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A Framework for Self-Evaluation and Increase of Resource-Efficient Production through Digitalization

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Abstract

Modern sensor technology and decreasing hardware costs enable the collection of a wide range of data. Nonetheless, the collection of data itself does not generate value. The collected data must be processed and analysed. Many small and medium-sized enterprises already collect a number of data. However, there is no definite strategy, which data needs to be collected in order to acquire relevant insights into processes.
The enormous potential of data analysis and the current lack of its implementation caused the development of this framework. It will assist enterprises to evaluate their own level of digitalization to assess resource use.

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Keywords: Digital Transformation; Industrie 4.0; Resource Efficiency; Data Analysis

1. Introduction

The resource consumption of humanity has increased with its growing population since the beginning of human life on earth. However, in the last century, with the beginning of the industrialization, the consumption of resources has accelerated. Especially in the last decade, the demand for material resources is increasing at a rapid rate. This development is due to the rapidly growing population on earth and the linkage between economic development and resource use. Large emerging economies (e.g. China and India) are industrialized with annual GDP growth of up to 15% [1]. With economic growth, income, and wealth resource consumption increases as well [2,3,4].

In industrialized countries, the main part of overall resources is used in industry processes and services (e.g. primary energy consumption in Germany [5]). Therefore, resource efficiency in industry is an important factor to reduce worldwide resource consumption. However, companies usually see several impediments for resource efficiency: e.g. costs, process stability, amortization times and unclear chances of success [6]. Furthermore, the evaluation of resource efficiency measures on the basis of company resource data is a problem especially for small and medium-sized enterprises (SME) [7]. It is necessary to generate data before and after implementation of measures to show its success.

Data acquisition and analysis is a central issue of digitalization. Enormous potential is attributed to it. Data is even called the new oil of our century [8]. Its amount in companies is increasing due to decreasing sensor costs and more automation [9,10]. As presented in [11] a lot of data is already collected in SME, but data analysis is often neglected. Additionally, it is concluded in the study that data acquisition is not concluded in a structured way. There is no systematic approach and no clear strategy to show which data is relevant to achieve a certain goal.

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Therefore, a framework for self-evaluation and increase of resource-efficient production through digitalization is presented in this paper. It focuses on the data acquisition for different natural resources as considered by the European Union [12] (e.g. raw materials, environmental media like air, water, etc.) and operational resources (e.g. energy, operating materials) and shows potentials in further steps of digitalization. The framework is based on the Guideline “Industrie 4.0” [13]. It is not only an evaluation tool, but in addition a planning tool to support resource efficiency efforts in companies with a strategic approach. It was developed for and with producing companies and therefore optimized during utilization.

2. Generalized Framework

As part of the study “Resource Efficiency through the Digital Transformation of Industry in SME” [7] a framework was developed, which identifies the possibilities of condition monitoring according to the different digitalization stages and to different operational resources - and in this context to natural resources. The resulting operational information shall be used by enterprises as a strategic instrument for the identification of operational resource savings and target controlling.

In the framework, different application levels are plotted in rows over the development stages (1 to 6) progressing from left to right. The stages show how the state of the digitalization in the company is pronounced. Thus, stage 6 corresponds to a very high digitalization grade. In contrast, six different operational resources, attributed to natural resources, are applied over six resource levels in the presented framework.

The derivation of natural resources is based on the definition of the European Union's thematic strategy on natural resources. The EU considers natural resources as “[…] raw materials such as minerals, biomass and biological resources; environmental media such as air, water and soil; flow resources such as wind, geothermal, tidal and solar energy; and space (land area) […] or as sinks that absorb emissions (soil, air and water) […]” [12]. Regarding industrial enterprises, the use of natural resources is too abstract for practice. Therefore, operating resources in the industry have been identified and attributed to natural resources. The relevant operating resources identified in [7] are: electrical energy, heat, raw materials, operational materials, specific air pollutants and disposal of waste. The association between natural resources and operating resources is shown in Table 1.

Table 1. Association between operating resources and natural resources

Operating resources	Natural resources [12]
Electrical energy and heat	Raw materials and flow resources
Raw materials	Raw materials
Operating materials	Raw materials, environmental media (water)
Specific air pollutants	Sinks (ecosystem services)
Disposal of waste	Sinks (ecosystem services)

The six different stages of digitalization extend from left to right, from a non-existent data acquisition for resource use, through an acquisition with higher resolution, to fully automatic systems that capture, analyse and are able to implement independently derived measures. The individual stages as shown in figure 1 are explained as follows and are applied to each of the six considered resources in the next chapter.

At **stage 1**, no or only disordered or irregular data is recorded for the respective resource. Even without the use of modern sensors, data about the use of operating resources is collected, e.g. from purchasing orders or invoices from energy suppliers. However, these remain in their respective organizational units and are not used for a holistic view of resource efficiency.

Enterprises at **stage 2** regularly and structurally record the relevant reference values on a company level. An awareness of the use of resources is created. The data can be extracted from the existing data sets or collected manually. A first use of sensor systems for automated data acquisition is also conceivable, but it is immediately accompanied by high demands on the existing IT infrastructure of the company. From the collected data, temporal courses can be created, seasonal fluctuations can be identified and first measures can be derived.

In **stage 3**, the resolution is increased by recording the resource data on the machine level. Automated data collection and vertical data integration is essential at this stage. The granularity of the data is increased. Specific measures for individual machines or production areas can be derived. The resulting knowledge about resource use can also be integrated into the work preparation.

The first three stages describe the way from a non-existent acquisition of resource data to a growing awareness of resource use by recording the relevant data as well as a subsequent increase in both the frequency and the reference points. This measure creates a growing transparency of processes in the company with regard to resource efficiency and forms the basis for further digitalization steps.

In **stage 4**, the acquired resource data is linked with likewise recorded operating data (machine or process data). An intensive analysis of the linked data leads to new insights about the correlation between production and resource use and allows the derivation of further measures to increase resource efficiency.

With the help of statistical methods or machine learning, patterns and regularities are identified in the processes in **stage 5**. Algorithms learn from continuously acquired data and are able to make predictions about future events. The artificial system can thus react to unknown data and independently derive measures to increase resource efficiency. As last step in this stage, the measures are proposed to the employees for implementation.

The highest **stage 6** of digitalization are autonomous systems, which independently implement the machine-derived measures. For this purpose, the networking of sensors, artificial intelligence and actuators are required. The use of autonomous systems results in numerous new opportunities, which cannot yet be estimated based on today's knowledge.

The underlying technologies of stages 1 to 4 are generally state of the art, but have not been implemented in a comprehensive manner yet. However, the technologies of steps 5 and 6 are objects of current research projects, which still have little or no application in industrial practice - especially in SMEs. The steps were nevertheless included to take account of the vision of a complete digitalization.

3. Detailed Framework

The six development stages were applied to the six regarded natural resources. The result can be seen in Figures 1, 2, and 3. The process of repetition as well as the recital of every stage for every resource were deliberate despite obvious similarities. It is essential that users address each resource individually. The individual resource levels are successively discussed hereafter.

3.1 Energy

The description of the six development stages takes place jointly for electrical energy and heat. For the sake of better legibility, both will be referred to simply as energy.

In the **first development stage** energy meters are read by utility companies at predetermined times and energy consumption is invoiced accordingly. The data concerning the consumed energy in a given billing period are on hand in the form of invoices. The invoices can be used to draw comparisons between billing cycles and to create simple trend analyses. Characteristic for this stage is that the temporal resolution is set by external factors.

In the **second development stage**, the company meters its own energy consumption in predetermined intervals. The intervals can be defined autonomously and the data can be explicitly recorded at the appropriate location. This allows for the creation of annual energy consumption graphs. Depending on the chosen interval, seasonal, monthly or weakly differences in consumption can be analysed and scrutinized.

The **third development stage** requires the use of additional energy meters on the plant, process or machine tier. Hereby, the locational resolution is increased. In this stage, it is expedient to automate the collection, processing and analysis of the sensor data depending on the number of deployed meters and the determined read interval. Based on the analyses, processes with high-energy consumption or individual heat sources and sinks can be identified and fluctuations in energy intake or absorbed and dispensed thermal energy can be detected and localized. Additionally, by means of the newly acquired information further prioritization of examinations of energy efficiency potential can take place.

In the **fourth development stage** a connection between the collected energy data and the respective operational data on the process or machine tier takes place. Correlations and causalities are highlighted. The identification of high-energy process steps becomes possible. Countermeasures, such as machine-internal as well as overall power peak reduction, can be accurately employed. Furthermore, energy usage can be classified as value-adding or non-value-adding on a process level and further extensive optimization potentials can be uncovered.

The above-described procedures are automated through the introduction of intelligent systems in the **fifth development stage**. The System calculates optimization potentials independently and forwards them to an employee at the appropriate level. Further measures are holistic optimization approaches through the inclusion of building, production, machines, building services etc.

The **sixth development stage** entails enabling and allowing the system to implement the derived measures autonomously.

3.2 Materials

As with electrical energy and heat, raw materials and operating materials are discussed jointly. They will be referred to as raw material. The separate listing in two levels of the framework is, however, essential, since raw materials and operating materials should be considered separately in the

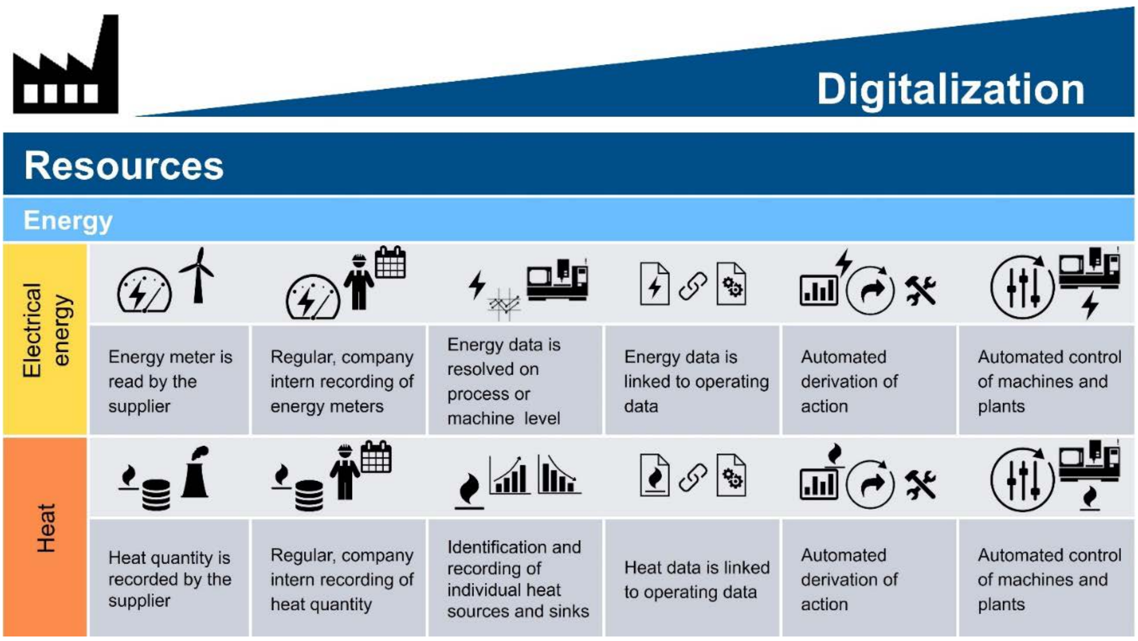

Figure 1: Framework Part 1 of 3 – Energy Resources

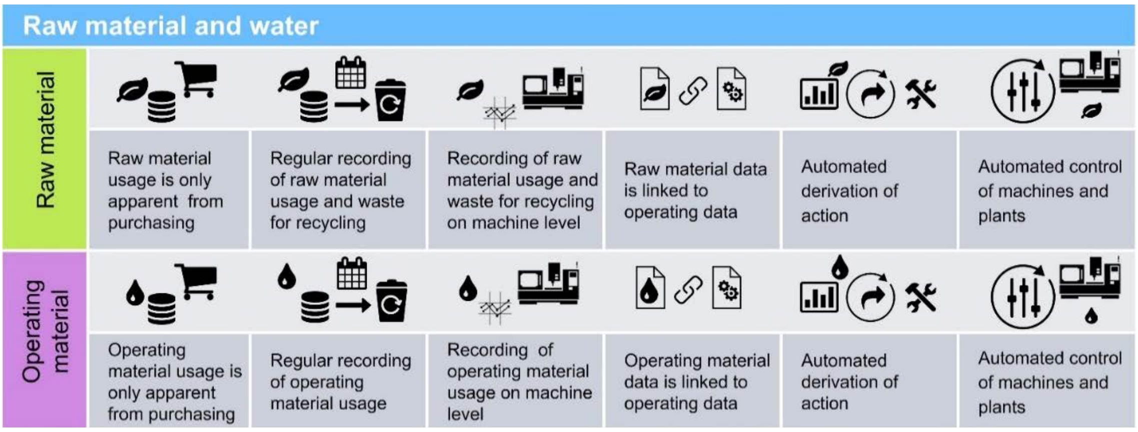

Figure 2: Framework Part 2 of 3 – Material Resources

production context. Operating materials are not incorporated into the product and are thus often times neglected in resource efficiency considerations. Also considered in this section is waste for recycling. Recycling can be carried out internally, which results in a return to the cycle as a raw material, or through the disposal of the waste, leaving the company's system boundary. Contrary to waste for recycling, waste for disposal is described in a separate level under ecosystem services.

In the **first development stage**, raw material data are not collected in a targeted manner. The quantities used are only shown in purchasing and must be manually extracted from the organizational unit of the company for a resource efficiency observation. Once this has been done, trends of raw material input can be visualized and possible fluctuations assessed. However, the set of data points is dependent on the frequency of the order of the respective raw material.

The **second development stage** is a regular observation of the use of raw materials at the company level. As with the previously described resources, an intentional periodic collection of resource usage data allows to set the query frequency, whether it is daily, weekly, or monthly, thus increasing data quality and meaningfulness. In addition, awareness about the use of resources is created, as well as the creation of reference states as a basis for efficiency enhancement considerations.

In the **third development stage**, the data on materials used and waste for recycling are broken down on a machine level, hence increasing the locational resolution. Automation of the data acquisition as well as processing in a central location also allow an increase in the temporal resolution. Production processes, machines or plants can be classified according to the use of raw materials and prioritized with regard to the investigation of potential savings. Through continuous analysis and visualization, changes can also be detected during operation. Particularly in the case of operating materials, increased use can indicate leakages or similar disturbances.

A link between the raw material data and the operating data is the **fourth development stage**. This allows the determination and evaluation of specific savings potentials. Raw material consumption and waste generated for recycling can be directly assigned to process steps and products. Due to the increased understanding of the respective contexts, extensive optimization potentials can be realized.

In the **development stages five and six**, intelligent systems automatically recognize the connections between processes and raw material use and derive measures automatically and adapt process parameters respectively in order to implement the derived measures autonomously.

3.3 Ecosystem services

Specific air pollutants generally have no direct influence on the product itself, but they must be considered in the context of

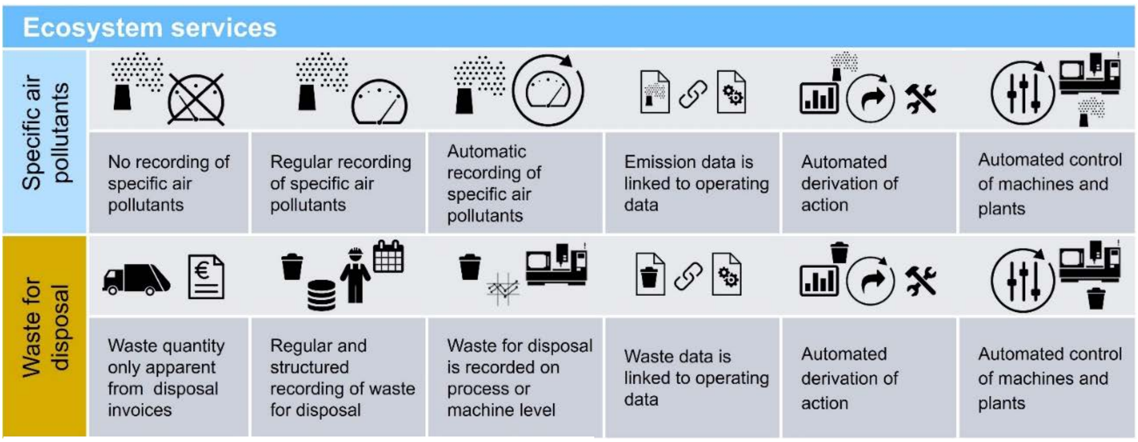

Figure 3: Framework Part 3 of 3 – Ecosystem Services

a resource-efficient production. Digitization can also influence these and other ecosystem services (e.g. climate regulation) through the use of modern networked sensors. Low hardware prices and automated processing and analysis of the data can provide a great insight into the actual pollutants emitted and can indicate needs or potentials for action.

No data on specific air pollutants are recorded in **stage one**, since there is no interest or legal requirements.

In the **second stage**, the pollutants emitted are regularly measured and recorded. This creates awareness and transparency. Furthermore, fluctuations can be detected and limit values can be observed.

A linkage of the emission data with the process data provides information on which processes are most involved in the emission of pollutants and shows where optimization measures are to be applied.

In the **fifth stage**, the system, on the basis of the collected data and with the aid of algorithms, independently uncovers links between production processes and the emission of specific air pollutants and derives an optimized system control. In the **last stage**, the system has the ability to implement control measures autonomously.

Waste for disposal is directly related to the raw material used, the material processed in the product and the separately disposed waste for recycling. If no regular and structured recording of the resulting wastes is carried out, these can be extracted from invoices from the waste disposal company. A conscious survey of the data at company level and machine level allows an increase in temporal and / or locational resolution.

By combining waste data with process, machine or plant data, waste-intensive production processes can be identified. The data thus give the impetus to optimize such processes with regard to their ratio of used raw material to incidental waste and at the same time serve as a reference state. In the visions-driven last two development stages, the measures for process improvement with respect to the raw material-waste ratio are automatically calculated and implemented autonomously.

4. Utilization of the Framework

The utilization of the framework in companies consists of six main tasks:

1. Task: List and categorize companies resources

It is necessary to list all resources that are consumed or disposed by the company as entirely as possible. The resource-categories in the framework can be used to structure the search for information. It is recommended to go gradually through the categories to ensure that all resources are listed. E.g. in Figure 4: Office, Factory, Steel Tubes, etc.

2. Task: Evaluate current state of data acquisition for every resource

For every resource, the current state of data acquisition can now be evaluated and marked in the framework (red dots in Figure 4). The connection of the different markers shows the actual state of the company (red line in Figure 4).

3. Task: Define relevance of resources for the company

Resource consumption and the number of resources vary significantly from company to company. Likewise, resource relevance varies for example due to:

- Costs of resources,
- Company strategy,
- Environmental influences of resources and
- Riskiness of resources.

It is therefore necessary to define the relevance of the resources specifically for the company. The result may be a prioritization of resources as shown in Table 2.

Table 2. Evaluation of resource relevance

Resource	Criteria* Cost	Company strategy	Environmental influence	Riskiness	Sum	Priority
Cooling Lubricant	2	1	3	2	**8**	**1.**
Electrical Energy Factory	2	3	2	1	**8**	**1.**
Electrical Energy Office	1	3	2	1	**7**	**2.**
Steel Tubes 1.0402	2	1	1	1	**5**	**3.**
Steel Plates 1.0501	1	1	1	1	**4**	**4.**

*1: slightly relevant, 2: relevant, 3: very relevant

4. Task: Estimate potentials

Similar to the relevance, the potentials of digitalization for different resources varies. For example, a small amount of a very expensive material might be completely used in one process step just once a year. In this case, a continuous material monitoring with combination of production data might be overdone. Obviously, the estimation of potentials is not always as easy as in this example, therefore the expertise of employees working with the resources should be considered and criteria for an objective evaluation should be defined. For example, the frequency of consumption or the resource efficiency (ratio of resource usage to disposal) can be considered.

5. Task: Define goals

Based on the relevance and potentials evaluated in task 4 and 5 the resource goals should be defined. The goals are marked for every resource (green dots in Figure 4). It is possible for certain resources to leave the mark at the current state. This is possible if the resource relevance is low, or the data acquisition is already at a good state.

The linkage of the marks is the intended state of resource monitoring in the company (green line in Figure 4).

6. Task: Implementation

With the definition of the goals the implementation can be started. The following figure shows an example for the utilization of the framework.

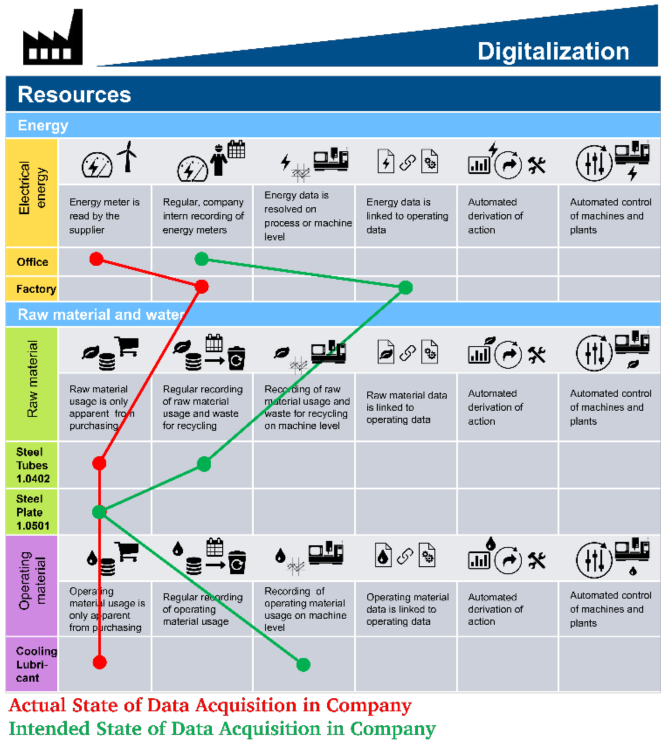

Figure 4: Utilization of the framework

The utilization of the framework is an iterative process. It is recommended to re-evaluate the resource monitoring on a regular basis. It can also be necessary to delay certain implementations due to a lack of suitable technology or economic reasons.

5. Summary

The framework is a holistic, strategic and structured approach to monitor resource data and detect efficiency potentials. It was developed to assist SMEs to assess their stage of digitalization in regard to resource efficiency and to generate ideas for the use of digitalization measures to increase resource efficiency. Using this framework, SMEs have the opportunity to assess their own degree of digitalization in data collection with respect to six operational resources (electrical energy, heat, operating materials, specific air pollution, disposal of waste), which in turn are linked to natural resources as considered by the EU (e.g. raw material, flow resources, sinks). The assessment of the current development stage is followed by the determination of the desired development level as well as the company-specific strategy for achieving it. These stages extend from left to right, from a non-existent data acquisition for resource use, through an acquisition with higher resolution, to fully automated systems that capture, analyse and are able to implement independently derived measures. The exemplary application of the framework showed how with a few steps, the company's digitalization status of the data monitoring can be identified.

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