The Differences and Commonalities between Green and Conventional Business Process Management

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Abstract— **Environmentally-aware resource usage has become an important aspect for today's industries, governments, and organizations. Customer demands, legal requirements, and financial aspects force organizations to rethink and reorganize their existing structures and business processes. Along with an increasing adoption of Business Process Management (BPM) in organizations, efforts are being made to also enable a green rethinking and change of BPM. However, in order to be capable of performing business in a green manner, the "delta" has to be known that distinguishes green business process management from the conventional one. In this paper, we investigate key perspectives of conventional BPM and compare them to requirements originating from an environmental perspective. The key perspectives we refer to are the business process lifecycle, key performance indicators, BPM architectures, and business and strategy. We highlight aspects that need to be extended, newly developed, or refined in order to achieve a holistic green BPM approach.**

Keywords-Green IT; Green Business Process Management; BPM Lifecycle; BPM Architecture

I. INTRODUCTION

More and more organizations develop an increasing awareness of sustainability with respect to the environmental impact of their business operations. Moreover, customer demands as well as legal requirements put pressure on organizations to rethink their existing processes in order to find possibilities for environmentally friendly adaptations. However, the optimization of ecological aspects within an organization requires a holistic perspective. Business Process Management (BPM), for example, provides such a perspective in terms of technology and related methodologies. BPM refers to concepts, methods, and techniques that support the design, configuration, enactment, evaluation, and administration of business processes [5]. Through the application of BPM, organizations try to optimize certain aspects of their business with the inherent intention to reduce costs, improve quality, save time, and increase flexibility [1]. In recent years, the concepts and methods of BPM are being extended in order to account for different cross-cutting concerns. Besides concerns like security or compliance, one new challenge is the proper application of BPM in the context of Green IT [27][19].

So far, there exist only few approaches discussing the use of BPM in the area of the environmental impact, for instance [3], [25]. The main problem which is still unsolved is to identify how existing BPM approaches and techniques can be leveraged with respect to environmental awareness. This, in turn, originates further questions like: What are the differences, compared to conventional BPM, when considering ecological indicators? What are the characteristics of green BPM? Is green BPM of the same nature as conventional BPM? So far, these basic issues are covered insufficiently in research.

The objective of this paper is to investigate and identify differences and commonalities of green BPM compared to conventional BPM. This serves organizations as a guideline how existing BPM environments can be leveraged and extended to support green BPM within organizations. For this reason, our proposed comparison is based on four common perspectives of BPM within organizations: (1) the business process lifecycle, (2) Key Performance Indicators (KPIs), (3) a service-oriented business process management architecture, and (4) business and strategy aspects related to BPM. These perspectives cover a wide range of relevant aspects regarding the impact of BPM to an organization. The lifecycle covers all phases of a business process, the performance indicators cover the monitoring and evaluation of a business process, the architecture covers its technical implementation, and the business and strategy aspects cover the impact of the management perspective. We further use this perspectives to present a classification of existing green BPM approaches. Consequently, the contribution of this paper is twofold: Firstly, we investigate differences and commonalities of conventional and green BPM based on the identified perspectives. Secondly, we classify existing green BPM approaches with respect to the identified differences and related BPM perspectives.

The remainder of this paper is structured as follows: Section II presents use cases motivating the use of BPM with respect to the environmental impact of organizations. The differences of green and conventional BPM are presented in Section III. Next, Section IV provides a classification of state-of-the-art approaches on green BPM. Section V concludes the paper and points out future challenges.

II. THE GREEN MOVEMENT

The importance of implementing environmentally-aware business processes can be observed in several industries. Various organizations have made first steps towards improving the environmental impact of their processes by defining and realizing corresponding business strategies and process adaptations. In the course of our comparison we have investigated existing scenarios already implemented by international organizations. These publicly available scenarios [6][7][8][9][10][11][12][13][14][15][16] as well as existing research approaches [3][18][19][21][25][29] provide the requirements for environmentally-aware BPM. Thus, their realization helped us to identify the specific aspects needed for Green BPM. Furthermore, these scenarios allowed us to define the relevant perspectives observed in our comparison. A selection of the scenarios is presented in the following:

- The railroad company Deutsche Bahn AG launched the “DB Eco Program” which consists of multiple projects for climate protection, using renewable energy, etc. [7].
- Swiss International Air Lines AG introduced methodologies to reduce their fuel consumption and spends research effort for alternative fuels which reduce the carbon footprint [10].
- The cargo company DHL Vertriebs GmbH & Co. OHG provides a “Go Green” option that compensates the environmental impact of their shipment by donating for climate projects [6].
- Danone Waters ecologically improved the PET bottles of their mineral water by using renewable and recycled materials [13].
- The outdoor equipment supplier Fjällraven optimizes its manufacturing processes to not use fluorocarbons, and to use natural impregnation, organic cotton, recycled polyester, and compensates climate impacts by appropriate projects [12].
- The German oil company Jet joins a project initiative that supports worldwide climate projects to compensate the fuel burned [9].
- Some energy companies or resellers, e.g. Tchibo or Austin Energy provide electricity from solar collectors or hydro power, for example [8].
- The Atmosfair organization supports worldwide climate projects. Passengers can calculate their carbon impact per flight to compensate them by donating the appropriate amount of money to various climate projects [16].

In most organizations, BPM is already in use to ensure their competitive capability. Consequently, with respect to the proposed scenarios, the central question to be answered is if we can use conventional BPM in order to provide environmentally-aware business processes? Or do we need to extend or refine current approaches? In order to answer these questions it is necessary to apply the new requirements to conventional BPM. This allows us to identify the corresponding impact and necessary adaptations.

III. DIFFERENCES OF GREEN AND CONVENTIONAL BPM

As we will show in this section, green BPM is not an entirely new way in optimizing organizations’ business processes. In fact, existing BPM methodologies and techniques such as discussed in [1] are leveraged, extended, or refined in order to support the new requirements emerging from environmental concerns. We first discuss the business process lifecycle. Based on the different phases of the lifecycle, we then discuss the other perspectives. Within the discussion we emphasize which aspects need to be extended, modified, or refined – and where new challenges arise. Additionally, at the end of each section we outline the major aspects of the corresponding perspective. The research method used for this comparison is based on the guidelines “design science in information systems research” introduced by Hevner et al. [4]. Thus, we incorporate the strategic guidelines and business needs emerged from organizations in order to improve their environmental impact and apply relevant foundations of BPM in order to identify the means of a holistic green BPM approach.

A. *Business Process Lifecycle*

The business process lifecycle provides a good overall understanding of the concepts and technologies that are relevant in BPM [5]. Hence, we will discuss the phases depicted in Figure 1. with respect to the characteristics of green BPM and emphasize the critical aspects that need to be considered when implementing a holistic green BPM approach. The boxes depicted with dashed lines represent new parts required for green aspects. The ones with doubled lines represent extended parts from conventional BPM.

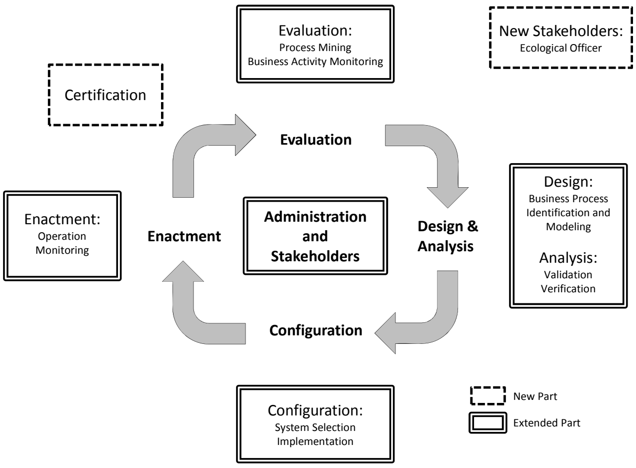

Figure 1. Conventional Business Process Lifecycle

Design and Analysis. The main goal of this phase is the identification and design of business processes. In order to consider the environmental impact we need to fully integrate a novel dimension besides the existing KPIs of an organization. We named this dimension Key Ecological Indicators (KEIs) [2]. A definition of KEIs can be found in Section III.B. In particular, KEIs significantly influence both design and analysis. Firstly, they influence the design of (new) business processes or at least the identification of new variants of a given business process. Therefore, a business process may be designed considering, for example, alternative raw materials that may influence production processes, or the use of different resources with different Service Level Agreements. Furthermore, in some cases a totally new way of design practices is conceivable, where customers may decide between two different business processes alternatives with different environmental impact and different cost structure. Secondly, the design of business processes needs proper methods and techniques to integrate the required KEI information during design-time. To support the business process modeler, different data sources need to provide ecological information about the tasks and services used in the composition of the process. This includes, for example, sensor information for measuring the energy or water consumption as well as specific ecological Service Level Agreements (SLAs) when the service is provided by a third party. The design of new business processes also entails proper validation and verification methods with respect to the strategic objectives and compliance to other business processes of an organization.

Configuration. The configuration phase has two important aspects: the system selection with its configuration and the implementation. While the selection of a runtime environment and services in conventional BPM environments is mainly focusing on economic, security or compliance aspects, we need to take a broader point of view when considering ecological aspects. For example, a specific task can be performed by an IT-system very quickly and efficient. However, a human being might perform this task with less direct energy consumption or environmental impact in general. This may lead to a trade-off decision in choosing the strategically best fitting systems and configuration to satisfy all strategic objectives. The configuration of a business process and its tasks or components might also involve the underlying execution environment [18] and its implementation. Considering the IT domain, improvements in the amount of emissions or energy consumptions can be achieved by associating the process tasks to specific resources or types of resources (top-down approach) or by designing the process to best fit a given energy efficient infrastructure (bottom-up). The top-down approach implies the selection of a more environmentally sustainable resource compared to the previously used resource, performing the process as well as the target-oriented usage of this resource. This approach, for example, might bundle tasks from different process instances and execute them all within a predefined time frame. Consequently, it is also important to collect information about the type of resource, the intensity of usage, or which sub-resources are used.

Enactment. This phase comprises the operation and monitoring of business processes. An important aspect here is to properly extend the monitoring components. Beside the existing KPIs and their representation of the performance of a business process, it is necessary to gather further information about the runtime environment. This concerns the values of the KEIs, which can be provided by specific sensors measuring the energy consumption or generated emissions, for example. Consequently, the monitoring component must also support the correlation of the different information sources in order to allow a proper evaluation of the ecological and economic behavior of the process. In addition, this phase also actively controls the execution of the business process instances. Considering the monitoring phases this encompasses two parts relevant for green BPM. The first part is the proper management of resources in order to achieve a minimal environmental impact. Cloud Computing, for example, provides the means for dynamically using the resources depending on the actual demand. The second part concerns the efficient execution of a business process, i.e. not only providing a demand-specific amount of resources but also using the right resources. In BPM, this can be realized by using methods for a dynamic binding of services, for example.

Evaluation. The evaluation phase utilizes the information available from the process monitoring to analyze the business processes. The information from conventional business activity monitoring needs to be extended with ecological information in order to identify the specific environmental impacts and dependencies of different activities and business processes. Thus, evaluation methods and techniques need to be extended in order to provide proper support for both, KPIs and KEIs. The concrete evaluation and analysis of business processes might be realized by adequate business dashboards and process analysis indicating the KEIs of interest. This enables stakeholders to identify new process-specific optimization patterns or to use existing patterns or best practices that cover specific issues for making processes more sustainable with respect to their environmental impact. In previous work [2], we already introduced process views as a suitable method to visualize and analyze business processes based on certain criteria like KEIs. This allows business process designers to analyze their processes and to compare different process alternatives with respect to their ecological and economic impact.

Administration and Stakeholders. Finally, the administration of the different artifacts of BPM also needs to be extended in order to manage all phases of the lifecycle in a suitable way. Especially the new information sources, the new business processes, activities, and their variants, and the closer concatenating of the processes and their infrastructure with respect to the processes KEIs necessitate an extensive administration and management. This administration is performed by the cooperation of different stakeholders. Besides the common stakeholders of BPM, such as the Top Management, Business and IT Architects, Business Analysts, IT Operators and Developers, or the Operational Staff [2], we introduce a new role: the *Ecological Officer* takes a cross-cutting role closely collaborating with other stakeholders like the *Process Designer*, the *System Architect*, or the *Business Engineer*. The task of this role is, amongst others, to specify relevant KEIs with respect to the organizations' strategic objectives, to identify and define proper measurement methods, to achieve an adequate correlation of existing processes and environmental information, and to find suitable adaptation strategies fulfilling the defined KEIs.

Certification. This new phase in the lifecycle represents the methods and tools for certifying the business processes of an organization with respect to their environmental impact. On the one hand this enables the traceability of process performance with respect to the corresponding environmental impact. According to [30], traceability denotes the ability to describe and follow an artifact from its origin through all phases of its life. On the other hand it can be used to verify the compliance of legislative requirements and also to make green changes visible to customers and business partners.

Major Aspects in Lifecycle:

- New Stakeholder: Ecological Officer
- Ecologically-aware Process Design
- Ecologically-aware Resource Selection
- Sensoring and Monitoring of Ecologically Relevant Data
- Green Process Analysis and Evaluation
- Certification

B. *Key Performance Indicators*

KPIs belong to the *Design*, *Enactment*, and *Evaluation* phase of the business process lifecycle and provide the means to monitor and evaluate the performed business processes. In order to identify and determine the environmental impact of business processes, we have introduced so-called Key Ecological Indicators (KEIs) in previous work [2]. These green Quality of Service (QoS) measures are used to identify which resources a process or single task employs. Therefore, the KEIs may consist of a wide variety of quantitative measures, such as greenhouse gases, energy consumption, CPU consumption, or water consumption. Qualitative measures may be land or air pollution. Based on the perspective of interest, e.g. IT-services, human services, or commodity services, different KEIs may be put in place. Of course, traditional QoS still need to be taken into account in order to keep an organization competitive. This, in turn, results in a trade-off between conventional QoS and green QoS. This is not trivial as not only the particular process observed, but also many other processes may be influenced by a certain ecologically-driven decision. A detailed trade-off analysis is beyond the scope of this paper.

Technically, we defined a KEI as a tuple consisting of an "ecological characteristic" (EC) metric and a target value function based on the ecological goals one wants to achieve [2]. For example, a KEI for a particular business process could be specified as "max (CO2 emission of process P) < x1". Therefore, the definition of a KEI is very similar to KPIs; the difference is that the underlying metric definition is based on ecological characteristics, while in case of KPIs the underlying metrics concern time, quality, or cost [20]. Based on the KEIs one is interested in, e.g. energy or water consumption, used paper, produced waste, or emitted carbon dioxide, a process can be "more green" in different situations. These situations include for instance: a resource needs less energy than before, an activity is performed using another resource, or a single process may be cut into two domain-specific processes that better adapt the ecological needs.

These examples reveal that the definition and use of KEIs allows stakeholders to measure and compare the environmental impact of a process from different perspectives. However, there is no need to consider all KEIs at the same time. One can, for example, distinguish them into general KEIs and process-specific KEIs. A general KEI may be the CO2 emission. A process-specific KEI may, for example, be specific for recycling in industrial manufacturing processes which are performed differently in each organization. The collective environmental impact of an organization is then determined as combination of different KEIs. First approaches in this area are presented by [21]. Furthermore, the KEI values can be analyzed and ranked by an independent certification authority in order to improve the transparency and comparability.

To consider the different and heterogeneous green measures within organizations several preliminaries are necessary in order to provide the means for using and comparing them. First, proper measurement techniques need to be defined in order to gather the required environmental information. This information may directly be assessed during process execution or gathered from other information sources, like sensors or environmental studies. Secondly, the information needs to be correlated with the executed process model. This implies both, the correlation with single activities or complete processes and the correlation with other QoS measures. Thirdly, it assumes adequate mapping functions that allow measurement results to be quantified.

Major Aspects in Key Performance Indicators:

- New Performance Indicators: Key Ecological Indicators
- New Strategic Objectives
- Trade-Off between conventional and new Indicators
- New Measurement and Aggregation of Indicators

C. *Business Process Management Architecture*

The different phases of the business process lifecycle can be supported by an adequate implementation of a service-oriented business process management architecture. This architecture is required in order to determine and correlate the different ecological metrics with business process runtime information. In Figure 2. , the *Input Data* represents the business process runtime (Enactment phase), the *Event Infrastructure* and the *Management Components* represent the Evaluation and Design phases, and the *Adaptation* represents the Analysis and Configuration Phases. When thinking about green business process management, however, some adaptations of those existing business process management aspects are necessary to cope with all green requirements. In order to describe the identified differences, we use an extended business process management architecture (see Figure 2.) originally proposed by [17]. A detailed explanation of each perspective of the architecture is provided in the following.

Input Data. At this first stage the *input data* provides primarily the BPM-related models. This includes the process models as well as business process events produced by the runtime environment or a simulation environment, respectively. The runtime environment of workflows usually consists of a process engine, various services, communication channels, human task managers, and connections to other business partners. Beside this information also specific green sensor data is needed which allows determining the defined KEI metrics. If such sensors are not available, due to the use of third party services for instance, assumptions must be made. Sensors can be provided, for instance, by specific web services which enable the information integration into existing event infrastructures [22]. In some cases, a sensor is insufficient as data cannot be provided based on simple measurements. This occurs, for example, if long term studies are necessary or in case particular services are used from by third parties. In these cases, the information needs to be supplied manually from studies or service level agreements from third parties. For the purpose of reusing this information may be stored in a knowledge repository, for example. A corresponding web service wrapper may than enable the integration in existing event infrastructures.

Event Infrastructure. The input data is sent to the *event infrastructure*. This could be, for example, a common enterprise service bus. The *K*I-services* are responsible for determining the different performance metrics an organizations is interested in. To account for KEIs within the *K*I-services* some extensions of existing KPI processing methods are needed [20]. The major issue relevant for KEIs is the proper processing and correlation of KEI-related events and process instances in order to calculate the performance metrics. Therefore, conventional complex event processing techniques may be used. An issue occurs when the same resources are used across different process instances. In these cases, proper distribution methods must be defined in order to cover the collective environmental impact of a resource (e.g. lifecycle assessment) [31].

Management Components. The *Extraction, Transformation, and Loading (ETL) service* processes the data from the *Event DB* to store the results in a data warehouse. Within a green BPM solution, the data warehouse schema needs to be adapted in order to efficiently support the green performance metrics. The implementation strongly depends on the type of metric that is used. Additionally, a management dashboard supporting green metrics retrieves data from the data warehouse and generates pre-defined reports. In [2], for example, we proposed an approach to analyze process models and their corresponding conventional and environmental process data stored in the data warehouse. This allows stakeholders to directly react on KEI deviations by investigating the relevant activities and also to evaluate alternatives and their environmental impact.

Adaptation. The process adaptation contains all relevant aspects of modifying the business process models towards a decreased environmental impact. This includes common business process modifications like adding or removing activities, change of control or data flow, or exchanging activities. However, in green BPM we may also consider adaptation forms which are not practically used in BPM yet. For example, a process could be split in two different process alternatives, a conventional one and a green one. Customers can then decide which one they want to use. Of course, this may affect the cost or quality of the process. One could also consider the change of existing infrastructure, e.g. the exchange of the electricity supplier. Another important aspect in green BPM is not to focus only on a specific process, but also consider "*general aspects*" of business processes, like recycling activities or reusable services, for example. If a need for adaptation has been discovered, the adaptation could be performed either manually, semi-automated or fully-automated. This strongly depends on the type of restructuring and cannot be generalized. There is also a strong relationship between BPM and Service-oriented Architectures (SOA). SOA defines how modular resources can be used by the business in an agile way. Consequently, SOA is relevant to the complete business process management architecture as many parts of BPM are supported by services. However, to consider environmental aspects within a SOA extensions of conventional mechanisms for finding and selecting services are required. Green Service Level Agreements (SLAs) need to be defined in such a way that they support the KEIs of interest and are able to describe services with respect to their conventional and environmental properties. Subsequently, this requires proper mechanism to aggregate the SLAs in order to provide efficient resource allocations. A first approach in this research area is proposed by [32] or [21]. Further, proper policy extensions are needed to implement these SLAs.

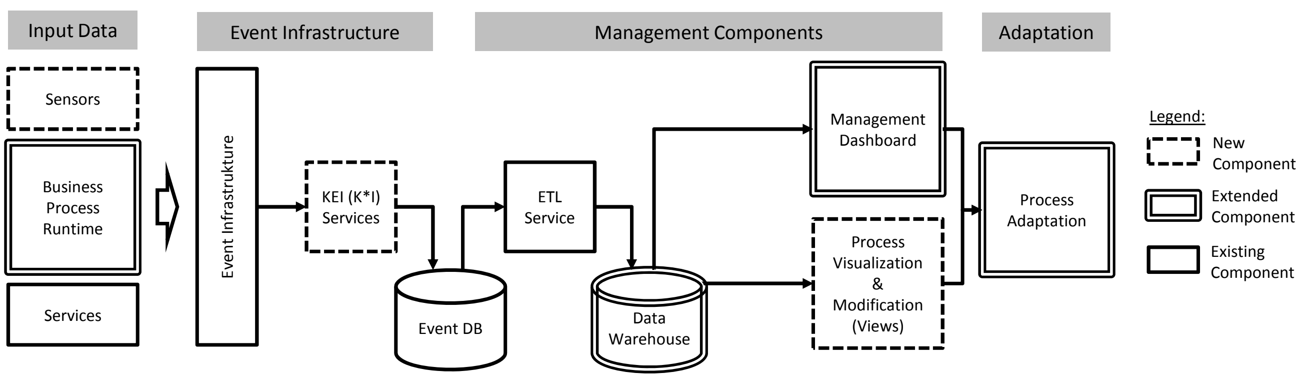

Figure 2. Business Process Management Architecture

Major Aspects in the Business Process Management Architecture:

- New Sensors provide data related to Business Processes
- New KEI services for determining Ecological Indicators
- Appropriate Monitoring Facilities supporting KEIs
- Ecological Management Dashboard
- Methods and Tools for Ecological Process Analysis
- Methods and Tools for Ecological Process Adaptation

D. Business and Stragegy Aspects

BPM is a management-driven approach [5]. Business strategies and objectives affect the way how business processes are designed, executed, managed, and optimized. For example, an organization that wants to achieve a price leadership tries to decrease its costs more than an organization with focus on superior quality. So, when planning strategic decisions it is also necessary to consider the impact such decisions have on the environmental impact. Thus, it is vital to decrease the energy consumption while not decreasing the performance. We use the value chain proposed by [23] (see Figure 3.) to identify and discuss the new business requirements relevant to green BPM. This allows stakeholders to adapt decisions with respect to their environmental impact at a very early stage in BPM maturity. The different phases of the value chain are discussed in detail in the following.

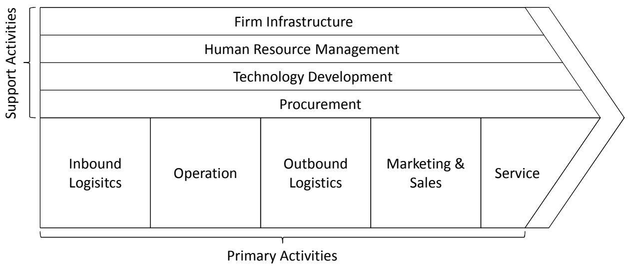

Figure 3. Value Chain proposed by Porter

Logistics and Operation. The parts *Inbound Logistics*, *Operation* and *Outbound Logistics* are widely relevant to the execution of business processes and their underlying infrastructure. An organization needs to determine and consider the environmental impact of their processes and infrastructure in order to decide how processes should be designed or optimized. Again, the strategic direction mainly influences this development. This has already been discussed in Section III.B and aims at properly solving the trade-off between the dimensions cost, quality, time, flexibility, and environment. On the other hand, it is also vital to achieve a proper usage of existing infrastructure. The organization needs to know how their infrastructure copes with the requirements of existing KPIs and new KEIs. This may lead to different design decisions of processes or services.

Marketing and Sales. The marketing department of an organization is responsible for the public appearance of the organization. By propagating the reengineering activities from *Logistics and Operations* or by utilizing smart marketing strategies the organization may significantly improve its public perception. Due to a green marketing the ecological image of an organization can be improved which may result in new customers or even novel business models. As an example, the organization may introduce an alternative green service or a new ecological product line, for example.

Procurement. This part deals with the procurement of all resources needed or processed within the organization. So, it has direct impact on the environmental impact that is “imported” into an organization. Depending on the decision which resources an organization procures it also affects the impact on their own products and services. If the organization, for instance, buys only materials or products declared as fair trade (see fairtrade.net), they can improve their environmental impact and also achieve a more positive appearance in public. This can be intensified by using adequate certificates (see Section III.A). Consequently, organizations need additional guidelines that account for green procurement considering the environmental impact of products and services.

Technology Development. This part includes research and development, process automation, and other development used to support the implementation of the value chain. Focusing on an ecological perspective, organizations need to establish the environmental dimension as basic requirement in order to ensure customer loyalty and legislative compliance in the long term. For example, the development of new, economical cars improves the consumer acceptance as well as a responsible usage of finite resources like fuel.

Human Resource Management. The employees of an organization are an important aspect in improving an organization’s environmental impact. Especially the exposure of resources within an organization is critical. Internal guidelines and activities can help to advise employees in their daily resource usage and may lead to rethink established usage patterns. If employees can be made aware for their daily resource consumption significant savings can be achieved [24]. This can be, for example, to question the necessity of business trips instead of video conferences or to define guidelines for meetings, trainings, and day-to-day business. First approaches are emerging on optimizing the carbon footprint of employees [24] which reveals potential for further environmental optimization.

Firm Infrastructure. This part is strongly related to the *Logistics and Operations* part. It determines the complete infrastructure of an organization, including the IT-infrastructure, facility infrastructure, machinery, and logistics. A well-defined infrastructure with respect to the environmental dimension thus helps to further improve the environmental impact by supporting proper communication and exchange between automated business processes and corresponding resources. An interesting aspect here is the outsourcing of parts of business processes or services. For example, companies that are specialized in certain services may provide a better performance from an ecological perspective. Consequently, the business outsourcing debate must also be extended to the environmental dimension which, again, may end up in another, new trade-off.

Major Aspects in Business and Strategy:

- New or Adjusted Strategic Objectives define extensiveness of Environmental Awareness
- Environmental Awareness affects both primary and support activities of organizations

IV. Classification of State-of-the-Art Approaches on Green BPM

In this paper we have identified various differences of green BPM compared to conventional BPM. The investigated perspectives *Lifecycle*, *Key Performance Indicators*, *BPM Architecture*, and *Business and Strategy* and their respective aspects are now suitable to classify existing approaches on green BPM. Thus, in the following we propose a lightweight classification of existing green BPM approaches in order to identify the individual aspects already addressed by these approaches. For the lack of space, we only provide a selection of commonly known research approaches that provide a good basic overview in this research area.

Ghohse et al. An early approach on capturing green BPM was proposed in [25] and has later been extended and detailed in [19], [21], and [26]. The authors provided a first approach for the computation of carbon emissions when modeling business processes. They identified environmental properties (describing water or energy consumption, or the impact to the flora and fauna) and resource types that can be annotated to the process model in order to calculate the total environmental impact of a process. They addressed these aspects by proposing a mechanism to aggregate heterogeneous environmental properties of activities [21] as well as a methodology on how to capture and utilize the relationship between resources and process activities [19]. Additionally, they introduced an approach to ecologically improve business processes by redesigning business process models using so-called process fragments. These fragments, usually comprising a specific functionality, can be exchanged based on their environmental impact.

Lifecycle: The approaches are mainly focusing on the *Design and Analysis* phase of the lifecycle. Process models are annotated during modeling time which allows determining the aggregated resource consumption. This information can also be used as decision support for process model adaptation. Runtime information from existing process instances is widely neglected. *Configuration*, *Enactment*, and *Evaluation* are not part of this work.

Key Performance Indicators: The information on emissions is taken as granted. However, the approaches support the annotation of this information to the process model and also consider the aggregation of heterogeneous green performance indicators.

Architecture: The approaches are mainly based on the Abnoba which provides a comprehensive business process management framework supporting environmental aspects of processes. However, the support of designing and analyzing the process models and fragments does not consider any runtime information.

Business Aspects: The approach does not consider any business-related aspects.

Ardagna et al. Another approach is provided in [27]. The authors developed mechanisms for energy-aware resource allocation and policies for SOA- and process-based applications while ensuring certain QoS requirements. The proposed approach identifies three layers: process layer, infrastructure layer, and control layer, which provide an integrated approach to decrease energy consumption in ICT. The approach has been further refined in [28].

Lifecycle: The approach comprises both, design time and runtime. Processes are designed considering ecological and economic requirements. The optimization of web services selection is performed within the process layer. The infrastructure layer deals with the trade-off between performance and energy consumption. Therefore it uses current runtime information and adapts services if possible, i.e. decrease the energy consumption while not worsen the performance. Additionally, the control layer performs server provisioning and virtual machine placement decisions.

Key Performance Indicators: The approach focuses only on energy consumption and how it can be reduced. Due to this focus no aggregation mechanisms are needed.

Architecture: The problem of efficient use of resources in order to decrease energy consumption does not require the full architecture as proposed in Section III.C. The focus here is on business processes and sensor data as well as the analysis of this data and corresponding adaptation mechanisms.

Business Aspects: The approach partly considers business related aspects. A basic assumption is to always fulfill customers' requirements and to addresses the trade-off between performance and energy consumption. This requires proper technology and services used in operation. Hence, this approach deals (at least partly) with ecologically optimized *Operation*, *Marketing and Sales*, *Procurement* and *Technology Development* parts of the Value Chain.

Capiello et al. The approach in [18] focuses on models and methods for the analysis and reduction of energy consumption associated with applications which are made energy-aware through annotations and Green Performance Indicators (GPI) in applications.

Lifecycle: The approach defines a green lifecycle for development of adaptive, self-healing, and self-managing application systems able to reduce energy consumption. The phases comprise the design, analysis, adaptation, and monitoring on the application level. These phases are very similar to the conventional BPM lifecycle proposed in Section III.A and covers all phases except certification.

Key Performance Indicators: Beside the consideration of conventional QoS the approach also uses so-called GPIs in order to determine the energy consumption of an application. They are intended to describe the green properties of an application. GPIs are, for example, the energy consumption, energy efficiency, energy saving possibilities, and all other energy`-related factors within an application. Due to only considering the energy consumption no aggregation mechanisms are needed.

Architecture: The architecture behind this approach differs only slightly from the one proposed in in Section III.C. The input data is gathered by an Energy Sensing and Monitoring Infrastructure which corresponds to the *Input Data* and *Event Infrastructure*. For the analysis an Energy Practice Knowledge Base is used that corresponds to the *Event Infrastructure* and *BPM Components*. Finally, the adaptation directly corresponds to the *Adaptation* part.

Business Aspects: Business Aspects are not covered explicitly within this approach. However, they are covered implicitly by considering conventional QoS that need to be fulfilled. Hence, this approach deals (at least partly) with ecologically optimized *Operation*, *Marketing and Sales*, *Procurement* and *Technology Development* parts of the Value Chain.

V. CONCLUSIONS AND FUTURE CHALLENGES

In our work we initially investigated different perspectives relevant to BPM and how they can be adopted, extended, or refined in order to decrease the environmental impact of organizations processes. Within these perspectives we identified different aspects that help organizations to determine a starting point for optimizing their business processes with respect to their environmental impact while also considering their business performance. We further classified state-of-the-art research approaches in the area of green business process management in order to determine which of those perspectives are currently addressed.

Sustainable handling of resources has become an important aspect in modern organizations. Our research has indicated that a proper mapping of monitored data to products, processes, service invocations, humans, or virtual machines is crucial. Thus, it would be suitable to have a monitoring layer underlying the arbitrary application layers where information about the environmental impact of processes can be abstracted. This information may then be used to support strategic decisions, the design of business processes, or the appropriate selection of resources.

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