15.2 Lean and green framework for energy efficiency improvements in manufacturing

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Abstract
With energy efficiency being one of the major development lines in production planning and control today, recent R&D activities have created a large amount of possible measures for improvements. However, in the daily business situation of existing factories, the implementation of available measures often still is limited to most obvious improvements, commonly known as "low hanging fruits". Further implementations are often neglected due to time, cost or information restrictions. For overcoming this shortage, the Lean and Green Framework introduced in this paper has been developed, providing a standard process of identifying and implementing energy efficiency improvements. The framework provides structured processes for the acquisition of production as well as energetic information on the considered factory, for deriving specific areas where, according to this information, improvements are needed and for the identification of appropriate measures to achieve the identified improvements.

Keywords:
Energy efficient production, sustainable Production, lean Production

1 INTRODUCTION
In recent years, energy efficiency has become more and more important for companies in the manufacturing industry. While the so called "low hanging fruits" are quite easy to find, they are limited in terms of their improvement potential, demanding more sophisticated measures to further foster energy efficiency. Hence, numerous publications, initiatives and research projects introducing new methodologies and guidelines with the aforementioned goal have been presented in recent years (e.g. [1-2]). Improvement measures can be found on all levels (from factory to process level) and within all disciplines (e.g. process and process chain design (e.g. [3]), production planning (e.g. [4-6]), or machine design (e.g. [7])). Hence, for fostering all improvement potentials the factory has to be considered from a holistic perspective, including production, technical building services (TBS) and the building shell, as defined by [8]. Taking also into account the conventional measures for optimizing production systems from e.g. the Toyota Production System (e.g. [9-10]), industrial engineers and managers are facing the challenge of finding and selecting appropriate measures for their respective factory or production system, by estimating the effects of different measures for several criteria. A structured process is required that supports the identification of improvement potentials and adequate measures to achieve the identified benefits. In this paper the Lean and Green framework is introduced as an approach to simplify it for production managers and industrial engineers as well as for system designers and maintenance staff to cope with these challenges. Investigating the correlations between lean and green paradigms within discrete part manufacturing is still a relatively new field of research and hence only few publications have been made so far (e.g. [11-13]).

2 LEAN AND GREEN FRAMEWORK
2.1 Overview
Basically, the developed Lean and Green Framework aims on supporting the process of evolving an existing lean-optimized factory into one optimized for both, lean and green objectives by iteratively applying adequate measures. The effort for applying a specific measure may differ significantly, e.g. replacing a large drive by one with a higher efficiency can be much more cost intensive than changing behavioral patterns of employees, while the latter requires a much higher effort in planning and implementation than the former one. It is evident that implementing measures is not trivial in every case, but can require a remarkable effort for planning and realization. Especially if the person responsible is not an expert on energy efficiency, extensive research for adequate measures is not a suitable option in a daily business environment. For overcoming this shortage, the lean and green framework is designed as a process consisting of the steps for acquiring information on the given situation, identifying need for actions based on the acquired information, and selecting and implementing appropriate measures for improving the initial situation. The whole framework is designed as a process based on continuous iterations, thus allowing consecutive measures to be applied. Additionally, by repeatedly checking improvement potentials, new developed measures for improving the energetic efficiency of a factory or a part of its production are successively integrated into the framework. An overview of the framework is depicted in Figure 1.
As the first step of each iteration, lean and green monitoring is conducted for the existing factory, leading to a detailed energetic assessment of the factory or at least a considered part of it.

For factory planning and improvement, in the following step, the given situation is evaluated in terms of energetic waste for the whole factory or subsidiary parts. Weak points are identified following an approach in which the actual situation in the considered factory is compared with the current state of the art. Areas requiring improvements are identified as Fields of Action (FoA).

Following the identification of FoA, the selection of measures appropriate for achieving improvements in the considered factory is conducted. For this purpose, a standard description format for improvement measures has been defined as the so-called lean and green guideline standard. Resulting from this step, the user of the framework gets a structured list of guidelines which should be implemented in the considered factory.

Besides the planning loop described above, a control loop is implemented in the lean and green framework, responsible for managing the operation phase of a factory (e.g. controlling process parameters of machinery on the shop floor). Factory control secures the operation of the whole production in the state it was defined for via the application of so-called eco-control strategies. To a certain extent, this control loop is based on the same data and information gathered during energy profiling (e.g. the real time energy value stream analysis – see section 2.2), especially concerning continuous data acquisition on production and technical building equipment.

2.2 Lean and Green Monitoring

With the given motivation and background of energy and resource consumption (improvement) in manufacturing companies, the developed method of lean and green monitoring focuses on providing a higher level of energy and resource flow transparency in production environments. The method has been developed based on a set of known methods that have been applied singularly in several case studies in different industry sectors. These methods have now been integrated in a step-by-step procedure which starts from a macroscopic perspective on a given production environment (e.g. a complete factory or a single production line).

Top down approach within the holistic perspective

The top down approach can be understood as the initial step when focussing on an existing brown field site. The approach consists of three steps: prioritisation of energy carriers used in the factory; creation of an energy portfolio to combine already present nominal power data from energy transforming machines and installations, equipment and devices with simplified time studies; micro analysis of single most impacting entities to derive their energetic "consumption" behaviour.

Prioritisation of energy carriers and usage profiles

In order to focus on the most relevant energy forms, a physical (joules), economical (€) and ecological (CO2 eq.) assessment of the energy throughput of external supplied energy carries such as electricity, gas, district heat etc. has to be conducted. A possible data basis for that is represented by billing documents and load profiles on 15 minute time base, available from the energy provider. Therefore no metering jobs are required at this step. Based on that data a first evaluation can be performed which provides a prioritized procedure for follow-up actions.

Energy portfolio

With the most relevant energy carriers at hand, the second step is to identify the most relevant energy transition processes (consumers) of the most relevant energy carriers with the highest identified saving factor (costs or ecological impact). As described by Thiede [4] the energy portfolio analysis can be performed initially by collecting nominal values (connected load) and estimated utilization times only as visualized exemplarily in Figure 2. The collected individual values from all entities transforming the addressed energy carrier are placed in a portfolio with the connected load on the y-axis and the estimated utilisation rate on the x-axis. The mean connected loads and the mean utilization rate form the horizontal and vertical separators for the four quadrants of the energy portfolio. Furthermore, the energy portfolio gives...
involved stakeholders a decision basis for qualifying entities for a continuous energy monitoring due to their leverage factor on energy costs either through runtime (quadrant IV) or power demand (quadrant II) or both (quadrant I).

Figure 2: Energy portfolio analysis (example).

### Micro Analysis of Entities

A detailed analysis of energy transforming entities (consumers) can be very time intensive. Therefore, the before mentioned prioritisation is necessary. The prioritisation is done on a basis of present data or data that is easily accessible e.g. through technical (electrical) specifications or documentations as well as production plans and expert knowledge. The first prioritisation basically defines the relevance of the entity with regard to their energetic impact in the factory (selected system boundary). Entities with a low relevance (quadrant III of the energy portfolio) should be excluded in the first run. The high prioritised entities are now evaluated regarding to their descriptiveness of their energy demand. Highly dynamic interdependent production process are energetically fairly difficult to describe with reference to a specific discrete product flow. Therefore, a continuous energy monitoring is recommended in order to calculate energetic performance indicators such as the specific energy intensity. On the other hand, if results from single energetic measurement series can be reproduced or at least be described in correlation to product and operating parameters, a continuous measurement is not necessary (virtual metering from energetic models).

### From static to dynamic evaluation methods and tools

As part of the best available production system evaluation tools identified in literature studies, e.g. the Energy Value Stream Analysis (EVSA), as introduced by Erlach [14], have been identified to be suitable for the evaluation of existing brown field process chains. When extended by process energy demands from peripheral processes and technical building services as done by Bogdanski et al. [15], the methodology meets the requirements of the holistic perspective.

As depicted in Figure 3 the static extended EVSA method is fed from two realtime (dynamic) data sources. Virtual metering data from mathematical models derived from single measurement and continuous physical data from various energy flow sensors in the field (real production system). With this new dynamic evaluation method based on an industrial hardware solution (metering and monitoring of relevant energy flows in the process chain), an adhoc transparency and live evaluation of conventional, throughput and material flow oriented, production parameters (lean and energetic as well as environmental (green) becomes possible. This developed tool provides a basis for adhoc desicion making and quick evaluation of applied improvement measures from a holistic perspective. The EVSA can thus be used to enhance the machine and factory oriented perspective of the energy portfolio analysis with the cost and process oriented view of value creation.

### 2.3 Identification of Fields of Action

After the acquisition and preparation of energetic consumption data during Lean and Green Monitoring (compare Figure 1), in the following step relevant improvement potentials have to be identified in order to derive, in a third step, relevant FoA. Potentials (or wastes) can be identified by mapping an entity of interest (e.g. an electrical consumer) with different categories (or reasons) of

Figure 3: Concept of the dynamic EVSA supported by the realtime metering and monitoring solution.

Figure 4: Identification of Fields of Action in the Lean and Green Framework.
waste and then comparing the current status quo of the entity with an ideal state. The comparison is conducted individually for each category. Based on these potentials, in the succeeding step, FoA are derived and appropriate measures for severe improvements within a factory are identified and selected for implementation. In a first approach the following categories of wastes were defined from an electrical consumer’s (transforming entity) perspective:

- improper consumer design (i.e. an alternative design for the consumer exists that is fulfilling the same requirements consuming less energy e.g. using pneumatic tools instead of electric ones)
- improper consumer utilization (i.e. the way the consumer is utilized/controlled – manually or automatically – is not ideal in terms of minimum energy consumption, e.g. conveyor belts that are moving permanently and not only when required)
- improper requirements, constraints (i.e. external requirements or constraints that define the design/utilization and thus the consumption of the transformation processes are improperly defined when compared with the actual requirements that are necessary to execute the value adding processes of the value stream)
- inefficient supply of resources (e.g. missing opportunities for heat recovery or leakages in a supply with pressurized air)

Excessive energy consumption can either directly be caused by the transformation processes of the consumer itself or by secondary effects induced by the consumer’s behavior increasing the energy consumption in other parts of the factory (e.g. the excessive use of a ventilation system not only requires the electrical energy for the fan itself but can also cause an excessive operation of the heating system).

The ideal state can for example be derived from current state of the art machines, logical reasoning or from alternative waste concepts like the seven “Lean-Wastes” [9]. It gives a good indication on which areas to focus on when trying to minimize energetic consumption. For example, the ideal state in terms of lighting-control is achieved when lighting intensity is always adjusted immediately to the lighting requirements given at each area of a building. Potentials are described relatively in comparison with the ideal state and thus an absolute saving potential (e.g. in kWh/year) can be estimated by multiplying the distinct relative numbers with the overall yearly energy consumption derived from the portfolio analysis. Furthermore, by using relative numbers, the identification of potentials and the Lean and Green Monitoring, can be executed independently from each other.

Using normalized values as the basis for comparison (e.g. percentage of achievement of the ideal factory’s score), a ranking of the different waste types is achieved. Including a threshold, defined in relation to the ideal score values, waste types showing a high deviation from the ideal values are used to identify fields of action. The whole sub process for deriving fields of action is depicted in Figure 4. Further examples for the categories of waste are listed in section 3.2.

2.4 Lean and Green Guidelines

Measures as Guidelines

Within the Lean and Green Framework, each relevant measure is described as a guideline, concentrating the core knowledge on how to implement the measure in general, thus naming the objective, implementation steps as well as main influences of a measure in a standardized way. Further, also the main information for a proper identification of a guideline in a particular case is to be provided per measure in a standardized way, e.g. by listing the particular performance indicators improved by the specific measure, or the factory level targeted by the measure. An overview of the guideline structure is given in Figure 5.

Guideline Selection Process

For the selection of appropriate measures for dedicated improvements of a factory in relevant fields of action, a process for stepwise narrowing down applicable guidelines is...
introduced (Figure 6). In the first step, guidelines matching the identified Fields of Action are filtered from all available guidelines. All the guidelines are selected whose target areas address the required fields of action/energetic wastes / KPIs. The result is a collection of all guidelines that could generally improve the identified fields of action. However, at this point, no consideration has been given to how well a guideline fits the given situation, e.g. in terms of improvement potential, but also in terms of applicability.

Thus, in a second step, all pre-filtered guidelines are evaluated according to criteria which influence the applicability as well as the expected outcome, separately for each criterion. Examples for these criteria are the effort for application (e.g. time or budget), KPI-improvement-potential, or the level of maturity of the guideline. The evaluation is conducted by the user of the overall framework, using the facts from the guideline sheet as a basis for his estimation. Additional information may have to be acquired during the evaluation (this might happen on different levels/with different effort, e.g. additional information might be sourced on a website or from a supplier).

After the elementary evaluation of each guideline, the results have to be transformed into one overall score for each guideline, representing the applicability and building the criteria for the later selection of the guideline. At this point, the framework user will define preferences which influence the calculation of the overall score, allowing the user to foster different strategies, e.g. a more ecological or more economical strategy. Thus, the user preferences are acquired as a pair wise weighting of the different criteria the guidelines have been evaluated in. A final score indicating the applicability as well as improvement potential for each guideline in the particular case is calculated, allowing a ranking of the guidelines. Thus, the most appropriate guideline to be applied can be selected easily. At this point it is possible to take into account multiple rankings, e.g. for comparing a strategy focusing on economical with one focusing on ecological performance.

After the selection of one or several guidelines, in the following step the application of the measures described in the guideline has to be performed. From the perspective of the overall lean and green framework, this step is represented as one process step. Thus, the framework process restarts after the implementation with the next iteration.

3 USE CASE

3.1 Pilot Description

The lean and green framework has been tested in a pilot application in an existing factory of the Siemens AG. The focus for application was laid on one building within the factory that is considered a bottleneck for the overall value stream of the plant as well as a hot spot in terms of energetic consumption. Various production processes take place (e.g. welding, milling, grinding and inspection) in a job shop like arrangement in manual as well as in fully automatic form. Due to the high weight of the products and the dense arrangement of workstations material transport is challenging and time consuming. Due to the different production processes different requirements in terms of technical building services (TBS) exist (e.g. ventilation of air, lighting, heating, pressurized air) that vary throughout the day. Hence, a systemic and scientific approach for fostering all energy saving opportunities as well as taking possible trade-offs with traditional production targets into account is required.

3.2 Application of Framework

Following the respective steps of the overall lean and green framework, as depicted in Figure 1, the Lean and Green monitoring was performed for the aforementioned building and its processes. The main energy carriers identified are electricity, pressurized air and district heating. An initial energy portfolio analysis based on nominal data and operation times was performed. Focusing on the transforming processes in quadrant 1 of the energy portfolio (critical entities) three consumers were selected for a detailed analysis: lighting- and ventilation system and the milling machine with nominal loads ranging from 30 to 160 kW. Detailed load measurements were performed on these three entities. In order to derive improvement potentials/wastes from the overall energy consumption of the selected entities, the waste approach, described in Section 2.3, was applied, taking into account further organizational information, requirements and building data. Exemplarily the further application of the framework is shown for the lighting system.

![Figure 7: Improvement potentials for lighting system](image)

The improvement potentials for the lighting system within the different categories of waste are shown in Figure 7. Based on the evaluation of potentials several measures for minimizing the energy consumption of lighting systems were proposed:

- automatic control techniques based on sensor systems like motion sensors, brightness sensors, time switches (FoA: TBS-Control)
- improving manual control of the lighting system by employee awareness, incentive systems, feedback signals, (FoA: Employee, Training)
- minimization of space requirements by an optimized building layout that allocates production processes with the same lighting requirements in the same areas (FoA: Layout Planning)
- minimization of time requirements for example by an optimized production schedule with the main objective to avoid additional working shifts. Other systemic methods like TQM, TPM that minimize rework and non-productive-time, may have the same effect. (FoA: Production Scheduling, Production Planning)
- replacement of the current fluorescent tubes (T8 with conventional ballast) with modern systems like electronic ballasts with T5 configuration or LED tubes (TBS-Design)
The proposed measures were evaluated among different categories indicating the applicability and effectiveness of each measure. Evaluation within the different criteria was based on expert interviews and simple models. A one-dimensional ranking of the measures can be achieved by weighting the different criteria using multi-criteria decision analysis like Analytic Hierarchy Process, Analytic Network Process or a simple value analysis. The results of the evaluations are depicted in Figure 8 indicating that several of the proposed measures might be applicable depending on strategic preferences of production management.

Figure 8: Evaluation of improvement measures for minimizing lighting consumption (scale of 0-6 with 6 being the best)

4 CONCLUSION & OUTLOOK

Increasing the energy efficiency of manufacturing companies has been identified as one of the major goals for today’s industrial environment. A large and still growing amount of possible measures for achieving this goal has become available from research and development. However, a wide implementation of such measures is often hindered by difficulties in identifying appropriate measures for specific situations, or by sometimes conflictive goals in comparison with conventional, economically driven objectives. For overcoming this shortage, responsible functions in factories – like production planners, equipment designers or maintenance units – need methodological support, providing guidance in identifying and selecting appropriate measures even if the person responsible is not an expert in energy efficiency.

In this paper a generic framework has been introduced that supports this identification of energy efficiency potentials and the selection of appropriate measures in the context of discrete manufacturing environments. Future research will concentrate on a stronger implementation of the lean aspects within the selection processes as well as concretizing and formalizing the single steps within the framework, so that less effort for application is required. Furthermore, the generic categories of waste will be specified based on the respective objects of interest allowing a more precise and quicker derivation of adequate measures in a specific case.

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6 REFERENCES


[13] Dües, C.M., Tan, K.H., Lim, M., 2011, Green as the new Lean: how to use Lean practices as a catalyst to greening your supply chain., In Journal of Cleaner Production 40, pp. 93–100.
