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Simulation-based Decision Support for the Reduction of the Energy Consumption of Complex Business Processes

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Abstract

With this paper we introduce a simulation approach to Green Business Process Management (Green BPM). While objectives for business processes are traditionally economic (e. g. costs or cycle time), our approach focuses on the energy consumption and the carbon footprint of complex business processes. We present an approach for applying Business Process Simulation (BPS) techniques to the subject, using established simulation software. After developing the simulation concept for reducing the energy demand of complex business process execution instances, we demonstrate its practical relevance by applying the simulation to a real-world business process of a German energy supplier. With the reduction of the energy consumption by 28% we could not only demonstrate that BPS is capable of optimizing the energy consumption of business processes. BPS also supports the analysis of path complexities of business process models and can therefore serve as preparation for effective decision-making in an ecological context.

1. Initial situation and objective

Business Process Management (BPM) is most commonly applied to manage business processes in terms of costs per iteration or cycle time [1]. With the rising environmental consciousness of modern society, these traditional premises are being extended by environmental factors such as the energy consumption or the emissions of carbon dioxide (CO_2). Technology-oriented solutions to enhance the energy efficiency of IT hardware, software and infrastructure are well established [2, 3]. Further work focuses now on the potentials of BPM with regard to ecological objectives.

In prior research, important steps towards establishing an infrastructure for Green BPM was presented by developing integration concepts for BPM and its underlying resources [4]. Even more, software sensors became available, which are able to detect the energy consumption of resources, to assign that energy consumption properly to their related business processes, and to derive effective optimization actions [4-6].

Nevertheless, if complex business processes are subject to environmentally-oriented decisions, new problems arise. Complex, real-world business process models usually consist of parallel branches, decision forks, sub-processes and loops. This results in large execution paths at run-time, especially if process instances need to repeat certain parts of the process model over and over again. This *path explosion* poses additional challenges to decision-makers if they need to consider ecological objectives at modeling time.

The *objective of this paper* is therefore to develop a Business Process Simulation (BPS) approach for decision-making in Green BPM. It makes use of the potentials which are provided through the fact that sensors for collecting the energy consumption of business processes are readily available. With BPS, changes to an underlying business process either by optimizing the underlying resources or by altering the process flow can be assessed in a more systematic manner [7]. Even more, complex execution scenarios become manageable already at modeling time.

The *research method of this paper* shall be classified as design-oriented [8, 9]. With the development of an approach to use, extend, and configure BPS for application in the context of Green BPM, an adaption of an existing method as an innovative application is explored. This serves at building prescriptive knowledge about the ecologically-aware design, implementation, execution and improvement of business processes.

The structure of the paper is as follows. After this introduction, the long-term research vision for Green BPM is presented in section 2. Section 3 gives an overview of related work to Green BPM and BPS. In section 4, the problems of simulating sustainable business processes are analyzed. Section 5 comprises the actual conduction of the simulation. After that, the

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strengths and weaknesses of the approach are discussed in section 6. The paper closes with a short summary and an outlook on future work in section 7.

2. Long-term research vision

It is the long-term research vision to support the lifecycle of Green BPM with adequate methodologies. In [4], the preconditions for the monitoring of sustainability indicators, like energy consumption, were set. So that, energy-related and BPM-integrated sensor application can become the source of data for the monitoring and controlling part of the future Green BPM lifecycle (Figure 1). In turn, this supports the execution of complex business processes with consideration of ecological objectives, based on prior simulation results.

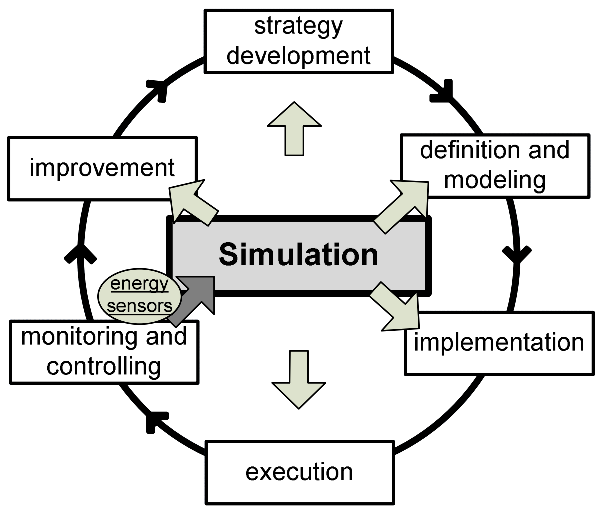

Figure 1. Adapted lifecycle of Green BPM derived from [10]

As a consequence, *Simulation* has been added to the original Green BPM lifecycle [10], pointing out its importance for all other phases in the long run. In analogy to *BPM-in-the-Large* [11], Simulation shall not only enable the use of sensor technologies during controlling and execution. It can support event-driven support architectures for the execution of sustainable business processes. By applying process mining technologies on energy consumption, patterns of resource consumption in relation to business process operations can be identified. These can be used for defining strategic objectives and core processes for both economic and ecological goals. For the modeling phase, reference models for ecologically-oriented business processes shall become available, allowing fast and flexible modeling activities by guaranteeing the use of best practices, concerning ecology. As such, a set of methodologies for the holistic management of green business processes is our long-term research vision ("Green-BPM-in-the-Large").

3. Theoretical foundations

3.1 Green Business Process Management

Green Information Technology (Green IT) can be attributed to the research which is devoted to support environmental issues in IT and through IT [12]. This encompasses the life-cycle-oriented management of IT devices, meaning design, manufacturing, transport, use, and recycling of hardware components [2]. Furthermore, it means changing operation parameters in data centers [3] or establishing software products which collect, process, and report environmental data for management support [13]. Nevertheless, to become most effective in corporate context, the ideas and concepts which are related to Green IT need to be integrated with widely-accepted management principles for corporations, which provide all the required methods and tools for supporting a given objective. This is the reason why Green BPM has established as a proper discipline in research about environmental issues in IT [12]. Green BPM means defining, implementing, executing and improving business process in corporations with the aim to support environmental objectives [14]. Environmental objectives can be the reduction of energy and material flows through efficiency gains, demand management, substitution of seldom or problematic materials, or the reduction of emissions and waste. First work on Green BPM can be found in [15] who propose the annotation of process models with appropriate indicators for selected performance indicators, like emissions of carbon dioxide (CO_2) or the energy consumption of activities in business processes. [4] propose a software-enabled solution to optimize the energy consumption of business processes. They define five measures, which are related to the elimination of activities, the shortening of the execution time, or the substitution of tools by simpler software in order to save energy. In [16] Novak et al. introduce a 4-step framework for green business process reengineering. [17] propose a methodology to estimate the carbon footprint of business processes which is called *Activity-based Emission (ABE) Analysis.*

As so far the topic of Green BPM has established in international research, the issues of transforming processes towards more sustainable business processes and the need for methodological foundations and tool support are obvious. Furthermore, there is the need to demonstrate clearly the usefulness of BPM tools and methods, like business process analysis, business process mining, or business process simulation to advance Green BPM.

3.2 Business Process Simulation

In the early 1990s simulation became a field of interest for practitioners in the area of business management, along with the emergence of the term BPM [18]. Researchers and practitioners aimed at applying simulation on business processes. With the emergence of software tools such as ARIS Toolset, it became convenient for practitioners and researchers to portray business processes as a graphical optimization model. While BPS in the past has been used to address resource allocation problems or to improve efficiency, there is currently only little research on how to use BPS for the optimization of IT-related business processes regarding environmental aspects.

Rozinat et al. use simulation methods to analyze and optimize workflow management [28]. The authors capture historic data in combination with process mining techniques to provide the applied simulation model with with relevant data. The simulation is then used to predict the behavior of the workflow depending on the introduction of certain optimization steps.

Karunakaran and Rao employ a Petri Net simulation to optimize resource allocation in terms of programmers, testers and hardware to improve the carbon footprint of a software development processes [20].

To the best of our knowledge there are no further publications addressing sustainable process optimization using a simulation approach.

4. Improvement of business processes using simulation techniques

4.1 Complexity of business processes

In the following we will highlight some of the characteristics of business processes in order to build a mutual understanding that is necessary for the simulation subject to this paper. We use the event driven process chain (EPC) [21] as graphical representation in combination with an extended version of a supplier change process at a German energy supplier for demonstration purpose (Figure 2).

Initial process models normally are being modeled by abstracting from the actual behavior of process instances (e. g. routing or cycle times). At this type layer, relationships between activities are defined at a rather general level, disregarding implications for actual process instances.

A simple way to express the complexity of process models on the type layer is the number of unique paths that the process can be passed through. Even though the process model in Figure 2 comprises only six activities it can be passed through 10 different unique paths. Cycles in process models or a structure with nested logical connectors could further increase this number dramatically. This explosion in possible paths makes it very difficult, if not impossible to evaluate the impact of a process improvement measure only cognitively. Hence to be able to evaluate the quality and complexity of a process model, information on the actual process instances is necessary.

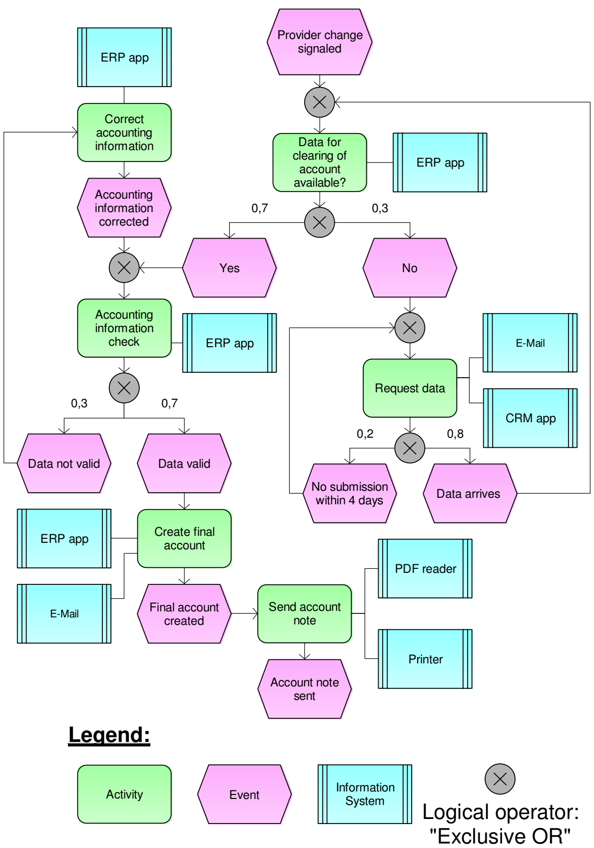

Figure 2. EPC of an energy supplier change process

On the instance layer, complexity is also driven by the real number of process instances that traverse the model through paths or cycles that are not desirable. For example, if the poor quality of a product makes a revision inevitable, it depends on the extent of this lack of quality whether a minor or major revision is necessary (Figure 3, Process A). By using simulation the impact of more extensive quality measures prior to the quality check could be assessed by regarding the number of instances that take the more favorable left path (50 Watt seconds per iteration) instead of the right (150 Watt seconds), accounted by the energy consumption that an additional process to enhance the quality prior to the quality check would consume.

Process B in Figure 3 represents another example of an undesirable process flow. The process will be terminated if necessary data is not available and the energy consumed until the termination is squandered.

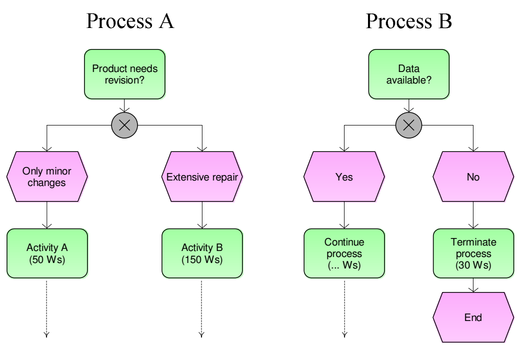

Figure 3. Two examples of adverse process flows at instance level

Both situations are undesirable and can be addressed on instance level by securing a certain quality respective data availability so that the undesired paths can be avoided.

In practice, the chance that a certain path will be traversed during the process flow can be determined empirically, for example by using log data from workflow management systems (WfMS) [22]. This approach requires a sufficiently large number of process iterations, thus a reasonably accurate determination of costs or consumed energy per process iteration or per single activity can only take place ex post. In case of rearranging the overall structure of a process model the impact on energy consumption will be hard to assess in advance. In this case, the path probabilities can only be estimated. If for example a logical XOR-connector is a predecessor of two events, the routing could follow a certain distribution function (*Bernoulli, Gaussian*). The probability whether the process flow will follow a certain path is then the product of the probabilities of the single parts along the route. Calculating the probabilities for every path with the energy demand of the activities along that path would be an impossible task if the process model would be somewhat complex. Process simulation is suitable to address this issue by computing the probabilities and energy consumption for every path with respect to stochastic probabilities.

4.2 Framing the objectives of Green BPM

One of the benefits of a BPS model is the ability to capture the stochastic behavior of a real-world business process while at the same time taking into account constraints and decision rules [7]. If the stochastic behavior of a real process is known, the variables of a process can be altered in order to influence the outcome of the process instances. Before such an alteration can take place, a clear vision on the *objectives* of the process optimization is required.

Regarding environmental sustainability, certain aspects can be addressed. First of all, the minimization of CO_2 emission is of interest both from a social and political point of view. By now, national and supranational governments try to restrict the CO_2 emission in order to prevent from global warming. To comply with regulation made by governments, more and more companies have to cut back on their carbon emissions. Against this backdrop, process optimization could be one way to gain compliance without the need to participate in emissions trading. Apart from CO_2 emission, companies can also directly benefit from reducing their energy expenses by cutting back on the consumed energy. This would also lead to a reduction of the CO_2 emission as there is a relationship between carbon dioxide and energy consumption. That means from an economic point of view, the reduction of the total energy consumption for a certain number of process instances would be a reasonable objective.

But there are also technical reasons why a firm should optimize their energy consumption. Running an IT infrastructure often requires firms to adopt measures to secure reliability of the infrastructure. One example is the uninterruptible power supplies (UPS) that need to be adjusted according to the actual power consumption of the IT infrastructure. This adjustment becomes a difficult task if the consumption over time is volatile and contains peaks, leading to overprovisioning.

Therefore, from a strategic standpoint, before an optimization can take place, it must be considered what type of optimization to pursue. The objective could require to smoothing the curve shape of the energy profile to prevent from peaks, to relocate demand to more favorable time slots or simply to reduce the total demand of energy just to name three examples.

Apart from ecological objectives, quantitative considerations could also be included in the set of objectives that underlie the simulation scenario. In this particular situation, a rivalry between the ecological and economical goals often cannot be avoided. A “real” optimization of both dimensions is hardly possible, as the decision space allows not only one but many “optimum” solutions, depending on the desired preferences of optimization, either towards ecological or economical goals. Although optimization of both dimensions, ecological and economical goals is not subject to this paper, the dependencies between both dimensions should at least be taken into consideration when planning a simulation project.

4.3 Process optimization through simulation

The complexity of business processes makes necessary the application of a simulation approach instead of cognitive analysis. With the ability to gather energy consumption data of a business process at execution time and the applicability of possible alterations to the process, the simulation approach presented in this paper enables to find out the impact of process changes prior to the actual implementation in a real workflow. Simulation also enables to compare different optimization measures against each other with respect to their impact on the business process. As a result, the contribution of certain optimization measures towards the designated objectives of the optimization can be evaluated. Hence, simulation with regards to environmental objectives becomes a vital tool for analysis and decision support in terms of ecology-oriented process optimization within the Green BPM lifecycle.

5. Simulation of business processes

5.1 Definition of the objectives

General. In the following we will explain our simulation approach more in detail. The next chapters will be parted into general assumptions on the specific simulation steps (*General*) and the implementation of these statements in our example simulation case (*Implementation/Example*).

We employ the simulation model in five steps based on [24] that should be applied in an iterative manner: *1. Definition of the objectives, 2. Information acquiring, 3. Modeling and validation, 4. Simulation, 5. Evaluation of the results*

Implementation/Example. As mentioned in 4.2, the target objective must be defined in the first step. We assume that the reduction of the total demand in energy is our primary goal. In order to set the scope on the energy consumption instead of human resources, we refrain from using temporal restrictions for each activity. That means we do not focus on the time a certain activity will need to finish but rather on the energy the activity consumes. We assume the given process will be executed 500 times each day.

In the next step, necessary information must be acquired. That includes the amount of energy each activity consumes, the interdependencies between activities (i. e. the underlying process model) as well as further information on the process that does not directly affect the process flow but that could be relevant for the optimization. This might include for example the person that is responsible for the process or constraints that must be considered when altering the process model.

5.2 Information acquisition

General. Capturing the data necessary often is a tender spot to many BPS projects. In the case of BPS with respect to energy consumption, knowledge on the energy demand of each activity is necessary. With the *EnergyManager*, we proposed a software artifact to continuously measure the energy consumption of a single activity and the physical hardware during the execution [4]. The data gets stored in a database and can be used as input to describe the energy profile of the respective activities in the simulation model, either by using the mean or a distribution function (e. g. *Gaussian*). The latter offers the advantage of more realistic data by regarding the variance when simulating the process instances compared to the mean.

Besides the energy consumption of the activities, the simulation model should incorporate the probabilities for the outgoing process flow at the logical connectors of the process model (XOR, OR, AND) in order to model the behavior of the process flow according to the real system. If however no probabilities are known for the connectors, using process mining techniques to extract the information from logs of workflow management systems could help to gain the necessary information [25].

Implementation/Example. For our simulation experiment we made assumptions on the split of the process flow based on a *Bernoulli distribution*. The actual values can be found in Figure 2 next to the XOR-operators.

We used energy consumption data (mean) measured from activities of a business process similar to the sample process that we use to annotate our process model with (PDF reader, e-mail). Due to a lack of data for ERP and CRM applications we used empirical measurements from another research paper [27] for an estimation of the energy demand based on the consensus of a discussion group (Table 1). Where available we also used technical specifications for the peripheral devices (printer, display). In the case of PDF reader and e-mail, we made sure that the energy profiles of the simulation model approximately fit to the energy profile of the processes that the values originally stem from. To be able to model the energy profile as a Gaussian distribution, we added a fictional but yet realistic standard deviation to the mean of the empirically measured or estimated value. Table 1 shows an excerpt of the used energy profiles. These energy profiles are split into three categories: *application*, *display* and *static*. Application stands for the amount of energy that has been consumed exclusively by the application thread on the workstation. Display represents the energy consumed by the monitor while static describes the base load of the workstation and printer that results

Table 1. Energy consumption of the processes of the simulation model (excerpt) [4, 27]

Activity	Application	Energy Consumption (application)	Energy Consumption (display)***	Energy Consumption (static)	Energy Consumption (total)
Data for clearing of account available	**sub total**	**μ=120 Ws**	**μ=1,230 Ws**	**μ=3,805 Ws**	**μ=5,155 Ws**
	ERP app** (browser)	μ=120 Ws σ=30Ws	μ=1,230 Ws σ=308 Ws	μ=3,805 Ws σ=952 Ws	μ=5,155 Ws
Request data	**sub total**	**μ=137 Ws**	**μ=1,439 Ws**	**μ=3,226 Ws**	**μ=4,802 Ws**
	CRM app** (browser)	μ=80 Ws σ=20 Ws	μ=980 Ws σ=245 Ws	μ=1,810 Ws σ=453 Ws	μ=2,870 Ws
	e-mail*	μ=57 Ws σ=12 Ws	μ=459 Ws σ=92 Ws	μ=1,416 Ws σ=284 Ws	μ=1,932 Ws
Send account note	**sub total**	**μ=38 Ws**	**μ=628 Ws**	**μ=7,299 Ws**	**μ=7,965 Ws**
	PDF reader*	μ=8 Ws σ=2 Ws	μ=420 Ws σ=105 Ws	μ=416 Ws σ=104 Ws	μ=844 Ws
	Printer (spool+print)***	μ=30 Ws σ=10 Ws	μ=208 Ws σ=55 Ws	μ=6,883 Ws σ=63 Ws	μ=7,121 Ws

* Based on empirical measurement from [4]
** Estimations based on browser energy profile and [27]
*** Based on device specifications for a typical color laser printer and a 24" LED display

from the execution of the business process. We use this separation in order to be able to capture the impact of alterations on the application side of the business process.

5.3 Modeling and validation

General. Currently there are many different software applications available that are capable of business process simulation, such as ARIS Toolset or Adonis. Most of these software suites however stem from the domain of process modeling and only provide rudimental simulation capabilities with a limited range of functionality (e. g. limited variety of distribution functions). On the other hand there are a number of genuine simulation applications with a rich set of simulation-related functionality. Some of these simulation tools are generic while others are domain-specific. One of the drawbacks of generic simulation tools is that they often cannot import process model files such as EPC or BPMN. To manually build a simulation model from a process model, the definition of transformation rules might be necessary.

Implementation/Example. To demonstrate our simulation approach we used the business process from Figure 2. We transformed the process model to a simulation model of the software that we used by taking into account the following transformation rules:

a) The EPC element "Event" except for start and end events does not need to be modeled
b) The start event will be modeled as source, the end event as sink
c) The EPC element "Information Systems" does not need to be modeled
d) The EPC element "Activity" will be modeled as single station
e) The EPC element "Logical connector" will be modeled as flow control element
f) Process instances will be modeled as mobile units (MUs)

With Plant Simulation [26] we used genuine simulation software with a wide range of functionality that further provides a scripting language to customize simulation models. In contrast to ARIS and Adonis, the latest version 11 of Plant Simulation provides functionality to measure the energy consumption of process steps that we could extend with the built-in scripting language. For the reasons given above we decided to use Plant Simulation after a preliminary comparison between the three applications was performed.

Plant Simulation originates from the domain of industrial manufacturing, thus the names of the elements of the model are being used accordingly. A single station is an element that normally functions as an assembly station where manufacturing tasks are performed. The single station can be annotated with certain information such as needed production time per instance, thus it can be used to model the activities of the EPC.

Events in EPC are necessary to indicate that a certain activity is finished or as a possible outcome of a decision in combination with logical connectors. However, in Plant Simulation they do not have a purpose since we model decision points based on our empirically collected data as a flow control unit (FCU). The same applies for Information System objects of our EPC. FCUs are used to split the process flow to one direction or another. Therefore, we spare modeling events in favor of the use of FCUs and to raise the clarity of the visual representation in Plant Simulation.

While modeling rules in EPC demand to connect activities to events and vice versa, in Plant Simulation we can directly connect activities with each other and with FCUs in any desired order. The process flow is modeled by using so called mobile units (MUs). A MU is the pendant to a physical work piece that is created at the source and carried from station to station where it undergoes several working steps to be transformed into the final product before it leaves the model by entering the sink.

In the first step after creating the process model we set the probabilities for the outgoing process flow at each FCU using the graphical user interface. Although Plant Simulation provides rudimental functionality for modeling the energy consumption of activities, these basic functions do not allow measurement of consumption of consecutive paths. We had to implement this function by using the proprietary built-in programming language Simtalk. Simtalk uses an object oriented programming approach that allowed us to profit from object oriented characteristics such as inheritance. We created a new MU class with the name ProcessInstance that inherits the attributes of its parent class and was further enriched with additional attributes such as the energy consumption of every single station and the total energy consumption of every station passed.

We further attached each station with a method *getEnergyConsumption()* that returns random values representing the energy consumption of that activity based on the Gaussian distribution. Every time a ProcessInstance enters the station, the *getEnergyConsumption()* method will be invoked and the respective random value for the energy consumption of the application, display and the static demand of the workstation will be bound to the ProcessInstance object. When the ProcessInstances arrive at a FCU, the process flow will be forwarded according to the respective Bernoulli distribution of every FCU. After a ProcessInstance reaches the sink it will be collected for further evaluation of the energy consumptions.

The validation of the final model can be performed by comparing simulation runs with actual process behavior. As we use a sample process for our simulation, we were not able to perform such a validation. Therefore, we validated the model qualitatively by performing certain checks of individual elements against validity (e. g. routing, calculation).

5.4 Simulation and evaluation

General. In BPM literature many ways to enhance the performance of business processes have been examined since the first ideas about business process reengineering were published [23]. These include, but are not limited to, the termination of unnecessary activities, addition of new activities to raise the quality of the outcome, or parallelization and reordering of the activities. Most of these actions address the organizational aspects of business processes.

But there are also measures that cover technical aspects of a business process [4]. Energy could for example be saved by leaving software applications (e-mail client, PDF reader) open instead of starting the application each time it is needed. Increasing the time interval for checking for new e-mails and renouncing attachments could further decrease the amount of energy needed during a process instance.

Implementation/Example and quantitative evaluation. The simulation of 500 ProcessInstances resulted in the total energy consumption in kilowatt seconds (kWs) shown in Table 2. As can be seen, the results show a gap between two groups of activities. The activities “Create final account” and “Send account note” turned out to have a higher demand compared to the remaining four activities. These two processes are mandatory and need to be passed at least once. The process for sending an account note further comprises a sub process where a PDF document needs to be printed in order to send it to the customer. Although we calculated with only 15 seconds for the print, this sub process results in a high margin of static energy demand. A similar energy profile applies to the process “Create final account”. This process needs a relatively long amount of time in order to create a customer account in the ERP system, thus resulting in a high margin of static and display energy demand. The remaining four activities have a higher margin of demand for the application threads compared to the display and static category.

As a first measure we tried to optimize the process path of the activities that every instance needs to pass at least once. We replaced the sub process “print” of the activity “Send account note” with the transmission of the account note via e-mail. Due to the high amount of static energy consumed by the printer, this step resulted in a decrease of total energy demand from 10,953 kilowatt seconds (kWs) to 8,326 kWs (-23.98%). Of course the substitution of printing in favor of e-mail leads to a higher load on the local e-mail server that we did not regard in our simulation. Nevertheless, the energy saving of this step is considerable.

Table 2. Energy consumption of n=500 ProcessInstances after the optimization

Process	*Energy Profile prior to optimization (in kWs)*				*Energy Profile (in kWs) after measure 1*				*Energy Profile (in kWs) after measure 2*			
	Total	**Static**	**Display**	**App**	**Total**	**Static**	**Display**	**App**	**Total**	**Static**	**Display**	**App**
Data for clearing account available	1.192	827	306	59	1.183	820	304	59	1.165	826	280	60
Accounting information check	1.091	426	605	60	1.086	420	605	61	1.091	420	611	60
Request data	590	190	379	21	564	187	356	21	385	137	232	15
Correct accounting information	550	387	140	23	543	384	137	22	551	387	142	22
Create final account	3.550	2.502	944	103	3.562	2.510	950	103	3.554	2.509	941	104
Send account note	3.980	3.650	311	19	1.388	916	440	33	1.383	918	432	32
Mand. reminder mail	-	-	-	-	-	-	-	-	160	105	27	28
Total Consumption	**10.953**	**7.982**	**2.685**	**285**	**8.326**	**5.237**	**2.792**	**299**	**8.289**	**5.302**	**2.665**	**321**

As second measure we employed the benefits of the simulation approach by analyzing the process path and cycles. The consumption of total energy of the activity “Request data” accounts at about 54% compared to the total energy demand of “Accounting information check”. However, only 30% of all instances pass “Request data” once and another 20% of that share more than once while on the other side 100% of the instances pass “Accounting information check” at least once and another 30% pass this activity more than once. Compared to the small probability of an instance to take the path to “Request data”, the activity consumes a relatively large amount of energy, which should be addressed. A measure to reduce the energy demand is to avoid instances to take the path to the activity “Request data” and further avoid cycles from and to “Request data”. The idea was to add another activity that might positively alter the distribution responsible for the process flow. In our example we can address this problem in two different ways: by supporting that the “data for clearing of account” is available either at the very start of the process or after the data was requested once in order to avoid cycles for a second or even third request. We decided to append a new process as a reminder for the customer’s new energy provider to hand in the necessary data. We modeled this new process as a predecessor to “Data for clearing of account available”. In a real-world scenario, this task could be performed either automatically or manually by the person in charge of the case. In our example we assumed that the task would be performed manually by sending an e-mail at some time before the process starts. We valued the impact of this measure conservatively as a reduction of missing data that would direct the process flow to “request data” from 30% to 25% of all instances. We further expected a decrease from 20% to 15% for all instances that need at least a second notice through the “request data” process. Although this newly employed process caused an additional energy demand of 160 kWs, it also resulted in a slight decrease of the total consumption from 8,326 kWs to 8,289 kWs which is a saving of 0.4% at 500 instances. Assuming that reality surpasses our conservative estimation, the saving could be even higher.

As a last measure we simulated the reduction of the brightness of the display to a level of 40%. This measure saves a total of 15% of the display share of the total consumption [4]. As a result, the total energy consumption decreased to 7,888 kWs (-4.8%).

Implementation/Example and qualitative evaluation. Apart from the mere analysis of the quantitative figures, the simulation approach allows us to observe the impact of measure 2 on the number of iterations of a single instance through the cyclic parts of the process model. We analyzed the change in total iterations over the following two different cycles which resulted from introducing measure 2:

(1) “data for clearing […] available” → “request data” → “data for clearing […] available”
(2) “request data” → “request data”

Before introducing measure 2, the cycle to request the data once and back to “data for clearing of account available” had been performed 219 times, resulting in a total consumption of 1,066 kWs. By introducing the optimization with measure 2, we could decrease the total cycle number to 157 at an accumulated energy demand of 763 kWs (-28.4%). That is a substantial amount, considering a reduction of the probability to take that certain route by only 5%.

The analysis of cycle type (2) before and after the optimization resulted in similar results. Before measure 2, the cycle of type (2) had been performed 61 times, being responsible for an aggregated energy consumption of 158 kWs. After the optimization, cycle type (2) was performed only 29 times, resulting in a total consumption of 74 kWs (-53.1%). Again, this improvement came along with a reduction of instances that needed at least a second data request by only 5%.

Finally, introducing measure 2 could also decrease the number of consecutive iterations through both of the cycles (Table 3). When considering not only the energy savings but also traditional evaluation criteria (costs, expenditure of time) these values could also be optimized along with a decrease of consecutive iterations through cycles.

Table 3. Number of consecutive iterations through cycles

# of consecutive iterations	Cycle (1): # of Instances		Cycle (2): # of instances	
	w/o meas. 2	w/ meas. 2	w/o meas. 2	w/ meas. 2
5	1	2	0	0
4	6	1	0	0
3	8	5	2	0
2	30	25	9	5
1	106	78	37	19

6. Discussion of our findings

The intention of this paper was to advance towards our long-term research vision by developing methodologies supporting the phases of the Green BPM lifecycle based on implications from the monitoring and controlling phase. Through the integration of the proposed simulation approach together with data automatically collected by energy sensors, the evaluation of alterations of a process on instances at run-time becomes possible.

We could demonstrate the value of sensor data in combination with a simulation approach by successfully reducing the total energy consumption of a complex business process. With applying three measures, we could reduce the energy consumption by a margin of 29.98% in total.

In addition to this quantitative approach, we performed an analysis to assess the impact of changes to the process from a qualitative point of view. We found that the proposed changes to the process are able to reduce the overall number of consecutive cycles by a margin of 28.4% for cycle (1) respectively 53.1% for cycle (2). Reducing the number of consecutively iterated cycle not only impacts on the energy consumption but on monetary and performance indicators as well.

However, the presented approach comes with some drawbacks as well. First of all, creating a simulation model requires an initial effort to collect necessary data and transform available process models to the notation used by the software of choice. Unfortunately we did not have available empirical data for every activity. We used data from energy sensors along with estimations for activities that we did not have data from yet. We are aware of this flaw and currently prepare a case-study to replace these assumptions by real world data.

A second flaw of process simulation is the complexity of the modeling process. With the energy consumption we focused on environmental objectives. If further indicators that typically are subject to simulation (time, costs) should also be considered and optimized at the same time, data collection and modeling can become a difficult task as continuous data as a function of time will be needed. Thus, the integration of further objectives in the decision analysis is a subject to future research.

Our results show a tendency that optimization of single process steps (measure 1) and of the information systems involved in every process step (measure 3) offer a higher potential for energy savings compared to process flow optimization (measure 2). But as our results based only on a single process, the observation of a higher number of cases is necessary in order to be able to make general statements.

7. Conclusion and future research

As Green BPM becomes a popular issue, methodical support for the optimization of complex business processes with respect to environmental objectives becomes necessary. We presented a simulation concept and the application along with a sample process to evaluate the impact of changes to the process at instance level. While incorporating existing research in terms of a software artifact to measure energy profiles [4], we took a step towards a more holistic approach to Green BPM.

Future work shall focus on the application of the simulation in a real-world scenario with the energy supplier that our sample process stems from. By doing so, we will have the opportunity for an extensive validation of our simulation model by comparing simulation runs with actual process behavior prior to the execution of optimization measures.

Another step towards a convenient and easy to apply simulation solution can be taken by automatizing the data import to the simulation software instead of copying the values such as energy consumption manually from the *EnergyManager* database. We further want to evaluate if the energy consumption can be extracted from log files of workflow management systems such as *Activiti*. With the application of process mining techniques, the combination of automatization together with sophisticated energy data could further enhance our simulation approach by all means.

Finally, the automatic generation of simulation models based on graphical process models and vice versa could help to rapidly incorporate the results of the process optimization to existing processes in the sense of a Green BPM lifecycle.

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