Towards Green Business Process Management: Concept and Implementation of an Artifact to Reduce the Energy Consumption of Business Processes

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Abstract

The consideration of ecological objectives has been identified as one of the major topics for IS research and Business Process Management (BPM). An essential precondition for advancing the emerging discipline of Green BPM still is the availability of methods and tools for detecting and matching the resource usage of a business process to its individual steps. In this paper, a conceptual integration model for the energy consumption of IT components and business processes is developed for the specific setting of administrative business processes. The integration concept is implemented as a software prototype, following a design-science approach. Its application is demonstrated in a sample scenario. Findings show, that the integration concept and the software prototype increase the transparency of the energy consumption of administrative business processes, and enable users to save energy. Furthermore, the prototype can be used to develop and validate effective methods for creating energy-efficient business processes.

1. Introduction

Aspects of sustainability have become of growing importance for the discipline of Business Process Management (BPM) [1]. Business processes are means for coordinating corporate resources for the achievement of a given objective. These objectives, having traditionally been economic objectives like cost or time, need now to be extended by ecological aspects.

Business processes rely on numerous resources for their proper operation, including raw materials, tools, machines, or energy as inputs. Their outputs are the desired products and services with value for a customer, and undesired outcomes, like emissions and waste. From an ecological point of view, business processes can be classified according to different ecological indicators, like their individual energy consumption, or the amount of produced emissions per executed process instance. As it is important to determine the total amounts of the required natural resources, the execution frequency of business process needs to be taken into account, too. Business processes which require only few resources per execution may become ecologically relevant, if they face high execution numbers.

Information technology (IT) can be regarded as a special resource for business processes. On the one hand, IT is useful for collecting, processing and providing information in order to determine and improve ecological indicators for business processes (perspective "IT for Green"). On the other hand, IT itself requires natural resources for the design, manufacturing, use, and disposal of the required hardware and software (perspective "Green for IT"). Depending on the underlying business process, the impact of IT on the total resource and energy consumption of the business process can vary. For manufacturing processes, this impact is rather low. If typical office settings are regarded, IT has a very prominent role, as most of these business processes rely mainly on IT services, besides human workforce. Although a typical process instance in an office setting, like creating an invoice, may require less resources than a business process in manufacturing, it can become relevant due to its high repetition numbers and its nearly identical structure in comparable corporations world-wide.

Independently from the type of business process all actions for improving the ecological footprint of a business process need to obtain information about its actual resource usage. This requires an integration concept which is able to assign that resource usage, usually expressed by the operation of machines and IT devices, to the corresponding steps in the business process. When this integration is achieved, the resource consumption of each step in the business process can be made transparent and related actions for improving this resource usage can be derived.

For this work, we focus on business processes in office settings. Although the individual resource usage of such business processes is rather low, they are executed frequently. Typically, they rely on IT services, which require IT hardware and related applications. From our knowledge, up to now no efforts have been made to make the resource usage of such business processes transparent and to take related actions in order to reduce their ecological impact.

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The objective and focus of this paper is therefore to develop an integration concept for business processes and their underlying IT resources for the example of office settings. This aims at establishing transparency about the energy consumption of local IT devices, and locally executed applications in order to enable the deduction of effective measures for reducing the energy consumption of IT from a business process perspective. The integration concept for IT devices, applications and business processes is developed and implemented as a software prototype, following a design-science approach. The usefulness of the software prototype is validated through the deduction of five measures, which were found effective at reducing the energy demand of a sample business process in an application scenario.

The paper is structured as follows: After this introduction, the related work to Green BPM, Green IS, and energy management is presented in section 2. Then, the conceptual integration model as well as the architecture and the implementation of the software prototype are described in section 3. In section 4 the software is applied to a sample business process in order to derive and validate energy saving measures. The results are discussed in section 5. Finally, the summary and an outlook on future work are provided in section 6.

2. State-of-the-art and related work

A business process can be defined as an interrelated set of activities which contributes to the creation of products or services with an economic value for a customer [2]. Business Process Management is the discipline which aims at modeling, implementing, operating, and monitoring business processes by providing the appropriate concepts, methods, and tools [3]. The management of the BPM lifecycle is well supported with mature software applications, like Workflow Management Systems (WfMS), or Business Process Management Systems (BPMS) [4].

Green Business Process Management can be regarded as an intersection of both BPM and Green Information Systems (Green IS) [1]. The intention behind Green BPM is the incorporation of ecological objectives into the management of business processes. To achieve this objective, BPM has to be extended by ecologically oriented complements, as are the consideration of environmental strategy as a part of the process strategy, or the awareness for energy consumption and pollution [1]. Actual research in Green BPM covers, among others, green process strategies, green Business Process Reengineering [5], and methods for capturing and modeling the resource consumption of the individual activities of a business process. As a prerequisite, knowledge about the resource and energy demand of every activity is important. This requires an extension of the process models, but even more the availability of procedures which are able to measure the resource and energy consumption of an individual activity and to assign it to the corresponding activities in the business process.

Besides BPM, the overall context of this work is set by the responses of IS research to the challenge of preserving natural resources. The concept of *Green Information Systems (Green IS)* emerged [6], which argues for a holistic concept to realize ecological objectives by incorporating information systems, people, and business processes. Clearly, Green BPM is supported by Green IS, but the specific role that Green IS play in enabling Green BPM is still a matter of research [7].

For administrative business processes, a central issue is the detection of the energy consumption of the underlying IT devices. Methods and software tools for detecting the energy consumption of IT devices is an important topic in related work [8-13], although integration with BPM has not yet been provided. Two major approaches can be distinguished: approaches which use additional hardware and sensors to capture the energy consumption physically, and approaches which use indirect methods, like temperature sensors or performance counters [8]. Indirect approaches usually model the energy consumption of an IT device as the sum of a static system load plus a variable part. The static part represents the energy consumption of an idle IT device, whereas the variable part represents the main IT components, which are responsible for dynamic energy consumption [10]. Research which follows this approach has e.g. been published in [8-10]. It relies on regression models, which serve to estimate energy consumption parameters, which are individual for each IT device and each IT component. To estimate the total energy consumption, performance counters for CPU, disc, memory and network are accessed via software interface and are set into relation with the data provided by a single energy sensor. This energy sensor usually covers the whole IT device and is in most cases the battery of a mobile IT device [9]. Comparable power models are currently implemented by Joulemeter [9], DiPART [10] or Mantis [8].

Although these tools are able to detect the energy consumption of IT devices, they do not support energy management from a BPM perspective. Therefore, establishing a link to BPM is advantageous for both energy management tools and for Green BPM. Green BPM provides the business context and established management methods and software. Nevertheless, for its further evolution it needs to incorporate the abilities of energy management software.

3. Integration concept and prototypical implementation for energy management between IT components, applications and business processes

3.1 Integration concept

To establish the link between the energy consumption of IT components, applications and business processes, an integration concept needs to be provided. As a first abstraction, a three-layer view is introduced in figure 1. It is derived from common Enterprise Architecture Frameworks [2] and aims at introducing an integrated view on business processes, their related applications and the corresponding IT components. Its main idea is the fact that business processes rely on applications for their enactment. Applications, in turn, require physical hardware, which are the IT devices. Typical IT devices are servers or workplace computers. IT devices are composed of a number of IT components. The most important IT components are CPU, main memory, discs, or network adapters. Further IT components are power supplies, chipsets, or graphics adapters. In the three-layer view, these individual elements are aggregated and assigned to the corresponding layer of the integration model.

In addition, it is assumed, that the three layers are interrelated through n:m-relationships. This means that every application can make use of all IT components, every IT component can be used by various applications, and that all applications can support several business processes, and vice versa (figure 1).
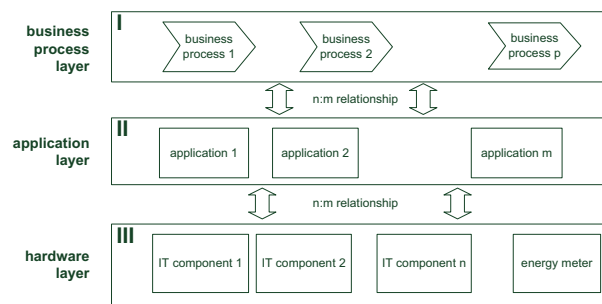
Figure 1. Three-layer view on business processes, applications and IT components

In figure 2, the conceptual integration model is refined, by modeling the most important entities and their relations on each layer in ER-Notation [14]. The parts of the model which correspond to the three different layers have been assigned a Latin number (I, II, III) whereas the parts which serve to link the layers are put in between and are referenced by the links I->II and II->III. The defined links need to be established in order to overcome the various n:m-relationships between hardware layer, application layer and business process layer.
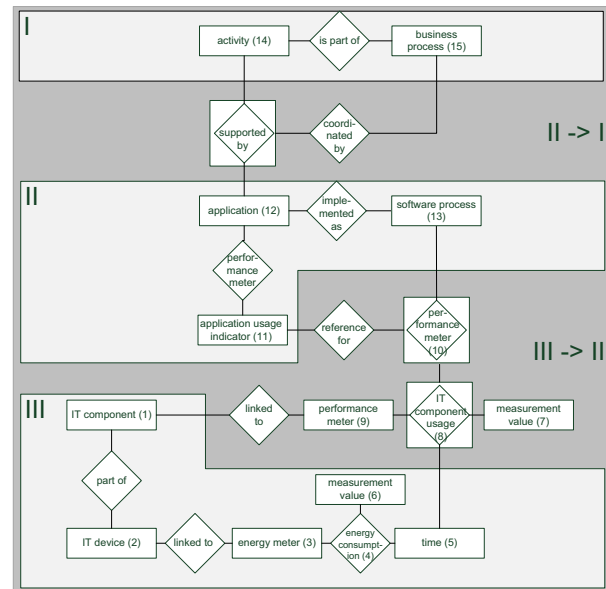
Figure 2. Conceptual integration model for IT components, applications and business processes

Hardware layer (III). The first relevant physical objects of the hardware layer are the IT components (1) which are required for the provision of computing power to applications and business processes. In data center configurations, these IT components are typically built as individual IT devices (2), like servers, storage systems, backup systems and network devices. In workplace configurations they are assembled as parts of IT devices, like a computer, a laptop, or a tablet. A special IT component is the energy meter (3). This IT component enables the continuous measurement of the energy consumption of all other IT components. As energy meters are usually not attached to the most important IT components the energy consumption of these IT components needs to be estimated indirectly. To enable this, performance meters (9, 10) are required, which monitor the usage of the individual IT components. In contrast to energy meters, performance meters are available for the most important IT components and can be accessed easily via software interfaces. The most prominent performance meters are the average CPU load, the average occupation of the main memory, bytes written to disc, or bytes transferred via network [9, 10]. Energy consumption (4) and IT component usage (8) are both composed of a corresponding measurement value (6, 7) and a point in time (5) at which the measurement took place (figure 2, III).

Application layer (II). Software is the constituting object of the application layer, including system software, middleware, application software and tools. Business processes are primarily supported by applications (12) which consist, simplified, of software processes (13), which can be monitored using a System Monitor. This is a performance meter on application level (10), which reports the share of each software process on the related IT components. Software processes trigger the activities of IT components. The system monitor collects and displays data about the IT component usage, like CPU load, bytes written to disc or the network traffic, in relation to every executed software process.

In order to establish an energy management on the application layer, the energy consumption of the IT devices and IT components has to be assigned to suitable application-related reference objects. Such a reference object can be the application itself (12), or the underlying software processes (13). As system monitoring usually reports on the consumption of software processes, they are chosen as reference objects. Furthermore, there is the need to introduce a usage-oriented reference indicator (application usage indicator, 11) on the application layer. Examples for an application usage indicator are the number of executed transactions (ERP-Software), sent mails (Mail-Server) or created documents (figure 2, II). This application usage indicator will serve as a reference for the energy consumption of the software processes and their related applications and serves to the definition of ecological KPIs on application level, like the amount of consumed energy per sent e-mail.

Linking hardware layer and application layer (III->II). The integration model aims at linking the energy consumption of the IT devices and the IT components to the applications, which trigger their operation. As an energy meter is physically not available for each IT component, this is realized indirectly by using the corresponding performance meter, in accordance with existing approaches. It is assumed that every action of an IT component is triggered by a software process. Actions on hardware layer include, but are not limited to, processing data (CPU), storing data (disc), or transferring data (network). These actions on the hardware layer can be monitored and can be reported by suitable IT component usage indicators (8), like CPU load, bytes written to disc or the network traffic. It is one of the underlying assumptions, that an IT component usage indicator reflects the energy consumption of its related IT component in a linear fashion. This means that energy consumption is proportional to the amount of data which is processed, transferred or stored. As these quantities can be monitored per IT component, a usage pattern per IT component

and period can be derived and can be matched to a corresponding software process. With this information, the total energy consumption of every IT component or group of similar IT components can be distributed to the corresponding usage indicators and consequently to the related software processes and applications. IT component usage indicator and performance meters serve therefore as linking elements (figure 2, III->II).

Business process layer (I). As introduced, a business process is an interrelated set of activities which contributes to the creation of a product or service with an economic value for a customer. A business process requires resources (like energy, raw materials or information systems) to create a product or a service. In this paper, only the dependencies of business processes on applications, IT components, and energy are considered (as introduced in figure 2). The business process (14) is introduced as an element of the model, consisting of different activities (13) which are, in turn, supported by several applications. A single application may be used by different activities and a single activity may be supported by several applications, resulting in an n:m-relationship between activities and applications. Furthermore, individual activities can also be part of different business processes, resulting in additional complexity. These interdependencies between business processes, activities and applications lead in consequence to an indirect n:m-relationship between business processes and an applications (figure 2, I).

Linking application layer and business process layer (II->I). Finally, the link between the application layer and the business process layer can be established. As already pointed out, the activities in the business process model have been considered relevant, as these are supported by applications. There is, once again, an n:m-relationship between business processes and activities as well as between activities and their supporting applications. For a matching between an activity and its related applications, the business process model can be identified as the coordinating element. During the model creation, the dependencies of the activities of the business process and their related applications need to be defined. So the business process model establishes the link between layer II and layer I (figure 2, II->I).

3.2 Power model and software prototype

After the principal elements and their links have been established in the previous section, the focus will now be on the conceptual foundation of the energy management software prototype. This software will serve at detecting the energy consumption of an IT device and will assign this energy consumption to IT components, software processes, applications and business processes, which are monitored.

As already introduced, one of the main problems about energy detection in workplace hardware is the fact, that there are no hardware sensors available, which detect and report the energy consumption of IT devices and IT components. Furthermore, the estimation of the energy consumption of IT devices which are connected via cord to the power grid is only possible with an additional measurement device. The remaining possibility is to use the discharging rate of a battery in stand-alone IT devices, like laptops [8, 9]. Indirect measurement has been identified as a feasible approach in related work [8-10], using performance meters, and a single energy meter for the whole system, which is typically the battery sensor of a mobile IT device. Using indirect measurement has also advantages, as neither additional hardware nor physical sensors are required [10] The detection and reporting of the energy consumption of an application can therefore be realized for local applications, using battery sensors. It will be realized according to the following procedure:

Step 1. The actual total power consumption of a laptop can be extracted, using the battery discharging rate, which can be received via existing operation system functions. Then, the energy consumption of a given period can be calculated by multiplying that actual total power consumption with the observed time interval. A suitable time interval needs to be chosen, which guarantees an acceptable trade-off between accuracy and the power consumption of the prototype itself. In case the time interval is too narrow, the prototype can become the major energy consumer of the system, what would contradict its actual purpose.

Step 2. The IT components are identified, which are assumed to contribute mostly to the total energy consumption of the IT devices. In this model, these are CPU, main memory, hard disc, and network, in accordance with [8, 10]. As the energy detection per hardware sensors on IT component level is not possible a workaround is established, which is based on performance meters. The corresponding measurement results are IT component usage indicators (ITCu) which represent the work performed by the underlying IT component during the execution of a software process. The underlying assumption is a linear dependence between IT component usage indicator and the energy consumption (ITCec) of the respective IT component. The IT component usage indicators have been chosen in accordance to the data which can be observed in usual system monitoring tools. In contrast to the individual energy consumption, they can be accessed via software interfaces, allowing an automatized detection and processing. In table 1, the IT components which are used in the power model, as well as their usage indicators, are provided.

Table 1. IT component usage indicators (ITCu)

display	CPU	memory	disc	network
brightness	load	page faults	bytes transferred	bytes transferred

After the IT component usage has been captured, its energy consumption can be calculated. For the calculation of the specific energy consumption, two further parameters are required. First, for every IT component, a specific static ratio for energy consumption per IT component usage (ITCecu) has to be derived. This is achieved by a calibration procedure, which is provided by the software prototype. The ITCecu parameters need to be calculated once per IT device, using a regression model [10]. Second, a static energy usage indicator (Sec) is required for representing those IT components, which are not part of the dynamic model, but which are regarded as responsible for the static energy consumption of the IT device. Typical representatives are capacitors, the chipset, USB ports, the graphics chip or the IO subsystem [8, 9]. The energy consumption of an IT component (ITCec) can finally be calculated as a product of the usage ITCu of the respective component and the specific static regression parameter ITCecu for that IT component. The total energy consumption of an IT device ITDec for a given period can then be determined as the sum of the static energy usage (Sec) plus the sum of the energy consumptions of all IT components for a given time interval.

Step 3. After the energy consumptions of the IT device and each IT component have been determined, the link to layer II (application layer) can be established. Therefore, the usage share of each IT component for a given software process (ITCsu) is captured via software interface, and the total energy consumption of the respective software process (SPec) for a given period can finally be calculated by multiplying this usage share ITCsu with the energy consumption ITCec of the corresponding IT components, under consideration of the respective time interval.

Step 4. The software prototype is now able to detect and report the energy consumption of every software process. A link to the business process can also be established by matching the energy consumption of each software process to the corresponding application, and by calculating the total energy consumption for all applications which have been modeled in the business process. This part is currently not implemented in the software prototype and needs to be realized through a manual interface to a common spreadsheet application. This can be used to calculate energy-related usage indicators, like the average energy consumption of each activity of the business process.

In figure 3, the architecture of the software prototype is visualized. The software is split into the main components user interface, controls, sensors, databases, and an interface for the external analysis.
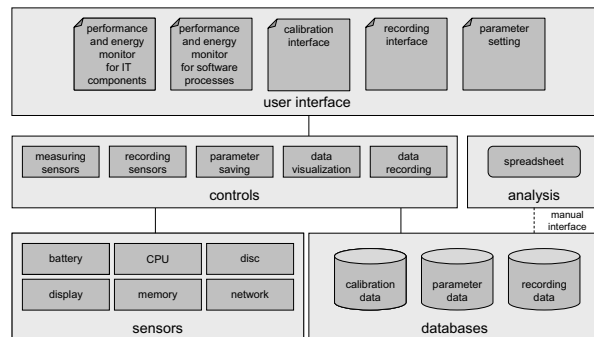
Figure 3. Architecture of the energy management prototype

The data for energy consumption and IT component usage are captured via sensors and are stored into a database. The required regression parameters are derived via calibration and are stored into another database. The user can access all information via user interfaces for the total energy consumption per IT component and for each observed software process. The analysis on business process level requires an external spreadsheet application, which is accessed via a manual data export interface. A screenshot of the prototype is provided in the application scenario in the next section (figure 5).

The energy management software was implemented in a Microsoft Windows environment, representing a typical office workplace. All system related information, like battery discharging rate or performance counters were accessed via the Windows Management Instrumentation (WMI), which provides the necessary classes. The application itself was written in Microsoft Visual Basic Express 2010, resulting in an easy accessibility of the implementation code.

A validation of the power model has been performed by comparing the calculated energy consumption with the measured battery discharging rate. A second validation was done by comparing the prototype's results with Joulemeter [9]. In both cases, the calculated energy consumption could be verified.

4. Application scenario Green BPM

4.1 Scenario description

In order to demonstrate the application of the software prototype, a simple, but realistic sample business process is provided in figure 4. This business process relies mainly on local business applications which are executed on workplace IT devices and their built-in IT components.
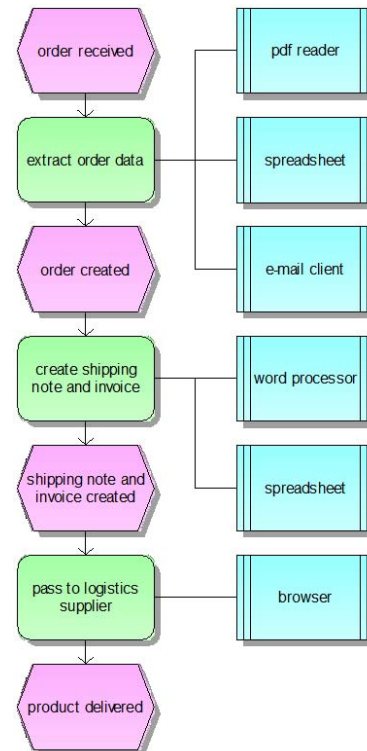

Figure 4. Sample business process and related local applications

In this scenario, the business process is required for coordinating the activities of receiving an order, processing the order, and for triggering a logistics partner to initiate the shipment. It is assumed that an order is usually received per e-mail, so a local e-mail client is required (1). As the order is provided as a pdf document, it has to be opened with a pdf reader application (2). After that, the order data like customer name, customer address, desired product, or order quantity have to be extracted and are stored in a local spreadsheet, using a spreadsheet application (3). After the order has been registered, a shipping note and a corresponding invoice are created (in this sample scenario, it is assumed, that the product is available on stock). Shipping note and invoice are created using a word processor (4) and the spreadsheet application. After that, the documents are passed to a logistics supplier, who is responsible for the shipment of the product. For this case it is assumed, that the data is transferred via a web interface, using a browser application (5). E-mail client and browser application are executed locally, although a remote part is required. The necessary server hardware in a data center (or a comparable unit) is not in scope in this scenario. In total, five local applications are used which consume energy in the local IT device.

## 4.2 Measurement the energy consumption with the software prototype

In the following, the sample business process is executed while the energy management software is running and tracing the energy consumption of the related IT components and software processes. Prior to that, the determination of the machine-specific parameters ITCecu has been performed in a single training session, using the energy management software and a spreadsheet application for the required regression analysis. After the parameters ITCecu have been determined, they are stored in the parameter database of the energy management prototype. In figure 5, a screenshot of the prototype is provided. It shows the actual energy consumption of the monitored IT components, plus the static system energy consumption of the system. In addition, the software process of the e-mail client is being monitored, and its usage data is stored into the internal database of the prototype.
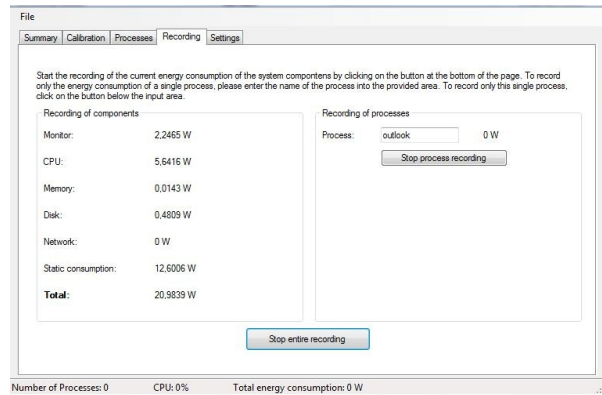
Figure 5. Monitoring the e-mail client (screenshot of the software prototype)

The detected energy consumption profile of the e-mail application is provided in figure 6. This figure represents the dynamic part of the energy consumption while the e-mail is being processed. The individual contribution of the IT components CPU and memory are provided, while disc and network have been summed up as IO. The energy consumption peaks reveal detailed information about the application's energy usage over time. Between the metering points 1 and 8, the application is opened, requiring considerable CPU activity. Between metering points 9 and 55 the checking of the mailbox is done, requiring primarily CPU, but also IO activities. The peaks between metering points 61 and 79 are related to searching and opening an e-mail. The low energy usage between 79 and 103 is caused by reading the e-mail. Finally, the application is closed, causing a last peak in energy usage between metering points 103 and 109.
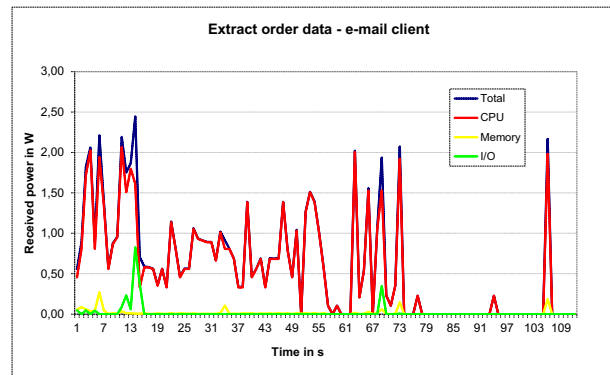
Figure 6. Energy consumption profile for the e-mail client

According to the example above, the total energy consumption of the business process can then be calculated as the sum of the energy consumptions of all applications which are executed in the business process. To minimize measurement errors, the business process was executed five times and the average of all measurement values was calculated. The total energy consumption of the sample business process could finally be determined with 8,501 Watt seconds [Ws]. The detailed results are provided in table 2.

Table 2. Energy consumption of the sample business process

activity	application	energy consumption (application)	energy consumption (display)	energy consumption (static)	energy consumption (total)
extract order data	**sub total**	**68 Ws**	**1,003 Ws**	**3,097 Ws**	**4,168 Ws**
	e-mail client	57 Ws	459 Ws	1,416 Ws	1,931 Ws
	pdf reader	8 Ws	246 Ws	761 Ws	1,015 Ws
	spreadsheet 1	4 Ws	298 Ws	920 Ws	1,221 Ws
create shipping note and invoice	**sub total**	**15 Ws**	**766 Ws**	**2,366 Ws**	**3,148 Ws**
	word processor	7 Ws	399 Ws	1,232 Ws	1,639 Ws
	spreadsheet 2	8 Ws	367 Ws	1,134 Ws	1,509 Ws
pass to logistics supplier	**sub total**	**101 Ws**	**265 Ws**	**819 Ws**	**1,185 Ws**
	browser	101 Ws	265 Ws	819 Ws	1,185 Ws
total		**184 Ws**	**2,034 Ws**	**6,282 Ws**	**8,501 Ws**

Table 2 shows the distribution of the total energy consumption on the different activities, as well as a split between the application-related energy consumption, the energy consumption of the display, and the static energy consumption. As a first interpretation, it can be stated that the main contributors to energy consumption are the static system usage with 6,282 Ws and the energy usage of the display (2,034 Ws). The dynamic part, which is caused by user actions in the business process, has been estimated with 184 Ws. These results confirm the findings of related work [8, 10]. It becomes obvious that effective energy saving approaches need to incorporate, besides application-related energy saving measures, the static energy consumption and the energy consumption of the display.

In the next section, four exemplary measures for reducing the energy consumption of the business process will be derived from the applications' energy consumption profiles and will be complemented with infrastructure-related measures. These energy saving measures will be defined and will be applied on the sample business process. Their effectiveness for reducing the total energy consumption of the business process will be measured and validated with the software prototype.

4.3 Deduction of energy saving measures

Measures 1 to 3 are related to layer II by trying to save energy on application level. They have been derived from the energy consumption profiles of all applications (as exemplarily provided for the e-mail client in figure 6), and aim at reducing an application's energy consumption by reducing the extent and the number of the peaks in the energy consumption profile. As a complement, an infrastructure-related measure (layer III) is defined, which decreases the brightness of the display. A combined approach is added as measure 5, applying all individual measures in combination. The software prototype will monitor the energy con-

sumption of the entire business process and its individual activities before and after the application of each measure and will serve at validating the effectiveness of each measure.

As measure 1, the action of opening and closing the respective application will be eliminated. Instead, it is assumed that every application will be started only once per day and closed once per day and that it will remain in the IT device's main memory. The performance of this measure achieves a decrease of energy consumption of 16 % on business process level. As measure 2, the time interval for checking for new e-mails by the e-mail client is increased. Checking for new mails is a rather energy-consuming action (figure 6), so it should be performed less often. In the sample business process, this measure achieved a reduction of the energy consumption by 13 %. As measure 3, the pdf attachment is replaced by a single text e-mail, which has two effects. First, the opening and scrolling, which are caused by the pdf application are eliminated. In opposition to that, only a slight increase in the e-mail client's energy consumption can be detected, caused by scrolling and reading the relevant data directly in the text message. This measure contributes to a reduction in energy consumption by 8 %. As a fourth measure, the business process was executed, using different brightness levels for the display. A brightness level of 40 % was found sufficient for an effective execution of the business process, resulting in an overall reduction of the energy consumption of 14 %. Finally, measure 5 is defined as a combination of all other measures. This measure is applied independently on the business processes, which means, that it was not simply derived as the sum of the previous measures, but measured in an individual session. The total savings on energy consumption after the application of measure 5 are 44 % for the entire business process. In table 3, the results of the application of measure 5 are displayed for each activity and for the main categories application, display, and static consumption.

Table 3. Energy consumption of the sample business process
after combined application of all energy saving measures (measure 5)

activity	application	initial energy consumption	application savings		display savings		static savings		total savings	
extract order data	**sub total**	4,168 Ws	52 Ws	*-76%*	835 Ws	*-83%*	1,799 Ws	*-58%*	2,686 Ws	*-64%*
	e-mail client	1,931 Ws	44 Ws	*-77%*	392 Ws	*-85%*	900 Ws	*-64%*	1,335 Ws	*-69%*
	pdf reader	1,015 Ws	8 Ws	*-100%*	246 Ws	*-100%*	761 Ws	*-100%*	1,015 Ws	*-100%*
	spreadsheet 1	1,221 Ws	0 Ws	*-11%*	197 Ws	*-66%*	139 Ws	*-15%*	336 Ws	*-27%*
create shipping note and invoice	**sub total**	3,148 Ws	-1 Ws	*+6%*	486 Ws	*-63%*	199 Ws	*-8%*	684 Ws	*-22%*
	word processor	1,639 Ws	-4 Ws	*+57%*	254 Ws	*-64%*	111 Ws	*-9%*	361 Ws	*-22%*
	spreadsheet 2	1,509 Ws	3 Ws	*-40%*	232 Ws	*-63%*	88 Ws	*-8%*	323 Ws	*-21%*
pass to logistics supplier	**sub total**	1,185 Ws	23 Ws	*-23%*	177 Ws	*-67%*	139 Ws	*-17%*	339 Ws	*-29%*
	browser	1,185 Ws	23 Ws	*-23%*	177 Ws	*-67%*	139 Ws	*-17%*	339 Ws	*-29%*
total		**8,501 Ws**	**74 Ws**	*-40%*	**1,498 Ws**	*-74%*	**2,137 Ws**	*-34%*	**3,709 Ws**	*-44%*

Findings show that all measures contribute to savings for the observed business process. In total a reduction of 44 % has been achieved. This is caused by mainly three different kinds of effects. First, the application-related measures proved to be effective on the application's direct energy consumption, as intended. Although a significant relative reduction could be achieved (-40 %), the total reduction is rather small (74 Ws), because of the low share of the application's energy consumption on total energy consumption. Second, the infrastructure-related measure to reduce display brightness was the most effective in relative reduction and contributed the highest absolute reduction of 1,498 Ws. Third, the static consumption could be reduced by 34 % (2,137 Ws), because of a secondary effect of measures 1 to 3. This is the reduction of the total execution time of the business process by approximately 170 seconds. It has an impact on the display and on the static components and is responsible for the additional considerable energy savings.

Regarding the individual measures on application level, measure 1 has the highest contribution to energy savings, presumed, that all applications are already opened. Nevertheless, as soon as the execution of the applications is put in sequence by a business process, opposing effects can arise. In the case of the word processor, an increase of the energy consumption could be observed (57 %). This was mainly caused by CPU and IO activities. A possible explanation could be that the word processor was put to swap space by the operating system, requiring a recovery when being used.

Eliminating e-mail attachments and leaving out the related applications had also a considerably high primary effect, but also as a secondary effect on the total business process execution time. The same could be observed for the prolongation of the e-mail polling interval in measure 3.

5. Discussion of results

For the evolution of Green BPM the following implications can be derived. First, by developing the integration concept, a link from the hardware layer to the business process layer could be established. This link is essential, as energy consumption is caused by IT devices and their related IT components, whereas the actual causes for the energy consumption are the business processes and their related applications. In addition to the integration concept, it becomes feasible to measure the local energy consumption of administrative business processes, using the implemented software prototype. Through an interface, the analysis on the business process level can be performed.

The energy consumption profile of applications, as provided for the e-mail client in figure 6, has proven to be an effective means for identifying those steps in an activity, which consume most energy. With that knowledge appropriate measures for the reduction of the energy consumption can be derived. Findings showed that all defined measures were effective in reducing the energy consumption. Furthermore, secondary impacts on the total execution time of the business process were observed, leading to a significant additional reduction on the total energy consumption. The reduction of the execution time becomes one of the most important energy saving measures on layer I and should therefore become a constraint for the design of green business processes.

The application energy profiles enable a detailed analysis of all minor steps during the execution of a predefined activity. Currently, the optimization measures have been derived manually, following a heuristic approach. For further development, it should be investigated if energy consumption patterns can be detected in software and if the appropriate measures can be derived automatically. Appropriate empirical instruments need to be implemented in order to deduct the energy consumption profiles.

Infrastructure-related measures, like the reduction of the display brightness or the activation of system power states become more effective, if coordinated by BPMS. This amplifies the effects, which arise from the reduction of process execution times. Opposing effects, like the swapping of the word processor in the sample scenario, can be prevented. Furthermore, a strict coupling of BPMS and energy saving measures prevent jeopardizing effects which may arise, if system-related energy saving is not automatically triggered after an activity has been finished.

An exact matching between the energy consumption peaks and the related activities in the green business process model has been found essential for the deduction of effective energy saving measures. For Green BPM this means that green process models should provide the appropriate level of detail.

An important limitation of the approach is its actual focus on administrative business processes which use local applications. For the further development of the solution, more complex scenarios need to be developed. This means to add more use cases like system start-up, or the conduction of backups as well as to rely on more complex process models. From the view of the underlying IT resources, the server-side part needs to be integrated. One important difference to the local scenario is the fact, that internal IT components, like disc or network, are realized as individual IT devices in a server environment, requiring individual measurement. Furthermore, additional direct and indirect energy-consuming IT components, like networks and cooling, will become part of the server model.

Concerning the practical implications of this work, the software prototype is intended to be easily usable on local workplaces. Besides the cost of the software, only external energy counters need to be installed. The cost of the system shall be compensated with the achieved energy savings, in order to establish a win-win-scenario.

6. Summary and outlook

In this paper, a conceptual integration model for the energy consumption of business processes, applications and IT devices was introduced and prototypically implemented. By applying the concept and the software the energy consumption of business processes in office settings can be detected and can be made transparent. Furthermore, the prototype enables the deduction of energy saving measures, which can directly be derived from energy consumption profiles of the applications which are used by the business process. Findings showed, that these measures proved to be effective and that primary and secondary effects on the observed business process could be identified. For Green BPM, the most important implications are the necessity for an integrated optimization of hardware layer, application layer and business process layer. Furthermore, green business processes should be optimized for short execution times and the underlying BPMS should be coupled closely with system-related power saving mechanisms. In addition, the granularity of business process models should match the granularity of applications' energy consumption profiles.

As an outlook on a more holistic concept of Green BPM, the integration concept and the software prototype need to consider any kind of resources. This would make them applicable in different domains. The effects on user behavior, which arise from better transparency, need to be investigated and should be incorporated into the model.

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