18.6 Evaluation of energy and resource efficiency supported by enterprise modeling – experiences from application cases and their significance for the multi-perspective modeling approach

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Abstract
The multi-perspective modeling method is an enhancement of enterprise modeling and will enable understandable, operational views (“perspectives”) on sustainable value creation. The goal is to allow all stakeholders to make decisions towards the sustainability in their context, ranging from individual enterprise decisions up to cooperation strategies. As known, the sustainability is based on the environmental, economic and social dimensions. The energy and resource efficiency is an essential subset within the sustainability context that affects mainly the first two dimensions. This paper presents an enterprise modeling driven and supported analysis of energy and resource efficiency, which was performed at several small and medium sized enterprises. The experiences gained from this application case are described and their consequences for the multi-perspective modeling method are argued.

Keywords: Multi-perspective Modeling, Enterprise Modeling, Business Process Modeling, Sustainable Manufacturing

1 MOTIVATION
Day by day hundreds of operations are performed in each company either to produce something or to control the manufacturing and to fulfill all the managerial tasks, which are the prerequisite for the manufacturing and economic success of the company. Usually, the most of those activities consume more or less energy (e.g. electricity, thermal energy for heating or cooling), several use raw materials or commodities to create new products, but often generate also waste and emissions.

Methods for business process modeling (BPM) are an appropriate way to effectively describe such sequences of activities and their relations to e.g. information, equipment and personal resources, products etc. By using the BPM it is possible to model the physical material flow correlated to products proceeded through the shop floor as well as all the orders and information that are controlling the physical material flow. These information are usually the result of strategic management processes like “determine strategy”, “quality management” and “budgeting” as well as operational management processes such as “marketing, acquisition”, “order processing”, “manufacturing planning and execution”, “accounting”, “maintenance” and so on. This description can be done on different levels of detail from workplace over the enterprises level up to the value creation network.

This is the reason why we talk about the enterprise model as result of the modeling process. But the enterprise modeling still pushes the envelope if it is requested to describe and evaluate energy and resource efficiency. For example the systematically embedding and allocation of indicator values to certain elements within the enterprise model is still insufficiently solved. Moreover, the description of reasons why something happens, how strong this reason influences which processes and why it is in the linked sequence of actions (cause-impact-relations) requires a strengthening. For example, it could be of interest which implications to certain enterprise processes has causing on the strategically management decision to invest into energy efficiency. This of course limits the use of enterprise models in the context of designing enterprise processes leading to energy and resource efficient acting especially due to its constrained evaluation capability.

This paper describes the application cases of energy and resource efficiency analyses at several companies driven and supported by enterprise modeling (chapter 2). The findings, lessons learnt and acquired company data such as models, indicators etc. are discussed and will directly influence the development of the method of multi-perspective modeling within the Collaborative Research Centre SFB 1026 - “Shaping Global Manufacturing Sustainable Value Creation” (chapter 3). This will be one step forward to develop a consistent toolbox for a rapid and enterprise model-based sustainability analysis. An investigation of existing approaches to handle energy and resource efficiency supported by models shall support this development (chapter 4).
2 THE APPLICATION CASE - OBJECTIVE AND OVERVIEW

The application case has been performed in the context of a Russian-German energy and resource efficiency project supported by the German Ministry of Education and Research [1]. This project specifically aims to strengthen the competitive position of Russian enterprises by stimulating environmental behavior and acting supported with practically applicable solutions for increasing their material efficiency and productivity with reduced energy consume [2].

Four companies in the Russian Samara region have been investigated. Hence, the application case took place under specific Russian economic and social condition, such as a closed energy market due to state-owned energy supplier or the Russian law and its implementation in the area of waste treatment or occupational health and safety. All enterprises are automotive supplier but from very different industrial sectors. They produce casted aluminum components for gear, motor and pumps, die cut and punched sheet metal parts, molded plastic paneling or vibro-damping and noise absorbing products. With 25 to 125 employees the companies are small and medium-sized enterprises.

In the analysis phase several appointments at the site of the participating SMEs have been taken place. During this time, the enterprise processes were modeled and analyzed as well as required data on production, transportation and auxiliary processes. For each company, the energy and resources relevant production processes were modeled in detail by the method of integrated enterprise modeling (IEM) [3] in the tool MO²GO [4,5]. Based on the enterprise process model, all energy and material consumptions have been recorded along the production processes.

In addition, information and data on building insulation, lighting, heating, office equipment and operation, etc. were collected. All this information led into energy flow models based on the energy value stream method [6].

An example for the relation between enterprise processes and energy flow model is shown in Figure 1. With the help of these models and the energy efficiency indicators, the participating companies were evaluated in terms of their energy and material efficiency. Subsequently, the largest energy consumer (sub-processes and individual process participants) were identified and the potential savings were calculated. These data were the basis for the determination of individual actions for energy and material efficiency gains in the participating companies.

In parallel two additional evaluations were performed. The Rapid Sustainability Plant Assessment (RSPA) is a questionnaire-based evaluation of an enterprise performed by experts. The aim is to get in limited time a rapid assessment of the enterprise’s conditions in economic, environmental and social area. On the one hand, the RSPA goes beyond the scope of energy and material efficiency, on the other hand it provides usable and structured results in a very early stage of the analysis, even if there are still no well-grounded or measured values available. A basic Life Cycle Assessment analysis (LCA) has been performed at one company to get an impression how the data gained in the energy and material efficiency analysis can be applied for further purposes. For example it has been calculate the impact of the energy consume to the climate change (in CO₂-equivalence) or the impact-category terrestrial acidification (SO₂) based on the material usage of the company.

An overview about the involved companies and the performed analysis can be found in table 1.

### Table 1: Performed application cases and related analysis

<table>
<thead>
<tr>
<th>Enterprise</th>
<th>Enterprise Model Management</th>
<th>Enterprise Model Production processes</th>
<th>Energy flow analysis</th>
<th>RSPA</th>
<th>LCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>✓</td>
<td>strategic and operational processes</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vibro-damping line</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Noise absorbing products line</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>✓</td>
<td>Metal treatment (die cutting and punching)</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>III</td>
<td>✓</td>
<td>Aluminum casting</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mechanical treatment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>-</td>
<td>Plastic injection molding products</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
</tr>
</tbody>
</table>

3 EXPERIENCES FROM THE APPLICATION CASE AND THEIR IMPACT ON THE MULTI-PERSPECTIVE MODELING APPROACH

The Multi-perspective Modeling Approach aims to support the planning engineer with an instrument for setting-up or redesign enterprise processes to fulfill sustainability goals [7]. This new modeling method will enable understandable, operational views (“perspectives”) on the enterprise processes along the value creation. The goal is to allow stakeholders to make decisions towards the sustainability in their context [8].

During the investigation an enterprise model based on the existing method IEM has been created. The approach of a combination with several other methods used to evaluate the sustainability status of an enterprise has been used to extract several requirements for the multi-perspective modeling approach. These requirements can be structured into the four fields: data acquisition and enterprise process modeling, data processing and calculation, analysis, and visualization of the analysis’ results.

### Data acquisition and process enterprise modeling

Different activities were performed in this filed: a) enterprise modeling with interview partners starting from a model template, b) collection of basic company information with RSPA and general questionnaire, and c) the detailed collection of indicator values for different periods over the year, such as monthly amount over one year of electricity and heating energy consumption, water, production volume etc.

As expected, the data recording in the participating Russian SMEs turns out to be very difficult and time consuming. Often, necessary data and information were not available or
are not electronically accessible, which increases the effort of data acquisition and processing. Also the kind of available data was different between each company. For example partially only the total electricity consumption for the complete company was available, another company provided it for a certain building, or values were given for a certain number of the equipment set but not for all. As consequence the data collection templates should support flexible ways to insert indicator values. For example it could contain the following four alternative options to enter the electricity consumption:

- measured electricity consumption - based on real measurement and related to a certain process and equipment
- demand of electric power * work time (for each activity)
- gaining the consumed energy for a certain area of the production e.g. value from the electricity meter of a shop floor or from the bill of the power supplier and support the calculation of the share of the consumption per process
- subjective evaluation by an expert (if no other data are available; e.g. RSPA over scale quantifiable)

Also an automatic consistency check and the check on missing data could ease the data collection.

A further challenge was the coordination between the different types of data collection because a) separate tools and instruments were used during the collection e.g. Word files, Excel tables, enterprise models, etc. and b) the collection templates were too general and non-adjusted to the available data from already performed collections. As exemplarily effect the processes and equipment from the enterprise modeling were not reflected in the energy consumption collection template. But the use of templates was fruitful in general, especially the tabular collection of the large amount of detail data. Only, the transfer of the data back to the enterprise processes was missing. As consequence, the multi-perspective modeling should be able to provide easy-to-use data collection templates. These should be integrated in the enterprise model and dynamically adapted to the model content (or later vice versa adapt the enterprise model to content filled in the template).

A comparable situation appeared during the application of the Rapid Plant Sustainability Assessment. It was very useful to gain in the beginning of the assessment a structured set of basic company data and expert’s evaluation. In this sense, the multi-perspective modeling acts on a more detailed information level than the RSPA, but requires its information as input. Nevertheless, the seamlessly further use of the data - for example in the enterprise model - was still insufficient. The integration of the collected RSPA indicators and information into the multi-perspective modeling is therefore one consequence from the experiences of the application case. This requires a mechanism to assign indicator values to certain elements within the enterprise model.

One potential approach to tackle the current constraints is the implementation of an additional information layer into the enterprise model. This information layer can be named “sustainability performance structure”. The main objective of this layer is the thematically clustering of enterprise model content in a topic-specific manner. Combined with the capability to link and assign indicator values and impact categories to the model content, this would enable the (semi-)automatic evaluation of enterprise models.

Another effect happened through the different requested levels of data details. For example, in the enterprise model the products are described with generic names like "plastic mat". But for a more detailed analysis - like for the LCA - the very exact specification of the material inclusive the specific weight is necessary to get an LCA-value. Instead of "plastic mat" the correct kind of plastic material like polyethylene or polyurethane is requested. This becomes much more challenging if we talk about composite material like metal-laminated foil. On the other side the enterprise model contains information like organizational or IT-related issues which are not of interest for the traditional LCA or energy flow analysis. As prerequisite for the integration of the data these different levels of details need to be aligned. But the result will open new options for the evaluation.

**Data processing and calculation**

In the application case the calculation of indicators and visualization are logically linked to the enterprise processes but made in separate Excel sheets and tools (e.g. to draw the sankey diagram for the energy distribution or GaBi for the LCA).

The data processing within the enterprise model would enable the calculation of indicators and visualization in relation to the enterprise processes. This would increase the data consistency, reduce double work in the data collection or due to data transfer and finally offer new evaluation capabilities. However, it is not reasonable to integrate all information. For example requires the calculation of LCA impact categories and areas of protections detailed background knowledge and the access to large databases. Eventually, here the establishing of an information exchange interface has more advantages.

**Analysis**

The link between enterprises processes and efficiency parameters is essential. Figure 1 shows exemplary that the managerial processes in the office of one application case company require 28% of the total consumption. This is more electricity than the manufacturing in the noise absorbing products workshop. Hence, in the performing of the managerial processes itself lays a very high saving potential. It is important to recognize this direct impact of managerial processes on efficiency. To know where and which activities consume how much energy is the base to react on it. More important is the indirect impact on efficiency due to the fact that some management processes influence decisions, e.g. on investments in less-energy consuming equipment and machines. The combination of enterprises processes with efficiency evaluation methods enables the analysis for example of the impact of a changed production strategy to the energy efficiency. Moreover, the affected processes, equipment and staff can be identified.

The applied methods of energy distribution and energy flow were very useful to recognize the process and equipment with the highest consume and therefore also high improvement potentials. For example, the vibro-damping workshop was identified with 50% as field with the highest electricity consumption (figure 1). A detailed investigation of the workshop’s manufacturing processes with the energy...
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The flow method shows that the bitumen cauldron has the highest energy intensity within the bitumen line. The adaptation of the cauldron insolation was identified as technological improvement action that would lead into a 10% reduced energy consumption. In addition, managerial improvements were identified in the enterprise model. The cauldron runs 24 h (because of the danger of harden bitumen) but the working time is currently only 8 h. The introduction of a shift plan could reduce the energy intensity dramatically because of lower idle periods and the switch-off of the empty cauldron. But this procedure of course affects other management issues like employment system and work plan.

Another example is the very high and over the year fluctuating water consumption identified in one company. Only 1% of the water was used for manufacturing and 99% for watering lawn and office tasks. In a further case, the identification of the missing thermostats and insulation of heating installations led to the suggestions: a) establishing of the missing equipment plus b) management instructions to the staff for energy efficient behavior (e.g. not to open the window if the heating is running). Both actions combined could save 25% heating cost with low investment and an amortization in 3.4 years. In this context the multi-perspective modeling is requested to support the design of alternative model scenarios that can be compared to each other.

Visualization of the analysis' results

The graphical visualization of the results e.g. in form of energy or material flow diagram (figure 1) was an effective way to easily find the largest consumers and therefore the area with a potentially high improvement as well as to create awareness in the analyzed companies on the field of acting. The integration into the enterprise model could offer new analytic views to the model content. Exemplary, the multi-perspective modeling could support following views (perspectives) (figure 2):

- enterprise processes combined with material flow, energy flow, value stream, the Intellectual Capital Structure (ICS) and individual Key Performance Indicators (KPI)
- marking or highlighting of direct energy or resource-intensive processes or equipment (e.g. with color-code or size of a graphic element)

Figure 1: Relation of enterprise models and specific energy and resource efficiency analyses
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- marking of the enterprise control and management process (strategic, operational) which indirectly influence the high energy intensive processes (where something happens, where something affects)
- distribution of the energy consumption to certain criteria (e.g. physical location, organizational unit, source of energy etc.)

The specification of the different views is one step forward to the Multi-perspective Modeling Approach.

4 MODEL-BASED SUPPORT OF ENERGY AND RESOURCE EFFICIENCY – A STATE OF THE ART

The investigation of existing approaches to handle energy and resource efficiency supported by models can help to support the development of the Multi-perspective Modeling. Duflou et al. [9] give an overview of methods for increasing energy and resource efficiency in manufacturing. Regarding the impact of unit manufacturing processes, they note that existing life cycle inventory databases (LCI) usually comprise only few and only conventional processes focusing on primary material production and recycling. This fact can hamper energy and resource efficient process modeling. However, Duflou et al. [10] suggest an LCA-based methodology for creating unit process datasets for LCI within the CO2PE program. As Duflou et al. [9] point out, commercial tools for simulating process chains or whole factories cannot yet include relevant energy and resource flows such as the flows of technical building services for assessing energy and resource efficiency.

Bunse et al. [11] analyze the gaps between scientific approaches to energy management in production and actual industry needs. Identified gaps exist in the area of enabling processes as energy efficiency is not sufficiently integrated into management systems and tools but also in the area of measurement as e.g. key performance indicators for assessing energy efficiency on process or plant level are missing. Bunse et al. reach the conclusion that available solutions for managing energy efficiency are not implemented in enterprises. An overview of different energy efficiency indicators is given.

As Smith and Ball [12] point out, there are no appropriate approaches for modeling material, energy and waste (MEW) flows, which allow quantitative analysis of the manufacturing operations of a company with regard to environmental impacts. They also notice that specifications for data
collection for MEW modeling are missing, and that Life Cycle Assessment (LCA) and Value Stream Mapping (VSM) focus on the “product stream rather than production function” [12]. Based on their experience in a case company, Smith and Ball therefore develop guidelines for MEW process flow modeling intended to enhance the environmental efficiency of manufacture. These guidelines resemble the steps followed for the analysis presented here following these guidelines, Smith and Ball create two unconnected models with the same final aim of the company in different software: a qualitative MEW process flow map which assists in building the corresponding detailed quantitative spreadsheet model used for analysis. Control processes and mechanisms are included rudimentary in the qualitative IDEF0 map only.

Value stream mapping (VSM) offers a variant focusing on energy consumption as presented by [6]: energy value stream mapping (EVSM). This approach visualizes and analyscs the energy consumption within a sequence of production processes in VSM manner. Here, every process is connotated with a data box with characteristic economical and energy-related parameters like process time, rate of yield, electric energy needs. For evaluation, the energy intensity and energy efficiency of the processes are analysed. Products are partitioned into product families and energy consumption is related to customer needs. There is a need for comprehensive parameter data is either measured at the corresponding machine or calculated. Management and other control processes as well as energy consumption of buildings, EDP systems etc. are not considered. Other resources than energy are neglected in EVSM but recently a CO2 value stream mapping method was presented by [13] which assesses the environmental impact of both material and energy. This method relies on model reproduction for LCA software though. A disadvantage of VSM is that it only works for one product flow and for a sequence of processes. Further, analysis of other potential states of a value stream map is not possible.

Keskin and Kayakutlu [14] combine energy based value stream maps (EVSM) and Bayesian networks for enhancing energy efficiency in small and medium manufacturing companies. They create a regular value stream map for the process chain of a product from which they subsequently omit “all processes which are unrelated to energy efficiency considerations” [14]. For the remaining processes, lines are added to represent the energy intensity and energy efficiency potential of the processes. This allows the detection of non-value adding energy consumptions in the process chain. Then, a Bayesian network is constructed highlighting the dependencies between different energy-related parameters. This step can be based on expert opinion when quantitative data is missing, as might be the case in SME. Using the Bayesian network, future state energy values stream maps can be created – e.g. by comparing different scenarios resulting from different changes in the non-value adding energy consumptions of certain processes. It is not elaborated how the energy efficiency potential of a process is defined and which parameters are connected to non-value-adding energy usage which serves as decision node in their Bayesian map. It is an interesting idea though to extend traditional EVSM by an efficiency potential and to develop a method for improving energy efficiency in SMEs which can deal without extensive sets of measured data. Management and control processes are neglected.

Seow and Rahimifard [15] present a framework for modeling energy flows within manufacturing systems from a product perspective as in life cycle assessment. Nevertheless, it allows “a breakdown of energy consumption within various processes” [15] using energy data at plant and process level. Seow and Rahimifard differentiate several types of energy such as direct, indirect, minimum and auxiliary energy. Indirect energy consumption is assessed for zones with similar indirect energy needs. Their calculations for assessing the total energy embodied in a unit product or the energy efficiency of processes are based on mathematical models provided for individual process types or on measurement results. A simple example model was implemented and a basic decision support tool created. Allocation methods and management processes are not considered. The product perspective is interesting though as it bridges process flow modeling and LCA.

The “Procedure for Energy and Material Balancing” (PEMB) suggested by Göschel et al. [16] also works with energy and material flows in order to enhance energy and resource efficiency in manufacturing process chains. It consists of four steps. First, the process chain is analyzed and single processes are specified regarding their type, technological parameters, equipment and their material and energy consumption. Then, the process elements, technological parameters and equipment are classified into the categories input, output, mechanism and control, and corresponding subcategories for each process. In order to calculate the input-output balances for the processes and process chain, experimental data or theoretical calculations are needed. For the balance, material and energy requirements are differentiated. Input energy is split into the active energy needed for the execution of a process and the basic energy needed for the standby state of the involved equipment. Output energy is determined for production of the product itself and for its by-products. The balance results are used for evaluating the resource and energy efficiency, e.g. by identifying high-energy consumers or by comparing process efficiencies. Calculations can be performed for different scenarios. The approach focuses on the production layer of an enterprise. Management processes are not included in the method, which is intended as a tool for engineers. If implemented into suitable software, the method could support decision-making for higher resource and energy efficiency. But it only considers the amount of consumed energy or resources, not their environmental or economic impact. Detailed data on machine level is needed in order to perform PEMB, which requires comprehensive measurements or mathematical models.

Despeisse et al. [17] developed a workflow and prototype tool within the THERM project which can be used to model material, energy, water, waste and product flows not only through manufacturing operations but also through buildings and equipment in order to analyze and improve resource efficiency. Their approach includes a tactics library for improving resource efficiency, which was inferred from industrial practices. Tactics are generic rules for enhancing resource efficiency, e.g. “remove unnecessary resource usage” or “align resource input profile with production schedule”. An improvement hierarchy prioritizes the tactics in descending order from prevention, reduction and reuse to...
substitution. The hierarchized tactics library is intended to bridge the gap between existing broad sustainability concepts and specific operational sustainability practices. The workflow comprises the creation of a building model, the integration of a process model into the building model, back-up of the model with process data and operational profiles and finally simulated analysis of resource efficiency and potential improvement opportunities.

5 CONCLUSION AND OUTLOOK
The use case has shown that the associated application of enterprise modeling with energy and resource efficiency analysis generates added values compared to their separated application. For example, the description of energy and resource efficiency relevant content with the relating personnel staff, IT and documentation enable new evaluations and cross analysis, e.g. which staff is related to which energy consume. Moreover, the enterprise management processes can be integrated into the analysis. This requests a higher effort in the beginning of the data collection due to the amount of information and their level detail. But, this drawback can probably be compensated a) by smart supporting instruments assisting the data collection and b) due to the added values caused in additional evaluation capabilities. Nevertheless, a stronger integration of both spheres is recommendable. Based on the requirements a framework for a multi-perspective modeling method and respective support tools will be developed that enables understandable, operational views (“perspectives”) on sustainable value creation.

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7 REFERENCES