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Availability-based payback method for Energy Efficiency Measures

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Abstract

Energy-efficient technologies can lead to high energy and monetary savings in numerous industries. However, a lot of potential identified in industries remains untapped due to comparatively short requested payback periods. Usually, companies base the calculation of their payback period on initial investment costs in conjunction with annual monetary energy savings. Energy efficiency measures, however, often lead to synergy effects which are not taken into account. Against this background, we illustrate that taking machine availability into account can shorten the payback period of energy efficiency measures considerably. Furthermore, we demonstrate a methodology to standardize this availability-based payback calculation.

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Keywords: energy efficiency; availability; payback period calculation;

1. Introduction

To participate in the marketplace and to be competitive in the future, the energy efficient production of goods and services will turn into a major success factor for manufacturing enterprises to reduce their energy costs. This situation is reflected in the average energy costs and trends. For example, electricity prices in industry increased between 2000 and 2013 by an average of 140% to a historic maximum of 10.6 Euro cents/kWh. However, prices in the vast majority of the EU are lower: Sweden (5.5 cent/kWh), France (6.6 cent/kWh), Spain (6.9 cent/kWh) are only some of the overall 25 countries in the EU where energy prices are lower than those in Germany.[1] Accordingly, German industry is under a high competitive pressure.

Besides the positive economic impact on industry, energy efficiency also induces environmental benefits. With a share of more than 40% of total electricity consumption German industry has a great impact on the national carbon footprint of Germany.[2] In addition to the climate goals within the EU, Germany also intends to reduce its primary energy consumption by 20% by the year 2020 compared to 2008. In View of the past development, national saving objectives will be jeopardized if no actions are taken with to intensify energy efficiency in the industry sector: industrial energy consumption has increased by 0.1% p.a. since 1992. At the same time industrial energy productivity increased by an annual average of 1.7% between 1995 and 2008. [4] In view of this development, an increase in energy productivity of 3 to 3.7 GDP/kWh is required for the remaining period until 2020 [5,6]. If current developments proceed, the current diffusion of energy efficiency is not sufficient to achieve national goals. [7]

1.1. Energy efficiency potentials in German industries

Although German Industries have already achieved significant energy savings through efficiency measures of more than 500 PJ in the past, big savings are still possible. [8] Figure 1 summarizes both electrical and thermal energy saving potential in German industries. The potential electrical savings consist of individual savings enabled by common cross-sectional technologies, which have a share of 87% of the overall electrical saving potential. [9] Thermal energy

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savings are mainly induced by branch- and process-specific technologies and are summarized from individual saving potentials of energy-intensive industries. These aggregated savings-categories are compared to the governmental saving objectives of the industry by 2020.

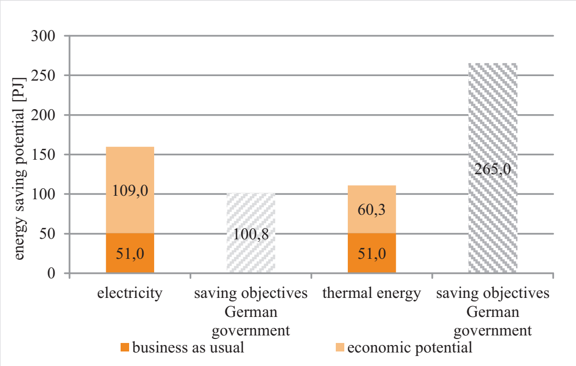

Fig. 1: Energy saving potential of German industry [10]

The specific savings are classified according to their level of implementation: the business-as-usual scenario is based on the current diffusion of technologies and efforts and has a value of 51 PJ by 2020, considering electrical and thermal saving potentials. However, the overall saving potential which can be economically tapped is much bigger and will be referred to as the "economic potential". The economic potential of electrical energy has a value of 160 PJ by the year 2020. Thus current efforts need to be tripled to tap the full economical electricity potential. To meet energy saving objectives (100 PJ) current efforts in the areas of energy efficiency still need to be doubled. The economically viable thermal potential has a value of 111 PJ. Based on this, current efforts must be doubled to achieve the energy saving goals in the area of thermal energy. [10] However, these economical potentials might induce high monetary savings. An incremental investment of roughly 5 billion euros would return nearly four times as much – 20 billion euros by 2020 based on 2009. The longer the observation period, the more saving effects are revealed through reduced energy costs. By 2030, incremental savings of 67 billion euros can be tapped by an investment of merely 8 billion Euros. [9] Roland Berger anticipates that investments of 24 billion euros may indicate a return of 100 billion euros by 2050 [11]. In summary, it can be concluded that huge economical saving potentials exist for the German industry with high profitability.

1.2. Common obstacles

Despite the high quantified monetary saving effects, a major part of existing economic energy saving potential remains unexploited. A variety of factors can be given, why the efficiency potential has not been realized. Apart from well-known non-monetary reasons, such as lack of transparency, corporate-culture and organizational framework conditions, two reasons are considered to be the main cause of unused efficiency measures: lack of knowledge about the existing potentials and insufficient financial resources. [12] But even if companies have sufficient financial capital, strict assessment standards cut investment opportunities. This is reflected in recent surveys on primary criteria guiding any investment decision: 80% of companies surveyed based their investment decisions only on the payback-period of the planned measures. [9] Furthermore, the generally accepted period shall typically not exceed 3 years. Depending on the technology, field of application and branch the acceptance-range may vary. [12]

Due to the required short payback periods many highly profitable efficiency projects are not exploited or will not be realized. This results from the gap between the investment costs and the lifecycle costs. Most energy efficiency measures have a significantly longer technical lifetime referring to the payback-period and thus generate a high profitability across their entire lifecycle. At the same time companies mostly base the calculation of payback period on initial investment costs in conjunction with annual monetary savings which are generated by increased efficiency. Against this background, investment costs do have a significantly higher influence on investment decisions. As a result, efficiency measures with lower investment costs are given preference over measures with lower lifecycle costs (and higher investment costs). Furthermore, energy efficiency measures often lead to synergies which are not taken into account. The cause for this is a result of the first category of obstacles: missing information and lack of transparency.

By raising the relevance of synergies derived from energy efficiency measures, such as increased machine availability, specific payback periods can be considerably shortened. As a result, previously unused measures pay back much quicker and will therefore be considered for implementation by enterprises. The influence of the applied evaluation method on the degree of realization of energy efficiency measures is summarized in the following figure.

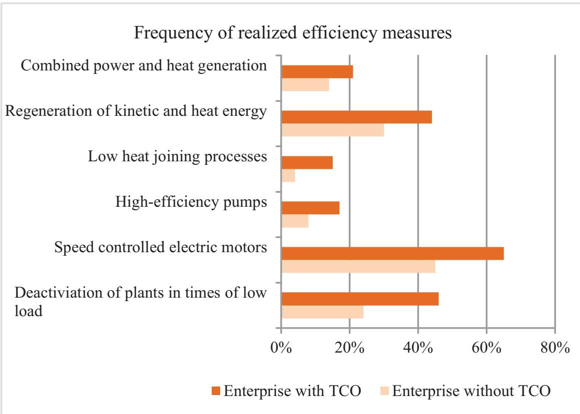

Fig. 2: Degree of energy efficiency realization [3]

Beyond all technologies, the figure shows that energy-efficient measures are more frequently realized by enterprises using a total-cost-of-ownership approach than without the use of a comparable evaluation method. In summary, it must be emphasized that there is a huge untapped economical potential in the German industry. This can partly be accomplished through an approach which recalculates the payback period by taking account of life-cycle based information.

2. Availability-based payback-period method for energy efficiency measures

Based on the specified disadvantages of common payback-period calculations, which are only based on initial investment costs in conjunction with annual monetary savings, a new approach to calculate the payback-period of efficiency measures has been developed. The general calculation of the payback period is shown in the following formula (1):

$$\text{payback period} = \text{t} = \frac{\text{initial invest cost}}{\text{revenue} - \text{energy cost}} \quad (1)$$

According to the commonly used calculation of an energy efficient measure, profit (denominator) is influenced by the reduced energy costs. The availability-based payback period method takes into account that the availability of a process, process chain, plant or single technology can be considerably increased by replacing the old machines with new energy-efficient alternatives with a lower failure rate. This also leads to reduced maintenance costs. Therefore the new approach adds the maintenance costs and the monetary benefits of increased availability to the common payback-period calculation. The following formula shows the extended approach:

$$\text{t} = \frac{\text{initial invest costs}}{\text{revenue} - (\text{ energy cost} + \text{maintenance cost})} \quad (2)$$

Below, the technology currently being used will be referred to as machine I, while the alternative energy-efficient machine is referred to as machine II. The maintenance costs can be included into the calculation both as planned and unplanned maintenance. The necessary method to quantify these maintenance values is explained below.

2.1. Planned and unplanned Maintenance

Planned or scheduled maintenance (technical availability) is mainly determined by maintenance time and thus incorporated into total effective equipment performance (TEEP). A higher TEEP is caused by efficient equipment utilization and increased plant profit. Therefore quantification is achieved by multiplying the profit of the considered machine by the total effective equipment performance (TEEP) ratio of the comparative plants as formula (3) shows.

$$\text{profit plant II} = \frac{\text{TEEP plant II}}{\text{TEEP plant I}} \times \text{profit plant I} \quad (3)$$

TEEP itself is calculated as a product of plant utilization and overall equipment effectiveness (OEE), which is a product of plant availability, plant efficiency, and quality rate. Formula (4) and (5) show the interrelationship between TEEP and OEE.

$$\text{TEEP} = \text{plant utilization} \times \text{OEE} \quad (4)$$

$$\text{OEE} = \text{availablity} \times \text{performance} \times \text{quality rate} \quad (5)$$

Within the OEE calculation, availability usually consists of inherent availability and operational availability. The graphic below shows how inherent, technical and operational availability interdepend. [15]

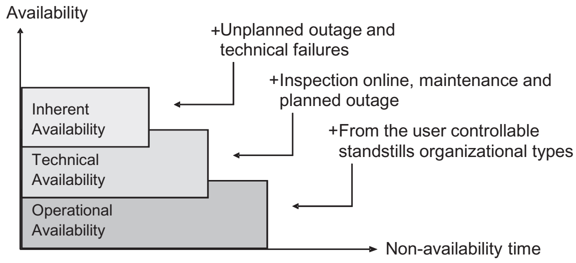

Fig. 3: The availability types based on VDI-Richtlinie 4004 Blatt 4[15]

Inherent availability (Ai) represents the product specific availability and is a function of reliability, also called mean time between failures (mtbf), and mean time to repair (mttr) [13]. Technical availability (At) differs from inherent availability because it includes not only the downtime for unscheduled maintenance (repair due to failures) but also for scheduled maintenance and logistics (mean time to maintain) [13].

$$\text{availability} = \frac{\text{mtbf}}{\text{mtbf} + \text{mttr} + \text{mttm}} \times 100\% \quad (6)$$

The parameter mtbf can be calculated by dividing production time by the number of failures. It is also the reciprocal of the failure rate. In the developed method the failure rate λ can be distinguished into constant pattern of failure, premature failure (infant mortality), fatigue failure (age-related) and a combination of the prior failures, called bathtub curve of failure rate. The development of particular failures can be seen in Figure 4 [14].

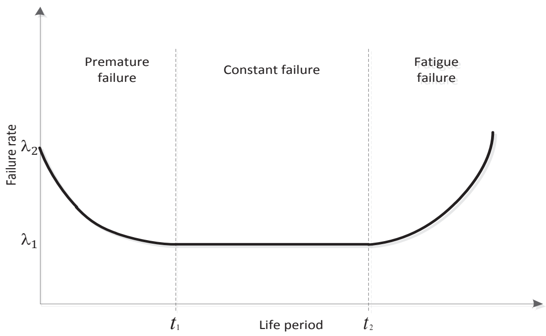

Fig. 4: Effect of the dynamic failure rate

The graphical representation of the possible failure curve developments shows the failure rate on the y-axis as a function of time. Thus, a constant failure has a constant value over lifetime. A premature failure has a high risk of failure in the very beginning of its lifetime. Its risk decreases over time and remains constant. A fatigue failure (age-related) behaves contrary to this with a high risk of failure at the end of its lifetime. The combination of both, premature and fatigue failure determines the bathtub curve.

However, the failure category depends on the particular technology that is examined. The corresponding outage costs are calculated by the product of the inherent non-availability (Ai) and the sum of the costs for installation, the removal of defective parts, the costs of the replacement parts, the costs of downtime and the inventory costs. These costs can be reduced by replacing the existing machine by a new machine with a higher energy efficiency level. This connection is shown in figure 5. According to the fatigue failure behavior, the failure rate λ_2 of machine I is higher during the periods t_1 and t_2, due to a number amount of working hours in the past. This contrasts with machine II, where the number of working hours between t_1 and t_2 is the same but without working hours before t_1. Therefore, the number of total working hours for machine II is lower during the whole life period, leading to a lower particular failure rate λ_1 and maintenance costs in the considered period of time.

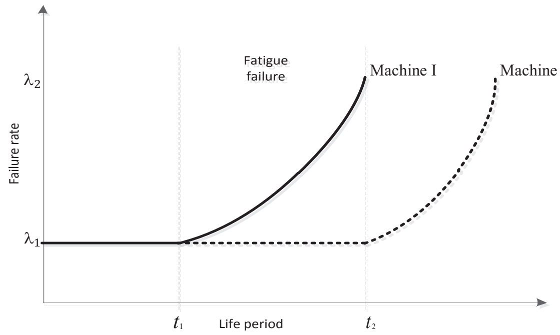

Fig. 5: Theoretical failure rate behaviour

In order to quantify how the consideration of machine availability affects the payback period calculation of energy efficiency measures, the following validation example is presented.

2.2. Validation example

Based on the previous explanations, an example will quantify the influence of availability on the payback period of efficiency measures. In this example it is assumed that the swivel angle and fixed displacement pumps of a 20 year old injection molding machine will be replaced by new asynchronous servo motors and new hydraulic pumps. This measure lowers energy consumption by 50%. Compared to the age-related wear on machine I, the components of machine II enable reduced maintenance times and a lower failure rate. It is assumed that both, machine I and machine II have the same number of working hours over the specified period. For a better understanding, the original example has been condensed to provide an initial impression of what impact the approach has on the investment decision data.*

* In the original calculation tool every variable is based on a specific calculation based on particular data

Based on these assumptions the following rates for OEE and TEEP have been calculated.

Table 1: Availability machine I and machine II.

	Machine I	Machine II
OEE	79.17%	80.53%
TEEP	71.72%	74.84%

The table shows clearly that the energy efficient machine benefits from its lower failure rate which manifests itself in the higher value of OEE and TEEP. Moreover this leads to both lower planned and unplanned maintenance costs. The following figure illustrates the development of the failure rates of machine I and machine II for a particular time period.

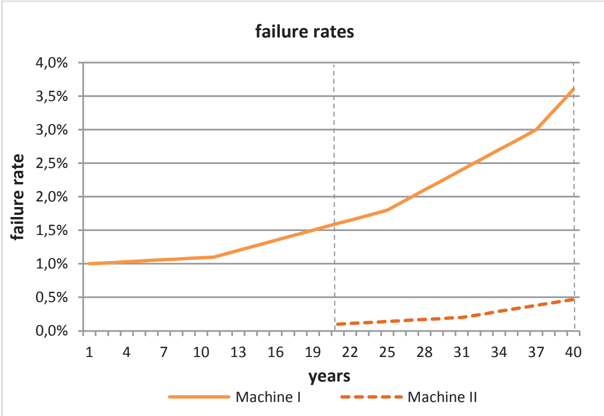

Fig. 6: Comparison of calculated failure rates over time

Due to the reduced failure rate and reduced maintenance costs of machine II, the net present value is higher and therefore the payback period is reduced by one year. Without considering the reduced maintenance costs machine II would amortize itself after roughly 4 years. Taking account of those costs reduces the payback period to 3 years as shown in the following figure.

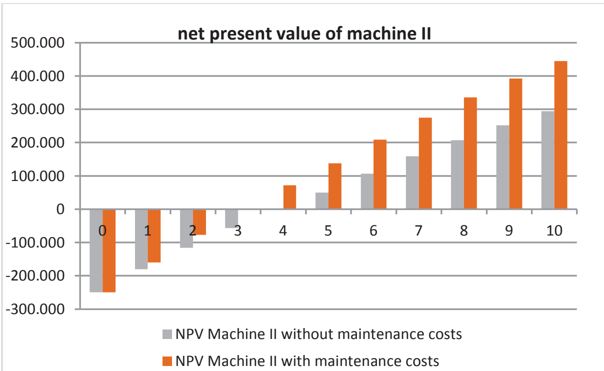

Fig. 7: Extract from net present value of machine II

In sum, these synergies have a significant impact on the profitability of the particular plant which also leads to a shorter payback-period. Without considering the maintenance in the calculation, the payback period of machine II has a value of roughly 4.1 years. By taking account of the reduced maintenance costs and increased availability in the payback-period calculation, the value was reduced to 3.0 years. The reason lies primarily in the fact that the maintenance costs influence the total costs over the machine lifetime. These effects are always present but are usually not considered and quantified in the payback period calculation. As a result, a payback period calculation that is only based on the reduced energy costs leads to a payback period that is longer as it actually is. Therefore, this calculation method discriminates energy efficiency measures.

3. Conclusions

Energy efficiency is a key technology to achieve both reducing national greenhouse gas emissions and global competitiveness of the German industry. However, an essential part of the existing saving potential is not exploited due to reservations regarding long payback periods. Also, when it comes to the decision whether to replace an existing technology by an energy-efficient technology or not, it is common practice for companies to base the calculation of the payback period only on initial investment costs in conjunction with annual monetary energy savings. Therefore, a high share of energy saving potential remains untapped.

However, implementing energy efficient measures within an enterprise may lead to synergies such as an increased availability and reduced maintenance costs, enabling enterprises to directly benefit from those effects. Considering those synergy effects will considerably shorten the calculated payback period of those measures.

In the presented example the payback period was shortened by one year. Therefore, this method proves that energy efficiency measures pay back much quicker as decision makers usually anticipate. In addition, using this new method will increase the diffusion and implementation rate of energy efficient measures due to the shortened payback-period. This will allow enterprises to realize additional measures with a high profitability with respect to their required payback period. The connection between payback period and profitability within the entire lifecycle of an energy efficiency measure is shown in figure 8.

Pay-back period	Internal interest rates / Plant lifetime							
	3	4	5	6	7	10	12	15
2	24%	35%	41%	45%	47%	49%	49%	50%
3	0%	13%	20%	25%	27%	31%	32%	33%
4		0%	8%	13%	17%	22%	23%	24%
5			0%	6%	10%	16%	17%	19%
6				0%	4%	11%	13%	15%
8					0%	5%	7%	9%
			Not-realized measures					

Fig. 8: Interest rates and payback periods [10]

In this example, an investment with a payback period of 2 years and an overall lifetime of 3 years generates an internal interest rate of 24%. Additionally a lifetime of 4 years will generate an interest higher rate of 35%. Assuming that no investments are made within a payback period that exceeds 3 years, internal interest rates between 24% and 13% depending on the plant lifetime can be additionally realized.

However, it is decisive for the success of this method that decision makers get all necessary information about the specific costs and revenues over the entire plant life cycle. Only an accurate allocation of costs enables an exact calculation.

Nevertheless, recent studies assume that European energy consumption cannot be expected to be significantly lowered in the future: The international agency shows that the final energy demand of EU is rising until 2035. Both in the CPS and NPS the main objective, reduction of energy consumption by 20% by 2020, will not be met. † Based on the new policies scenario the reduction will only be 14% by 2020. Only in the so called 450 Scenario, which assumes that the atmospheric CO_2-emission concentration is limited to 450 ppm, slightly decrease final energy consumption will be more or less achieved. [16]

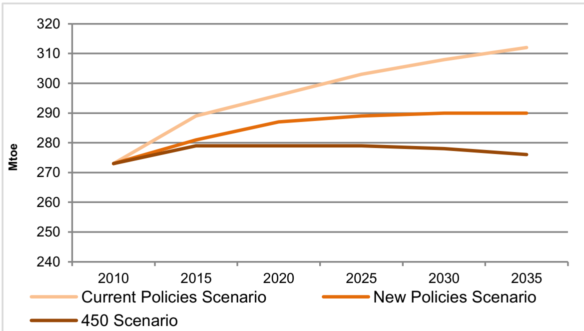

Fig. 9: Final energy consumption in the European industry by 2035[16]

However, all scenarios are based on the full development of the existing efficiency potential. If the potential develops only partially, the total energy consumption would be even higher. Therefore, the presented evaluation method could be an important instrument to ensure ecological and economic objectives. Without incentives and the promotion of energy-efficient technologies, cost-effective energy efficiency measures will remain unexploited and environmental objectives will be missed.

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† Based on the assumption that both current policies and development are retained (current policies scenario - CPS) and already planned and new measures are enabled (new policies scenario – NPS) the final energy consumption increases

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