Sustainability Analysis Patterns for Process Mining and Process Modelling Approaches

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Abstract. Business Process Management (BPM) has the potential to help companies manage and reduce their activities' negative social and environmental impacts. However, so far, only limited capabilities for analysing the sustainability impacts of processes have been integrated into established BPM methods and tools. One of the main challenges of existing Sustainable BPM approaches is the lack of a sound conception of sustainability impacts. This paper describes a set of sustainability analysis patterns that integrate BPM concepts with concepts from existing sustainability analysis methods to address this challenge. The patterns provide a framework to evaluate and develop process modelling and process mining approaches for discovering, analysing and improving the sustainability impacts of processes. It is shown how the patterns can be used to evaluate existing process modelling and process mining approaches.

Keywords: Process Patterns, Business Process Management, Process Mining, Sustainable Development, Life Cycle Assessment

1 Introduction

The demand for more sustainability is being put forward to companies from various sides, be it from politics, non-governmental organisations, customers or the company's workforce [12]. The term sustainability or Sustainable Development stands for a long-term perspective to satisfy human needs today and in the future in light of escalating global challenges such as the climate crisis [33]. From a company's point of view, contributing to sustainable development means considering the (negative) effects of its activities on humans (social justice) and the environment (environmental protection) [33]. A consequence of this perspective is that the area of responsibility for a company expands [13]. It is not enough to consider only the direct impacts within the company's boundaries, such as wages to the company's workforce or pollutant emissions on its premises. Rather, the effects triggered by the company's activities along its value chain must also be considered [16, 30]. For example, a company that manufactures batteries bears responsibility for lithium mining and the associated contamination of water resources [22]. This idea is central to existing sustainability analysis methods, such as Life Cycle Assessment (LCA) [35, 16, 30].

Business Process Management (BPM) concepts, methods, and tools have the potential to help companies become more sustainable. BPM aims to analyse and improve the activities of companies [36]. While traditionally improvements in terms of costs, lead times, and error rates are being sought [7], researchers have begun to include sustainability aspects in their approaches [5, 10]. These Sustainable BPM approaches include concepts, methods and tools to support the modelling, analysis, improvement, implementation and management of business processes [36, 7], taking into account their environmental and social impacts. One of the challenges of existing Sustainable BPM approaches is the lack of a sound conception of how to measure the impacts of a business process [5, 10].

This paper provides a set of sustainability analysis patterns to address this challenge. The definition of the patterns is inspired by "workflow patterns" that have been used to evaluate process modelling and process mining approaches regarding their capabilities to represent control flow and data flow aspects of business processes [28, 27]. Similarly, the sustainability analysis patterns describe different aspects of a process' environmental and social impacts. Note that the patterns are not intended as *design* patterns, meaning they do not describe how an organisation can operate sustainably. Rather, they describe what aspects a business process *model* should represent to provide a foundation for a sound, comparable and transparent sustainability analysis. This way, they guide (1) process analysts who aim to analyse the sustainability of business processes and (2) developers and researchers who integrate sustainability analysis capabilities in process modelling and process mining approaches. The patterns are derived by mapping a meta-model of BPM concepts with a meta-model of concepts from existing sustainability analysis methods (i.e. LCA). They are evaluated by applying them to compare the capabilities of existing process modelling and mining approaches and derive improvement possibilities for future developments.

In Section 2, we provide background on BPM and LCA as well as an overview of related pattern proposals. Section 3 provides a synopsis of BPM and LCA meta-models. Section 4 presents the developed sustainability analysis patterns, and in Section 5, the patterns are applied to a review of existing process modelling and mining approaches. Finally, we conclude in Section 6 and provide an overview of future work.

2 Background and Related Work

2.1 Business Process Management (BPM) and Process Mining

BPM is concerned with improving business processes and thus the performance of a company [36, 7]. A distinction can be made between management and technical BPM approaches [5]. Management approaches address issues such as organisational structure, values, roles, and responsibilities within a company [34]. Technical approaches are concerned with the modelling, analysis, improvement and implementation of business processes [7, 36]. Process mining is a branch of BPM [1]. The basic idea of process mining is to automatically create business process models from event log data (e.g. events logged by IT systems) [1].

2.2 Sustainability Analysis and Life Cycle Assessment (LCA)

In the so-called Brundtland report, the term Sustainable Development was coined as a guiding principle for global change [33]. The goal is to satisfy the needs of current generations without endangering the ability of future generations to satisfy their needs [33]. The joint consideration of social, environmental, and economic factors is an essential aspect of the sustainability concept described in the Brundtland report [25].

It is important to consider that an activity's sustainability impacts may occur outside the company's boundaries. An important concept in this context is life cycle thinking [13]. It means that a systemic perspective is adopted when analysing the sustainability of a product or a company. This includes the interactions between the product or company under consideration, the environment, and other stakeholders along its value chain (also called life cycle) [16]. The goal is to improve the entire system [16]. Life Cycle Assessment (LCA) is a method for conducting such an investigation [16].

The LCA method was initially developed to analyse the environmental impacts of products, e.g., contribution to climate change, acidification, ecotoxicity and waste [18, 16]. The method was adapted and extended for analysing the environmental impacts of an entire company [17], as well as social impacts [30]. The corresponding standards and guidelines define that an LCA study consists of four phases [16, 17, 30]. The first phase is the *definition of goal and scope*. Here, the system boundaries, as well as basic requirements and assumptions, are defined. Second, *inventory analysis* is carried out, in which data about the system is collected, and calculations are made to quantify relevant inputs and outputs. The third phase is the *impact assessment*, where the significance of sustainability impacts is evaluated. And finally, as the last step, the *interpretation* of the results, where improvement potential is identified. The GHG Protocol [35] guidelines can be considered as a restricted variant of LCA since it only considers one impact category (climate change) [32]. It largely follows the structure outlined by the LCA standards and provides definitions for different assessment scopes regarding GHG emissions [35]: *Scope 1* refers to direct GHG emissions within the premises of a company, *Scope 2* refers to indirect GHG emissions that stem from the generation of energy consumed by a company, and *Scope 3* addresses further indirect GHG emissions in the value chain.

2.3 Related Work

In Sustainable BPM literature, several proposals for sustainable or green business process patterns can be found [19–21]. These proposals for patterns describe, in a structured way, how the sustainability of a business process can be improved (e.g. using resources with reduced environmental impact [21]). In each case, it is implicitly assumed that the impacts of a business process *have already been measured*. The patterns described in this paper focus on the more fundamental question, *how* the sustainability impacts of a business process should be measured.

3 Mapping of BPM and LCA Meta-Models

3.1 Meta-Models for BPM and LCA

This section maps basic concepts from the BPM and LCA disciplines using meta-models. This way, a synopsis of concepts from both disciplines is constructed that allows for adapting insights from LCA for Sustainable BPM. From this synopsis, patterns that describe how the sustainability impacts of a process can be modelled are derived in the next section.

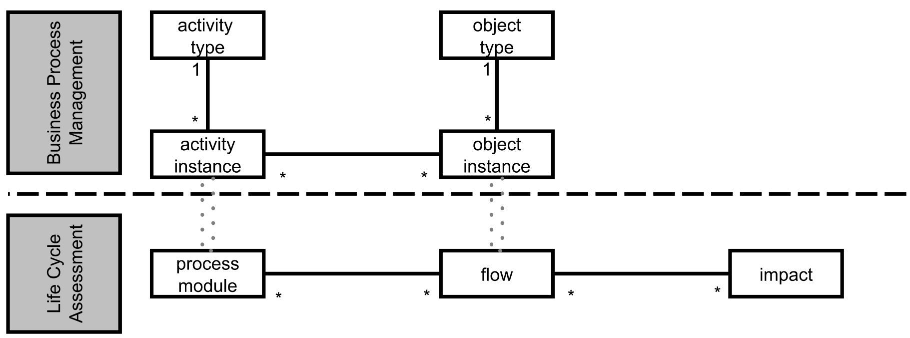


Fig. 1: Mapping of BPM and LCA meta-models.

Fig. 1 shows a mapping between the meta-models of BPM and LCA. From left to right, it shows similar concepts in the respective disciplines. As a basis for describing BPM concepts, we refer to the OCEL 2.0 standard [3]. The choice is motivated by the concise form of the given meta-model and its interoperability between BPM technologies. Similarly, as a basis for describing LCA concepts, we refer to a description of the ILCD standard [38], which is used to exchange data between LCA tools. Note that in both cases, some of the terminology has been adapted for consistency and clarity within this paper. For example, the OCEL standard defines a concept *event* as an execution of an activity. In Fig. 1, this concept is called an *activity instance*. In the following description of Fig. 1, we additionally refer to basic sources of BPM [36, 23] and LCA [16, 18] to explain the concepts and conclusions.

In BPM, the notion of a process refers to a business process, i.e. a set of *activities* that are performed by a company to realise a business goal [36]. Processes are modelled and analysed to improve a company's performance or to support the development of information systems [36]. Activities may be associated with *objects*: objects can be inputs or outputs of an activity, they may be altered by an activity, or they may be resources (machines, humans) that are needed to execute an activity [3, 36]. It is common to differentiate between *activity and object types and instances* [36, 3]. Typically, a business process is modelled at the type level, where the model describes a general frame for executing the process

[23]. Activity instances refer to executions of an activity at a specific time [3]. BPM traditionally focuses on causal and temporal relationships between activities (control flow) [36, 7]. However, several approaches aim to integrate the data flow perspective more tightly [29]. Similarly, the early focus of process mining approaches was on the relationships between activities, with a recent uptake of interest in analysing the relationships between activities and objects [3].

In LCA, process models are created to analyse the sustainability impacts of a product, service or company [16, 17, 30]. Different to how processes are typically modelled in BPM, these process models represent the phases of a value chain (also called life cycle) and are built from *process modules* [18, 38]. A process module may represent a phenomenon similar to an activity in BPM (e.g. manufacturing of a workpiece), but it may also represent a whole industry (e.g. energy generation in Germany) [18]. Process modules are associated with *flows* [38]. Similar to the object concept in BPM, flows may be products, information or data, but the focus is on material and energy flows [18, 16]. When modelling processes, LCA doesn't distinguish between types and instances. Instead, a process model represents the quantified flows along a value chain relative to a "functional unit" (e.g. the flows required to provide a certain amount of mineral water) [16]. The identified flows are then associated with different *impacts* [16, 38]. The resulting impact indicators quantify the extent of a certain flow's impact on an environmental or social problem area [16]. For example, emissions of *CO2* and other GHG emissions ("flows") contribute to the problem area *climate change* (an "impact"). This impact is typically measured in CO2 equivalents (CO2e) [18]. Other environmental impacts include ozone depletion, land use, ecotoxicity and acidification. Examples of impacts addressed in social LCA are excessive working hours, work accidents or discrimination [31]. Note that any list of considered impacts depends on scientific progress and societal awareness [18]. For an overview of environmental impact lists, see [18]. For a list of impacts considered in social LCA, see [31].

3.2 Specific Characteristics of Process Modelling in LCA

Several notable aspects of process modelling in LCA are relevant when considering how to model sustainability aspects in BPM. In particular, the relevant flows depend on the the assessed impacts. For example, the assessment of climate change requires the identification of GHG emissions, while the assessment of ozone depletion requires the identification of gas emissions that damage the ozone layer [18].

The scope definition is another important factor in the identification of relevant flows. For example, a "gate-to-gate" analysis only considers flows within a company [16]. A "cradle-to-gate" analysis extends the scope of considered flows to include the upstream value chain of the company (the company's suppliers and their suppliers etc.) [16]. Scopes 1 to 3, as defined in the GHG Protocol, are another example of a scope definition specific to climate change impacts [35].

A further important aspect is the allocation of impacts. When dealing with process modules that have multiple inputs or outputs (e.g. mining produces diamonds and rubble), it needs to be decided how the associated impacts are distributed [18]. This is a central problem in LCA and conventions exist how to handle these situations (e.g. allocation by weight or economic value) [16, 18]. In any case, allocation decisions can have significant consequences in the resulting assessment, so they must be carefully considered and documented [16, 18].

3.3 Conclusion: Sustainability Impacts of a Business Process

In both disciplines, BPM and LCA, processes are modelled and analysed. The observed similarities allow for using LCA as a reference to reason about how to measure sustainability impacts in BPM [5, 10, 11]. From the mapping conducted above, there are several lessons to be learned. First, Sustainable BPM requires some kind of object or data flow perspective to capture impacts (see also [11]).

Second, Sustainable BPM needs a conception of the scope of an analysis. Speaking in LCA terms, a gate-to-gate analysis may yield significantly different results than a cradle-to-gate analysis. Taking, for example, a business process supported by IT, it needs to be clarified if an analysis considers Scope 2 (electricity would be the main relevant input) or Scope 3 (the IT infrastructure and its impact along the value chain would have to be considered as well).

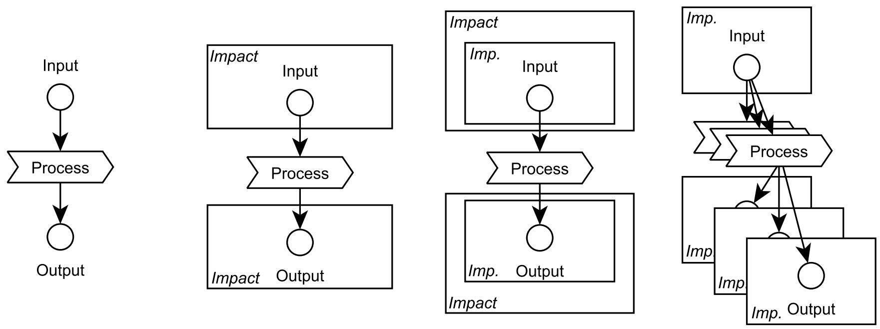
Third, allocation is an important challenge to be addressed by Sustainable BPM. In the BPM modelling perspective, multi-input and multi-output processes are commonplace (e.g., a resource is used by multiple activity instances, an activity may have multiple object outputs). Thus, mechanisms for transparently and consistently allocating impacts are required.

4 Sustainability Analysis Patterns

Based on the results of Section 3, the following sustainability analysis patterns for business processes are defined. They describe different sustainability-relevant aspects of business processes and adapt concepts of LCA for BPM. Their implementation in approaches for Sustainable BPM thus enables the analysis of process sustainability from a life cycle perspective. For the four patterns, a description, a motivation and variants (if applicable) are provided. In the following, the term *process component* refers to any of the BPM concepts shown in Fig. 1.

(AP 1) Sustainability-Relevant Inputs and Outputs: A process component can be assigned sustainability-relevant inputs and outputs (see Fig. 2a). For example, an activity instance requires a certain amount of energy as input or produces a certain amount of waste as output.

Motivation: The recording of inputs and outputs of a business process corresponds to the inventory analysis of LCA. It is a basic requirement to enable reasoning about the sustainability impacts of a process.



(a) AP 1 (b) AP 2 (c) AP 3 (d) AP 4

Fig. 2: Sustainability Anaylsis Patterns

(AP 2) Sustainability Impacts: A process component can be assigned sustainability impacts (see Fig. 2b). Different environmental and social impacts can be distinguished (see the following variants).

AP 2-Env: A process component can be assigned environmental impacts (e.g., an activity instance contributes to ozone depletion with 3 kg CFCe).

AP 2-Climate: A process component can be assigned a climate impact (e.g., an activity instance causes a climate impact of 5 kg CO2e).

AP 2-Social: A process component can be assigned social impacts (e.g., an activity instance causes work accidents).

Motivation: The assignment of impacts to a process component corresponds to the impact assessment in LCA. The assessment of impacts is to be differentiated from the mere recording of inputs and outputs. A comprehensive assessment of impacts allows for identifying shifts between them. AP 2-Climate is defined as a special case of AP 2-Env because climate impacts are particularly relevant in the context of sustainability analysis [35].

(AP 3) Scoping of Sustainability Impacts: A process component can be assigned impacts for different scopes (see Fig. 2c). This scope definition can be made for different sustainability impacts (see the following variants of AP 3).

AP 3-Env: A process component can be assigned environmental impacts for different scopes (e.g., an activity instance contributes to ozone depletion with 3 kg CFCe when including direct emissions, and 15 kg CFCe when including emissions in the value chain).

AP 3-Climate: A process component can be assigned climate impacts for different scopes (e.g., following the scoping concept of the GHG Protocol an activity instance causes a Scope 1 impact of 5 kg CO2e and a Scope 3 impact of 30 kg CO2e).

AP 3-Social: A process component can be assigned social impacts for different scopes (e.g. an activity instance causes an average of 0.00001 work accidents within the company and 0.00002 work accidents when considering the value chain of used resources).

Motivation: Following the idea of life cycle thinking, Sustainable BPM should enable the identification of impact shifts along value chains. However, fully considering the value chain may not always be feasible. Still, a transparent definition of the considered scopes should be supported for comparability.

(AP 4) Allocation of Sustainability Impacts: Sustainability impacts assigned to a process component can be (partially) allocated to other process components (see Fig. 2d). For example, the impact associated with the production of a resource can be allocated to individual activity instances.

Motivation: To identify improvement potential in a business process, an analysis should yield results on which process components are responsible (to what extent) for various impacts. For this, transparent mechanisms are needed to allocate impact assessment between process components.

5 Application of Sustainability Analysis Patterns

5.1 Criteria and Overview

To show the utility of the proposed sustainability analysis patterns, they are applied to evaluate existing Sustainable BPM approaches. The evaluation focuses on modelling approaches since this has been the focus of Sustainable BPM literature [10]. Corresponding publications were extracted from a literature review on Sustainable BPM [10]. In the extracted publications, it can be seen that various authors developed their approaches across several publications. Due to space restrictions, we only reference selected publications for each approach. For an overview of all publications on Sustainable BPM identified in [10], see [9]. The modelling approaches considered were examined based on the sustainability analysis patterns described in Section 4. The criteria and their evaluation are explained in the following.

Regarding *AP 1* an approach is evaluated ● if modelling of inputs/outputs is supported, and ○ if not. For *AP 2* an approach is evaluated ● if modelling of impacts is supported, and ○ if modelling of impacts is not supported. The evaluation for *AP 3* distinguishes between ● if scoping is supported, ◑ if scoping is considered but explicitly limited, and ○ if scoping is not supported. Finally, for *AP 4* an approach is evaluated ● if allocation is supported, and ○ if not.

5.2 Evaluation of Sustainable Process Modelling Approaches

Table 1 provides an overview of existing modelling approaches for Sustainable BPM, the respective modelling languages used, and the evaluation according to the described criteria.

Houy et al. [15] describe the idea of annotating activities in EPC models with indicators such as resource consumption or energy demand. The publications describe an initial concept. Various sustainability-relevant inputs and

Table 1: Review of existing sustainable process modelling approaches.

Approach	**AP 1**	**AP 2**			**AP 3**			**AP 4**
		Climate	Env	Social	Climate	Env	Social	
Houy et al.	●	○	○	○	○	○	○	○
Hoesch-Klohe et al.	●	●	○	○	◑	○	○	●
Recker et al.	●	●	○	○	●	○	○	●
Wesumperuma et al.	●	●	○	○	●	○	○	●
Zhu et al.	●	○	○	○	○	○	○	○
Betz	○	●	●	●	●	●	●	○

outputs, such as water consumption, energy demand, and CO2 emissions, are mentioned as possibilities for annotation (● for AP 1), but the measurement of sustainability impacts is not addressed (○ for AP 2). No modelling support is provided for scoping or allocating impacts (○ for AP 3 and AP 4).

In the publications of *Hoesch-Klohe et al.* [14], activities are also annotated with sustainability indicators, in this case, in BPMN process models. For the considered indicators, a distinction is made between sustainability-relevant inputs and outputs (such as energy demands) and climate impacts (measured in CO2e) (● for AP 1 and AP 2-Climate). The consideration of climate impacts is explicitly limited to Scopes 1 and 2 of the GHG Protocol (◑ for AP 3-Climate). Other sustainability impacts are not addressed (○ for AP 2-Env, AP 2-Social, AP 3-Env and AP 3-Social). Regarding allocation, [14] proposes a resource modelling concept (● for AP 4). With these models, the total impacts for different process instances can then be calculated.

In the approach of *Recker et al.* [26], a BPMN extension for sustainability aspects is proposed. With these new notation elements, activities can be marked, as paper-consuming or fuel-consuming (● for AP 1). Furthermore, the resulting climate impact for different groups of activities is displayed in a special notation element (● for AP 2-Climate). The calculated climate impacts also consider the production of used resources, i.e. Scope 3 (● for AP 3-Climate). Concepts for considering additional impacts are not developed (○ for AP 2-Env, AP 2-Social, AP 3-Env and AP 3-Social). A procedure is proposed in which the climate impacts of resources are allocated (● for AP 4).

Closely related to *Recker et al.* is the approach of *Wesumperuma et al.* [37], which also proposes and elaborates an extension of BPMN with notation elements for capturing climate impacts (● for AP 2-Climate). A procedure is described in which the climate impact is summed up for individual activities, and processes. Furthermore, a calculation method is proposed that can be used to allocate the sustainability impacts caused by resources to individual activities (● for AP 1 and AP 4). As with *Recker et al.*, the approach considers different scopes of climate impacts, including Scope 3 (● for AP 3-Climate). Other environmental or social impacts are not considered (○ for AP 2-Env, AP 2-Social, AP 3-Env and AP 3-Social).

The approach of *Zhu et al.* [39] involves enriching BPMN process models with sustainability-relevant context data such as resources, countries, or people (● for AP 1). In terms of impacts, the approach remains unspecific. It is shown that integration of data from environmental information systems is possible, but the adequate integration of sustainability data in terms of allocation, different impacts, and scoping is not addressed (○ for AP 2, AP 3 and AP 4).

Betz [4] describes the idea of modelling sustainability aspects of business processes with a variant of high-level Petri Nets. It is mentioned that various environmental and social impact indicators can be integrated into a process model. A distinction is made between direct, indirect, and socio-economic impacts (● for AP 2 and AP 3). However, the identification of sustainability-relevant inputs/outputs and allocation are not considered (○ for AP 1 and AP 4).

The identified modelling approaches have only reached a limited degree of maturity. The majority of developed concepts focus on energy aspects and GHG emissions. Apart from measuring climate impacts based on the GHG Protocol, a systematic distinction between inputs/outputs and impacts, as well as concepts for impact scopes, are missing. The approach from *Betz* is an exception with its distinction of direct, indirect and socio-economic impacts. This scoping concept takes an even broader perspective than conventional LCA analyses since it does not only consider the value chain. Of the approaches that consider the allocation of sustainability impacts, *Hoesch-Klohe et al.* appears to be the most sophisticated with detailed resource modelling concepts.

5.3 Evaluation of Sustainable Process Mining Approaches

So far, sustainability aspects have only been addressed to a limited extent in process mining. A systematic literature review on Sustainable Process Mining approaches [11] finds that existing publications on the topic provide mainly high-level descriptions. Four case studies identified in the review directly address social or environmental sustainability aspects. Three of them, however, only address sustainability-related domains (health and safety [24], wind turbine maintenance [6] and sustainable agriculture [8]). The described approaches do not attempt to measure sustainability aspects in processes. Rather, conventional measures (e.g. time usage) are applied. Only [2] addresses measuring sustainability aspects in processes by relating energy needs to identified process models (AP 1). This shows that further work is required to provide more expressive sustainability analyses with process mining. One solution proposed by [11] is to enrich process models with object quantities. This, in turn, would enable future approaches that provide support for allocating impacts between process components (AP 4).

6 Conclusion and Outlook

Sustainable BPM approaches need a solid concept of sustainability impact measurement to provide meaningful and comparable analyses. The sustainability analysis patterns proposed in this paper provide an initial framework to critically assess Sustainable BPM approaches. The mapping provided in Section 3 shows that Sustainable BPM and LCA share common goals and concepts. Therefore, in the future, further insights from LCA can be adapted for Sustainable BPM to elaborate and extend the proposed patterns. The LCA standard [16] primarily defines certain principles but does not prescribe specific techniques. In this sense, Sustainable BPM approaches can be seen as a technical variant of other LCA approaches. However, the BPM (modelling) perspective provides specific advantages regarding the continuous support of process changes, as well as the implementation of tools and IT support [36]. Sustainable BPM thus brings a unique and promising contribution to effectively improving the sustainability performance of companies.

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