EnviroInfo 2013: Environmental Informatics and Renewable Energies
Copyright 2013 Shaker Verlag, Aachen, ISBN: 978-3-8440-1676-5

Simulating Sustainability

Andi H. Widok[1], Volker Wohlgemuth[2]

Abstract

This paper highlights specific steps considering the inclusion of a holistic sustainability approach in manufacturing companies by focusing especially on the integration of social criteria in an existing Environmental Management Information System (EMIS). This EMIS combines discrete event simulation (DES), life cycle analysis (LCA) as well as material flow analysis (MFA) and thus already encompasses the main aspects of the economical and the environmental perspective at least for the consideration in the production phase itself. The contribution will focus on the reasons for an integrated approach and the demarcation/mapping of social aspects and indicators for the integration in a single simulation software where the other two perspectives already exist. Moreover, methodologies picking up on holistic approaches on the sustainability assessment of the whole life cycle of products are highlighted.

1. Motivation and Introduction

Many recent publications pick up at the bottom of today's environmental problems considering the existing consumption patterns, the environmental damage and the social stress on multiple levels, resulting from a manufacturing industry with a single integrated objective/point of view, namely the economical (Machning 2011; Bosshart 2011; Hilty, Ruddy 2010; Widok, Wohlgemuth, Page 2011). Many more describe the problem societies face and will face considering the grow rates of today's economies and more specific the "physical impossibility" (Hilty, Ruddy 2010) of extending the present consumption patterns of the industrialized countries to all parts of the world, as well as the harmful effects that result from a continued development in that direction (OECD 2008, Pinzler 2011; Fuchs 2011, Reller Holdinghausen 2011). This development is ongoing, also due to the unbroken "attraction potential of the (wasteful and inefficient) western way of life" (von Lucke 2011), which is also mainly due to the disregard of more complex societal, environmental needs by the individual (considering the consumption). This disregard can be understood as the consequence of two major drivers (among others), one the lack of awareness/understanding (also of the personal influence) and two the subsumption made by that individual, that it is more "sustainable" for itself and or a relevant group (which is normally a small group for example family, friends) to make decisions in opposition to the higher societal, environmental needs.

From a capitalistic orientated viewpoint, one can argue that the consumption patterns of individuals represent also be the cure for this problem, as once the awareness of imminent danger reaches a tipping point (and thus changes the personal perception and then the decision process), the consumption should result in a change to greener and more socially compatible products (through the steering of the capital). However this poses multiple problems namely the awareness of danger by the majority of the individuals, then a greener, more socially compatible production itself, i.e. availability of alternatives (providing the individual with similar products, without harming the environment) and lastly the comparability of products (allowing for the individuals to actually make the right choice). Acknowledging that the

[1] University of Hamburg, Dept. of Informatics, Vogt-Kölln-Straße 30, 22527 Hamburg, Germany, E-Mail: a.widok@htw-berlin.de

[2]HTW Berlin, Industrial Environmental Informatics Unit, Wilhelminenhof Str. 75A, 12459 Berlin, Germany, E-Mail: volker.wohlgemuth@htw-berlin.de

awareness is growing (Kiron et. al. 2012), this paper focuses on an approach for the last two problems. In that regard research was conducted over the last decade on how to integrate the environmental perspective in an existing simulation software for producing companies and thus enabling them to perceive their production processes not only from an economical point of view, but through the integration of environmental aspects, promote the concepts of a more holistic perception, as well as increase the comparability and the understanding of the correlations between environmental and economical aspects (one example would be the goal of higher resource/energy efficiency) (see Wohlgemuth, Bruns and Page 2001, Wohlgemuth 2005, Wohlgemuth, Page and Kreutzer 2006).

After successful first implementations of the software and the realization that an integrated approach was still only depicting two of the so called three pillars of sustainability, research was intensified from 2009 on, considering the definition and the integration of the social aspects of sustainability. This also followed the realization that today's products have in general no indication whatsoever of, for example, the social working environments from which they resulted and that if an actual choice from the individual should steer capital in a more socially compatible production, a different form of assessment (not only through reading corporate information from the media, which can actually be very relevant, see von Pappenheim 2009) would have to be at the basis. From extensive modeling and research in this area, it became obvious that most of today's simulation software solutions in the manufacturing industry represent human beings are as resources, that are either available or not (if they are displayed at all), yet other attributes or interactions are usually disregarded. The following chapters will focus on why this it is relevant to change this, how a holistic sustainability perspective can be conceived/simulated and furthermore outline first approaches about the ongoing integration in the existing software solution.

2. Sustainability Assessments and Simulation

2.1 Sustainability Perceptions and Resulting Challenges

The concept of sustainability has been well researched, discussed and described since its modern invocation, i.e. the Brundtland Report 1987, Rio 1992 and many following publications. Since that time the problems remain the operability and appliance. This may mainly be due to the encompassing nature of the concept itself and the lack of standards/standardized parameters.

Moreover, the abundance and *"bipolarity"* (cf. Lee 2000) of the interpretations of the concept resulted in the fact that it is often applied and adapted to a multitude of business processes and products, in order to facilitate a sort of global tolerance for the process/product in question, even though only a single or a limited number of parameters may have been under special observation (cf. Solding 2009). Also a process or measure is often labeled sustainable or having sustainable impact under specific conditions, or placed in a specific context (for example: "This process is economically very sustainable"). It is important to make a differentiation between the usage of the term ¨sustainable¨ to describe a well established change in a specific direction (described as normative value) and an approach that intends to grasp the full complexity of the system in question or is a part of such an (holistic sustainability) approach (see also section 2.2). Critical voices argue that current sustainability departments are used to derive sustainability reports that are purely intended to create a positive image of companies in a way a marketing strategy would (cf. Crook 2005).

Furthermore, author Pezzey already issued in 1992 that another big problem with sustainability approaches is that the system, that is bound to be made sustainable, changes over time and thus new values or even indicators become the subject of assessing its future sustainability – thus noting, that in order to assess sustainability of a system in question the assessment method would have to change with it in order to remain accurate or applicable at all (so might the system itself/its borders). Following that thought, in order to assess sustainability, iterations and the possible change of parameters for the evaluations have to be taken into account (see also Lynam and Herdt 1989).

The system-thinking approach adapted for that perception enables to perceive different layers of requirements and notably strategies. To clarify one can consider that an individual has an own perception of what is sustainable for itself and realize that its choices for investing capital (resources, time) in products will not necessarily follow the requirements of the encompassing system (society, environment), which is exactly the same for producing companies and thus referring to the challenge issued before.

In order to acknowledge the need for regulation in this matter environmental and societal regulations have been established throughout the world in different extends of intervention in the sovereignty of the entities in question (producing companies in this case). Regulations in this regard, can be understood as functions that convert previously non-relevant criteria to criteria that have to be met in order for the system to continue to work properly. To clarify this, before environmental regulations about waste management had been in place not every company would invest in waste management, as from an economical point of view it did not always make sense. By attributing financial sanctions to the neglecting of such a regulation, under the same pretence, the regulation is becoming relevant (also under economical criteria) and thus the sustainability criteria, even from and purely economical point of view, change. *"When investors and corporate boards believe action on sustainability will lead to the creation of value - not in a generic sense, but in definable and measurable way, sector-by-sector and company-by-company - then the case for corporate action on sustainability will be unstoppable"* (Gilding, Hogarth et al. 2002). On that matter we have to note that neither current environmental nor social regulations are comparable nor really accessible (considering most foreign products) to the consumers and thus a choice regarding sustainability criteria can only be made on unreliable or local data.

A change into the right direction can be observed nonetheless and thus it becomes more and more important to facilitate tools in order to assess sustainability in the production. In that regard we gave an example on how it is possible to perceive sustainability under a capital based approach (Widok, Wohlgemuth 2011, Widok, Wohlgemuth, Page 2011) and thus making it measurable/usable in simulation.

2.2 Approaches for the Assessment of Sustainability

In order to generally differentiate existing assessment methodologies one can consider following categorization taking the mentioned challenges under advisement: There are:

- approaches that focus on the optimization of one or multiple rather non-related parameters (no real sustainability perception, however often labeled as such, often sustainability reports/marketing),
- approaches that try to take into account all available (existing) parameters (weak sustainability, usually footprints with a limited amount of parameters, see Neumayer 2004 for examples),
- approaches that start by considering the system(s) in question, extrapolate resulting parameters, build an assessment-framework and then start assessing it (without iterations),
- approaches that do the above as well as take into account normative values for different iterations and compare the sustainability of the processes/products/systems in question in comparison to those (it is important to measure the sustainability impact of measures considering long and short term normative goals in order to take into account that very sustainable measures might have negative short term consequences and vice versa - see Hjorth, Bagheri 2006),
- approaches that do the above and consider/enable clear rules for iterations, as well that the possibility to integrate new unknown parameters with a special the focus on the variability/adaptivity of the methodology (strong sustainability).

2.3 Sustainability Perspective and Simulation

One has to note that methods of modeling and simulation are already used for a long time for the optimizations of production processes (examples under Kuhn and Rabe 1998 or Thiede et Al. 2011), also the usage in the context of sustainability has seen a rise in (research) impact in the last years (examples in Seliger 2012, or Andersson 2011, Reinhard et al. 2013).

As mentioned in Section 2.1 it is very difficult to combine the holistic orientation of sustainability with the exclusion of system-environments (demarcation) when considering the governing dynamics (especially when one considers social aspects). In order to assess and at a later point being able to simulate sustainability these question have to be well elaborated before the definition of indicators (see figure 1).

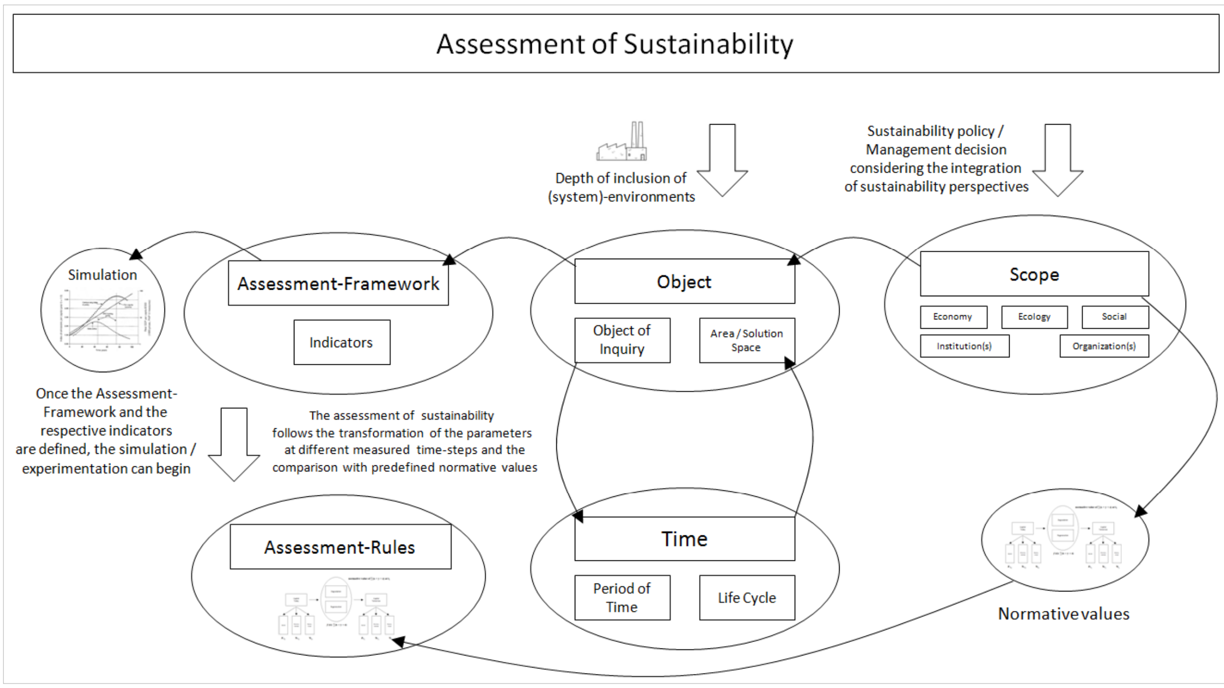

Figure 1: Assessment of Sustainability

Figure 1 depicts a first possible iteration of the assessment of sustainability considering a producing company as system in question. Once this system has been defined and its system-borders well established - resulting from the management/policy decision on the extend of sustainability integration - the definition of necessary parameters for the simulation can follow and values/distributions can be attributed. In recent years the integration of LCA data enabled former purely factory orientated simulation software to go beyond the borders of the factory and thus the once established system borders of the simulation by integrating known environmental and even social impact values from used materials. Furthermore, recent developments also make use of the possibility of using different simulation techniques (for example discrete event simulation DES, agent based simulation ABS, system dynamics SD) for the simulation of different phases of the life cycle of products. This integration of different techniques basically represents a first step into sustainability simulation by not anymore limiting the perception to the production phase.

The problem of the differentiation between the defined “sustainability goal” during the scope and definition phase and an actual sustainable goal cannot be resolved with this methodology, except in case parameters are predefined, suggestions in this regard are integrated in the prototype software.

3. Definition of Social Criteria/Capital for the Use in the Simulation

3.1 Multi-Polarity of the Social Nature of Sustainability

The holistic approach on how to assess sustainability is only the beginning, considering the fact that the definition of social criteria in general and the usage of social parameters for the simulation of producing companies in particular is still at its very beginning (examples for a framework and footprints under Colantinio 2009 and McElroy 2007). Social criteria are as well often labeled as bi-polar, considering their respective orientation on either a single individual or a group of individuals (society/organizations/etc.) (cf. Lin-Hi 2009), yet when establishing the object of inquiry as a production process we can even define at least 3 different layers, namely an individual, groups of individuals (teams, departments, branches, the factory, organizations) and encompassing societies (theoretically even countries). Furthermore, Figure 2 depicts different areas where social criteria can be found to have influence on individuals; the first three are direct influences from the work environment, whereas 4 and 5 represent exterior influences.

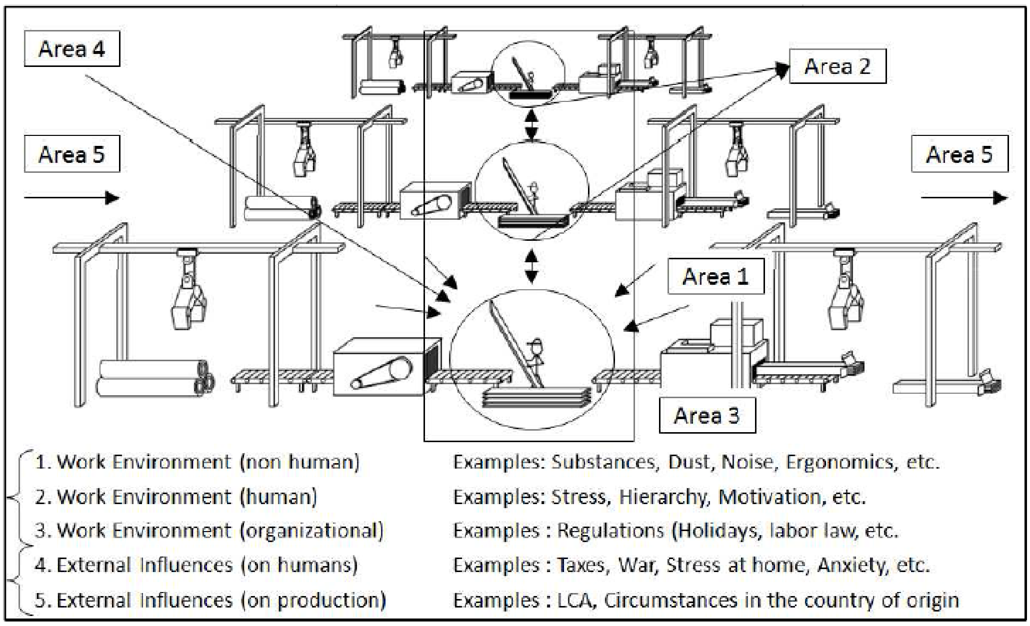

Figure 2: Social influences in producing companies (Widok, Wohlgemuth 2011)

The first goal of any attempt to simulate the system as a whole was to derive indicators for the social perspective that where indeed usable in simulation studies and worthwhile in combination with the economical and environmental criteria (which were already well established – see Wohlgemuth, V., Schnackenbeck, T., Panic, D., Barling, R.-L. 2008). As we are still at the beginning of the research we started with the exclusion of area’s 2-4 and only concentrated on aspects where we either already had data (Social LCA/SLCA) or data could be collected relatively easily (compared to the other areas, such as the eluding influence of interaction relations at work).

In order to integrate criteria in the simulation first a concept for their intended usage had to be derived. On that matter health and safety standards were considered, as well as working labor regulations, furthermore research was intensified about different methodologies on how to qualify stress/negative influence on human beings (see Lohmann-Haislah 2012).

3.2 Integration of Social Criteria in Producing Companies

The first point of the integration was the definition of the social parameters; as mentioned in 3.1 the first choice was the integration of impacts that resulted from the direct interaction between the considered human being and its working environment. These interactions may include: inhaling, or touching of substances (generally the contact/dealing with materials and substances, see WHO 1999), repeated behavior/human machine interactions, noise and other ergonomic aspects (see also Heilala et al. 2008).

The second part was the integration of dose concepts – the most prominent are: the stress-strain model by Rohmert & Rutenfranz, 1975, the Job-Demand-Control-Model, JDC by Karasek, 1979, the cognitive trans-actional stress model by Lazarus & Folkman, 1984 and the model for effort-reward imbalances (Modell beruflicher Gratifikationskrisen - Siegrist, 1996), see also (Fleischer et al. 2003, BGW 2012). This means that every influence coming from a mentioned criteria is contributed a matrix representing a dosage influence in such a way, that if the individual in question has to suffer under a certain length/period of time and quantity of exposure, different short term and long term results will follow (Figure 3).

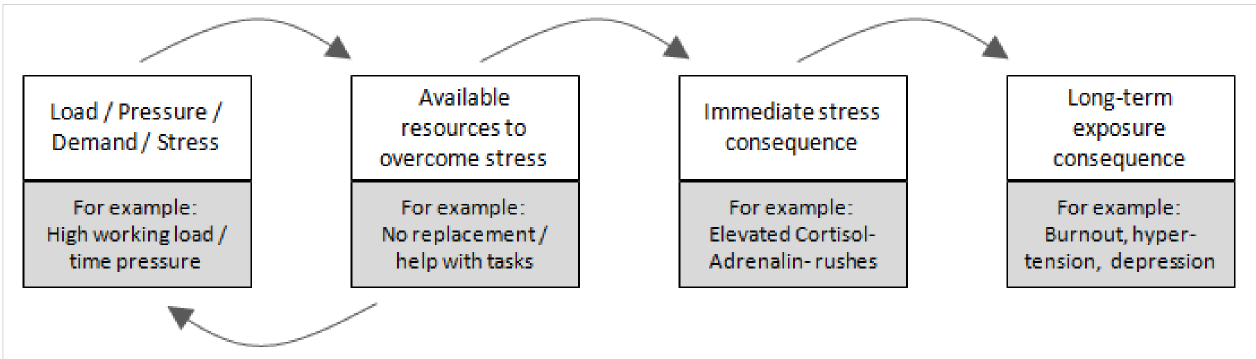

Figure 3: Basis for stress consequences (Lohmann-Haislah 2012)

The third step was to determine/define more complex and controversial parameters, such as a high working load, as depicted in figure 3 (or for example stress from having to do multiple tasks at once). The controversial part here is that a high load and pressure in this regard is highly subjective, however so are material and noise tolerances for example and as with these, there is a possible maximum and a minimum; all that is needed as missing information is a further qualification (parameterization) of the individual (resource) in question to determine individual consequences (simplified) – these can be implemented as distributions or absolute values. This leaded to the next step, the design for the implementation.

3.2 Conceptual Design for Implementation

The implementation of the social aspects in the current simulation software (MILAN – see Widok Wohlgemuth 2011, Reinhard et al. 2013) is still at its very beginning. A new project with this aim has just started. So far 18 different measurable and comparable parameters have been identified, including the ones already mentioned. Furthermore these are in 6 different groups (for example human machine interaction, stress from material/substance interaction, etc.), the design follows a traditional resource layout for the human resources to be attributable to different workstations (maybe also additional processes, this has not been decided yet). The dosage concept will be in close relation to the shift management, while the human resources can be grouped in different pools (to map their qualifications, as well as other relevant parameters – for example it is possible to attribute a hindering for workstations or processes due to age, or handicaps/disabilities. This would make it possible to project such influences as well.) Data sources considering the mathematical functions behind possible consequences from short and long term exposure are coming from various WHO reports and further studies such as mentioned the stress report. In order to allow for variance distributions can be attributed and the mentioned flexibility considering the subjective nature of some parameters is taken into account. To summarize the conceptuall design:

- The data to form the needed transformation processes is coming from various scientific studies considering health (e.g. WHO 1999), labor regulations (e.g. BGW 2012), and similar aspects relevant to the wellbeing of human beings (e.g. Lohmann-Haislah 2012).
- Using the described dosage concepts (may be adapted), mathematical functions will be extrapolated and related to the depicted social parameters (their implementations).
- These parameters will be one the one hand modeled through editors considering the human resources, as well as their grouping in pools, their time management in shift management and on the workstations/processes themselves; on the other hand the parameterization will logically be in dependence of getting real data from real individuals (one would not build a model from a manufacturing plant without knowing the performance data from the machines).
- Different reports are envisioned, notably with a concentration on the pressure, in different forms, put on the individual in question and possible consequences.
- Furthermore a module is envisioned that puts the so formed results in relation to the economical and environmental data, in order to derive additional correlations/findings.

4. Conclusion and Outline

Sustainability is a concept that addresses the hope for continuous well-managed change in the world. This change will only be well-managed if the data at its basis and the approach on how to assess it are going to be balanced and encompassing a multitude of different perceptions. It is a fact that in today's simulation software for the manufacturing industry social criteria are almost non-existent, even though everyone knows the importance of motivation, well being and human interaction for the productivity of an individual and thus a company. Studies have shown that ergonomic and other health influencing aspects in the manufacturing industry can be assessed (see for example Fleischer et al. 2003), in addition to this recent studies (Lohmann-Haislah 2012) have shown ways to assess different psychological, human orientated aspects at work and have highlighted their importance. This leads back to the introduction and the missing comparability of products regarding social (and also still environmental aspects). Considering this deficit it is our conviction that the integration of social criteria in the simulation of manufacturing processes can be one step in the right direction, acknowledging that it is only a small one.

To answer a recurring question on why this integration should be done in simulation software and if social criteria should not rather be addressed in management approaches and in the daily routine (see Dubielzig 2009), we point out that 75% of the product costs are committed by the end of the conceptual design phase (of product lines) (Shetty 2002) and that simulation software is of course also used to plan such lines ahead. Naturally, in the same way as 75% of the costs are determined prior to the actual production, also most of the errors considering pressure on individuals is determined in that phase. The neglecting of social criteria in simulations would only contribute to this fact. Besides, considering an unknown amount of correlations between environmental, economical and social aspects, simulation studies may enable the finding of new strategies and new best practices for that matter.

Lastly we acknowledge the fact that this is still far from the holistic approach hinted under point 2.1, however if the integration of social criteria succeeds in the production phase of a products life cycle, the integration of similar approaches on the other levels of the life cycle becomes more and more realistic and thus hopefully in the near future a simulation that is able to address sustainability as a whole.

References

Andersson, J.; Skoogh, A.; Johansson, B. (2011): Evaluation of Methods used for Life-Cycle Assessments in discrete event simulation, Proceedings of Winter Simulation Conference 2011

Banks, J., Carson, J., Nelson, B., L., Nicol, D. (2005): Discrete-event system simulation (4th ed.), Upper Saddle River, NJ: Pearson Prentice Hall. ISBN 978-0-13-088702-3.

BGW (2012): BGW-Stresskonzept - Das arbeitspsychologische Stressmodell - Erstveröffentlichung 06/2006, Stand 07/2012 Berufsgenossenschaft für Gesundheitsdienst und Wohlfahrtspflege (BGW)

Bell, S., Morse, S. (2008): Sustainability Indicators: Measuring the Immeasurable, Sterling, Second Edition

Bosshart, D. (2011): The Age of Less – Die neue Wohlstandsformel der westlichen Welt, Murmann Verlag, Hamburg

Colantonio, A. (2009): Social Sustainability, ed. Oxford Institute for Sustainable Development Downloaded under: http://Fec.europa.eu/research/sd/conference/2009/presentations/7/andreacolantonio-socialsustainability.ppt, (15th May 2011)

Crook, C. (2005): The Good Company, in: The Economist (The Good Company – A Survey of Corporate Social Responsibility), 22.01.2005, S. 3-4.

Dubielzig, F. (2009): Sozio Controlling in Unternehmen, Das Management erfolgsrelevanter sozialgesellschaftlicher Themen in der Praxis, Gabler Edition Wissenschaft, Dissertation Leuphana Universität Lüneburg, 2008, First edition

Fleischer, A. G., Becker, G., Grünwald, C., Hartl, L., Hartmann, B., Steinbock, D. (2003): Vergleichende Analyse der körperlichen Belastungsstrukturen von Bauarbeiten, Hamburg

Fuchs, W. (2011): Wachsen ohne Wachstum – Weniger Ressourcen Bessere Technik Mehr Wohlstand, Carl Hanser Verlag, München

Gilding, P., Hogarth, M., & Humphries, R. (2002): Safe companies: An alternative approach to operationalizing sustainability, Corporate Environmental Strategy, 9(4), 390-397.

Heilala, J., V. Saija, H. Tonteri, J. Montonen, B. Johansson, J. Stahre & S. Lind (2008): Simulation-Based Sustainable Manufacturing System Design. Proceedings of the 2008 Winter Simulation Conference. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Hilty, L., M., Ruddy, T., F. (2010): Sustainable Development and ICT interpreted in a natural science context,Information, Communication & Society, 13: pp. 1, 7 — 22

Hjorth, P., Bagheri, A. (2006): Monitoring for sustainable development: a systemic framework International Journal of Sustainable Development, Issue: Volume 8, Number 4 / 2005, p. 280-301

Karim, M., A., Ernst, M., Amin, M., A. (2012): A Method for Evaluating Lean Assembly Process at Design Stage, in Seliger 2012 P. 169

Kiron, D., N. Kruschwitz, K., Haanæs and I. V. S. Velken (2012): Sustainability nears a tipping point MIT Sloan Management Review, 53:69-74.

Kuhn, A.; Rabe, M. (Hrsg.) (2008): Simulation in Produktion und Logistik, Fallbeispielsammlung, Springer Verlag, Berlin

Lin-Hi, N. (2009): Eine Theorie der Unternehmensverantwortung, Berlin

Lohmann-Haislah A. (2012): Stressreport Deutschland 2012. Psychische Anforderungen, Ressourcen und Befinden, 2012 1. Auflage. Dortmund: Bundesanstalt für Arbeitsschutz und Arbeitsmedizin 2012.

Lynam, J. K., Herdt, R. W. (1989): Sense and sustainability: Sustainability as an objective in international agricultural research, Agricultural Economics, volume 3, n° 4, p. 381 – 398

Neumayer, E. (2004): Weak versus Strong Sustainability: Exploring the Limits of Two Opposing Paradigms, second ed. Edward Elgar, Cheltenham

Machning M. (HG) (2011): Welchen Fortschritt wollen wir – neue Wege zu Wachstum und sozialem Wohlstand, Interlude Machning S. 8, Campus Verlag, Frankfurt/New York

McElroy, M. W., Jorna, J. R., van Engelen, J. (2007): Sustainability Quotients and the Social Footprint published in Corporate Social Responsibility and Environmental Management, John Wiley and Sons Ltd and The European Research Press Ltd

OECD (2008): Measuring material flows and resource productivity, Synthesis Report, Paris, Organization for Economic Cooperation and Development (OECD)

Page, B. and Kreutzer, W. (2005): The Java Simulation Handbook: Simulating Discrete Event System with UML and Java, Shaker Verlag, Aachen

Pezzey, J. (1992): Sustainability: An Interdisciplinary Guide, Environmental Values 1, 1992, p. 321 – 362

Pinzler, P. (2011): Immer mehr ist nicht genug. Vom Wachstumswahn zum Bruttosozialglück, Pantheon Verlag, erste Auflage, München

Reinhard, J., Zah, R., Wohlgemuth, V., Jahr, P. (2013): „Applying Life Cycle Assessment within Discrete Event Simulation: Practical Application of the Milan/EcoFactory Material Flow Simulator"

Reller, A.; Holdinghausen, H. (2011): Wir konsumieren uns zu Tode – Warum wir unseren Lebensstil ändern müssen, wenn wir überleben wollen, Westend Verlag, Frankfurt/Main

Rohmert, W.; Rutenfranz, J. (1975): Arbeitswissenschaftliche Beurteilung der Belastung und Beanspruchung an unterschiedlichen industriellen Arbeitsplätzen. Bonn

Seliger G. (Editor).(2012): Sustainable Manufacturing, Springer, Heidelberg, New York, London

Shetty, D., S.o.m. Engineers (2002): Design for product success: Society of Manufacturing Engineers, in Karim et al. in Seliger 2012

Solding, P., D. Petku and N. Mardan. (2009): Using simulation for more sustainable production systems – methodologies and case studies, International Journal of Sustainable Engineering, 2, 111-122.

Stahlmann, V. (2008): Lernziel: Ökonomie der Nachhaltigkeit, München

Thiede, S.; Herrmann C.; Kara S. (2011): State of Research and an innovative Approach for simulating Energy Flows of Manufacturing Systems, in: Globalized Solutions for Sustainability in Manufacturing CIRP Braunschweig

Von Lucke, A. (2011): Mehr Gleichheit, weniger Wachstum: Für das Primat der Politik, in Machning

Von Pappenheim, J. R. (2009): Das Prinzip Verantwortung, Gabler, GWV Fachverlage GmbH

WHO (1999): Hazard Prevention and Control in the Work Environment: Airborne Dust, Geneva - World Health Organization (WHO)/SDE/OEH/99.14

Widok, A., Wohlgemuth, V., and Page B. (2011): Combining Event Discrete Simulation with Sustainability Criteria Proceedings of the Winter Simulation Conference 2011

Widok, A. H., Wohlgemuth, V. (2011): Simulation and Sustainability - Enhancing Event-Discrete-Simulation Software with Sustainability Criteria. SIMUL 2011, Barcelona

Wohlgemuth, V., Bruns, L., Page, B. (2001): Simulation als Ansatz zur ökologischen und ökonomischen Planungsunterstützung im Kontext betrieblicher Umweltinformationssysteme (BUIS), in: Hilty, L.M., Gilgen, P.W. (Hrsg.): Sustainability in the Information Society. 15. Internationales Symposium "Informatik für den Umweltschutz" der Gesellschaft für Informatik (GI), Zürich 2001. Metropolis Verlag, Marburg, Band 2, S. 999-1008.

Wohlgemuth, V. (2005): Komponentenbasierte Unterstützung von Methoden der Modellbildung und Simulation im Einsatzkontext des betrieblichen Umweltschutzes, University of Hamburg: Thesis (PhD). Aachen: Shaker

Wohlgemuth, V., Page, B., Kreutzer, W. (2006): Combining discrete event simulation and material flow analysis in a component-based approach to industrial environmental protection, Environmental Modelling & Software: 1607-1617.

Wohlgemuth, V., Schnackenbeck, T., Panic, D., Barling, R.-L. (2008): Development of an Open Source Software Framework as a Basis for Implementing Plugin-Based Environmental Management Information Systems (EMIS), Proceedings of the 22nd Int. Conference Environmental Informatics – Informatics for Environmental Protection, Sustainable Development and Risk Management