Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 15 (2014) 90 – 95

www.elsevier.com/locate/procedia

21st CIRP Conference on Life Cycle Engineering

Investigation of advanced energy saving stand by strategies for production systems

Nils Weinert* , Christian Mose

Siemens AG, Corporate Technology, Systems Engineering, Otto-Hahn-Ring 6, 81739 München , Germany

* Corresponding author. Tel.: +49 173 7359653; *E-mail address:* nils.weinert@siemens.com

Abstract

Switching machinery into standby during non-productive phases for saving energy is rarely applied in today's production environments. Frequent reasons for this are lack of information on potential benefits and the uncertainty on resulting, potentially negative effects. Thus, in a recent project an approach for investigating both economical and ecological benefits was developed, integrating a facile definition process of possible standby modes and basic production system simulation for investigation of different switching strategies. The results of this estimation are evaluated both economically and ecologically, providing a clear decision base for strategy selection. In this paper, the approach is introduced along with exemplary results.

Selection and peer-review under responsibility of the International Scientific Committee of the 21st CIRP Conference on Life Cycle Engineering in the person of the Conference Chair Prof. Terje K. Lien

Keywords: Energy Efficiency; Standby Strategy; Production Planning and Control

1. Introduction

Societal awareness for environmental issues over the last few decades has led to a strong consideration of topics like resource and energy efficient manufacturing in both, scientific research as well as industrial application. Numerous investigations have been conducted, analyzing the use of energy in manufacturing environments from multiple perspectives. Amongst other findings, results have shown significant energy consumptions during non-value adding phases – thus during times when production equipment is paused or idling – for almost every considerable way of classifying machinery and throughout almost all considerable manufacturing branches (e.g. [1]–[4]). Depending on the specific characteristics of a given production site, costs for energy not used for adding value – and therefore considerable as waste according to the principles of lean production – can sum up to several thousands of Euros. As an example, a documented case of a highly automated car manufacturing plant can be named, requiring annual energy costs of more than 400.000 € for non-productive times during weekends, as reported by Engelmann et al. [5]. But also for smaller applications, e.g. machining centers, standby losses sum up to a relevant share during the machines life cycle (e.g. [6]).

2. Reasons for lacking industrial application

Although the amounts of energy wasted during non-productive times have been a major subject in research for several years now, the potentials are rarely developed in industrial applications. While the reasons for e.g. switching off equipment during idle times are manifold, continuous consultancy work for different production sites shows two major causes: lacking information on efforts and benefits in specific cases, and uncertainty on resulting, potentially negative effects.

Lacking information is mainly caused by imprecise tracking of energy related performance figures: On the one

2212-8271
Selection and peer-review under responsibility of the International Scientific Committee of the 21st CIRP Conference on Life Cycle Engineering in the person of the Conference Chair Prof. Terje K. Lien
doi:10.1016/j.procir.2014.06.009

hand, detailed energy consumption tracking is only done in few applications, and energy costs are often still accounted as general expenses. Further, energy costs in relation to other cost positions for industry are still comparably low, and are therefore not a major concern in management decisions. When, on the other hand, considering possible benefits of energy savings during non-productive times, basic estimations are easily feasible. Advanced calculations, however, require a notable higher effort, what makes them less practically achievable in a daily business environment.

Even if awareness was raised, in most cases considerations lead to decisions against switching off equipment, mainly due to fear of proper restart afterwards. Production equipment, in general, is not designed for repeatedly being switched on and off on a daily basis, and therefore damage-free switching operations in high amounts often cannot be ensured. Especially in complex, interlinked production systems, restarting equipment usually requires synchronization of different controls, sensors or protocols. This, on the one hand, makes starting up equipment time consuming, on the other hand synchronization errors are not unlikely, and therefore makes it difficult to have production equipment ready for operation on time without additional effort. Since unscheduled downtimes and therefore production losses typically are more cost intensive then the energy which is saved instead, all machinery is kept running in order not to risk output.

3. Requirements to standby-enabled production systems

From the technical point of view, production equipment has to be equipped with the required functionality for repeatedly being switched off and powered up again, with special focus on providing this functionality without risking a delay before being ready for production on time. Since the additional functionality requires additional engineering efforts during system planning or revision, economical feasibility of respective implementations is endangered. Consequently, a procedure is required for investigating the possible benefits of additional functionality.

To fulfill these requirements, an approach for investigating both economical and ecological benefits was developed within a recently finished project. It included integrating a facile definition process of possible standby modes and basic production system simulation for investigation of different switching strategies.

4. Procedure for estimation of standby saving potential

4.1. Overall Approach

For estimating the saving potential which can be achieved by using standby modes for production equipment, the approach depicted in Fig. 1 was defined.

Non-productive times of production machinery appear due to two different reasons, which are planned pauses and unplanned downtimes. In principle, every production equipment available can be set to saving / less energy using states during these non-productive times, since at least switching off is an option. However, this requires time for proper shutdown and restarts, and therefore is only suitable when breaks or downtimes are long enough for these transitions. Thus shorter interruptions are neglected in terms of saving energy. Consequently, for enabling production equipment to participate in advanced standby strategies which save energy in shorter interruptions, several standby modes must be implemented. The implementation of multiple standby modes in production equipment should be made according to the developed scheme as described in section 4.2. The implementation can be considered as selecting proper components to be integrated in each module of a production system, thus for each module transition times between the different states can be estimated as well as the energy demand per state, as described in section 4.3. Furthermore, based on the hardware selection, the engineering effort for realizing the implementation becomes possible to be calculated (section 4.4).

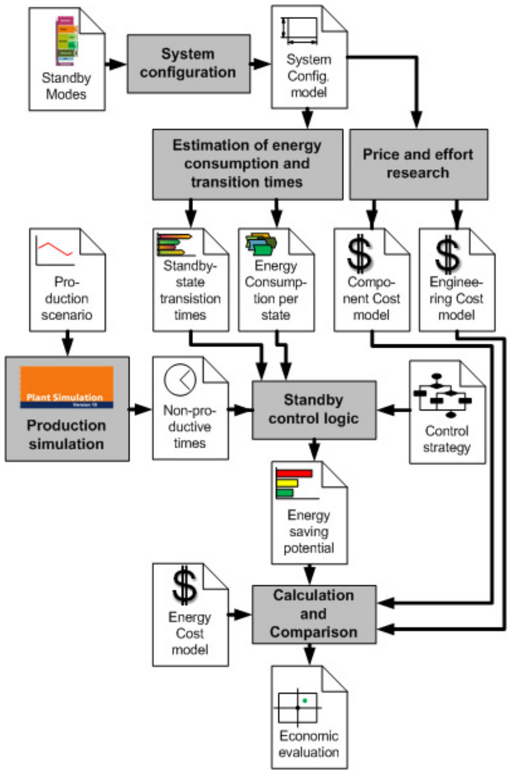

Fig. 1: Methodology overview.

In a basic strategy for production equipment standby management, a production system is considered as a whole. Non-productive times are easily to be determined, since pauses and free shifts are known in advance, potentials thus can be simply derived. Once it comes to strategies more advanced than this, detailed information on non-productive times of the overall production system is required. Non-productive times, e.g. phases of equipment idling due to uneven cycle times or while waiting for material, can also be used for energy saving by setting equipment to standby. In advanced standby strategies, production systems or even individual modules can be set to standby states during such interruptions. Since, especially in system planning, the required information cannot be retrieved from an actual running system, a discrete-event simulation is applied instead, providing the required times for one or multiple production scenarios considered (see section 4.5).

In the next step, saving potential can be calculated by integrating non-productive times and transition times according to the chosen control strategy in coordination with the energy consumption of each possible energy saving state according to the chosen hardware configuration. Further on, these saving potentials are interlinked with engineering as well as energy cost models for estimating and interpreting the overall efforts and benefits (section 4.6).

4.2. Energy saving states for production equipment

For providing a standardized set of possible energy saving states for production equipment, a scheme was developed, clustering these states according to commonly applicable equipment behavior. Although the defined classification covers a vast majority of production equipment available, additional standby modes can be introduced if required. As depicted in Fig. 2, the basic definition includes off, sleepmode, standby short and long and ready as possible saving states. In Off-Mode, the equipment is considered to be physically switched off, so that no energy is used at all. In sleepmode, only little energy is used for being able to receive and react to start up signals, like Wake-on-LAN functionalities. In comparison to that, for the standby modes defined, energy consumption is required for maintaining the state. The differentiation between standby long and short is made from the time required to reach the ready state again. In ready state, operation can be started immediately. Operational states, in contrast, are not included since operation is not in scope of standby strategy investigations.

The differentiation of the states defined can be illustrated quite figuratively using an industrial robot as an example, see [7]: during ready state the robot is not moving, its position is kept by drives in control. In short standby, the position is maintained using mechanical breaks, and in long standby additionally the intermediate circuit is being discharged. During all, ready as well as standby long and short, the control is running, while in sleep mode it is set to hibernate only maintaining ability for reacting to a wake-on-LAN-magic-package. In Off-Mode, the main switch is turned off, making it impossible to react on command signals, but also cutting down energy demand to absolutely zero.

The definition of energetic states includes required transitions from one state to another, since these are time consuming and thus do strongly influence the decision to which state equipment can be set during interruptions. Additionally, during transitions from one state to another, no static energy consumption is present as in the states defined above. Volatile power intake is common, and also consumption peaks are likely.

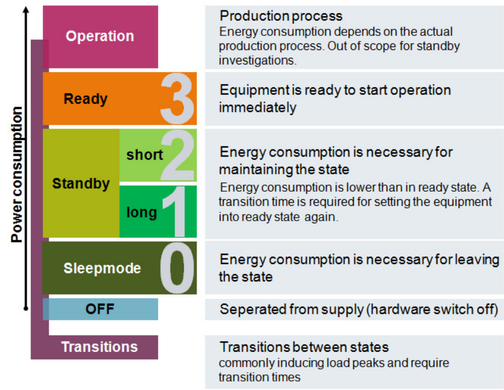

Fig. 2: Definition of possible energy saving states.

4.3. Energy consumption estimation for system modules

In order to reduce the complexity of estimating the energy demand of each module of a production system, the demand of each state is aggregated by summing up the consumptions of all components relevant in that module for each standby state. Following this, it is mainly possible to use the nominal energy consumption per component during idling, since in general each component is either idling or switched off while a module is set to an energy saving state. Further, during idling, a module as well as its components is unlikely to show varying power intakes, thus average values can be applied per state without losing accuracy in a non tolerable way.

For estimation of the required transition times from one standby state to another, again the transition time per component is sufficient to be analysed, since the longest transition time here is dominant on module level. In some cases, dependencies between single components lead to longer transition times than each component individually displays. Hence, for both, transition times as well as energy consumption, the values calculated component-wise may be overridden if required.

For providing a standardized, reusable way of preparing the required information on energy consumption per state as well as transition times from one state to another, a spreadsheet based tool was developed, schematically depicted in Fig. 3. Information can be inserted individually per component and hardware configuration, allowing the

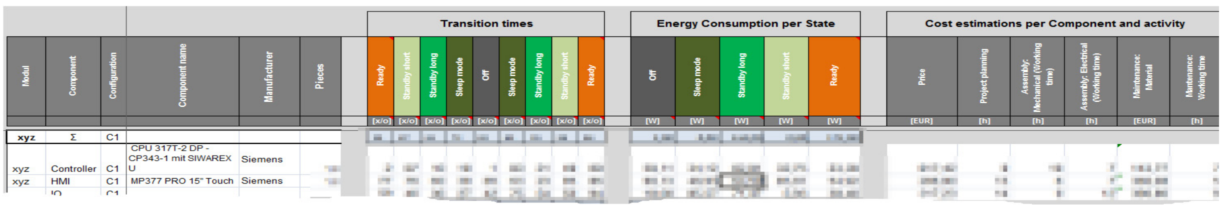

Fig. 3: Spreadsheet-based tool for energy demand, transition time and economical effort estimation (numbers made unreadable).

investigation of alternative configurations in combination with different production control scenarios later in the process (section 4.5).

4.4. Economical / Engineering effort estimation

The spreadsheet tool was enhanced for estimating the economical efforts related with technically enabling the standby states for production systems. Therefore, information like purchasing costs for components, estimated engineering and maintenance efforts are included in the calculation. The simple way to collect and aggregate the required information is maintained since complexity is broken down to component level, and hence can be investigated piece by piece. Only effort for integration has to be evaluated, but therefore is usually available none the less due to economical planning and experience.

4.5. Simulation-based production system investigation

While the occurrence of planned interruptions – such as breaks, free shifts or factory vacations – can be easily determined, for interruptions during production the calculation is more complex. Interruptions, in this phase, are times when production equipment is waiting for material to be processed. Common causes may be deviating cycle times or failures upstream in the material flow.

For determining interruptions during operation, a discrete-event simulation is applied. By using this approach, it becomes possible to easily investigate different production scenarios, e.g. by adapting production quantities, orders and production tasks, or cycle times and availability/failure rates for naming the most influencing properties. Furthermore, results for each strategy can be statistically secured by multiple simulation runs, using e.g. altering random numbers.

While the employed simulation environment (Siemens Plant Simulation) is able of accounting all required figures as integrated values, for investigations as targeted here the exact time for each interruption of each module has to be determined. Hence, the required routines for collecting this information from the simulation have been developed. For providing an alienable library of methods, the programming was done in a quite generic manner. As results from applying the simulation, a detailed time listing becomes available. Additionally, standard production figures can be estimated by using simulation.

4.6. Switching Strategy selection and Principle Results

Selecting the adequate standby strategies mode for energy saving during non-productive times mainly relies on the duration of the interruption. Knowing the duration, one can easily determine whether switching to a specific energy saving state and return to readiness for operation can be achieved in the time available or not. The saving state to aim for then is the one providing the highest saving potential, and therefore in general the one with the lowest power intake available considering its transition times.

In the presented approach this step is conducted by correlating the times and durations of interruptions which have been calculated using production simulation combined with the equipment's energy consumption patterns and transition times defined. The algorithm applied here basically calculates how long each interruption had taken, and selects the most saving standby state available in the used hardware configuration. By parameter input it is possible to decide whether the investigated production system is considered as a whole, or if each module is handled individually.

Using this approach it becomes possible to evaluate alternative hardware configurations against the same production scenario, and vice versa. Thus, for each combination the most beneficial strategy can be selected, leading to the identification of the most appropriate switching strategy for each combination.

Saving potentials are then calculated by comparing the energy demand of a scenario utilizing energy saving states to one on the ready state all the time (see Fig. 4). Those results are then used as input for an economical estimation, which uses an energy pricing model for the calculation of potential savings through lower energy demand. Furthermore, the additional efforts for equipping a production system with the ability for using advanced energy saving strategies are calculated. Finally, both economical and ecological benefits are made comparable by using the so called Eco Care Matrix (ECM) [8].

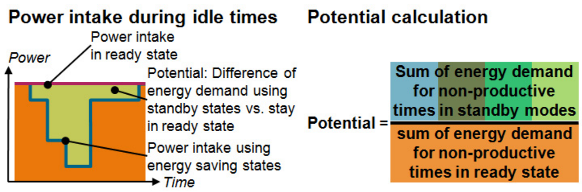

Fig. 4: Calculation of Potentials.

5. Exemplary application results

The introduced approach was first applied for a smaller production system as it is common in the electronics industry. The system consists of several processing modules, which are connected by a conveyor belt transportation system. A set of similar products is processed, varying in the number of different processes required, and partially redundancy among the modules in the system.. Additionally, process times differ slightly from module to module, as they do per variant in some of the modules. The conveyor system is set up to allow different material flows, e.g. reprocessing a product in a specific module after a failure was detected in a quality test station upstream. Overall, the conveyor system is considered as one module as well, implying that all individual belts are running or stopping collective.

For analyzing standby potentials, five modules and respective system configurations have been considered in several production scenarios. While the first configuration just displays the actual system is available as reference case, which is idle equipment stays in ready mode constantly between production times, two configurations are developed from the actual system available. One of these configurations uses the production system as-is, meaning that only setting the whole system and not the individual modules to energy saving states. In the second configuration, the system is able to handle each module individually, thus allowing for individual standby of each module even while other ones are processing. In both configurations, modules provide some different states which can be used as energy saving states, but most of the modules can only be set into two saving states (off and one intermediate mode between off and ready).

In the other two configurations, all modules are redesigned for providing all energy saving states as introduced shown in Fig. 2. These two configurations differ in the minimal power intake achievable, which in one case is sleep mode (like it could be achieved e.g. by using ProfiEnergy-enabled equipment, which on a signal from a hierarchy level above can be triggered to wake up). In the other configuration a full 'Off state' can be achieved, leaving a module at zero power intake when set to. In the latter case, a higher level control unit would be able to restart equipment by reconnecting it to the electrical supply.

The power intake, for each state in all configurations was measured or directly derived from measurements on the existing system investigated. For the transition between two states, for this investigation a constant power intake per transition was considered. The value used for each transition always was the higher one from the two states the transition connected. Thus, no peaks or similar events during the transition have been considered so far.

For the production scenarios, several settings for orders and lot sizes have been simulated. Additionally, failure rates and repair times have been considered in some scenarios, as well as processing times. The duration each scenario was simulated for has been one shift, respectively eight hours of production. Two planned breaks appeared within one shift, one of 15 and one of 30 minutes. The results later have been extrapolated for lifecycle evaluations, considering one, two as well as three shift production scenarios.

As displayed in Fig. 5, the achievable potentials are remarkable for some of the cases investigated. Clearly, every way of using energy saving states provides a reduction of the overall energy need during idle times in comparison to the conventional strategy of always staying in ready mode. While by only shutting down equipment during pauses, a consumption reduction of 9% is possible, by setting equipment to saving states available by conventional design increases the potential by further 5% (compared to the reference configuration). Potential saving rises as soon as equipment failures are considered. The availability of each module – in this case – was set to 95% for simulating the production system, with mean repair times of something between 5 and 20 minutes. The reason for the significantly higher potential of course is based in the high interdependence of the different modules with each other in the production system. Failures and downtimes in some modules lead to blocking the material flow. Hence downstream modules are likely to run out of material to process. In this case additional saving potential arises and these modules can be switched into an energy saving state.

By using production equipment which has been specifically enabled for going into energy saving states, remarkable higher potentials can be achieved, reaching 50% to 60% consumption reductions in comparison to the reference case. This behavior is caused by two reasons: Firstly, through implementing additional saving states, the transition times from one state to another become shorter, allowing switching standby modes ("standby short") more often than it was possible with longer transition times. Secondly, a sleep mode, and off mode respectively in the fifth configuration, are now enabled by adequate components applied in the production equipment. This has not been the case in the prior configurations, thus only a higher power intake was possible, even during saving phases while a module is not in production.

It should be emphasized that the potential indicated in the example is referring to the consumption within idle times, and not for the value adding processing phases. Furthermore, the calculations display a best-case scenario, since the figures introduced are calculated knowing the duration of each production interruption for each module and selecting the most appropriate targeted saving state is possible in every case. For the economic evaluation, these results have been used as input for different cost scenarios, with variations in e.g. energy prices, or work and engineering prices. Of course the different settings lead to variations in achievable amortization times. As the main conclusion which can be drawn from the findings, amortization times of not much more than 2 to 3 years can be achieved for the investigated

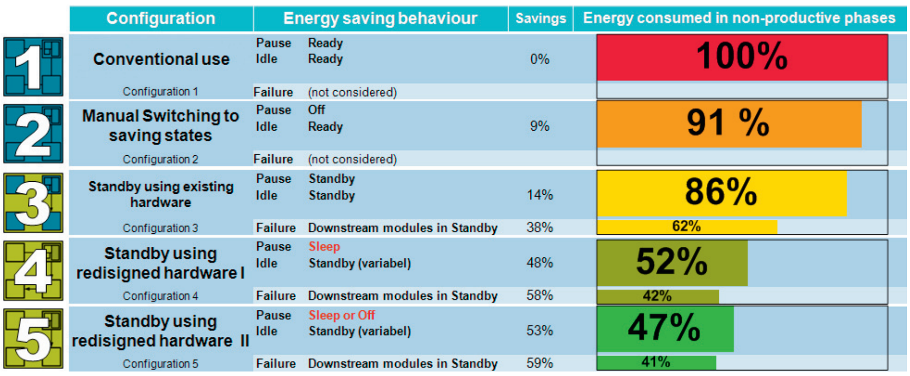

Fig. 5: Energy saving potentials for the investigated production system for one shift.

case, if a centralized standby management is implemented (Fig. 6), and therefore can be considered competitive. On the other hand, applying standby manually is even more competitive for about 6 to 7 years, if an effort of one employee needing about 30 minutes per shift shutting down and repowering up equipment. This time is considered as a rough estimation for the actual switching and reacting to required actions for e.g. synchronization of the different modules (quitting failures, starting additional processes), as well as for moving between the control terminals in the considered system. Hence, if the considered lifespan the equipment is in use becomes longer than this time span, additional effort for implementing an automated standby management is beneficial. On the other hand, if a significant lower power intake during ready state is considered for the system combined with energy prices at the lower bound of common industrial prices today, it is likely that amortization times rise significantly. Even more important, in this case it is also likely that the effort for manual standby management – measured in terms of workforce costs – exceed the costs for the energy consumed when the production equipment stays in ready state during idle times.

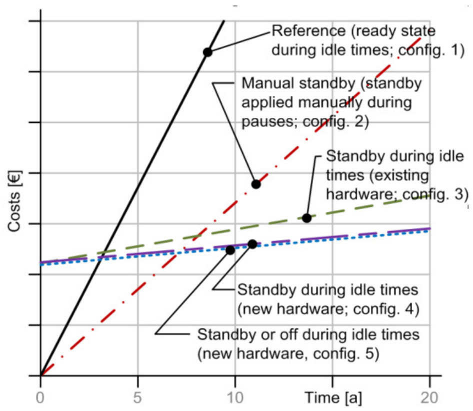

Fig. 6: Schematic display of cost development for the introduced case.

6. Conclusions and Outlook

In this paper, an approach for investigating energy saving potentials by setting production equipment to standby modes during non-productive times is introduced. Investigating different hardware configurations – which result in different abilities for going into saving modes – and different production scenarios – e.g. varying in production quantities, orders and production tasks, cycle times or failure rates – are combined. The energetic saving potentials, derived from these investigations, are then combined with cost models for allowing evaluating the overall results, both economically as well as from the energy efficiency point of view.

The approach defined was applied for the case of a manufacturing system typical for electronics production, thus consisting of several process modules linked by a conveyor belt system. The results achieved display significant saving potentials concerning the energy use during non-productive times, which are planned pauses and free shifts as well as idle times caused by uneven cycle times, or failures at some point in the material flow. However, concerning the whole lifecycle perspective, the major potential is raised by switching off equipment during free shifts, weekends and e.g. factory vacancies. When correlating the found results with cost models, it becomes visible that implementing energy saving states for production equipments can achieve reasonable amortization times nowadays, even for smaller and hence low energy using applications. The calculations confirmed once more that manually switching off equipment in general is expedient, although in complex, strongly interrelated but systems and processes with a low energy intensive it may cause costs exceeding the potential reductions through saving energy.

The results achieved so far are representing a best case investigations, since the duration of all non-productive times was considered as known in advance, so that the optimal energy saving state could be applied in every case. Since this is virtually not achievable for unscheduled events in reality, next steps are to use the developed approach in combination with a strategy development, defining how the system and respectively each module should react when it starts unplanned idling. More advanced, by using the presented method designing production equipment explicitly for providing the optimal saving modes for a specific task could be approached.

Acknowledgements

The results presented in this paper were developed in a joint project of the Advanced Technologies & Standards unit (ATS) of the Siemens Industry Sector together with the author’s affiliation.

References

[1] J. R. Duflou, J. W. Sutherland, D. Dornfeld, C. Herrmann, J. Jeswiet, S. Kara, M. Z. Hauschild, and K. Kellens, “Towards energy and resource efficient manufacturing: A processes and systems approach,” CIRP Annals - Manufacturing Technology, Vol. 61, No. 2, 2012.

[2] R. Neugebauer, E. Westkämper, F. Klocke, D. Spath, M. Schenk, A. Michaelis, M. ten Hompel, and E. Weidner, “Untersuchung zur Energieeffizienz in der Produktion, Abschlussbericht,” 2008.

[3] R. Neugebauer, M. Putz, A. Schlegel, T. Langer, E. Franz, and S. Lorenz, “Energy-Sensitive Production Control in Mixed Model Manufacturing Processes,” in Proceedings of the 19th CIRP Life Cycle Engineering Conference (LCE), 2012, pp. 401–406.

[4] T. G. Gutowski, J. Dahmus, and A. Thiriez, “Electrical Energy Requirements for Manufacturing Processes,” Energy, vol. 2, no. Cvd, pp. 623–628, 2006.

[5] J. Engelmann and J. Strauch, “Aspekte zur Planung energieeffizienter Fabriken,” in 1. Braunschweiger Symposium für ganzheitliche Produktionssysteme, 2008.

[6] E. Abele, M. Dervisopoulos, and B. Kuhrke, “Bedeutung und Anwendung von Lebenszyklusanalysen bei Werkzeugmaschinen,” pp. 51–80, 2009.

[7] P. Klüger, “Die ‘grüne’ Robotik,” Comput. Autom., vol. 5/12, no. 5/12, pp. 29–34, 2012.

[8] D. Wegener, M. Finkbeiner, D. Geiger, S. I. Olsen, and F. Walachowicz, “Comprehensive Approach to Energy and Environment in the Eco Care Program for Design , Engineering and Operation of Siemens Industry Solutions,” in Proceedings of the RISO International Energy Conference, 14-16 September, 2009, Copenhagen, 2009, pp. 14–16.