. *The importance of the drivers and types of environmental innovation for firm performance.* Business Strategy and the Environment 25, 102-119.

Dreyer, L.C., Niemann, A.L., Hauschild, M.Z., 2003. *Comparison of Three Different LCIA Methods: EDIP97, CML2001 and Eco-indicator 99.* The International Journal of Life Cycle Assessment 8 (4), 191-200.

EC, 2011. *Innovation for a sustainable Future – The Eco-innovation Action Plan (Eco-AP).* https://www.mos.gov.pl/g2/big/2014_01/cfaedfdcf2dcf1c98c72af9c3a79df3b.pdf.

Eder, P., 2003. *Expert inquiry on innovation options for cleaner production in the chemical industry.* Journal of Cleaner Production 11 (4), 347-364.

EEA, 1999a. *Making Sustainability Accountable: Eco-efficiency, Resources, Productivity and Innovation*. European Environmental Agency Topic Report No. 11/1999. Copenhagen.

EEA, 1999b. *Environmental indicators: Typology and overview*. European Environmental Agency Technical Report No. 5/1999. Copenhagen.

Egilmez, G., Kucukvar, M., Tatari, O., 2013. *Sustainability assessment of U.S. manufacturing sectors: an economic input output-based frontier approach.* Journal of Cleaner Production 53, 91-102.

Egilmez, G., Kucukvar, M., Tatari, O., Bhuttac, M.K.S., 2014. *Supply chain sustainability assessment of the U.S. food manufacturing sectors: a life cycle-based frontier approach.* Resources, Conservation and Recycling 82 (1), 8-20.

Ehrenfeld, 2005. *Eco-efficiency. Philosophy, Theory, and Tools.* Journal of Industrial Ecology 9(4), 6-8.

EIO, 2011. *The Eco-Innovation Challenge: Pathways to a resource-efficient Europe.* http://www.eurosfaire.prd. fr/7pc/doc/1308928736_eco_report_2011.pdf.

EIO, 2013. *Europe in transition. Paving the way to a green economy trough eco-innovation*. DG Environment, Brussels.

EIO, 2016. *Policies and Practices for Eco-Innovation Up-take and Circular Economy Transition.* https://ec.europa.eu/environment/ecoap/sites/ecoap_stayconnected/files/eio_2016_report.pdf.

EIO, CfSD, 2013. *Eco-innovate: A guide to eco-innovation for SMEs and business coaches.* http://cfsd.org.uk/si- te-pdfs/eco-innovate-sme-guide.pdf.

Erkko, S., Mickwitz, P., Melanen, M., 2005. *Eco-efficiency in the Finish EMAS report – A buzz word?* Journal of Cleaner Production 13(8), 799-813.

European Commission, 2017. *Agriculture in the European Union and the Member States – Statistical Factsheets.* https://ec.europa.eu/agriculture/statistics/factsheets_en.

Eurostat, 2014. *The Community Innovation Survey 2014 (CIS 2008) – The Harmonised Survey Questionnaire.*
https://circabc.europa.eu/faces/jsp/extension/wai/navigation/container.jsp.

Eurostat, 2017. *Land use: number of farms and areas of different crops by type of farming.* http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ef_oluft&lang=en.

Eurostat, 2018a. *Agri-environmental indicator – energy use.*
http://ec.europa.eu/eurostat/en/web/products-datasets/-/NRG_100A.

Eurostat, 2018b. *Water use by supply category and economical sector.*
http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_wat_cat&lang=en.

Eurostat, 2018c. *Agri-environmental indicator – mineral fertilizer consumption.*
http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=aei_fm_usefert&lang=en.

Eurostat, 2018d. *Agri-environmental indicator – consumption of pesticides.*
http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=aei_fm_salpest09&lang=en.

Eurostat, 2018e. *Air emissions accounts by NACE.*
http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_ac_ainah_r2&lang=en.

Eurostat, 2018f. *Generation of waste by the Agriculture, forestry and fishing sector, by country, year and waste category.*
http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_wasgen&lang=en.

Eurostat, 2018g. *Gross value added and income by A*10 industry breakdowns. Percentage of gross domestic products (GDP)*
http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nama_10_a10&lang=en.

Ewertowska, A., Galán-Martín, A., Guillén-Gosálbez, G., Gavaldá, J., Jiménez, L., 2016. *Assessment of the environmental efficiency of the electricity mix of the top European economies via data envelopment analysis.* Journal of Cleaner Production 116, 13-22.

Ewertowska, A., Pozo, C., Gavaldá, J., Jiménez, L., Guillén-Gosálbez, G., 2017. *Combined use of life cycle assessment, data envelopment analysis and Monte Carlo simulation for quantifying environmental efficiencies under uncertainty.* Journal of Cleaner Production 166, 771-783.

Fiksel, J., Wapman, K., 1994. *How to design for environment and minimize life cycle costs*. Paper presented at the IEEE International Symposium on Electronics and the Environment. San Francisco.

Frondel, M., Horbach, J., Reinnings, K., 2008. *What triggers environmental management and innovation? Empirical evidence from Germany.* Ecological Economics 66, 153-160.

García-Granero, E., Piedra-Muñoz, L., Galdeano-Gómez, E., 2018. *Eco-innovation measurement: A review of firm performance*. Journal of Cleaner Production 191, 304-317.

Gbededo, M.A., Liyanage, K., Garza-Reyes, A., 2018. *Towards a Life Cycle Sustainability Analysis: A systematic review of approaches to sustainable manufacturing*. Journal of Cleaner Production 184, 1002-1015.

Geldermann, J., Treitz, M., 2008. *Quantifying eco-efficiency with multi-criteria analysis*. Research Paper 5. Göttingen.

Giljum, S., Lieber, M., Doranova, A., 2017. *EU Eco-Innovation Index 2016*. https://ec.europa.eu/environment/ecoap/sites/ecoap_stayconnected/files/eio_brief_eco-innovation_index_2016_final.pdf.

Giljum, S., Lieber, M., Gozet, B., Doranova, A., 2018. *EU Eco-Innovation Index: 2017 version – Technical note.* https://ec.europa.eu/environment/ecoap/sites/ecoap_stayconnected/files/eco-innovation_index_eu_2017_technical_note.pdf.

Goedkoop, M., Heijungs, R., Huijbregts, M., de Schryver, A., Struijs, J., Zelm, R., 2013. *ReCiPe 2008 A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level*. Ministry of Housing, Spatial Planning and Environment (VROM).

Goedkoop, M., Oele, M., Leijting, J., Ponsioen, T., Meijer, E., 2016. *Introduction to LCA with SimaPro.* https://www.pre-sustainability.com/download/SimaPro8IntroductionToLCA.pdf.

Goedkoop, M., Oele, M., Vieira, M., Leijting, J., Ponsioen, T., Meijer, E., 2016. *SimaPro Tutorial*. https://www.pre-sustainability.com/download/SimaPro8Tutorial.pdf.

Guinée, J.B., Gorrée, M., Heijungs, R., Huppes, G., Kleijn, R., de Koning, A., van Oers, L., Wegener Sleeswijk, A., Suh, S., Udo de Haes, H.A., de Bruijn, H., van Duin, R., Huijbregts, M.A.J., 2004. *Handbook on Life Cycle Assessment. Operational Guide to the ISO Standards*. Kluwer Academic Publishers. New York, Boston, Dordrecht, London, Moscow.

Güler, A., ed. 2015. *Sustainable Markets for Sustainable Business. A Global Perspective for Business and Financial Markets*. Routledge, Londyn.

Guziana, B., 2011. *Is the Swedish environmental technology sector 'green'?* Journal of Cleaner Production 19 (8), 827-835.

Hellström, T., 2007. *Dimensions of environmentally sustainable innovation: the structure of eco-innovation concepts*. Sustainable Development 15 (3), 148-159.

Hellweg, S., Doka, G., Finnveden, G., Hungerbühler, K., 2005. *Assessing the Eco-Efficiency of End-of-Pipe Technologies with the Environmental Cost Efficiency Indicator.* Journal of Industrial Ecology 9(4), 189-203.

Hinterberger, F., 2000. *Eco-efficiency of regions. How to improve competitiveness and create jobs by reducing environmental pressure*. Sustainable Europe Research Institute SERI. Wien.

Hinterberger, F., Schneider, F. 2001. *Eco-efficiency of regions: Toward Reducing Total Material Input*. Sustainable Europe Research Institute SERI. Wien.

Hofstra, N., 2007. *Sustainable entrepreneurship in dialogue*. Progress in Industrial Ecology: an International Journal 4 (6), 495-513.

Hofstra, N., Huisingh, D., 2014. *Eco-innovation characterized: a taxonomic classification of relationships between humans and nature*, Journal of Cleaner Production 66, 459-468.

Hojnik, J., 2017. *In Pursuit of Eco-innovation. Drivers and Consequences of Eco-innovation at Firm Level*. University of Primorska Press. Koper.

Hojnik, J., Ruzzier, M., 2016. *What drives eco-innovation? A review of an emerging literature*, Environmental Innovation and Societal Transitions 19, 31-41.

Horbach, J., 2016. *Empirical determinants of eco-innovation in European countries using the community innovation survey.* Environmental Innovation and Societal Transitions 19, 1-14.

Horbach, J., Rammer, Ch., Rennings, K., 2012. *Determinants of eco-innovations by type of environmental impact – The role of regulatory push/pull, technology and market pull*. Ecological Economics 78, 112-122.

https://www.wbcsd.org/Projects/Education/Resources/Eco-efficiency-Learning-Module.

Huang, J., Yang, H., Cheng, G., Wang, S., 2014. *A comprehensive eco-efficiency model and dynamics of regional eco-efficiency in China*. Journal of Cleaner Production 67, 228-238.

Huppes, G., Ishikawa, M., 2005. *A framework for quantified eco-efficiency analysis.* Journal of Industrial Ecology 9(4), 25-41.

Huppes, G., Ishikawa, M., 2007. *Quantified Eco-Efficiency An introduction with Applications*. Springer. Dordrecht.

Huppes, G., Kleijn, R., Huele, R., Ekins, P., Shaw, B., Esders, M., Schaltegger, S., 2008. *Measuring eco-innovation: Framework and typology of indicators based on causal chains.* Final report of the ECODRIVE project. Leiden, London, Lüneburg.

IEC, 2017. *European Standard IEC 60300-3-3. Dependability management – Part 3-3: Application guide – Life cycle costing*.

Iribarren, D., Hospido, A., Moreira, M.T., Feijoo, G., 2011. *Benchmarking environmental and operational parameters through eco-efficiency criteria for dairy farms*. Science of the Total Environment 409 (10), 1786-1798.

Iribarren, D., Martín-Gamboa, M., Dufour, J., 2013. *Environmental benchmarking of wind farms according to their operational performance.* Energy 61, 589-597.

Iribarren, D., Marvuglia, A., Hild, P., Guiton, M., Popovici, E., Benetto, E., 2015. *Life cycle assessment and data envelopment analysis approach for the selection of building components according to their environmental impact efficiency: a case study for external walls.* Journal of Cleaner Production 87, 707-716.

Iribarren, D., Vázquez-Rowe, I., 2013. *Is labor a suitable input in LCA + DEA studies? Insights on the combined use of economic, environmental and social parameters*. Social Science 2 (3), 114-130.

Iribarren, D., Vázquez-Rowe, I., Moreira, M.T., Feijoo, G., 2010. *Further potentials in the joint implementation of life cycle assessment and data envelopment analysis.* Science of the Total Environment 408 (22), 5265-5272.

Iribarren, D., Vázquez-Rowe, I., Rugani, B., Benetto, E., 2014. *On the feasibility of using emergy analysis as a source of benchmarking criteria through data envelopment analysis: a case study for wind energy.* Energy 67, 527-537.

ISO, 2006a. *International Standard ISO 14040. Environmental management – Life cycle assessment – Principles and framework.*

ISO, 2006b. *International Standard ISO 14044. Environmental management – Life cycle assessment – Requirements and guidelines*.

ISO, 2012. *International Standard ISO 14045. Environmental management – Eco-efficiency assessment of product systems – Principles, requirements and guidelines.*

ISO, 2015. *International Standard ISO 14001. Environmental management systems – Requirements with guidance for use*.

Jan, P., Dux, D., Lips, M., Alig, M., Dumondel, M., 2012. *On the link between economic and environmental performance of Swiss dairy farms of the alpine area.* International Journal of Life Cycle Assessment 17 (6), 706-719.

Jansson, J., Marell, A., Nordlund, A., 2011. *Exploring Consumer Adoption of a High Involvement Eco-innovation Using Value-belief-norm Theory.* Journal of Consumer Behaviour 10, 51-60.

Johnstone, N., Hascic, I., Popp, D., 2010. *Renewable energy policies and technological innovation: evidence based on patent counts.* Environmental and Resource Economics 45, 133-155.

Joint Research Centre – Institute for Environment and Sustainability, 2011. *International Reference Life Cycle Data System (ILCD) Handbook – Recommendations for Life Cycle Impact Assessment in the European context.* http://eplca.jrc.ec.europa.eu/uploads/ILCD-Recommendation-of-methods-for-LCIA-def.pdf.

Jolly, A., Philpott, J., 2004. *A Handbook of Intellectual Property Management: Protecting, Developing and Exploiting Your IP Assets.* Kogan Page Publishers. London.

Kemp, R., Pearson, P., 2008. *Final report of the MEI project measuring eco-innovation.* UM-MERIT Maastricht. https://www.oecd.org/greengrowth/consumption-innovation/43960830.pdf.

Kesidou, E., Demirel, P., 2012. *On the drivers of eco-innovations: empirical evidence from the UK.* Research Policy 41, 862-870.

Kleiber, M. ed., 2011. *Ekoefektywność technologii [Eco-efficiency of technology]*. Wydawnictwo Naukowe Instytutu Technologii Eksploatacji Państwowego Instytutu Badawczego, Warszawa.

Kobayashi, Y., Kobayashi, H., Hongu, A., Sanehira, K., 2005. A practical method for quantifying eco-efficiency using eco-design support tools. Journal of Industrial Ecology 9(4), 131-144.

Kouchaki-Penchah, H., Nabavi-Pelesaraei, A., O'Dwyer, J., Sharifi, M., 2017. *Environmental Management of Tea Production Using Joint of Life Cycle Assessment and Data Envelopment Analysis Approaches.* Environmental Progress & Sustainable Energy 36 (4), 1116-1122.

Kowalski, Z., Kulczycka. J., Góralczyk. M., 2007. *Ekologiczna ocena cyklu życia procesów wytwórczych (LCA) [Ecological life cycle assessment of manufacturing processes (LCA)]*, Wydawnictwo Naukowe PWN, Warszawa.

Laso, J., Vázquez-Rowe, I., Margallo, M., Irabien, Á., Aldaco, R., 2018. *Revisiting the LCA+DEA method in fishing fleets. How should we be measuring efficiency?* Marine Policy 91, 34-40.

Lee, Ch-H., Wu K-J., Tseng M-L., 2018. *Resource management practice through eco-innovation toward sustainable development using qualitative information and quantitative data.* Journal of Cleaner Production 202, 120-129.

Lorenzo-Toja, Y., Vázquez-Rowe, I., Chenel, S., Marín-Navarro, D., Moreira, M.T., Feijoo, G., 2015. *Eco-efficiency analysis of Spanish WWTPs using the LCA + DEA method.* Water Resources 68, 651-666.

Lozano, S., Adenso-Díaz, B., Barba-Gutiérrez, Y., 2011. *Russell non-radial eco-efficiency measure and scale elasticity of a sample of electric/electronic products.* Journal of the Franklin Institute 348 (7), 1605-1614.

Lozano, S., Iribarren, D., Moreira, M.T., Feijoo, G., 2009. *The link between operational efficiency and environmental impacts: a joint application of life cycle assessment and data envelopment analysis.* Science of the Total Environment 407 (5), 1744-1754.

Lozano, S., Iribarren, D., Moreira, M.T., Feijoo, G., 2010. *Environmental impact efficiency in mussel cultivation.* Resources, Conservation and Recycling 54 (12), 1269-1277.

Marcon, A., de Medeiros, J.F., Duarte Ribeiro, J.L., 2017. *Innovation and environmentally sustainable economy: Identifying the best practices developed by multinationals in Brazil*. Journal of Cleaner Production 160, 83-97.

Martín-Gamboa, M., Iribarren, D., Dufour, J., 2018. *Environmental impact efficiency of natural gas combined cycle power plants: A combined life cycle assessment and dynamic data envelopment analysis approach.* Science of the Total Environment 615, 29-37.

Martín-Gamboa, M., Iribarren, D., García-Gusano, D., Dufour, J., 2017. *A review of life-cycle approaches coupled with data envelopment analysis within multi-criteria decision analysis for sustainability assessment of energy systems.* Journal of Cleaner Production 150, 164-174.

Masternak-Janus, A., Rybaczewska-Błażejowska, M., 2015. *Life cycle analysis of tissue paper manufacturing from virgin pulp or recycled waste paper*. Management and Production Engineering Review 6 (3), 47-54.

Masternak-Janus, A., Rybaczewska-Błażejowska, M., 2017. *Comprehensive regional eco-efficiency analysis based on date envelopment analysis: the case study of Polish regions.* Journal of Industrial Ecology 21 (1), 180-190.

Masuda, K., 2016. *Measuring eco-efficiency of wheat production in Japan: a combined application of life cycle assessment and data envelopment analysis.* Journal of Cleaner Production 126, 373-381.

Melanen, M., Mickwitz, P., Rosenström, U., Seppälä, J., 2011. *Eco-efficiency indicators – tools for regional sustainability policy.* https://www.researchgate.net/publication/ 268399994_Eco-efficiency_indicators__tools_for_regional_sustainability_policy.

Melanen, M., Seppälä, J., Myllymaa, T., Mickwitz, P., Rosenström, U., Koskela, S., Tenhunen, J., Mäenpää, I., Hering, F., Estlander, A., Hiltunen, M-R., Toikka, M., Mänty, E., Liljeqvist L., Pesari, J., 2004. *Measuring regional eco-efficiency – case Kymenlaakso*. Edita Prima Oy. Helsinki.

Menke, D.M., Davis G.A., Vigon, B.W., 1996. *Evaluation of life-cycle assessment tools.* Environment Canada. Hazardous waste branch. Ottawa.

Mickwitz, P., Melanen, M., Rosenström, U., Seppälä, J., 2006. *Regional eco-efficiency indicators – a participatory approach*. Journal of Cleaner Production 14(18), 1603-1611.

Ministry of the Environment, 2004. *Najlepsze dostępne techniki (BAT) – wytyczne dla branży spożywczej: owocowo-warzywnej (soki i nektary, przetwory, mrożonki) [Best available techniques (BAT) – guidelines for food industry: fruit and vegetables (juices, nectars, preserves, frozen food]*.
http://www.ekoportal.gov.pl/fileadmin/Ekoportal/Pozwolenia_zintegrowane/poradniki_branzowe/17._Najlepsze_Dostepne_Techniki__BAT__wytyczne_branzy_spozywczej_-_przetworstwo_owocowo-warzywne.pdf.

Mohammadi, A., Rafiee, S., Jafari, A., Dalgaard, T., Knudsen, M.T., Keyhani A., Mousavi-Avval. S., Hermansen J., 2013. *Potential greenhouse gas emission reductions in soybean farming: a combined use of life cycle assessment and data envelopment analy*sis. Journal of Cleaner Production 54, 89-100.

Mohammadi, A., Rafiee, S., Jafari, A., Keyhani, A., Dalgaard, T., Knudsen, M.T., Nguyen, T., Borek, R., Hermansen, J., 2015. *Joint Life Cycle Assessment and Data Envelopment Analysis for the benchmarking of environmental impacts in rice paddy production*. Journal of Cleaner Production 106, 521-532.

Mohseni, P., Borghei, A.M., Khanali M., 2018. *Coupled life cycle assessment and data envelopment analysis for mitigation of environmental impacts and enhancement of energy efficiency in grape production*. Journal of Cleaner Production 197, 937-947.

Motta, W.H., Issberner, L.-R., Prado, P., 2018. *Life cycle assessment and eco-innovations: What kind of convergence is possible?* Journal of Cleaner Production 187, 1103-1114.

Motta, W.H., Prado, P., Issberner, L.-R., 2015. *Life cycle assessment and the eco-innovation generation.* PLATE Conference Proceedings. Product Lifetimes and the Environment. Nottingham.

Nesta, L., Vona, F., Nicolli, F., 2014. *Environmental policies, competition and innovation in renewablekk energy.* Journal of Environmental Economics and Management 67, 396-411.

Nicolli, F., Vona, F., 2016. *Heterogeneous policies, heterogeneous technologies: the case of renewable energy.* Energy Economics 56, 190-204.

OECD, 1998. *Eco-efficiency*. Organization for Economic Cooperation and Development, Paris.

OECD, 2009. *Sustainable Manufacturing and Eco-innovation: Towards a Green Economy.* http://www.greengrowthknowledge.org/sites/default/files/downloads/resource/Sustainable_Manufacturing_and_Eco-innovation_OECD.pdf.

OECD, 2018. *Agri-Environmental other indicators – Agriculture freshwater abstraction*. https://stats.oecd.org/viewhtml.aspx?datasetcode=AEI_OTHER&lang=en#.

OECD, Eurostat, 1999. *The Environmental Goods and Services Industry – Manual for Data Collection and Analysis*. OECD Publications Service. Paris.

OECD, Eurostat, 2005. *Oslo Manual: The Measurement of Scientific and Technological Activities. Guidelines for Collecting and Interpreting Innovation Data*. https://www.oecd-ilibrary.org/science-and-technology/oslo-manual_9789264013100-en.

OECD, Eurostat, 2018. *Oslo Manual 2018: The Measurement of Scientific, Technological and Innovation Activities. Guidelines for Collecting, Reporting and Using Data on Innovation.* https://read.oecd-ilibrary.org/science-and-technology/oslo-manual-2018_9789264304604-en.

Pang, J., Chen, X., Zhang, Z., Li, H., 2016. *Measuring Eco-Efficiency of Agriculture in China*. Sustainability 8 (398), 1-15.

Paramesh, V., Arunachalam, V., Nikkhah, A., Das, B. 2018. *Optimization of energy consumption and environmental impacts of arecanut production through coupled data envelopment analysis and life cycle assessment.* Journal of Cleaner Production 203, 674-684.

Park, M.S., Bleischwitz, R., Han, K.J., Jang, E.K., Joo, J.H., 2017. *Eco-Innovation Indices as Tools for Measuring Eco-Innovation*, Sustainability 9 (12), 1-28.

Piedra-Muñoz, L., Vega-López, L.L., Galdeano-Gómez, E., Zepeda-Zepeda, J.A., 2018. *Drivers for efficient water use in agriculture: an empirical analysis of family farms in Almería (Spain).* Experimental Agriculture 54 (1), 31-44.

Pigosso, D.C., Zanette, E.T., Guelere Filho, A., Ometto, A.R., Rozenfeld, H., 2010. *Ecodesign methods focused on remanufacturing.* Journal of Cleaner Production 18 (1), 21-31.

Reid, A., Miedzinski, M., 2008. *Eco-Innovation – Final Report for Sectoral Innovation Watch.* Technopolis Group. Brussels.

Rennings, K., 2000. *Redefining innovation – eco-innovation research and the contribution from ecological economics.* Ecological Economics 32 (2), 319-332.

Rice, G., Clift, R., Burns, R., 1997. *Comparison of currently available European LCA software.* The International Journal of Life Cycle Assessment 2 (1), 53-59.

Rodríguez, J., Wiengarten, F., 2017. *The role of process innovativeness in the development of environmental innovativeness capability.* Journal of Cleaner Production 142, 2423-2434.

Rybaczewska-Błażejowska, M., 2014. *Narzędzia oceny cyklu życia (LCA) a modelowanie systemów gospodarki odpadami [Tools of life cycle assessment (LCA) and modelling of waste management systems]* in: *Zarządzanie środowiskiem i zrównoważona energetyka*. Oficyna Wydawnicza Uniwersytetu Ekonomicznego we Wrocławiu. Wrocław.

Rybaczewska-Błażejowska, M., Baran, J., Czajka, D., 2018. *Product environmental footprint of automotive glass.* In printing.

Rybaczewska-Błażejowska, M., Bujak, E., 2016. *Ekologiczna ocena cyklu życia (LCA) opakowań – butelka PET versus butelka szklana [Ecological life cycle assessment (LCA) of packaging – PET bottle versus glass bottle]* in: *Innowacje w zarządzaniu i inżynierii produkcji*. Oficyna Wydawnicza Polskiego Towarzystwa Zarządzania Produkcją. Opole.

Rybaczewska-Błażejowska, M., Gierulski, W., 2018. *Eco-Efficiency Evaluation of Agricultural Production in the EU-28*. Sustainability 10 (12), 4544.

Rybaczewska-Błażejowska, M., Luściński, S., 2014. *The application of life cycle assessment with GS1 system support* in: *Innowacje w zarządzaniu i inżynierii produkcji*. Oficyna Wydawnicza Polskiego Towarzystwa Zarządzania Produkcją. Opole.

Rybaczewska-Błażejowska, M., Masternak-Janus, A., 2018. *Eco-efficiency assessment of Polish regions: joint application of life cycle assessment and data envelopment analysis*. Journal of Cleaner Production 172, 1180-1192.

Rybaczewska-Błażejowska, M., Masternak-Janus, A., Gierulski, W., 2016. *Inverse problem of life cycle assessment (LCA): its application in designing for environment (DfE)*. Management 20 (2), 234-241.

Rybaczewska-Błażejowska, M., Palekhov, D., 2018. *Life Cycle Assessment (LCA) in Environmental Impact Assessment (EIA): principles and practical implications for industrial projects*. Management 22 (1), 138-153.

Rybaczewska-Błażejowska, M., Sulerz, A., 2017. *LCA as a tool for assessing product and process oriented eco-innovations undertaken by enterprises*. Management and Production Engineering Review 8 (3), 60-69.

Rybaczewska-Błażejowska, M., Sulerz, A., 2017. *LCA as a tool for assessing product and process oriented eco-innovations undertaken by enterprises*. Management and Production Engineering Review 8 (3), 60-69.

Sabadie, J.A., Kwiatkowski, C., 2016. *The Community Innovation Survey and the innovation performance of enterprises funded by EU's Framework Programmes*. https://ec.europa.eu/eurostat/cros/system/files/173-2015-the_cis_and_the_innovation_performance_of_enterprises_funded_by_eus_fp.pdf.

Sanjuan, N., Ribal, J., Clemente, G., Fenollosa, M.L., 2011. *Measuring and improving eco-efficiency using data envelopment analysis. A Case Study of Mahón-Menorca Cheese.* Journal of Industrial Ecology 15 (4), 614-628.

Schaltegger, S., Sturm, A., 1989. *Ökologie Induzierte entscheidungsprobleme des managements. Ansatzpunkte zur ausgestaltung von instrumenten [Ecology induced management decision support. Starting points for instrument formation]*. WWZ-Discussion Paper No. 8914. Basel, Switzerland:WWZ.

Schaltegger, S., Sturm, A., 1992. *Ökologieorientierte Entscheidungen in Unternehmen. [Environmentally Oriented Decisions in Companies]*. Haupt, Bern, Stuttgart.

Selech, J., Kurczewski, P., 2012. *Life cycle costing (LCC) jako nowoczesny model zarządzania kosztami cyklu życia na przykładzie obiektów technicznych [Life Cycle Costing (LCC) known as modern model of life cycle cost management based on example of technical object]*. Problemy Eksploatacji [Operational Problems] 1, 99-108.

Seppälä, J., Melanen, M., Mäenpää, I., Koskela, S., Tenhunen, J., Hiltunen, M., 2005. *How can the eco-efficiency of a region be measured and monitored?* Journal of Industrial Ecology 9(4), 117-130.

SETAC, 1991. *A Technical Framework for Life-cycle Assessment.* Society of Environmental Toxicology and Chemistry and SETAC Foundation for Environmental Education . Washington.

SETAC, 1993. *Guidelines for Life-cycle Assessment: A 'Code of Practice'*. Society of Environmental Toxicology and Chemistry. Brussels.

Sierra-Pérez, J., López-Forniés, I., Boschmonart-Rives, J., Gabarell, X., 2016. *Introducing eco-ideation and creativity techniques to increase and diversify the applications of eco-materials: the case of cork in the building sector.* Journal of Cleaner Production 137, 606-616.

Speirs, J., Pearson, P., Foxon, T., 2008. *Adapting Innovation Systems Indicators to Assess Eco-innovation.* http://orca-mwe.cf.ac. uk/40682/1/Foxon_Speirs_Pearson_final.pdf.

Śledzik, K., 2013. *Schumpeter's view on innovation and entrepreneurship*. in: *Management Trends in Theory and Practice*. University of Zilina & Institute of Management by University of Zilina. Zilina.

Tatari, O., Kucukvar, M., 2012. *Eco-efficiency of construction materials: data envelopment analysis.* Journal of Construction Engineering and Management 138(6), 733-741.

Theyel, G., 2000. *Management practices for environmental innovation and performance.* International Journal of Operations & Production Management 20 (2), 249-266.

Ullah, A., Perret, S.R., Gheewala, S.H., Soni, P., 2016. *Eco-efficiency of cotton-cropping systems in Pakistan: an integrated approach of life cycle assessment and data envelopment analysis.* Journal of Cleaner Production 134, 623-632.

UN ESCAP, 2009. *Eco-efficiency indicators: Measuring Resource-use Efficiency and the Impact of Economic Activities on the Environment*. United Nations Economic and Social Commission for Asian and the Pacific. Bangkok.

UNEP, 1996. *Life Cycle Assessment: What it is and how to do it.* United Nations Environmental Programme Industry and Environment. Leiden.

Van Hemel, C., Cramer, J., 2002. *Barriers and stimuli for ecodesign in SMEs.* Journal of Cleaner Production 10, 439-453.

Vázquez-Rowe, I., Iribarren, D., Hospido, A., Moreira, M.T., Feijoo, G., 2011. *Computation of operational and environmental benchmarks within selected galician fishing fleets.* Journal of Industrial Ecology 15 (5), 776-795.

Vázquez-Rowe, I., Iribarren, D., Moreira, M.T., Feijoo, G., 2010. *Combined application of life cycle assessment and data envelopment analysis as a methodological approach for the assessment of fisheries.* International Journal of Life Cycle Assessment 15 (3), 272-283.

Vázquez-Rowe, I., Villanueva-Rey, P., Iribarren, D., Moreira, M.,T., Feijoo, G., 2012. *Joint life cycle assessment and data envelopment analysis of grape production for vinification in the Rías Baixasappellation (NW Spain).* Journal of Cleaner Production 27, 92-102.

Vlontzos, G., Niavis, S., Pardalos, P., 2017. *Testing for Environmental Kuznets Curve in the EU Agricultural Sector through an Eco-(in)Efficiency Index*, Energies 10 (12), 1-15.

Vlontzos, G., Pardalos, P.M., 2017. *Assess and prognosticate greenhouse gas emissions from agricultural production of EU countries, by implementing, DEA Window analysis and artificial neural networks*. Renewable and Sustainable Energy Reviews 76, 155-162.

WBCSD, 2006. *Eco-efficiency Learning Module.* World Business Council for Sustainable Development.

Wursthorn, S., Poganietz, W. R., Schebek, L., 2011. *Economic-environmental monitoring indicators for European countries: A disaggregated sector-based approach for monitoring eco-efficiency.* Ecological Economics 70, 487-496.

Xavier, A., Naveiro, R.M., Aoussat, A., Reyes, T., 2017. *Systematic literature review of eco-innovation models: Opportunities and recommendations for future research*. Journal of Cleaner Production 149, 1278-1302.

Xing, Z., Wang, J., Zhang, J., 2018. *Expansion of environmental impact assessment for eco-efficiency evaluation of China's economic sectors: An economic input-output based frontier approach.* Science of the Total Environment 635, 284-293.

Zbycinski, I., Stavenuiter, J., Koslowska, B., van de Coevering, H.P.M., 2006. *Product Design and Life Cycle Assessment.* The Baltic University Press. Uppsala.

Zhang, B., Bi, J., Fan, Z., Yuan, Z., Ge, J., 2008. *Eco-efficiency analysis of industrial system in China: a data envelopment analysis approach*. Ecological Economics 68 (1-2), 306-316.

Zurano-Cervelló, P., Pozo, C., Mateo-Sanz, J.M., Jiménez L., Guillén-Gosálbez, G., 2018. *Eco-efficiency assessment of EU manufacturing sectors combining input-output tables and data envelopment analysis following production and consumption-based accounting approaches.* Journal of Cleaner Production 174, 1161-1189.