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BibTeX:

```
@inproceedings{NowakL13,
  author    = {Alexander Nowak and Frank Leymann},
  title     = {Green Business Process Patterns - Part II},
  booktitle = {Proceedings of the 6th IEEE International Conference on Service
                        Oriented Computing & Applications, SOCA 2013,
               16-18 December 2013, Kauai, Hawaii, USA},
  year      = {2013},
  pages     = {TBA},
  doi       = {TBA},
  publisher = {IEEE Computer Society}
}
```


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***Abstract*—The environmental impact of doing business becomes an increasingly relevant aspect for organizations, not only because of legal requirements but also because more customers care about. Most organizations, however, do not have comprehensive knowledge on how to restructure their business processes accordingly. In previous work we proposed green business process patterns that address the environmental impact explicitly as one possible solution. Beyond those patterns, we now provide a method to extract environmentally relevant patterns from existing patterns of different domains. Moreover, we present a set of such patterns related to automated business processes. The proposed approach as well as the identified patterns support stakeholders when analyzing their business processes with respect to the environmental impact and, therefore, supporting green business process reengineering.**

Keywords— Green Business Process Management, Green Business Process Reengineering, Green Business Process Patterns, Process Patterns, Application Architecture Patterns, Cloud Computing Patterns

I. INTRODUCTION

Business processes are an inherent part of today's organizations as they describe the way of doing business [1]. Therefore, business processes compose and orchestrate various business services that are used to achieve certain business objectives. Due to the fact that business processes nowadays are getting more and more complex [2], their optimization has become an important aspect within organizations. Methods and techniques that enable and support this optimization are subsumed under the term Business Process Management (BPM). So far, the optimization objectives of BPM typically refer to cost, quality, time, and flexibility aspects of business processes. In recent years, however, the scope of BPM has been extended. New approaches deal with compliance [3] or the environmental impact [4] of business processes, for example.

In previous work we provided a set of *Green Business Process Patterns* [5] that help stakeholders to reduce the environmental impact of their business processes. We use the term *green* as a synonym for addressing all aspects related to the environmental impact of business processes, like pollution, waste, and emissions. So far, those patterns address the environmental dimension explicitly. However, we argue that existing business process as well as application architecture design and optimization patterns emerged from the commonly known dimensions of BPM are also able to reduce the environmental impact. A more precise consideration of this statement leads us to the research questions of this work: (i) how do those explicit green business process patterns influence the environmental impact of business processes? (ii) How can common optimization and design patterns that improve the environmental impact be identified? (iii) How can those new pattern variants be described and used in comprehensive optimization strategies?

To address these research questions we first propose a research method that guides through the different steps of identifying existing patterns that are suitable to improve the environmental impact of business processes. This includes the analysis of existing green business process patterns which explicitly address the environmental impact of business processes, the identification of environmental relevant characteristics of these patterns, and the appliance of those characteristics to existing patterns. The result is a new set of patterns that form variants of the existing and commonly known patterns. As a proof-of-concept of our method we provide a set of patterns from the domains of business process design and application architecture design. The selected patterns are derived from existing pattern languages based on the identified environmental characteristics. Consequently, the contribution of this work can be summarized as following: we provide (i) a comprehensive research method that guides stakeholders through the process of identifying relevant green business process patterns out of commonly known patterns, (ii) a set of characteristics that describe the impact of patterns to the environmental of business processes, and (iii) a set of new patterns that are derived from commonly known patterns based on their fitness for the identified characteristics.

The remainder of this work is structured as following: Section II provides an overview on the used research method which is used to identify suitable patterns that are able to improve the environmental impact of business processes. Section III provides some basic information about regular and green business process management and its characteristics. Section IV presents different patterns emerged from applying the research method. Subsequently, Section V provides the results and some discussion, Section VI presents related work, and Section VII concludes the work and states out future work.

II. RESEARCH METHOD

The research method proposed in this section describes one possible way of how existing patterns can be mapped to a new domain. We applied this abstract procedure to identify new patterns in the domain of environmentally-aware business processes. However, due to the abstract description of the method it can also be used to find new patterns within other domains. Fig. 1 provides an overview of the method.

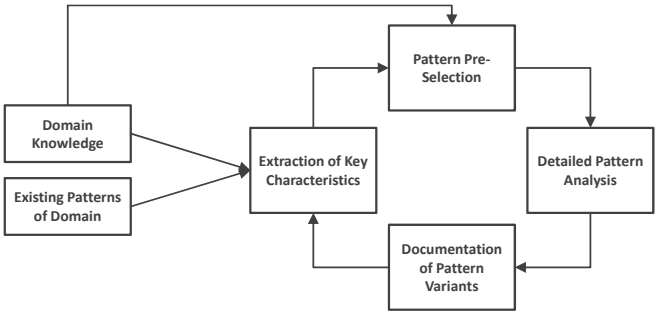


Fig. 1. Research method for pattern variant identification

First, we start to define the domain of interest. The domain we use in this work is green business processes. Thus, we need to clarify how the environmental impact of business processes can be captured and which aspects and components are affected. We need to identify and extract some key characteristics that are significant for that domain. These key characteristics are intended to describe the applied domain in more detail. We use both experiences and existing literature about domain knowledge as well as existing patterns of that domain. As a result of this phase we get a set of characteristics that represent the primer influence factors that may be optimized through the newly identified patterns. More details about such an analysis are presented in Section III.

Based on those findings we are able to pre-select a set of patterns that might be suitable for our domain. For this selection no detailed previous knowledge is necessary. The result might be a very diverse set of patterns which have originally been formulated for many different domains. To confine the pre-selected patterns and focus on the domain of interest, the next step, the detailed pattern analysis, is performed to apply the identified key characteristics to the set of pre-selected patterns. The objective of this step is to determine the degree of how the characteristics are covered by the different patterns. Depending on the estimated suitability some of the pre-selected patterns may be neglected while other patterns may be very useful to solve problems within that domain. Note, the degree of coverage and therefore the influence on the environmental impact of a business processes is also dependent on concrete use case scenarios. Thus, we do not evaluate the concrete potential for optimizations but the general impact on the identified key characteristics.

The last step in the cycle, documentation of patterns variants, comprises the identification and definition of a suitable pattern format as well as the documentation of the derived pattern variants. The documentation especially includes the extended problem statements and the context within the new domain but also appropriate solutions. The objective here is the definition or extension of an existing pattern language that provides a set of solutions within the problem domain. Fig. 1 does also show a loopback link between the documentation of the pattern variants and the extraction of key characteristics. The intention of this loopback is to consider that patterns in other domains and improve the key characteristics.

III. Analysis of Green Business Processes

Green business process management addresses the increasing trend of improving the environmental impact of organizations. While conventional business process management focuses on the optimization of cost, quality, time, and flexibility of business processes, green business process management additionally considers the environmental perspective and the trade-off between them. The environmental impact of a business processes can be embodied by all aspects that somehow influence the environment before, during, or after process execution. Examples are the energy consumption or production waste emitted by the execution of a process.

To better understand the challenges of optimizing business process as well as to understand the identified key characteristics described in Section III, we want to introduce our terminology used in business process world. Business processes are used to orchestrate different activities or tasks within an organization in order to achieve a specified objective. The design of a process, i.e. the activities and the sequence in which the activities are performed, is captured as business process model. Each invocation of this process model is handled as process instance. Consequently, each invocation of an activity within this process instance is handled as activity instance. The way how activities are interacting is described by a so called control flow. This control flow describes the dependencies between the activities and defines the sequence of execution. If the complete business process is performed under control of the process owner, we call it an orchestration. In some cases, however, business processes are performed in collaboration with other external partners. These partners need to communicate and exchange messages to coordinate the different activities. In such scenarios where multiple external partners are involved in a business process we talk about process choreographies. Consequently, such choreographies represent a global perspective on the complete business process. However, this does not mean that every partner has insights into all partner's processes. It is also possible to hide internal activities and execution sequences from other partners.

Each activities invoked by a process is using resources that support and ensure the correct execution of that activity. Such resources can be raw-materials, a drill bit, a hard disk drive, electricity, and another process or service, for example. Therefore, the impact of resources to the environmental impact of a business process is crucial. We need to differentiate and consider two different aspects: (i) which resources are environmentally compatible and best fit a given work item or objective, and (ii) in which way should resources be used within a business process. To identify the potential of reducing the environmental impact of a business process, we analyzed existing patterns and specified characteristics that can be applied to new patterns. We decided to use the different perspectives of business processes described by [6]. Especially, we emphasize their influence on the environmental impact. The perspectives are described in the following.

Process perspective: The process perspective describes the control flow of a business processes, i.e., it defines the order in which activities are executed. Usually, this perspective is represented by some graphical model. Depending on the defined control flow a business processes may lead to a

different environmental outcome. Process models that contain many different roles, for example, may lead to a higher environmental impact due to the necessary context transmission. In other scenarios it might be useful to structure process models in such a way that the use of particular resources is somehow bundled. Different database queries, for example, may be fetched at once. This allows keeping resources in standby for a longer time which saves energy consumed by the database management system.

Data perspective: The data perspective describes the structure of the data objects used by a business processes as well as the way they are associated to the business process. The way of associating data elements to processes has significant influence on the total environmental impact. For example, consider an automated business processes that invokes an activity multiple times. If this activity is designed as stateless component, all information necessary for the execution must be provided to the activity each time it gets invoked. If you use a stateful component or some caching functionalities instead, information transfer will be reduced which may lead to a decrease in energy consumption. A similar scenario may be envisioned in industry where raw materials or semi-finished goods need to be transferred from one place to another.

Organization perspective: The organization perspective describes the roles and organizational units that are involved in a business process. That includes both internal and external roles. For a sustainable execution of processes a lot of changes in different roles or even external organizational units may be disadvantageous. In this case, the process context needs to be transferred each time the role changes or goods need to be transported to other sites, for example. Thus, when considering the environmental perspective of business processes, the proper selection of roles and of collaboration partners as well as their integration becomes even more important than in regular process design.

Resource perspective: The resource perspective is another important perspective as it covers which types of resources are used within business process. Resources may be humans, machines, raw-materials, and auxiliary materials like energy, for example. Depending on the chosen resources, different environmental outcomes may be achieved. In some IT scenarios it might be useful to use Thin-Clients or renewable energy. Another example is the use of centralized environments which allows utilizing economies of scale or the bundling of activity executions in order to prevent servers from changing their state too often.

Operation perspective: The operation perspective describes how the atomic elements of a business process are used. This may be represented, for example, by a scripting language defining how to invoke external applications. For environmental-aware business processes, this perspective is strongly correlated with the resource and data perspective. It defines the way activities are invoked or which kind of activities or additional services are executed within the business process. The use of the *Green Compensation Pattern* from [5], for example, may be implemented as part of the invocation of an activity.

Integration perspective: The integration perspective describes how the different perspectives are joined together. In most scenarios this ends up in some hierarchy of processes and activities. In our use case this may be interesting as the relations between the different activities and processes are described explicitly. However, this perspective is more important for the analysis of existing structures as many relations are already covered by the single perspectives. Nevertheless, in some scenarios this perspective may help stakeholders to coordinate process executions especially with respect to the distribution and sharing of resources that are needed for process execution.

The analysis of each of these perspectives indicates that every perspective has an individual potential to decrease the environmental impact of business processes. Therefore, we assume that patterns that address these perspectives from an environmental point of view may also have a significant relevance in designing environmentally-aware business processes. However, their application is strongly dependent on the scenario in which they are used. In order to support stakeholders that focus on the sustainable (re-) design of their business processes, we want to provide a set of patterns that are transferred into the context of this paper. This means that we analyze existing patterns addressing at least one of the introduced perspectives and check their applicability to environmental aspects of business processes. For better usability of our pattern language, we describe variants of those existing patterns so that they are ready to use in green business process reengineering scenarios. Please note that the integration perspective is influenced whenever any of the other perspectives is modified. Thus, we do not describe this perspective in each of our patterns but consider it in the results presented in Section V.

IV. GREEN BUSINESS PROCESS PATTERNS

In this section we want to provide a set of patterns that are derived from existing patterns of other domains but put in the context of environmentally-aware improvement of business processes. To provide an easy and comprehensible usage of the patterns we describe all of them in the same structured format (see Section IV.A). The patterns have been selected based on the described perspectives from Section III. We have selected patterns from the domains of workflows [7], application architectures [8] in general, and Cloud architectures [9] in particular. Please note that the selection of these patterns is based on our personal investigations related to green business process patterns, their corresponding influence factors, and therefore their ability to positively support these influence factors. We do not claim that these are all patterns related to that subject. However, we think they provide a good starting point for (re-)designing business processes.

A. Pattern Format and Language

In the following sections we want to extend our previously proposed pattern language described in [5]. When talking about a “language of patterns” we stick closely to the interpretation of Hanmer [10] who describes a language as a set of patterns that are used to solve a problem of a particular domain. The patterns comprised in a language are structured in such a way that stakeholders can navigate through the complete set of patterns, selecting suitable patterns, and recognize the relations between the patterns in order to solve even bigger problems.

To describe and document the patterns of this work we have decided to choose a simple and straightforward format. This format is geared to commonly known literature, like the work of Alexander [11], Fowler [8], and Gamma et al. [12]. However, our format differs from the original formats of the observed patterns. This is done on purpose as we want to emphasize the new aspects, problems, and solutions in the domain of environmental improvement of business processes. Moreover, the uniform format eases the use of patterns significantly. Please note that we do not intend to describe the existing patterns one-to-one. In fact, we want to present variants that are directly related to the subject of this work.

For documentation, each pattern is defined by a name that is unique within our pattern language. The name helps to identify patterns and to navigate through the language. Moreover, we did not use the original name of the patterns but added the prefix "green" that emphasizes the new application domain. Besides the name of a pattern we also provide a visual representation and the intent of that pattern that describes the purpose of the pattern in a single sentence. Next, we describe the context the pattern may be used in. The context is strongly related to the new domain and represents the new challenges arising. In this section, we also provide some information about the affected business process perspectives, introduced in Section III. Subsequently, we provide an abstract solution for the problem. Like any other patterns, this solution is typically not "ready-to-use". We still need to consider the concrete use case and the corresponding constraints to develop a suitable solution. Next, we provide information on the result after applying the pattern and one or more examples, describing concrete application scenarios of the patterns. The last section points out the relations to other patterns either because they are usually used together, they might be considered to be used together, or because they do not fit together due to mutual constraints.

In the pre-selection phase of our method we have analyzed various patterns of the aforementioned domains that qualify for a detailed analysis. The resulting patterns of the detailed analysis phases of our method are the following:

Workflow Patterns: *Green Control Flow, Green Explicit Termination, Green Multiple Instances With a Priori Runtime Knowledge, Green External Choice, Green Cancel Activity.*

Application Architecture Patterns: *Green Client Session State, Green Server Session State, Green Data Transfer Object, Green Lazy Load, Green Gateway.*

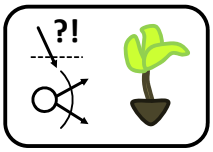
Cloud Patterns: *Green Public Cloud, Green Loose Coupling, Green Batch Processing Component, Green Eventual Consistency, Green Shared Component.*

This list is not complete and more patterns might be identified. But it serves as a good starting point for further research in this area. Due to space limitation we only present one single pattern in this work. The interested reader will find a list of all of the patterns at [13].

B. Green Workflow Pattern Example

Workflow patterns basically describe solutions on how to design business process in order to achieve certain business objectives. So far, these patterns did not consider the environmental impact as an explicit design criterion. The following pattern presents a green variant of the *External Choice Pattern* that focuses on the improvement of the environmental impact. For further details on the original patterns see [7].

P-1: Green External Choice



Provide several alternative control flow branches that are selected depending on the environment.

Context: Business processes are usually not only sequences of activities. They contain different decision points, branches, and paths. To realize such constructs, workflow languages provide different possibilities like (1) AND constructs are able realize parallel splits where all outgoing edges are run in parallel, or (2) XOR constructs that are able to realize explicit decision points where a single outgoing edge is chosen based on the incoming edges, for example. Beside those explicit constructs that are modeled within a process model, the selection of a particular path or branch can also be transferred to the environment in which a process is running, i.e. external events influence the control flow of that process. When using this pattern the following process perspectives are affected:

Process Perspective: In order to react to external events the process model and the control flow need to support those events as well as the corresponding alternatives in the process model.

Data Perspective: In order to use external events it must be defined which information is required to come to a decision.

Resource Perspective: Based on the decision made different resources may be used for further processing.

Solution: The process model needs to be extended by introducing external choices at those positions where external information should be used to distinguish different process behavior. The required information must be defined and provided to the runtime environment of the process. For example, the total power consumption of a process may be retrieved and used for the decision about the resource to be used in a process step. Depending on specific use cases the control flow of the process may be explicitly designed to address various business objectives.

Result: Due to the integration of external information a process designer is able to explicitly consider information of the runtime as well as ecological environment. Like when using the *Green Variant Pattern*, the execution path as well as the resources that are used to perform an activity can be defined during runtime. Moreover, the decision making based on environmental information is able to optimize the resource usage in general.

Example: One opportunity to choose between different paths of a process was described as *Green Variant Pattern* in [5]. The example here was describing the choice for DHL customers to either ship their packages regularly or carbon-free. Using this pattern we can modify that example. As from now, the customer does not make the decision, but the process

automatically checks information about the total carbon footprint at that time. Based on that information the process may decide which shipping option would be best to not violate defined business objectives for carbon emissions.

Relations to other Patterns: The design of external choices usually influences the design of the control flow of a process (*Green Control Flow Pattern*), i.e. the introduction of a new alternative path or the use of different resources that might be handled in a new way. Instead of creating new process path the external information may also be able to trigger certain compensation activities or processes (*Green Compensation Pattern*). Moreover, a green variant (*Green Variant Pattern*) of a process may be used that describes a modified process model or the process model contains a "green path". The external information supports the selection of which of the different path should be used in which case. When deciding for a specific path in the process model all activities of the other paths can be canceled (*Green Cancel Activity Pattern*). Beside that, data may only be provided for the most common paths of the process model (*Green Lazy Load Pattern*).

V. Results and Discussion

Our resulting set of patterns (see [13]) shows that utilizing systematic analysis methods involving certain domain knowledge as well as existing patterns may lead to a bunch of new patterns that are related to new domains and objectives. Like with any other patterns, however, it is important to note that we cannot derive completely generic solutions that can be used in each and every application scenario. Depending on concrete requirements, like the degree of business change, stakeholders need to traverse the pattern language and chose the patterns that are appropriate for their scenario.

Table 1 Patterns and business process perspectives

	Process Perspective	Data Perspective	Organization Perspective	Resource Perspective	Operation Perspective	Integration Perspective
Green Control Flow	X		X		X	X
Green Explicit Termination	X			X		X
Green Multiple Instances With a Priori Runtime Knowledge	X			X	X	X
Green External Choice	X	X		X		X
Green Cancel Activity	X			X	X	X
Green Client Session State		X		X	X	X
Green Server Session State		X	X	X	X	X
Green Data Transfer Object		X			X	X
Green Lazy Load	X	X			X	X
Green Gateway				X	X	X
Green Public Cloud		X	X	X	X	X
Green Loose Coupling		X		X	X	X
Green Batch Processing Component				X	X	X
Green Eventual Consistency		X		X		X
Green Shared Component			X	X	X	X

To provide guidance for identifying patterns that can be applied to an organization's business processes we suggest using the introduced process perspectives as a first indicator for the selection. An overview of these relations is shown in Table 1. Here, each "X" indicates that a pattern is related to the corresponding process perspective. Moreover, to better navigate through our extended pattern language, consisting of the patterns presented in [5], [13] and in this work, we provide an overview of the mutual relations between the different patterns in Table 2. This eases the traversal of the pattern language, i.e., the navigation through the patterns, and helps to find a set of suitable patterns for concrete use cases.

VI. Related Work

Different appraoches have indicated the need to optimize business processes from an environmental perspective. Ghose et al. [15] describe a high-level carbon modelling framework to annotate process tasks. On a more technical level, Ardagna et al. [16] present an active energy-aware resource management for business process based applications and Cappiello et al. [17] present an approach to reduce the environmental impact of Information Systems. All of these approaches, however, describe only very specific solutions for individual poblems and do not follow the pattern-based optimization principle which is providing good but abstract solutions for reoccurring problems. Works on pattern identification, like Hanmer [10], Reiners et al. [18], and Takashi & Taichi [19], describe different ways on how to build a pattern language out of experience and existing knowledge. However, these approaches always start with identifying patterns from scratch without recognizing and reusing the welth of knowledge in existing work, i.e., knowledge already captured in patterns.

VII. Conclusion and Future Work

In order to advance the acceptance and usage of green business process management, suitable solutions and guidelines must be available. The introduction of explicit green business process patterns in our previous work [5] was a suitable starting point. Unfortunately, only a few of today's optimization projects do consider such explicit solutions. However, they do apply a lot of solutions that provide implicit opportunities to improve the environmental impact of business process, applications, and infrastructures. Consequently, we developed a method that guides stakeholders through the process of identifying suitable solutions, i.e., patterns, which properly fit to their domain of interest. Moreover, we used that method to identify a set of patterns from the domains of Workflow Management, Application Architectures, and Cloud Computing Architectures that are applicable for the improvement of the environmental impact of organizations and their business processes.

In our future work we want to use the proposed method to identify some more key characteristics that help to identify more patterns from the introduced as well as new domains. Based on the identified patterns we want to extend our pattern language for green business processes. Moreover, we want to improve the decision support for stakeholders by introducing reasonable dependencies between patterns. This allows correlating the structure, use cases, and characteristics that are common for a specific type of pattern.

Table 2 Relations between the green business process patterns

	Green Control Flow	Green Explicit Termination	Green Multiple Instances	Green External Choice	Green Cancel Activity	Green Client Session State	Green Server Session State	Green Data Transfer Object	Green Lazy Load	Green Gateway	Green Public Cloud	Green Loose Coupling	Green Batch Processing C.	Green Eventual Consistency	Green Shared Component	Green Compensation	Green Variant	Resource Change	Green Feature	Common Process	Process Automation	Human Process Performance	Insourcing	Outsourcing
Green Control Flow																								
Green Explicit Termination																								
Green Multiple Instances	X	X																						
Green External Choice	X																							
Green Cancel Activity	X	X	X	X																				
Green Client Session State																								
Green Server Session State						X																		
Green Data Transfer Object	X					X																		
Green Lazy Load		X	X	X	X			X																
Green Gateway	X						X	X																
Green Public Cloud		X				X																		
Green Loose Coupling	X			X		X	X	X	X	X	X													
Green Batch Processing Component										X	X	X												
Green Eventual Consistency				X							X	X	X											
Green Shared Component	X					X		X		X	X			X										
Green Compensation																								
Green Variant	X			X				X				X			X									
Resource Change	X		X			X	X				X	X	X											
Green Feature									X		X		X				X							
Common Process Improvement		X	X	X	X																			
Process Automation	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					
Human Process Performance	X																			X	X			
Insourcing						X	X									X								
Outsourcing					X	X				X	X	X				X	X	X	X	X	X	X	X	

ACKNOWEGMENT

This work was partially funded by the BMWi project Migrate! (01ME11055).

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