A dissertation presented in partial fulfillment of the requirements for the degree of Doctor in Engineering Sciences

LCA of building materials that include a biobased binder: lessons and challenges

Saïcha Gerbinet

2018

Supervisor: Prof. Angélique Léonard

University of Liège
Faculty of Applied Sciences
Chemical Engineering
PEPs - Products, Environment and Processes

A dissertation presented in partial fulfillment of the requirements for the degree of Doctor in Engineering Sciences

LCA of building materials that include a biobased binder: lessons and challenges

Saïcha Gerbinet

2018

Supervisor: Prof. Angélique Léonard

University of Liège
Faculty of Applied Sciences
Chemical Engineering
PEPs - Products, Environment and Processes

Members of the PhD thesis Jury

Prof. Wouter Achten
Université Libre de Bruxelles (Brussels, Belgium)

Dr. Sandra Belboom
HELMo (Liège, Belgium)

Vincent Briard
Knauf Insulation (Visé, Belgium)

Prof. Luc Courard
University of Liège (Liège, Belgium)

Prof. Angélique Léonard (Supervisor)
University of Liège (Liège, Belgium)

Prof. Guido Sonnemann
University of Bordeaux (Bordeaux, France)

Prof. Dominique Toye (President of the Jury)
University of Liège (Liège, Belgium)

ABSTRACT

There is growing concern over the sustainability of our lifestyles that are fueling initiatives for eco-design, or finding ways to reduce our environmental footprint at every level (individual, industrial, state). One of the sectors with the largest environmental impact is construction, and manufacturers are looking into substituting certain fossil-based, toxic, and polluting elements with biobased ones. An example of this is the development from Knauf Insulation of a new binder named ECOSE®, based on sugar extracted from wheat or corn, to replace the traditional formaldehyde-based one. Binder is used in numerous construction products, namely insulating wool such a glass mineral wool or wood panels. These concerns require a complete evaluation of the environmental impact of these building materials that include a biobased binder.

The most rigorous method to date to exhaustively evaluate the environmental impact of a product (or a service, system, process, etc.) is Life Cycle Assessment (LCA). The idea is to inventory everything that goes into making the product and everything that is generated, including waste, emissions, and byproducts, and measure their impact in all pertinent categories, not only green-house gas emissions but also land occupation, air, water, and soil pollution, resource depletion, toxicity, and more. Using a biobased binder might reduce toxicity and fossil fuel depletion, but will it improve overall the environmental impact of the product ?

To answer this question, this PhD thesis looks at the life cycle of ECOSE® and its use in insulating wool produced by Knauf Insulation, and compares them to those made with a conventional binder. The ECOSE® binder, when applied in glass mineral wool allows to reduce the environmental impact in climate change and fossil fuel consumption, but this is not the case in other categories such as acidification and eutrophication. For some categories, no clear conclusion can be draws due to uncertainties. Nevertheless, as this study does not include the use phase, the benefit on indoor air quality of reducing formaldehyde emissions are not included.

In this work, we also show the challenges of responding to these environmental concerns, in terms of measuring the impact and how to translate the results into clear-cut answers. We have found and described the many sources of variation in the measurements, from the uncertainties in the data to the differences in implementation of the LCA methodology in software. The difficulties to have accurate method to evaluate the impact, in some categories such as toxicity is also underlined, such as the difficulties related to background data and database and the need of local data, especially for biobased product. We then explained the difficulty in deriving impactful decisions from the interpretation of the results, as there is never a perfect solution. As the methods and the data improve and LCA becomes more widespread, the hope is that for things such as biobased materials, we will make the right choice, and thus leave a healthy planet.

RÉSUMÉ

Les préoccupations grandissantes concernant la durabilité de notre mode de vie ont mené au développement d'initiatives d'éco-design ou visant à réduire notre impact sur l'environnement et ce à tous les niveaux (individuel, industriel, national). Le secteur du bâtiment a un impact environnemental non négligeable et les producteurs essaient de remplacer certains constituants toxiques et issus de ressources fossiles par des constituants bio-basés. C'est par exemple le cas de Knauf Insulation qui a développé un nouveau liant bio-basé appelé ECOSE® pour remplacer le liant conventionnement utilisé à base de phénol-formaldéhyde. Ce nouveau liant est produit à partir de sucre venant de céréales (blés ou maïs). Les liants ont de nombreuses applications dans les produits de la construction, comme les produits isolants comprenant notamment la laine de verre ou les panneaux en bois. Ces préoccupations requièrent une analyse environnementale complète de ces matériaux de construction, y compris du liant bio-basé.

La méthode la plus rigoureuse disponible actuellement pour évaluer l'impact environnemental d'un produit (ou d'un service) est l'analyse du cycle de vie (ACV). L'idée est d'inventorier toutes les entrées nécessaires à la production du produit étudié mais également tout ce qui est généré, en incluant les déchets, les émissions et les éventuels coproduits et de mesurer leurs impacts dans toutes les catégories pertinentes, pas seulement le réchauffement climatique mais aussi l'occupation des sols, la pollution de l'air, de l'eau ou du sol, la diminution des ressources, la toxicité, etc. L'utilisation d'un liant bio-basé va probablement diminuer la toxicité du produit et la consommation de ressources fossiles mais est-ce que cela va aussi réduire les autres impacts sur l'environnement?

Pour répondre à cette question, le cycle de vie du liant ECOSE® produit par Knauf Insulation et son utilisation dans un isolant ont été étudiés et comparés avec le liant conventionnel. Le liant ECOSE®, quand il est utilisé dans de la laine de verre, permet de réduire le réchauffement climatique et la consommation de ressources fossiles mais ce n'est pas le cas dans d'autres catégories telles que l'acidification et l'eutrophisation. Pour certaines catégories, il n'est pas possible de conclure à cause des incertitudes trop élevées. Néanmoins, comme cette étude ne prend pas en compte la phase d'utilisation, les bénéfices sur la qualité de l'air de la réduction des émissions de formaldéhyde ne sont pas inclus.

Dans ce travail, nous avons aussi mis en évidence les challenges à relever pour répondre à ces préoccupations environnementales, en terme de mesure de l'impact et de comment traduire les résultats en réponses claires. Nous avons identifié et décrit plusieurs sources de variations dans les mesures, des incertitudes dans les données en passant par les différences d'implémentation des méthodes d'évaluation d'impact dans les logiciels d'ACV. Les difficultés d'avoir des méthodes précises d'évaluation de l'impact dans certaines catégories comme la toxicité ont aussi été soulignées comme les difficultés liées aux données d'arrière-plan et aux bases de données et la nécessité d'utiliser des données locales dans le cas de matériaux bio-basés. Nous avons aussi expliqué les difficultés à trouver des solutions pertinentes en interprétant les résultats. En effet, il n'y a jamais de solution parfaite. Comme les méthodes et les données disponibles pour faire des ACV deviennent de plus en plus nombreuses, l'espoir est que nous puissions faire les bons choix sur des sujets tels que les matériaux bio-sourcés et ainsi préserver notre planète.

ACKNOWLEDGEMENTS

I first want to thank my PhD supervisor, Angélique Léonard, for her welcome in her lab for my Master's thesis and to allow me to continue to work in Life Cycle Assessment. She has been an invaluable help and support, and her scientific rigor has been instrumental for the accuracy of this work. I would like to acknowledge Sandra Belboom who helped me during my Master's thesis , gave me the desire to pursue work in this field, and was there again during my PhD for any questions I had, scientific or not. I also want to thank all the other members of the LCA team of the ULiège, especially Sylvie Groslambert and Angel Merchand: without all the discussions we have about LCA, this PhD might not have had the same depth.

This work would not have been possible without the great collaboration with Knauf Insulation. I am especially thankful to Vincent Briard, who made me enjoy this work thanks to his passion for environmental topics and his sense of duty. I also thank Carl Hampson who provided great support on the understanding of ECOSE®, Jean-Pierre Pigeolet for his critical look on all the modelling, Eric Pezennec for its analytical point of view that really improved my results, and Marc De Roeck for its help on several topics. I also want to thank Philippe Coune, Jean-Claude Lejeune, Nadège Herlet and Jean-Marie Desert, who gave me valuable information about the Knauf Insulation plants. More broadly, I would like to thank all the people of Knauf Insulation who helped me with data collection.

I would like to thank Dominique Toye, member of the PhD committee, who helped me have a critical view of my work and improve the quality of my work. I also have to thank Luc Courard who, as another member of the committee, took time to participate at the meetings. His exterior look made these meetings useful.

I would also like to acknowledge the members of the jury who have accepted to evaluate this work and took the time to do it. I would like to thank Professor Sonnemann from the University of Bordeaux who has made the travel and Prof. Dominique Toye who have accepted the presidency of the jury.

I would like to thank the people from ThinkStep who provided great support for the GaBi software, and for their availabilities to all events. Especially, I would like to thank Martin Baitz for all the exciting discussions we had about LCA and his explanations of all the related topics. I also want to thank Isabel Fullana and Sonja Weible for their help with all the possibilities of GaBi, and the content team, especially Matthias Rudol, Morten Kokborg and Sebastian Schulz who took time to answer all my questions, even the most finicky one.

I am also grateful to all those from the glucose compagny who helped me understand and analyze the glucose production (even if I cannot mention them) and those from the lignosulfonates companies who took the time to explain how lignosulfates are produced, especially Guro Fredheim from Borregaard LignoTech and Arturo Perdomo from Tembec.

A special thanks to the people of the Department of Chemical Engineering who have made it such a pleasant work environment. Some of them are more than colleagues. Thanks to Sébastien Calvo, Angélique Delafosse, Thierry Salmon, Sylvie Groslambert. Thanks also to those who have left before me: Marie-Laure Collignon, Raphaëlle Melon, Françoise Laruelle, Anne de Lamotte and all the others. Special thanks to Erwan Plougonven, he first was a colleague who scared me but he is now the person who makes me smile in almost all circumstances. I hope he will help me stay young in my head for a long time. I also want to thank my horses, even though their injuries and the fact that they are getting older can stress me a lot, I guess the people around me would find me more difficult to stand if my horses did not help me keep a calm and positive mood.

Finally, I want to thank my family, especially my mother for always being there for me and making me able to do the things I love. Her presence and her watchful eye helped me in everything I undertook.

CONTENTS

CHAPTER IX BIBLIOGRAPHY

1. Aulakh, D., *Green Marketing: Think Before You Act*, in *Stategic sustainability consulting*. 2012.
2. Dabija, D.C. and C.M. Pop, *Green marketing - Factor of competitiveness in retailing.* Environmental Engineering and Management Journal, 2013. **12**(2): p. 393-400.
3. Zbicinski, I., et al., *Green Marketing and Eco-labelling*, in *Product Design and Life Cycle Assessment*, Baltic University Press, Editor. 2007.
4. République Française Ministère en charge du développement durable et du logement, République Française Ministère en charge de la santé, and République Française Ministère en charge de la culture. *INIES, base nationale française de référencre sur les impacts environnementaux et sanitaires des produits, équipements et services pour l'évaluation de la performance des ouvrages*. 2013 [cited 2014; Available from: http://www.base-inies.fr/Inies/.
5. Cherubini, F. and A.H. Strømman, *Life cycle assessment of bioenergy systems: State of the art and future challenges.* Bioresource Technology, 2011. **102**.
6. Rabl, A., et al., *How to account for CO2 emissions from biomass in an LCA.* International Journal of Life Cycle Assessment, 2007. **12**(5): p. 281-281.
7. Kim, H., S. Kim, and B.E. Dale, *Biofuels, Land Use Change, and Greenhouse Gas Emissions: Some Unexplored Variables.* Environmental Science & Technonology, 2009. **43**.
8. Murphy, C.W. and A. Kendall, *Life cycle analysis of biochemical cellulosic ethanol under multiple scenarios.* GCB Bioenergy, 2014.
9. Oxford University Press. *Oxford Dictionaries, Language matters*. 2014 [cited 2014.
10. Dunster, A., *Characterisation of Mineral Wastes, Resources and Processing technologies – Integrated waste management for the production of construction material*, in *Mineral wool insulation*, DEFRA, Editor. 2007.
11. Knauf Insulation. [cited 2014; Available from: http://www.knaufinsulation.ua/en.
12. National museum of american history and Smithsonian institution, *The Bakelizer*, American Chemical Society, Editor. 1993.
13. Knauf Insulation. *About Knauf Insulation*. [cited 2014; Available from: http://www.knaufinsulation.co.uk/en-gb/more/about.aspx#axzz38Bafmjxh.
14. Design & Technology, *Manufactured boards*. 2007.
15. APA, *Glulam Product Guide*. 2008.
16. Tian, S., G. Pavlovich, and D. Baily, *A Life Cycle Assessment of Particle Board: UF vs. MDI as the Binding Agent*, Bayer Material Science, Editor., Product Safety and Regulatory Affairs.
17. U.S. Department of Health and Human Services, Public Health Service, National Toxicology Program, *Report on Carcinogens*. 2011.
18. World Health Organization and International agency for research on cancer, *Formaldehyde, 2-Butoxyethanol and 1-tert-Butoxypropan-2-ol*, in *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*, I.W.G.o. the and Evaluation of Carcinogenic Risks to Humans, Editors. 2004: Lyon. p. 497.
19. LE PARLEMENT EUROPÉEN and LE CONSEIL DE L'UNION EUROPÉENNE, *RÈGLEMENT (CE) No 1272/2008 DU PARLEMENT EUROPÉEN ET DU CONSEIL*, in *relatif à la classification, à l'étiquetage et à l'emballage des substances et des mélanges, modifiant et abrogeant les directives 67/548/CEE*

et 1999/45/CE et modifiant le règlement (CE) no 1907/2006. 2008, Journal officiel de l'Union européenne.
20. *ISO 1600-3: Air intérieur -- Partie 3: Dosage du formaldéhyde et d'autres composés carbonylés -- Méthode par échantillonnage actif* 2001.
21. Eurofins, *Specifications Indoor Air Comfort ® and Indoor Air Comfort Gold ®*. 2006. p. 25.
22. *ISO 14040, Environmental management - Life cycle assessment - Principles and framework*. 2006.
23. *ISO 14044, Environmental management - Life cycle assessment - Requirements and guidelines*. 2006.
24. Curran, M.A., *Life Cycle Assessment: principles and practice*, Scientific Applications International Corporation (SAIC), Editor. 2006.
25. Belboom, S., *Évaluation de l'impact environnemental de la production de bioéthanol à partir de canne à sucre, betterave ou froment par analyse du cycle de vie. Comparaison des utilisations biocarburant et bioplastique.*, in *Faculté des Sciences Appliquées,*. 2012, Université de Liège,. p. 314.
26. Jensen, A.A., et al., *Life Cycle Assessment: A guide to approaches, experiences and information sources*, in *Environmental Issues Series*, European Environment Agency, Editor. 1977.
27. European Commission - Joint Research Centre and Institute for Environment and Sustainability, *International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance.* 2010.
28. Hauschild, M.Z., R.K. Rosenbaum, and S.I. Olsen, *Life Cycle Assessment: Theory and Practice*. 2018: Springer, Cham.
29. UNEP, *Life Cycle Assessment: A product-oriented method for sustainability analysis*, in *UNEP LCA Training Kit*.
30. European Commission - Joint Research Centre and Institute for Environment and Sustainability, *International Reference Life Cycle Data System (ILCD) Handbook- Recommendations for Life Cycle Impact Assessment in the European context.* 2011.
31. Goedkoop, M., et al., *ReCiPe 2008 : A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level* R.O.e.M. Ministerie van Volkshuisvesting, Editor. 2009, Ruimte en Milei. p. 132.
32. Stranddorf, H.K., L. Hoffmann, and A. Schmidt, *Update on Impact Categories, Normalisation and Weighting in LCA*, in *Environmental Project Nr 995.*, Danish ministry of the environment and Environmental Protection Agency, Editors. 2005. p. 290.
33. Guinée, J.B., *Development of a methodology for the environmnetal life-cycle assessment of products with a case study on margarines*. 1995, Universirty of Leiden.
34. RIVM;, et al. *ReCiPe*. 2015 [cited 2017 23.01.2017]; Available from: http://www.lcia-recipe.net/home.
35. UNEP/SETAC Life Cycle Initiative. *USEtox*. 2017 [cited 2017; Available from: http://www.usetox.org/.
36. Rosenbaum, R.K., Bachmann, T.M., Gold, L.S., Huijbregts, M.A.J., Jolliet, O., Juraske, R., Köhler, A., Larsen, H.F., MacLeod, M., Margni, M., McKone, T.E., Payet, J., Schuhmacher, M., van de Meent, D., Hauschild, M.Z., *USEtox - The UNEPSETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in Life Cycle Impact Assessment.* International Journal of Life Cycle Assessment, 2008. **13**(7).
37. Thinkstep and University of Stuttgart, *Part 1: Introduction to LCA and modelling using GaBi*, in *GaBi paper Clip Tutorial*.
38. IPCC, *2006 IPCC Guidelines for National Greenhouse Gas Inventories* S.E. National Greenhouse Gas Inventories Programm, Leandro buendia, Kyoko Miwa, Todd Ngara and Kiyoto Tanabe,, Editor. 2006.

39. Potting, J.a.H., M., *Background for spatial differentiation in life cycle impact assessment – the EDIP2003 methodology*, in *Environmental project no. 996*, D.E.P. Agency, Editor. 2005: Copenhagen.
40. Silva, D.A.L., et al., *Life Cycle Assessment of Urea Formaldehyde Resin: Comparison by CML (2001), EDIP (1997) and USEtox (2008) Methods for Toxicological Impact Categories*, in *Re-engineering Manufacturing for Sustainability: Proceedings of the 20th CIRP International Conference on Life Cycle Engineering, Singapore 17-19 April, 2013*, C.A.Y. Nee, B. Song, and S.-K. Ong, Editors. 2013, Springer Singapore: Singapore. p. 529-534.
41. Rabl, A.a.S., J.V. *The RiskPoll software, version is 1.051*. 2004; Available from: www.arirabl.com.
42. Greco, S.L., Wilson, A.M., Spengler J.D., and Levy J.I., *Spatial patterns of mobile source particulate matter emissions-to-exposure relationships across the United States.* Atmospheric Environment, 2007. **41**.
43. Universiteit Leiden, Faculty of Science, Institute of Environmental Sciences (CML). *CML-IA Characterisation Factors*. 2010 [cited 2014 17-03-2014]; Available from: https://www.universiteitleiden.nl/en/research/research-output/science/cml-ia-characterisation-factors.
44. Jolliet, O., Margni, M., Charles, R., Humbert, S., Payet, J., Rebitzer, G., Rosenbaum, R.L., Earle, *IMPACT 2002+: A New Life Cycle Impact Assessment Methodology.* International Journal of Life Cycle Assessment, 2003. **8**(6).
45. Brand, G., Braunschweig, A., Scheidegger, A., Schwank, O., *Weighting in Ecobalances with the Ecoscarcity Method – Ecofactors 1997*, in *Environment Series*, BUWAL, Editor. 1998: Bern.
46. Seppälä, J., Posch, M., Johansson, M., Hettelingh, J.P., *Country-dependent Characterisation Factors for Acidification and Terrestrial Eutrophication Based on Accumulated Exceedance as an Impact Category Indicator.* International Journal of Life Cycle Assessment, 2006. **11**(6).
47. Canals, L.M.i., J. Romanya, and S.J. Cowell, *Method for assessing impacts on life support functions (LSF) related to the use of 'fertile land' in Life Cycle Assessment (LCA).* Journal of Cleaner Production, 2007. **15**.
48. Frischknecht, R., Steiner, R., Jungbluth, N., *Methode der ökologischen Knappheit – Ökofaktoren 2006*, B. Bundesamt für Umwelt, Editor. 2008.
49. Kägi, T., et al., *Session "Midpoint, endpoint or single score for decision-making?"—SETAC Europe 25th Annual Meeting, May 5th, 2015.* International Journal of Life Cycle Assessment, 2016. **21**(1): p. 129-132.
50. LBP, University of Stuttgart, and Thinkstep, *GaBI 7*. 2012: Leinfelden-Echterdingen. p. Software and database for life cycle engineering.
51. *About SimaPro*. [cited 2011 23-05-2011]; Available from: http://www.pre.nl/content/simapro-lca-software.
52. Thinkstep and University of Stuttgart, *Part 2 Scenario modelling for eco-design*, in *GaBi Paper Clip Tutorial*. 2013.
53. Rousseaux, P., *Analyse du cycle de Vie (ACV).* Techniques de l'ingénieur, 2005. **g5500**.
54. Garcia, R. and F. Freire, *Carbon footprint of particleboard: A comparison between ISO/TS 14067, GHG Protocol, PAS 2050 and Climate Declaration.* Journal of Cleaner Production, 2014. **66**: p. 199-209.
55. Koellner, T. and R.W. Scholz, *Assessment of land use impacts on the natural environment - Part 1: An analytical framework for pure land occupation and land use change.* International Journal of Life Cycle Assessment, 2007. **12**(1): p. 16-23.
56. Bringezu, S., et al., *Assessing biofuels*, in *Towards sustainable production and use of resources*, UNEP, Editor. 2009.

57. Canals, L.M.i., et al., *Key elements in a framework for land use impact assessment within LCA.* International Journal of Life Cycle Assessment, 2007. **12**(1): p. 2-4.
58. Cherubini, F., et al., *Energy- and greenhouse gas-based LCA of biofuel and bioenergy systems: Key issues, ranges and recommendations.* Resources Conservation and Recycling, 2009. **53**(8): p. 434-447.
59. Delucchi, M., *A conceptual framework for estimating the climate impacts of land-use change due to energy crop programs.* Biomass & Bioenergy, 2011. **35**.
60. Lal, R., *Soil carbon sequestration to mitigate climate change.* Geoderma, 2004. **123**.
61. European Commission. *Waste*. Environment 2018 [cited 2018; Available from: http://ec.europa.eu/environment/waste/construction_demolition.htm.
62. Stamatiadou, M. *LCA European Standards*. 2015; Available from: http://amanac.eu/wiki/european-standards/.
63. Frischknecht, R., et al., *Life cycle assessment in the building sector: analytical tools, environmental information and labels.* 2015. **20**(4): p. 421-425.
64. Vigovskaya, A., O. Aleksandrova, and B. Bulgakov, *Life Cycle Assessment (LCA) in building materials industry.* MATEC Web of Conferences, 2017. **106**.
65. *Mirzaie, S. The EN 15804 building product LCA standard: more challenges than benefits*. 2016.
66. *EN 15804*. p. EN 15804:2012-04: Sustainability of construction works — Environmental Product Declarations — Core rules for the product category of construction products.
67. Starch Europe. *The European Starch Industry*. [cited 2017 03.05.2017]; Available from: http://www.starch.eu/european-starch-industry/.
68. Agriculture and Rural Development, E.C., *Evaluation of Common Agricultural Policy measures applied to the starch sector* in *Evaluation of policy measures in agriculture* 2010.
69. Ferreira Guiné, et al., *Engineering aspects of cereal and cereal-based products*. 2014, Boca Raton, FL: Boca Raton, FL : CRC press.
70. Botanical-online SL. *Corn Characteristics*. [cited 2014; Available from: http://www.botanical-online.com/english/maize.htm.
71. Add Organic Gardering. *Corn Plant Desription*. 2012 [cited 2014; Available from: http://www.addorganicgardening.com/corn-plant-description/.
72. Division of Biological Sciences and Division of Plant Sciences, *Maize Genetics cooperation newsletter 86*, University of Missouri, Editor. 2013: Columbia.
73. Odell's World. *Corn Growth Stages*. 2010 [cited 2014; Available from: http://odells.typepad.com/blog/corn-growth-stages.html.
74. Plant & Soil Sciences eLibrary. *Anatomy and Reproduction of Corn*. Corn Breeding: Lessons From the Past [cited 2014; Available from: http://passel.unl.edu/pages/informationmodule.php?idinformationmodule=1075412493&topicorder=3&maxto=12.
75. National corn growers association, *World of corn 2014*. 2014.
76. BeMiller, J.N., *Starch Chemistry and Technology*. Starch (Third Edition), ed. R.L. Whistler. 2009, Burlington: Burlington : Elsevier Science.
77. Georgie Corn Growers Association. *Corn Overview*. 2012 [cited 2015 16.04.2015]; Available from: http://georgiacorngrowers.org/corn-overview/.
78. Gibson, L. and G. Benson. *Origin, History, and Uses of Corn (Zea mays)*. 2002 [cited 2014; Available from: http://agron-www.agron.iastate.edu/Courses/agron212/readings/corn_history.htm.
79. Rüdelsheim, P.L.J. and G. Smets, *Baseline information on agricultural practices in the EU Maize (Zea mays L.)*, EuropaBio aisbl, Editor. 2011: Belgium.
80. FAO. *FAOSTAT*. 2015 [cited 2015; Available from: http://faostat3.fao.org/home/E.

81. IPM center, *Corn Growth and Development*, in *Extension and Outreach*, Iowa State University, Editor.
82. Kim, S. and B.E. Dale, *Cumulative energy and global warming impact from the production of biomass for biobased products.* Journal of Industrial Ecology, 2004. **7**(3-4): p. 147-162.
83. Kim, S. and B.E. Dale, *Effects of nitrogen fertilizer application on greenhouse gas emissions and economics of corn production.* Environmental Science and Technology, 2008. **42**(16): p. 6028-6033.
84. Kim, S., B.E. Dale, and R. Jenkins, *Life cycle assessment of corn grain and corn stover in the United States.* International Journal of Life Cycle Assessment, 2009. **14**(2): p. 160-174.
85. Necpálová, M., et al., *Understanding the DayCent model: Calibration, sensitivity, and identifiability through inverse modeling.* Environmental Modelling & Software, 2015. **66**(Supplement C): p. 110-130.
86. Pimentel, D., T. Patzek, and G. Cecil, *Ethanol Production: Energy, Economic, and Environmental Losses.* Reviews of Environment Contamination and Toxicology, 2007. **189**.
87. Hill, J., et al., *Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels.* Proceedings of the National Academy of Sciences of the United States of America, 2006. **103**(30): p. 11206-11210.
88. Liska, A.J., et al., *Improvements in life cycle energy efficiency and greenhouse gas emissions of corn-ethanol.* Journal of Industrial Ecology, 2009. **13**(1): p. 58-74.
89. Feng, H., O.D. Rubin, and B.A. Babcock, *Greenhouse gas impacts of ethanol from Iowa corn: Life cycle assessment versus system wide approach.* Biomass and Bioenergy, 2010. **34**(6): p. 912-921.
90. Farrell, A.E., et al., *Ethanol can contribute to energy and environmental goals.* Science, 2006. **311**(5760): p. 506-508.
91. Mamani-Pati, F., et al., *Production, economic, and energy life cycle analysis can produce contrary results for corn used in ethanol production.* Journal of Plant Nutrition, 2011. **34**(9): p. 1278-1289.
92. Murphy, C.W. and A. Kendall, *Life cycle inventory development for corn and stover production systems under different allocation methods.* Biomass and Bioenergy, 2013. **58**: p. 67-75.
93. Börjesson, P. and L.M. Tufvesson, *Agricultural crop-based biofuels - Resource efficiency and environmental performance including direct land use changes.* Journal of Cleaner Production, 2011. **19**(2-3): p. 108-120.
94. Zucaro, A., et al., *Life Cycle Assessment of maize cropping under different fertilization alternatives.* International Journal of Performability Engineering, 2014. **10**(4): p. 427-436.
95. Bacenetti, J., D. Lovarelli, and M. Fiala, *Mechanisation of organic fertiliser spreading, choice of fertiliser and crop residue management as solutions for maize environmental impact mitigation.* European Journal of Agronomy, 2016. **79**: p. 107-118.
96. ADEME. *L'outil Agribalyse*. 2014 [cited 2014; Available from: http://www.ademe.fr/expertises/produire-autrement/production-agricole/passer-a-laction/loutil-agribalyse.
97. Koch, P., et al., *Agribalyse: Rapport methodologique*, ADEME, Editor. 2016.
98. Boone, L., et al., *Environmental life cycle assessment of grain maize production: An analysis of factors causing variability.* Science of the Total Environment, 2016. **553**: p. 551-564.
99. Van Stappen, F., et al., *Sensitive parameters in local agricultural life cycle assessments: the illustrative case of cereal production in Wallonia, Belgium.* International Journal of Life Cycle Assessment, 2017: p. 1-26.
100. European Commission - Joint Research, C. and S. Institute for Environment and, *International Reference Life Cycle Data System (ILCD) Handbook- Recommendations for Life Cycle Impact Assessment in the European context*. 2011.

101. Pelletier, N., N. Arsenault, and P. Tyedmers, *Scenario modeling potential eco-efficiency gains from a transition to organic agriculture: Life cycle perspectives on Canadian canola, corn, soy, and wheat production.* Environmental Management, 2008. **42**(6): p. 989-1001.
102. Whitman, T., S.F. Yanni, and J.K. Whalen, *Life cycle assessment of corn stover production for cellulosic ethanol in Quebec.* Canadian Journal of Soil Science, 2011. **91**(6): p. 997-1012.
103. Fazio, S. and A. Monti, *Life cycle assessment of different bioenergy production systems including perennial and annual crops.* Biomass and bioenergy, 2011. **35**(12): p. 4868-4878.
104. Pieragostini, C., P. Aguirre, and M.C. Mussati, *Life cycle assessment of corn-based ethanol production in Argentina.* Science of the Total Environment, 2014. **472**: p. 212-225.
105. Polansek, T. *Analysis: Facing drought, U.S. farmers return to crop rotation*. Reuters 2013 [cited 2015 01.10.2015]; Available from: http://www.reuters.com/article/2013/01/18/us-usa-drought-corn-idUSBRE90H0KR20130118.
106. *Ecotron*. [cited 2018 23/06/2018]; Available from: http://www.gembloux.ulg.ac.be/environmentislife/ecotron-2/.
107. Walloon Agricultural Research Centre (CRA-W), *ALT4CER project*. 2014.
108. *MECACOST: running costs for tractors and agricultural machines*. [cited 2015 30.09.2015]; Available from: http://mecacost.cra.wallonie.be/.
109. Harris, S. and V. Narayanaswamy, *A Literature Review of Life Cycle Assessment in Agriculture*, A.G. Rural Industries Research and Development Corporation, Editor. 2009.
110. Statistics Belgium. *Agriculture - Estimation de la production des cultures agricoles (2007-2015)*. 2016 [cited 2016 10/10/2016]; Available from: http://statbel.fgov.be/fr/modules/publications/statistiques/economie/downloads/agriculture_-_estimation_de_la_production_des_cultures_agricoles_2007-2015_.jsp.
111. Nemecek, T. and T. Kägi, *Life Cycle Inventories of Agricultural production Systems*, in *ecoinvent report*. 2007, grosope Reckenholz and Tänikon Research Station ART.
112. Mackle, S., *Trade & Economic policy: Outlook of the EU nitrogen fertilizer industry*, fertilizers europe, Editor.
113. Food and agriculture organization of the United Nations, *Current world fertilizer trends and outlook to 2015*. 2011: Rome.
114. Arovuori, K. and H. Karikallio, *Consumption Patterns and Competition in the World Fertilizer Markets.* Paper Prepared for Presentation at the 19th Symposium of the International Food and Agribusiness Management Association, 2009: p. 15.
115. ecoinvent Center, *The life cycle inventory data version 3*, ed. Swiss Center for Life Cycle Inventories. 2012.
116. Nemecek, T., *Estimating direct field and farm emissions*, Agroscope Reckenholz - Tänikon Research Station ART, Editor. 2013: Zurich, Switzerland. p. 31.
117. EMEP/EEA, *Air pollutant emission inventory guidebook. Part B: sectoral guidance chapters; Chapter 3.D: Agriculture - Crop production and agricultural Soil.* 2013: p. 43.
118. Richner, W., et al., *Modell zur Beurteilung des Nitratausweschungspotenzials in Ökobilanzen - SALCA-Nitrat.* Agrocsope Reckenholz-Tänikon (ART), 2006.
119. IPCC, *2006 IPPC Guidelines for National Greenhouse Gas Inventories*, in *IPCC National Greenhouse Gas Inventories Programme. Intergovernmental Panel on Climate Change*, S. Eggleston, et al., Editors. 2006. p. 642.
120. Freiermuth, R., *Modell zur Berechnung der Schwermetall-flüsse in der Landwirtschaftlichen Ökobilanz - SALCA-Schwermetall*, F.A.R.-T. (ART), Editor. 2006. p. 28.
121. Piazzalunga, G., V. Planchon, and R. Oger, *CONTASOL - Evaluation des flux d'éléments contaminants liés aux matières fertilisantes épandues sur les sols agricoles en Wallonie - Rapport final*, Centre wallon de Recherches agronomiques (CRAW-W), Editor. 2012. p. 201 + annexes.

122. Sonnet P, B.L., Bogaert P, Colinet G, Delcarte E, Delvaux B, Ducarme F, Laroche J,Maesen P, Marcoen J,WibrinM, *Etablissement et cartographie des teneurs bruits de fond en éléments traces métalliques (ETM) et micro-polluants organiques (MPO) dans les sols de la Région wallonne. Rapport final du groupe d'étude APP, "Application de la pédologie aux problèmes de pollution" (SPAQUE - UCL - FUSAGx - BEAGx - CAFX)*, U.d.s.d.s. UCL, Editor. 2003. p. 124.
123. Prasuhn, V., *Erfassung der PO4-Austräge für die Ökobilanzierung - SALCA-Phosphor*, Agroscope Reckenholz - Tänikon (ART), Editor. 2006. p. 20.
124. Renouf, M.A., M.K. Wegener, and L.K. Nielsen, *An environmental life cycle assessment comparing Australian sugarcane with US corn and UK sugar beet as producers of sugars for fermentation.* Biomass and Bioenergy, 2008. **32**(12): p. 1144-1155.
125. Hong, J., et al., *Life cycle assessment of corn- and cassava-based ethylene production.* Biomass and Bioenergy, 2014. **67**: p. 304-311.
126. Ren, J., et al., *Determining the life cycle energy efficiency of six biofuel systems in China: A Data Envelopment Analysis.* Bioresource Technology, 2014. **162**: p. 1-7.
127. de Vries, S.C., et al., *Resource use efficiency and environmental performance of nine major biofuel crops, processed by first-generation conversion techniques.* Biomass and Bioenergy, 2010. **34**(5): p. 588-601.
128. ADEME, *Analyses de Cycle de Vie appliquées aux biocarburants de première génération consommés en France*, BIO Intelligence Service, Editor. 2010. p. 236.
129. IPCC. *Fertilizer manufacture*. Climate Change 2007: Working Group III: Mitigation of Climate Change 2007; Available from: http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch7s7-4-3-2.html.
130. Intelligent Energy Europe, et al., *Biomass gasification - State of the art description*, in *Gasification guie*, European Comission, Editor. 2007, Graz University of technology - Institute of Thermal Engineering: Graz, Austria.
131. International Energy Agency (IEA). 2013; Available from: http://www.iea.org/.
132. Barnhart, J., *Chromium chemistry and implications for environmental fate and toxicity.* Soil and Sediment Contamination, 1997. **6**(6): p. 561-568.
133. United States Environmental protection Agency, *Framework for Metals Risk Assessment* 2007: Washington. p. 172.
134. Krüger, O., et al., *Determination of chromium (VI) in primary and secondary fertilizer and their respective precursors.* Chemosphere, 2017. **182**: p. 48-53.
135. Cressey, D. *Widely used herbicide linked to cancer*. Nature international weekly journal of science 2015 [cited 2017 25.10.2017]; Available from: http://www.nature.com/news/widely-used-herbicide-linked-to-cancer-1.17181.
136. Initiative, U.S.L.C. *USEtox*. 2017 [cited 2017; Available from: http://www.usetox.org/.
137. Plum, L., L. Rink, and H. Haase, *The Essential Toxin: Impact of Zinc on Human Health.* International Journal of Environmental Research and Public Health, 2010. **7**(4).
138. Roohani, N., et al., *Zinc and its importance for human health: An integrative review.* Journal of Research in Medical Sciences 2013. **18**(2).
139. Vangheluwe, m., et al., *MERAG: Metals Environmental Risk Assessment Guidance*, International Council on Mining and Metals (ICMM), Editor. 2007.
140. Pichard, A., et al., *Zinc et ses dérivés*, in *Fiche de données toxicologiques et environnementales des substances chimiques*, INERIS, Editor. 2005.
141. Kokborg, M. 2017, Think Step.
142. Australian cotton cooperative research center, *Section A1 Weed ID and Information*, in *WEEDpak a guide for integrated management of weeds in cotton*, Cotton Catchment Communities CRC, Editor. 2012.

143. Gwirtz, J.A., M.R. Willyard, and K.L. McFall, *Wheat Kernel Composition*, in *Wheat: more than just a Plant*.
144. professional PASTA. *Grain and wheat flour*. [cited 2014; Available from: http://www.professionalpasta.it/dir_1/flour_1.htm.
145. Seutin, B., F. Vancutsem, and B. Bodson, *La culture en association de froment et de légumineuses*, in *Livre Blanc "Céréales"*. 2011, ULg Gembloux Agro-Bio Tech and CRA-W Gembloux.
146. Mercier-Poirier, S. and J.-P. Cassagne, *Pratiques culturales 2006*, in *Agreste Les Dossiers*, Ministère de l'alimentation de l'agriculture et de la pêche République Française, Editor. 2010, Bureau des statistiques végétales et forestières.
147. Rosenberger, A., et al., *Improving the energy balance of bioethanol production from winter cereals: The effect of crop production intensity.* Applied Energy, 2000. **68**(1): p. 51-67.
148. Brentrup, F., et al., *Environmental impact assessment of agricultural production systems using the life cycle assessment (LCA) methodology II. The application to N fertilizer use in winter wheat production systems.* European Journal of Agronomy, 2004. **20**(3): p. 265-279.
149. Brentrup, F. and C. Pallière, *Energy efficiency and greenhouse gas emissions in Europe nitrogen fertilizer production and use*, in *Sustainable agriculture in Europe*, fertilizers europe, Editor. 2008. p. 23.
150. Bernesson, S., D. Nilsson, and P.A. Hansson, *A limited LCA comparing large- and small-scale production of ethanol for heavy engines under Swedish conditions.* Biomass and Bioenergy, 2006. **30**(1): p. 46-57.
151. Malça, J. and F. Freire, *Renewability and life-cycle energy efficiency of bioethanol and bio-ethyl tertiary butyl ether (bioETBE): Assessing the implications of allocation.* Energy, 2006. **31**(15): p. 3362-3380.
152. Punter, G., et al., *Well-to-Wheel Evaluation for Poduction of Ethanol from Wheat.*, LowCVP Fuels Working Group, Editor. 2004, WTW Sub-Group.
153. Piringer, G. and L.J. Steinberg, *Reevaluation of energy use in wheat production in the United States.* Journal of Industrial Ecology, 2006. **10**(1-2): p. 149-167.
154. Meisterling, K., C. Samaras, and V. Schweizer, *Decisions to reduce greenhouse gases from agriculture and product transport: LCA case study of organic and conventional wheat.* Journal of Cleaner Production, 2009. **17**(2): p. 222-230.
155. Huerta, J.H., E.M. Alvear, and R.M. Navarro, *Evaluation of two production methods of Chilean wheat by life cycle assessment (LCA).* Idesia, 2012. **30**(2): p. 101-110.
156. Mondelaers, K., J. Aertsens, and G.V. Huylenbroeck, *A meta-analysis of the differences in environmental impacts between organic and conventional farming.* British food journal, 2009. **111**(10).
157. Niggli, U., Fließbach, A., Hepperly, P. and Scialabba, N., *Low greenhouse gas agriculture: mitigation and adaptation potential of sustainable farming systems.* FAO, 2009. **April 2009**(2).
158. J.F.F.P. Bos, J.J.d.H., W. Sukkel, R.L.M. Schils, *Comparing energy use and greenhouse gas emissions in organic and conventional farming systems in the Netherlands*, in *3rd QLIF Congress*. 2007: Hohenheim, Germany.
159. Coppola, F., S. Bastianoni, and H. Østergård, *Sustainability of bioethanol production from wheat with recycled residues as evaluated by Emergy assessment.* Biomass and Bioenergy, 2009. **33**(11): p. 1626-1642.
160. SenterNovem, *Participative LCA on biofuels*, 2GAVE, Editor. 2005.
161. Scacchi, C.C.O., et al., *Greenhouse gases emissions and energy use of wheat grain-based bioethanol fuel blends.* Science of the Total Environment, 2010. **408**(21): p. 5010-5018.

162. Cargill. *Glucose syrup*. [cited 2014 13.07.2014]; Available from: http://www.cargillfoods.com/ap/en/products/sweeteners/corn-sweeteners/glucose-syrup/index.jsp.
163. Tate & Lyle. *Glucose syrup*. [cited 2014 16.07.2014]; Available from: http://www.tateandlyle.com/ingredientsandservices/chooseaningredientorservice/europemiddleeastandafrica/pages/glucosesyrups.aspx.
164. Kearsley, M.W. and S.Z. Dziedzic, *Handbook of Starch Hydrolysis Products and their Derivatives*, ed. Springer. 1995.
165. Linden, G., *New ingredients in food processing : biochemistry and agriculture*, ed. D. Lorient and M. Rosengarten. 1999, Boca Raton, FL, Cambridge: Boca Raton, FL : CRC Press [Chemical Rubber Company]; Cambridge : Woodhead Publishing.
166. Godon, B., *Biotransformation des produits céréaliers*, ed. B. Godon. 1991, Paris: APRIA; INRA; Technique et Documentation-Lavoisier;.
167. Hull, P., *Glucose Syrups: Technology and Applications*, ed. Wiley-Blackwell. 2010.
168. Vercalsteren, A., E. Dils, and K. Boonen, *Life Cycle Assessment study of starch products for the European starch industry association (AAF): sector study*, ViTo, Editor. 2012.
169. Vercalsteren, A. and K. Boonen, *Life Cycle Assessment study of starch products for the European starch industry association (Starch Europe): sector study*. 2015, vito. p. 30.
170. Tsiropoulos, I., B. Cok, and M.K. Patel, *Energy and greenhouse gas assessment of European glucose production from corn-a multiple allocation approach for a key ingredient of the bio-based economy.* Journal of Cleaner Production, 2013. **43**: p. 182-190.
171. Tsiropoulos, I., *Energy and emissions assessment on dextrose production from corn starch: Life cycle principles and multiple allocations*, in *Faculty of Geosciences Theses*. 2010, Utrecht University.
172. LBP, University of Stuttgart, and Thinkstep, *GaBi 7*. 2012. p. Documentation of GaBi6-Datasets for life cycle engineering.
173. Patel, M., et al., *Medium and Long-term Opportunities and Risks of the Biotechnological Production of bulk Chemicals from Renewable Resources - The Potential of white Biotechnology*, in *the BREW Project*. 2006, European Commission's GROWTH Programme.
174. Vink, E.T.H. and S. Davies, *Life Cycle Inventory and Impact Assessment Data for 2014 Ingeo® Polylactide Production.* Industrial Biotechnology, 2015. **11**(3): p. 167-180.
175. Corn Refiners Association, *Corn starch*. 2006.
176. GEA Mechanical Equipment, *Wheat Starch Processing: Engineering Excellence for Custom-Fit Solutions*.
177. Van Der Borght, A., et al., *Fractionation of wheat and wheat flour into starch and gluten: overview of the main processes and the factors involved.* Journal of Cereal Science, 2005. **41**(3): p. 221-237.
178. Kent, N.L. and A.D. Evers, *Dry Milling Technology*, in *Technology of cereals, An introduction for students of food science and agriculture*, Pergamon, Editor. 1994.
179. Galitsky, C., E. Worrell, and M. Ruth, *Energy Efficiency Improvement and Cost Saving Opportunities for the Corn Wet Milling Industry*, in *An ENERGY STAR Guide for Energy and Plant Managers*, Environmental Energy Technologies Division, Editor. 2003, Ernest Orlando Lawrence, Berkeley National Laboratory,: US.
180. Ramirez, E.C., et al., *Engineering process and cost model for a conventional corn wet milling facility.* Industrial Crops and Products, 2008. **27**(1): p. 91-97.
181. European Commission, *Reference Document on Best Available Techniques in the Food, Drink and Milk Industries*, in *Integrated Pollution Prevention and Control*. 2006.
182. Air Liquide. *Engineering & Construction: A New Lurgi-MTP® Unit for China*. 2011 26-08-2011 21-11-2011]; Available from:

http://www.lurgi.com/website/SingleNews.125.0.html?&L=1&cHash=e42d013d32465cac141912ead7430f1c&tx_ttnews[backPid]=27&tx_ttnews[tt_news]=224.

183. Alfa laval, *The all-round choice for starch equipment.* 2004.

184. Singh, V., D.B. Johnston, and S.L. Neoh, *Enzymatic corn wet milling process: Enzyme optimization & commercial trial.* Industrial Biotechnology, 2010. **6**(1): p. 34-40.

185. Cornell, H.J., *Wheat : chemistry and utilization*, ed. A.W. Hoveling. 1998, Lancaster, PA: Lancaster, PA : Technomic Publishing Co.

186. Zeist, W.J.v., et al., *Wet Milling Industry*, in *LCI data for the calculation tool Feedprint for greenhouse gas emissions of feed production and utilization*, blonk consultants, Editor. 2012.

187. Ramírez, E.C., et al., *Enzymatic corn wet milling: Engineering process and cost model.* Biotechnology for Biofuels, 2009. **2**.

188. murray, B.C., D.H. Gross, and T.J. Fox, *Starch Manufacturing: A Profile*, Research Triangle Institute, Editor. 1994.

189. Zainab, A., et al., *Laboratory scale production of glucose syrup by the enzymatic hydrolysis of starch made from maize, millet and sorghum.* Biokemistri, 2011. **23**(1).

190. Sara Drescher, et al., *A review of energy use in the food industry*, A.a.B.E. Department, Editor. 1997.

191. personal communication

192. Sugden, D. and T. Acklin. *Wheat starch and Gluten Manufacturing*. 1997 [cited 2015; Available from: http://www.world-grain.com/news/archive/wheat%20starch%20and%20gluten%20manufacturing.aspx?cck=1.

193. Sayaslan, A., *Wet-milling of wheat flour: Industrial processes and small-scale test methods.* LWT - Food Science and Technology, 2004. **37**(5): p. 499-515.

194. *Wheat flour*, in *agribusiness handbook*, FAO Investment Centre Division, Editor. 2009.

195. Buseman, J. *Particle size reduction*. 2012 [cited 2016; Available from: http://www.insta-pro.com/en/2012/11/22/particle-size-reduction/.

196. Serna-Saldivar, S.O., *Cereal Grains: properties, processing and Nutritional Attributes*. Food Preservation technology Series, ed. T.F. Group. 2010.

197. Zeist, W.J.v., et al., *Dry Milling Industry*, in *LCI data for the calculation tool Feedprint for greenhouse gas emissions of feed production and utilization*, B. Consultants, Editor. 2012.

198. Bechtel, D.B., et al., *Fate of dwarf bunt fungus teliospores during milling of wheat into flour.* Cereal Chemistry, 1999. **76**(2): p. 270-275.

199. Nielsen, A.M. and P.H. Nielsen, *Flour and oat flakes production*, in *LCAfood*, -.O.L. consultants, Editor. 2003.

200. Deng, Y., et al., *Life cycle assessment of wheat gluten powder and derived packaging film.* Biofuels, Bioproducts and Biorefining, 2013. **7**(4): p. 429-458.

201. Espinoza-Orias, N., H. Stichnothe, and A. Azapagic, *The carbon footprint of bread.* International Journal of Life Cycle Assessment, 2011. **16**(4): p. 351-365.

202. Smetana, S., et al., *Meat alternatives: life cycle assessment of most known meat substitutes.* International Journal of Life Cycle Assessment, 2015. **20**(9): p. 1254-1267.

203. *Mémoire de l'académie impériale des sciences de St Petersbourg, Tome IV*, ed. L.h.d. l'académie. 1811, St Petersbourg.

204. Eshra, D.H., S.M. El-Iraki, and T.M. Abo Bakr, *Performance of starch hydrolysis and production of corn syrup using some commercial enzymes.* International Food Research Journal, 2014. **21**(2): p. 815-821.

205. Silla, H., *Chemical process engineering: Design and Economics*, ed. Marcel Dekker. 2003, New York.

206. DECLOUX, M. and B. RÉMOND, *Évaporation - Agencement des évaporateurs et applications - Applications dans l'industrie alimentaire* Techniques de l'ingénieur, 2009. Opérations unitaires: évaporation et séchage.
207. Vink, E. and S. Davies, *Life Cycle Inventory and Impact Assessment Data for 2014 Ingeo™ Polyactide Production.* Industrial technology, 2015. **11**(3): p. 15.
208. Griffing, E.M. and M.R. Overcash. *Chemical Life Cycle Database*. 1999-present; Available from: www.environmentalclarity.com.
209. MacAllister, *Nutritive sweeteners made from starch.* Advances in Carbohydrate Chemistry and Biochemistry, 1979. **36**.
210. Earle, R.L. and M.D. Earle, *Unit operation un food processing*, ed. NZIFST. 1983.
211. Vellinga, T.V., et al., *Methodology used in FeedPrint: a tool quantifying greenhouse gas emissions of feed production and utilization*. 2013, Wageningen UR Livestock Research,.
212. JOHNSTON, A.E., *Understanding Potassium and its use in Agriculture*, European Fertilizer Manufacturers Association, Editor.
213. *SelfNutritionData*. Know what your eat [cited 2016 22.05.2016]; Available from: http://nutritiondata.self.com/.
214. Gunier, R.B., *Exposure to Manganese from Agricultural Pesticide Use and Neurodevelopment in Young Children*. 2013, University of California, Berkeley. p. 80.
215. Jolliet, O., et al., *Analyse du cycle de vie, Comprendre et réaliser un écobilan*, ed. P. Presses and U. Romandes. Vol. 2e édition mise à jour et augmentée. 2010, Italy.
216. Pré Consultant, *Simapro 8.3*. 2016.
217. Baitz, M. 2017, ThinkStep.
218. Ames, J.M., *Applications of the Maillard reaction in the food industry.* Food Chemistry, 1998. **62**(4): p. 431-439.
219. Machiels D and Istasse L, *La réaction de Maillard: importance et applications en chimie des aliments.* Annales de Médecine Vétérinaires, 2002. **146**.
220. Attokaran, M., *Natural Food Flavors and Xolorants*. 2017: Wiley Blackwell,.
221. Sengar, G. and H.K. Sharma, *Food caramels: a review.* journal of Food Science and Technology, 2014. **51**(9).
222. Yang, J.E., et al., *One-step fermentative production of aromatic polyesters from glucose by metabolically engineered Escherichia coli strains.* Nature communication, 2018. **9**(79): p. 10.
223. Hampson, C., *Confidential communication*. 2016.
224. Shamrock. [cited 2014; Available from: http://base.shamrockoils.com/group-i-oil/bright-stock/basic-type.
225. Sasol. 2014; Available from: http://www.sasol.com/products/fuels-and-oils/sasol-oil/industrial-lubricants/bright-stock-150.
226. Sasol, *Sasol Bright Stock 150, Process Oil, lubricant blending, Grade 150*.
227. Polczmann, G., J. baladincz, and J. Hancsok, *Investigation of producing modern base oil.* Hungarian Journal of Industrial Chemistry, 2008. **36(1-2)**.
228. Kazimierczuk, R., et al., *Synthesis of 3-aminopropyltriethoxysilane via catalytic hydrogenation of 2-cyanoethyltriethoxysilane.* Applied Organometallic Chemistry, 2000. **14**(3): p. 160-163.
229. Chauhan, M., B.P.S. Chauhan, and P. Boudjouk, *A new catalyst for exclusive β-hydrosilylation of acrylonitrile.* Tetrahedron Letters, 1999. **40**(22): p. 4127-4128.
230. Fushite. *SILICON TETRACHLORIDE*. [cited 2018; Available from: http://www.fushite.com/en/product.asp?id=304&djid=35.
231. Saadatian, S.S., *Integrated life-cycle analysis of six insulation materials applied to a reference building in portugal* in *Faculdade de Ciências e technologie*. 2014, Universidade de CoimBra.

232. Barrau, J., M. Ibanez, and F. Badia, *Impact of the insulation materials' features on the determination of optimum insulation thickness.* International Journal of Energy and Environmental Engineering, 2014. **5**(2): p. 79.
233. Gorshkov, A., et al., *Using Life-cycle Analysis to Assess Energy Savings Delivered by Building Insulation.* Procedia Engineering, 2015. **117**: p. 1080-1089.
234. Marshall, M. and B. Noble. *Advantages of Boron in Glass Mineral Wool Insulation*. 2007 [cited 2018; Available from: https://www.glass-ts.com/news/advantages-of-boron-in-glass-mineral-wool-insulation.
235. Zamurs, A. *Insulation*. [cited 2018; Available from: https://www.borax.com/markets/insulation/.
236. NREL, *U.S. Life Cycle Inventory Database*, N.R.E.L. NREL, Editor.
237. Smokefoot. *Steps in formation of urea-formaldehyde resin*. 2015 [cited 2017; Available from: https://en.wikipedia.org/wiki/Urea-formaldehyde#/media/File:UFresinSyn.svg.
238. Anne-Claire, A., *Active textile for indoor air depollution: quantifying expected health benefits and adverse side effects by LCA*, in *AVNIR*. 2018: Lille, France.
239. Gerbinet, S., V. Briard, and A. Léonard, *Modeling of a glass mineral wool process in view of life cycle analysis.* Matériaux & Technique, 2014. **102**(5).
240. *ISO 14025, Environmental labels and declarations — Type III environmental declarations — Principles and procedures*. 2009; DIN EN ISO 14025:2009-11: Environmental labels and declarations — Type III environmental declarations — Principles and procedures].
241. Griffiths, P., *PF binder*. 2018.
242. Gosselink, R.J.A., et al., *Co-ordination network for lignin - Standardisation, production and applications adapted to market requirements (EUROLIGNIN).* Industrial Crops and Products, 2004. **20**(2): p. 121-129.
243. Tran, H. and E.K. Vakkilainnen, *The kraft chemcial recovery process.*
244. Higson, A., *Lignin*, in *Renewable Chemicals Factsheet: Natural Polymer*, NNFCC, Editor. 2011.
245. Olivares, M., et al., *Kraft lignin utilization in adhesives.* Wood Science and Technology, 1988. **22**(2): p. 157-165.
246. Schöll, S. 2014.
247. Perdomo, A. 2014.
248. Richel, A. 2014.
249. Boerio-Goates, J., *Heat-capacity measurments and thermodynamic functions of crystalline α-D-glucose at temperatures from 10K to 340 K.* Journal of Chemestry Thermodynamics, 1991. **23**.
250. Chem-End-Musings. *Latent Heat of Vaporization - Delta Hvap - of Water calculated by corresponding states correlation in a one cell formula*. 2013 [cited 2018; Available from: https://mychemengmusings.wordpress.com/2013/09/03/latent-heat-of-vaporization-delta-hvap-of-water-calculated-by-corresponding-states-correlation-in-a-one-cell-excel-formula/.