Technology radars for energy-efficient data centers: A transdisciplinary approach to technology identification, analysis and evaluation

Ralph Hintemann
Borderstep Institute for Innovation and Sustainability

Technology radars for energy-efficient data centers

A transdisciplinary approach to technology identification, analysis and evaluation

Ralph Hintemann
Borderstep Institute for Innovation and Sustainability
Berlin
hintemann@borderstep.de

Simon Hinterholzer
Borderstep Institute for Innovation and Sustainability
Berlin
hinterholzer@borderstep.de

***Abstract*— Data centers are responsible for a constantly growing demand for energy and resources. Numerous studies show that there is still considerable potential for improving the energy and resource efficiency of data centers. Against this background, it is of great importance that existing efficiency technologies be applied to a greater extent and new technologies put into practice. One instrument to support this development is a technology radar for energy efficiency technologies in data centers. A technology radar is an instrument for monitoring technology that supports the identification, evaluation and observation of relevant technologies in specific areas. This paper describes how such technology radars are developed in a transdisciplinary process and presents current and future efficiency technologies for data centers.**

Keywords- data center, energy efficiency, technology radar, transdisciplinary approach, energy, cooling, power supply, IT management)

I. Introduction

The advancing digitalization of economy and society means that in business, science and public authorities, but also in all other areas of social life, ever larger amounts of data are being transported, stored, managed and made available for various services. Scientific studies on the worldwide energy requirements of data centers assume a magnitude of between 300 and 400 billion kWh [1]–[4], some studies even expect it to rise to some 1.000 billion kWh until 2025 [5]. This means that data centers are responsible for about 1.5% of the world's electric power consumption. The demand for computing and storage capacity in data centers is predicted to increase significantly in the future. Cisco expects global data center IP traffic to triple to 20.6 zettabytes per year between 2016 and 2021, with server workloads increasing by a factor of 2.3 to 567 million installed workloads over the same period. In connection with this development, the global energy requirements of data centers will continue to rise significantly in the future, despite existing efficiency advances in IT and data center infrastructure [1], [4], [6], [7].

To illustrate the increasing energy demands of data centers, a current development is briefly presented. According to current calculations, energy requirements due to bitcoin mining alone are increasing very strongly [8], [9]. Forecasts assume that the energy requirements of bitcoin mining could reach more than eight gigawatts in the course of 2018 [10]. This is equivalent to the average annual power demand for all of Austria or about one-fifth of annual data center power consumption worldwide [11].

Against the background of the increasing energy demand of data centers, it is of great importance that energy efficiency technologies are used in data centers. This applies both to existing technologies and to new approaches that are still in the research stage. As numerous studies show (e.g., [4], [12]–[16], up to 50% of the current energy requirements of data centers could be saved if available efficiency technologies were used across the board. However, new energy-efficient and environmentally-friendly technologies often do not become established as quickly as is desirable from an environmental policy perspective [17], [18]. Data center operators, in particular, often fear that a new technology may have a negative effect on the availability of the data center.

This is where the technology radars for energy-efficient data centers presented in this paper come in. In a transdisciplinary process, current and future efficiency technologies for data centers are identified, evaluated and communicated within the data center expert community. The transdisciplinary approach is particularly well suited to the sustainability-oriented problem with its high degree of uncertainty and different values [19], [20].

II. Methodology

Section 2 explains the methods by which the technology radars were created. In 2.1 the background of the investigation is described, in 2.2 the transdisciplinary approach is considered and in 2.3 the graphical structure of the technology radars is explained.

A. Project background

The technology radars presented in this article were developed within the research project "Total Energy Management for Professional Data Centers" (TEMPRO), which is funded by the German Federal Ministry of Economics and Energy. The overriding goal of TEMPRO is holistic increase in the energy and raw material efficiency of data centers in Germany, taking into account the upstream and downstream stages of the value chain. TEMPRO has two complementary project priorities for achieving this goal:

On the one hand, a basis for evaluating the holistic energy and raw material efficiency of data centers should be created, and the necessary information about the energy and raw material requirements of data centers should be compiled. TEMPRO analyses and documents the entire life cycle of the infrastructure elements (information technology, power supply, cooling and air conditioning) using selected data centers as examples. On this basis, suitable key figures and processes can be jointly developed that enable the energy and raw material efficiency of data centers to be holistically evaluated.

Secondly, new efficiency technologies in data centers, which lead to considerable energy savings, should be examined, and confidence in their reliability strengthened. To this end, information on new technological approaches to improving the holistic efficiency of energy and raw materials should be gathered and communicated to the professional public. Selected, promising energy efficiency technologies are prototypically developed by the participating companies in cooperation with research institutes.

B. The Bordersstep transdisciplinary approach to the development of technology radars

As an independent and non-profit research institution, Borderstep is active in the field of application-oriented innovation and entrepreneurship research and is committed to the guiding principle of sustainable development. The research projects are characterized by their close relationship to real-world practice. The majority of the projects are cooperative projects with partners in the business world, as is the case with TEMPRO. One focus of the work of the Borderstep Institute is the identification, analysis and evaluation of new sustainable technologies and the support of their implementation. For this purpose, a transdisciplinary approach developed and applied at the Institute is followed.

Transdisciplinarity is a methodological approach that combines scientific and practical knowledge. The use of such transdisciplinary approaches is driven by the need to solve complex problems in the real world, taking into account the diversity of scientific and social perspectives on these problems. Since the end of the 20th century, more and more transdisciplinary orientations have prevailed in science and the knowledge society [19].

The transdisciplinary approach developed at the Borderstep Institute involves experts from science and society in the identification, analysis and evaluation of new sustainable technologies in a stepwise process. Transdisciplinary research is particularly suitable for problems where there is a high degree of uncertainty and where different values come into play [21], [22]. Transdisciplinary research approaches are especially valuable in sustainability issues [20], [23]–[25].

Transdisciplinary research primarily addresses three different kinds of knowledge: systems knowledge, target knowledge and transformation knowledge. System knowledge refers to questions about the origin and possible development of a problem field and about interpretations of problems in the real world. Target knowledge includes knowledge about the determination and explanation of practice-oriented targets, and transformation knowledge refers to the development of pragmatic means and possibilities for transforming existing systems [26]. These three types of knowledge are also addressed in the technology analysis of the Borderstep Institute. On the one hand, new technologies are analyzed and described in a combination of knowledge from research and practical application (system knowledge). Secondly, the technologies are evaluated with regard to sustainability goals (target knowledge). Thirdly, the knowledge gained is transferred and the technologies identified as promising (transformation knowledge) are promoted in cooperation with business partners.

In this specific case, the transdisciplinary approach was applied to support the development of technology radars for energy-efficient data center technologies. A technology radar is an instrument for technology monitoring, and supports the identification, evaluation and observation of relevant technologies [27]. The approach is based on the typical three phases of a transdisciplinary project: the problem identification and structuring phase, the problem research phase and the implementation phase [26], [28].

A total of about 50 data center experts from science and industry were involved in the process. These included representatives from industry such as data center operators, data center service providers (planners and consultants) and data center suppliers (manufacturers of IT hardware and software, air-conditioning technology, energy technology, measurement and control technology). In addition, scientists from six different disciplines (computer science, air conditioning, economics, materials science, environmental technology and energy management) were involved in the process.

Within the scope of problem identification, the topic area of holistic energy and resource efficiency was first processed and the fields of technology to be investigated were structured. Based on analyses of the German data center structure, the following technology areas were identified as essential for energy requirements:

- Cooling/air conditioning/ventilation
- Electric power supply/generation
- IT and IT management

In 2015, 59% of the energy requirements of data centers in Germany were accounted for by IT, 25% by cooling/air conditioning/ventilation and 14% by electric power supply [29], [30]. This covers the essential areas in which energy is needed in the data center. This distinction also takes into account that competencies in data center operations and in the planning and implementation of data centers are almost always differentiated in terms of facility management and IT management. In the field of facility management, it makes sense to distinguish between cooling/air conditioning/ventilation and power supply/generation, because the technologies and systems used here are largely independent of one another. In the area of IT hardware and IT management, a distinction could be made between server, storage and network. However, because there are more and more solutions, especially for future technologies, in which the boundaries between these areas become blurred, a subdivision was dispensed with.

Based on extensive technology research, an interdisciplinary team of Borderstep scientists developed the first drafts for three technology radars in the above technology fields within the problem research phase. The sources used were trade journals for data center technologies such as dcd, IT Business, Technology Review and the following online portals: Data

Identify applicable sponsor/s here. *(sponsors)*

Center Knowledge, Network World from IDG, The Datacenter Journal, Data Centre Dynamics, Data Center Week, DataCenter-Insider by Vogel IT-Medien and LANline. Interviews were also conducted with experts on individual technologies. In addition, the winners of recent data center awards such as the DCD Award, the Datacloud Award, the Datacenter Week Award and the German Data Center Award were analyzed. The analyses and technology forecasts of market analysts such as IDC and Gartner, e.g. Gartner Hype Cycles, were also included in the research.

The technology radars developed in this way were presented to experts from business and science at an internal TEMPRO workshop in Berlin on October 11, 2017. A six-week commentary phase followed, during which the technology radars were further developed and supplemented. The interim results were then presented to external experts at an innovation workshop in Berlin on December 5, 2017. A total of 15 experts took part in the workshop. These included representatives of major international IT manufacturers, international manufacturers of air-conditioning and power supply infrastructure, data center consultants and representatives of various scientific disciplines at universities. In the course of the workshop, the innovation radars were slightly supplemented and adapted once again. In addition, a joint prioritization of the particularly important energy efficiency technologies was carried out.

The implementation phase of the transdisciplinary project has been under way since March 2018. First results and excerpts from the technology radars were presented at a non-public technical workshop at the Future Thinking conference (April 2018). In addition, the technology radars were presented and discussed at a meeting of the working group "Computer Center" of the German digital association Bitkom (June 2018). The members of the working group confirmed the basic contents and provided some additional information. The international publication of the results in this paper is another important step. The technology radars will be made available to large sections of the expert public later, in a coordinated process with industry partners through lectures, publications in journals, blog articles and the like.

C. Basic structure of the Borderstep technology radars

Figure 1 shows the basic structure of a technology radar used in TEMPRO. With the help of this instrument, energy efficiency technologies can be presented clearly and communicated effectively. The technology radar currently distinguishes between solutions already in use in data centers (Technology A), solutions for which there is already a niche market (Technology B), solutions that are in the pilot stage of application (Technology C) and solutions that are still in the research stage (Technology D). The technologies are further differentiated according to whether they are currently already intended for use in data centers or whether they come from other areas of application (Technology E or Technology F).

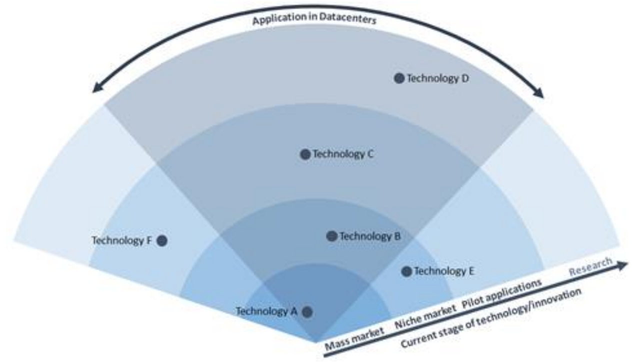

Figure 1. Basic structure of the Borderstep technology radars

III. RESULTS

The technology radars are presented in a very short form in the following chapter. The chapter is divided into the three technology fields ‘cooling/air conditioning/ventilation’, ‘energy supply and generation’ and ‘IT and IT management’. For each technology radar, three technologies identified by experts as relevant are briefly presented. Technology radar for cooling/air conditioning/ventilation in data centers plus a short description of three relevant technologies

A. Technology radar for cooling, air conditioning and ventilation in data centers

Figure 2 shows the technology radar for energy efficient cooling, air conditioning and ventilation technologies in data centers.

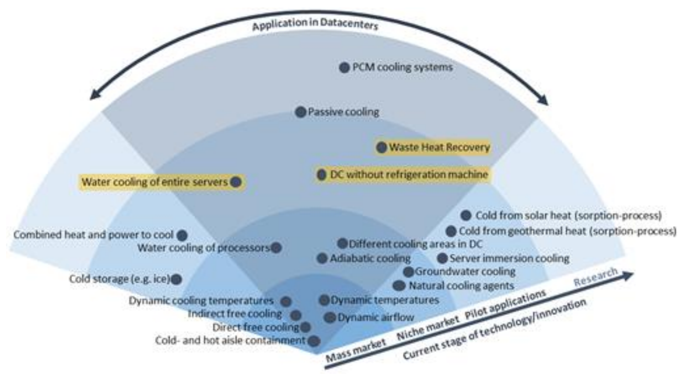

Figure 2. Technology radar for cooling/air conditioning/ventilation

In the area of cooling, air conditioning and ventilation, 21 different energy efficiency technologies were identified and analysed in detail. For each of the technologies mentioned in the technology radars, a one-page fact sheet was prepared together with the experts. The solutions range from established technologies such as Direct Free Cooling to the research projects like use of Phase Change Materials (PCM) for refrigeration in data centers. Cooling solutions from other industries, which have not yet been used in data centers, were also considered. These are, for example, cold storage solutions with ice.

In the innovation workshop (December 2017), described in section II.B, experts voted on the significance of the various technologies. The top three technologies are highlighted in the radar above and a short description of each can be found below.

Water cooling of entire servers: Water cooling of entire servers is a server cooling method where all relevant components of a server are thermally conduced to a water drained system. To do this, an individually shaped metal body connected to water pipes collects all the heat from the components. As this concept uses only one inlet and one outlet, the risk of leakage is minimized.

This system can improve energy efficiency by reducing the mass flow of the coolant as a result of the higher heat capacity of water (compared with air). In addition, water cooling improves capacity for waste-heat-recovery enormously as it binds the heat in a more compact way and allows higher operational temperatures.

Waste heat recovery: The entire electric energy that supplies all the data center equipment (e.g., IT, UPS, lighting) is ultimately transformed into thermal energy. This low-temperature heat can be recovered for secondary appliances through the use of various technologies.

A direct method of heat recovery is the use of the heat to supply the rooms of the data center with heat, for example to regulate the temperature in offices during the winter. In addition, some secondary appliances can be supplied with low temperature heat; for example, greenhouses or swimming pools. Indirect heat recovery can be carried out with a heat pump system that supplies a thermal load at a higher temperature. If the heat needs to be transported over some distance, it is mandatory to transfer the heat to fluids with much higher heat capacity than air -- for example water.

To improve effectiveness and temperature level, heat recovery can be combined with direct fluid cooling of components for example through immersion cooling or water cooling of entire systems.

Data center without refrigeration: The operation of refrigeration systems in data centers depends mainly on two temperatures, the maximum permissible temperature of the heat source (IT hardware, UPS) and the temperature of the heat sink. As long the temperature of the heat sink is lower than the maximum permissible inlet temperature for the cooling cycle (plus a ΔT for a heat exchanger) the cooling can be provided without refrigeration.

B. *Technology radar for electric power supply/generation in data centers*

The second field targets new technologies and innovations that improve the efficiency of the electric power supply in data centers. Figure 3 shows the technology radar for energy supply and generation.

A total of 14 different energy efficiency technologies were identified in the area of power supply/generation. Solutions were discussed and analyzed in detail that are already being used in data centers today, but whose use should also be further promoted, such as modular UPSs. But also solutions that are still in the state of research, such as the e48V POL technology, in which the power is supplied with 48V without its own server power supply to the point of load (POL).

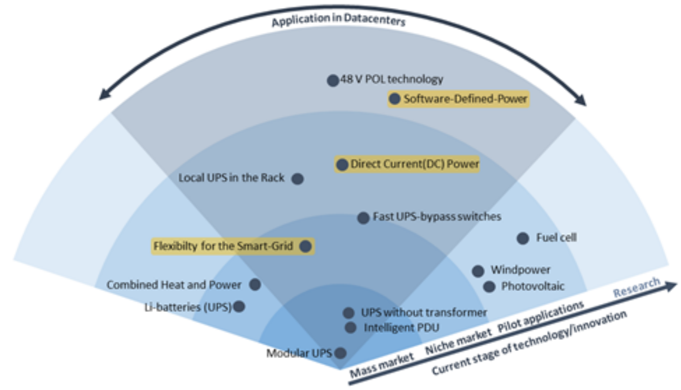

Figure 3. Technology radar for electric power supply/generation

The following technologies (marked yellow) were selected by the experts in the innovation workshop (December 2017) as the most significant innovations:

Flexibility for the smart grid: The components of a data center, especially uninterruptible power supply and a diesel generator can supply the electricity system with flexible power. Depending on local technical and market regulations (e.g., government, grid operator, energy market) it can be possible and profitable to use those facilities to provide flexibility in the electric grid.

Direct current (DC) power supply: Almost every data center is supplied with AC power from an electric grid. Depending on the power architecture, this AC power from the grid is transformed a small number of times through the UPS (AC to DC to AC) as well as inside the servers to low voltage DC power (e.g. 12 V, 5 V) to provide energy to the electronic components. A central DC supply at the input and DC power distribution reduces the electric conversion losses and makes the overall electricity supply more efficient.

Software-defined power: New server technologies integrate all components of local power conversion from servers and racks into the data center management. This can help to optimize the whole power supply and adapt it to the current workload. The adaptation of voltage can also ensure more stable operation in connection with aging IT equipment [31], [32].

C. *Technology radar for IT and IT management in data centers*

The third field of efficiency technologies in data centers focuses on technologies within IT and IT-management itself. It includes energy-efficient computing technologies as well as management tools that improve the overall efficiency of IT hardware in data centers. Figure 4 shows the technology radar for this field.

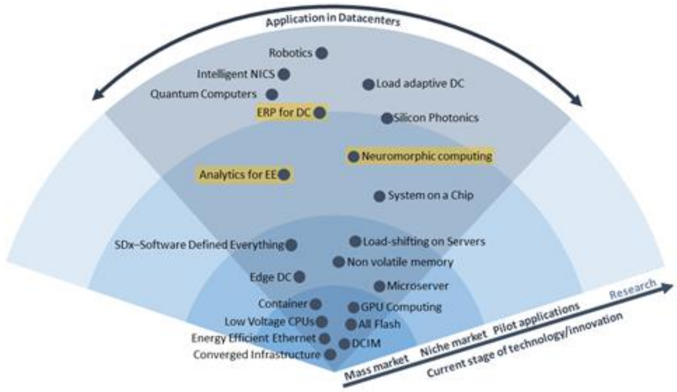

Figure 4. Technology radar for IT and IT management

In the area of IT and IT management, a total of 21 different technologies were identified and analyzed that are suitable for further increasing the energy efficiency of data centers in the future. The range of technologies extends from existing solutions such as All Flash solutions to quantum computers.

The following technologies were identified as highly significant for the energy efficiency of data centers in the innovation workshop in December 2017:

Enterprise resource planning (ERP) for data centers: ERP optimizes overall operations in a business such as a data center. Modern implementations use software tool to monitor and adjust operating processes. Through this constant optimization, a data center can operate at maximum efficiency in both economic and also ecological terms.

Analytics for energy efficiency: Modern data centers are equipped with high numbers of sensors as well es meters that constantly monitor processes relevant to energy consumption. Raw data having varying structure is complex and hard to interpret. Data analytics can improve the value of such sensor data for making decisions leading to greater energy efficiency.

Neuromorphic computing: Neuromorphic computing is an approach which involves imitating the function of the central nervous system within complex circuits through a combination of digital and analogue components. Most artificial intelligence (AI) algorithms still only simulate neuronal networks, but these functions can be directly integrated into silicon. This is called a "neuromorphic chip." These chips carry out specific tasks much faster and with greater energy efficiency compared with traditional chips, and are able to improve the overall efficiency of ICT [33].

IV. Discussion and Outlook

The transdisciplinary method has the potential to accelerate the diffusion of technologies that improve the overall efficiency of data centers. The graphical elements of technology radar help to illustrate the stage of development for each individual technology. In addition to the technology radars, a standardized form for analyzing each technology is currently in development. The form includes a short description of each technology, the main use of the technology, facilitators and restraints, the targeted type of data center, a forecast of market availability and, of course, potential to improve efficiency.

To ensure an up-to-date overview of current trends in technologies that enhance energy efficiency in data centers it is necessary to have a comprehensive view which also involves adjacent technological fields, and a constant feed of information on new innovations. The technology radars as well as the standardized forms for analysis will be updated on the basis of another expert workshop in the summer of 2019.

Acknowledgment

This contribution is a result of the project TEMPRO - Total Energy Management for professional data centers, which is funded by the German Federal Ministry of Economics and Energy. We would like to thank all project partners and especially the project manager Alexandra Pehlken for the constructive and excellent cooperation. We would also like to thank the working group "data center" of the German digital association Bitkom for their constructive criticism and further input on the individual technology radars.

References

[1] T. Bawden, „Global warming: Data centres to consume three times as much energy in next decade, experts warn“, The Independent, Jan. 2016.

[2] G. A. Brady, „Energy Efficiency in Data Centres and the Barriers to Further Improvements: An Interdisciplinary Investigation“, The University of Leeds, Leeds, 2016.

[3] G. Cook, T. Dowdall, D. Pomerantz, und Y. Wang, „Clicking clean: how companies are creating the green internet“, Greenpeace Inc., Washington, DC, 2014.

[4] R. Hintemann und J. Clausen, „Green Cloud? The current and future development of energy consumption by data centers, networks and end-user devices“, in Proceedings of ICT for Sustainability 2016, Amsterdam, The Netherlands, 2016.

[5] A. S. Andrae, „Total Consumer Power Consumption Forecast“, gehalten auf der Nordic Digital Business Summit, Helsinki, Finland, 2017.

[6] G. Cook u. a., „Clicking Clean: Who is winning the race to build a Green Internet?“, Greenpeace Int. Amst. Neth., 2017.

[7] R. Hintemann und J. Clausen, „Rechenzentren in Deutschland: Eine Studie zur Darstellung der wirtschaftlichen Bedeutung und Wettbewerbssituation. Studie im Auftrag des Bundesverbandes Informationswirtschaft, Telekommunikation und neue Medien e.V. (BITKOM)“, Berlin, 2014.

[8] K. J. O'Dwyer und D. Malone, „Bitcoin mining and its energy footprint“, 2014.

[9] A. de Vries, „Bitcoin's Growing Energy Problem“, Joule, Bd. 2, Nr. 5, S. 801–805, 2018.

[10] Digiconomist, „Bitcoin Energy Consumption Index“, Digiconomist, 2018. [Online]. Verfügbar unter: https://digiconomist.net/bitcoin-energy-consumption. [Zugegriffen: 26-Sep-2018].

[11] International Energy Agency (IEA), „World Energy Outlook 2009“, 2009.

[12] K. Fichter und R. Hintemann, „Beyond Energy. The Quantities of Materials Present in the Equipment of Data Centers“, J. Ind. Ecol., Bd. 18, Nr. 6, S. 846–858, 2014.

[13] J. Gröger und M. Köhn, Leitfaden zur umweltfreundlichen öffentlichen Beschaffung: Produkte und Dienstleistungen für Rechenzentren und Serverräume. Umweltbundesamt, 2016.

[14] J. Koomey, „Growth in data center electricity use 2005 to 2010“, Rep. Anal. Press Complet. Req. N. Y. Times, 2011.

[15] J. G. Koomey, „Worldwide electricity used in data centers“, Environ. Res. Lett., Bd. 3, Nr. 3, S. 034008, 2008.

[16] A. Shehabi u. a., „United States Data Center Energy Usage Report“, Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, CA, LBNL-1005775, 2016.

[17] J. Clausen, E. Göll, und V. Tappeser, „Sticky Transformation – How path dependencies in socio-technical regimes are impeding the transformation to a Green Economy“, gehalten auf der IST-Conference 2016, Wuppertal, 07-Sep-2016.

[18] K. Fichter und J. Clausen, „Diffusion Dynamics of Sustainable Innovation - Insights on Diffusion Patterns Based on the Analysis of 100 Sustainable Product and Service Innovations“, J. Innov. Manag., Bd. 4, Nr. 2, S. 30–67, 2016.

[19] G. H. Hadorn u. a., „The emergence of transdisciplinarity as a form of research“, in Handbook of transdisciplinary research, Springer, 2008, S. 19–39.

[20] D. J. Lang u. a., „Transdisciplinary research in sustainability science: practice, principles, and challenges“, Sustain. Sci., Bd. 7, Nr. 1, S. 25–43, 2012.

[21] S. Funtowicz und J. Ravetz, „Values and uncertainties“, in Handbook of transdisciplinary research, Springer, 2008, S. 361–368.

[22] S. Funtowicz und J. Ravetz, „Post-normal science“, Int. Soc. Ecol. Econ. Ed Online Encycl. Ecol. Econ. Httpwww Ecoeco Orgpublicaencyc Htm, 2003.

[23] S. Baumgärtner, C. Becker, K. Frank, B. Müller, und M. Quaas, „Relating the philosophy and practice of ecological economics: The role of concepts, models, and case studies in inter-and transdisciplinary sustainability research“, Ecol. Econ., Bd. 67, Nr. 3, S. 384–393, 2008.

[24] P. Brandt u. a., „A review of transdisciplinary research in sustainability science“, Ecol. Econ., Bd. 92, S. 1–15, 2013.

[25] P. Nanz, O. Renn, und M. Lawrence, „Der transdisziplinäre Ansatz des Institute for Advanced Sustainability Studies (IASS): Konzept und Umsetzung“, GAIA-Ecol. Perspect. Sci. Soc., Bd. 26, Nr. 3, S. 293–296, 2017.

[26] C. Pohl und G. H. Hadorn, Principles for designing transdisciplinary research. oekom Munich, 2007.

[27] R. Rohrbeck, J. Heuer, und H. Arnold, „The technology radar-an instrument of technology intelligence and innovation strategy“, in Management of Innovation and Technology, 2006 IEEE International Conference on, 2006, Bd. 2, S. 978–983.

[28] A. Elzinga, „Participation“, in Handbook of transdisciplinary research, Springer, 2008, S. 345–359.

[29] R. Hintemann, S. Beucker, J. Clausen, L. Stobbe, M. Proske, und N. F. Nissen, „Energy efficiency of data centers - A system-oriented analysis of current development trends“, in EGG 2016+ Proceedings, Berlin, 2016.

[30] L. Stobbe, R. Hintemann, M. Proske, J. Clausen, H. Zedel, und S. Beucker, „Entwicklung des IKT-bedingten Strombedarfs in Deutschland - Studie im Auftrag des Bundesministeriums für Wirtschaft und Energie“, Fraunhofer IZM und Borderstep Institut, Berlin, 2015.

[31] DataCenter Insider, „Neue Stromversorgungsarchitekturen drücken die Datacenter-Kosten“, 2017. [Online]. Verfügbar unter: https://www.datacenter-insider.de/neue-stromversorgungsarchitekturen-druecken-die-datacenter-kosten-a-590569/. [Zugegriffen: 25-Okt-2017].

[32] electronicspecifier.com, „On the road to software defined power architecture“, 2017. [Online]. Verfügbar unter: http://www.electronicspecifier.com/power/on-the-road-to-software-defined-power-architecture. [Zugegriffen: 25-Okt-2017].

[33] W. Knight, „Intel wants to move beyond today’s architecture, with brain-inspired and quantum chips.“, MIT Technology Review, 2018. [Online]. Verfügbar unter: https://www.technologyreview.com/s/609909/intels-new-chips-are-more-brain-like-than-ever/. [Zugegriffen: 28-Mai-2018].