Simulating Environmental Impacts of Business Processes with SimuBridge and the SOPA Framework

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Abstract

Assessing the environmental impact of business processes is an important factor for organizations to contribute towards meaningfully facing climate change. However, existing contributions and frameworks are often rather conceptual, and no unified and user-friendly implementation exits. For this, we draw on previous studies and extend an existing tool, SimuBridge, which allows process analysts to create, manage, and execute business process simulation scenarios. We incorporate concepts of SOPA, a framework for sustainability-oriented process analysis that uses Life Cycle Assessments as holistic indicators of environmental impact. In doing so, we enable simulation-based analyses of business processes and allow analysts to develop process re-design scenarios and compare them regarding their environmental impact.

Keywords

Business Process Simulation, Sustainability, Environmental Impact Assessment, LCA

Metadata description	Value
Tool name	SimuBridge
Current version	2.0.0
Legal code license	MIT
Languages, tools and services used	Typescript, Java, Scylla, Simod, openLCA, Docker
< Supported operating environment	Microsoft Windows, GNU/Linux
Download/Demo URL	https://github.com/INSM-TUM/SimuBridge--SOPA-Extension
Documentation URL	https://github.com/INSM-TUM/SimuBridge--SOPA-Extension/#readme
Source code repository	https://github.com/INSM-TUM/SimuBridge--SOPA-Extension
Screencast video	https://doi.org/10.6084/m9.figshare.26885872

1. Introduction

In light of climate change and the environmental impact of human activity, it is increasingly important for organizations to assess, quantify, and reduce the environmental impact of their business processes [1]. For this, various frameworks and approaches exist in a subfield of Business Process Management (BPM), known as *Green BPM*, that aims at incorporating *sustainability* into traditional BPM [2]. Examples of these approaches include, i.a., [3, 1]. However, often there

ICPM 2024 Tool Demonstration Track, October 14-18, 2024, Kongens Lyngby, Denmark
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is no open-source implementation made available, or existing tools are cumbersome and not user-friendly.

In particular, the *Sustainability-Oriented Process Analysis* (SOPA) framework has been proposed [4]. Concretely, SOPA combines *activity-based costing* with *business process simulation* [5] and *life-cycle assessment* (LCA), for *holistically* assessing the environmental impact of business process executions based on the environmental impact of activity instances and process instances [4]. LCA, in particular, allows analysts to assess environmental impacts of products, processes, and services across a wide range of dimensions (e.g., toxic impacts, global warming, land and resource use) for the entire life cycle (i.e., from material acquisition to production, use, and disposal) into a single aggregated numeric score [6, 7]. For many industry sectors, existing LCA databases provide pre-collected data for various goods and services, so that the effort of conducting LCAs can be reduced. In this light, SOPA enables end users to manage and evaluate re-design scenarios for their potential to reduce the environmental impact of business processes. Currently, SOPA provides a conceptual framework and a *prototypical* implementation, which requires process analysts to manually create, manage and execute simulation scenarios, as well as to handle LCA analyses and results. Notably, a unifying UI is missing, as well as support mechanisms for managing simulation scenarios and visualizing results.

Therefore, we: 1.) integrate formal concepts of SOPA into *SimuBridge* [8] to allow easier management and execution of simulation scenarios and visualization of their results; 2.) integrate the LCA tool *openLCA* [9] to allow process analysts to import results of LCA analyses directly into SimuBridge; and 3.) extend the business process simulator *Scylla* [10] to use SOPA concepts and openLCA data during process simulation. This allows easier management and execution, as well as evaluation of SOPA analyses. Figure 1 shows the main concepts and capabilities of SimuBridge and the SOPA integration. In the following, we present the tool's features and its architecture, as well as its applications and potential future development.

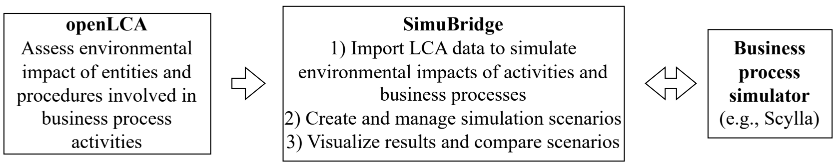

Figure 1: Main features of SimuBridge and the SOPA integration

2. Tool Description

In the following, we describe the main features of the SimuBridge-SOPA-integration, and its architecture. The entire tool and its source code, including a tutorial and a demonstration screencast, is available online.

2.1. Features

The extension of SimuBridge and Scylla to include SOPA concepts enables the following capabilities:

1) Import environmental cost driver data for SOPA analyses from openLCA. To facilitate the analysis of business processes with process simulation, we extended SimuBridge to import LCA data from openLCA. Concretely, process analysts with experience in LCA model *product systems* in openLCA, which represent concrete entities that are involved in the execution of activities. These product systems represent *concrete environmental cost drivers* of SOPA, that is, concrete entities, products, or materials involved in the execution of activities, that cause environmental impact for which LCA analyses can be conducted. Groups of product systems represent *abstract environmental cost drivers*, being an abstract notion of what kinds of products are involved in activity execution [4].

For example, a process activity where a good is packaged may use three distinct carton boxes (distinguished, e.g., by their dimensions, quantity, or material, such as large and small cartons made from bleached corrugated cardboard and a small carton made from unbleached recycled fibres) as packaging material — the packaging material would be the abstract environmental cost driver, and the three types of carton boxes, for which LCA analyses produce environmental impact scores, the concrete environmental cost drivers belonging to the abstract one [4].

In SimuBridge, these product systems are fetched via a TypeScript API and library offered by openLCA[1]. After fetching, a method to calculate the environmental impact of each concrete environmental cost driver (i.e., each product system) can be selected. This method defines the aggregation of environmental impact dimensions into a single score. Once the method is selected, SimuBridge can trigger the calculation and stores the resulting impact scores internally.

2) Manage and run SOPA analyses. In order to conduct a SOPA-based analysis, that is, to holistically assess the environmental impact of business processes and test various re-design options based on process simulations, process analysts can use our tool in the following manner:

First, a BPMN process model to be used for the analysis can be either uploaded or discovered from an event log with the *Simod* tool [11], which is already integrated into SimuBridge. Then, after defining (or refining, in the case that Simod has been used to discover a process model and an initial simulation scenario) general simulation parameters such as activity durations and branching probabilities, the process analyst can assign abstract environmental cost drivers to the process' activities, extending the traditional cost perspective. In a subsequent step, the process analyst can configure *environmental cost variants*, which describe how, during simulation, abstract environmental cost drivers are translated into concrete environmental cost drivers that cause a quantified environmental impact. For each environmental cost variant, the process analyst also configures how many of the process executions to be simulated are executed with which environmental cost variant. For example, 90 of 100 process instances use one specific carton box when packaging a good, and 10 of 100 a different one, both with different environmental impact scores. [4]

For reference, a formalization of these concepts, including a metamodel, formalisms describing the exact calculations of environmental costs of activities and processes, in addition to a case study, is provided in the original SOPA article [4] — here, we rather provide a high-level overview.

3) Visualize results of SOPA analyses. After simulation runs, which produce event logs enriched with environmental impact indicators, the results can be visualized via a dashboard written in

[1]https://greendelta.github.io/openLCA-ApiDoc/ipc/ [Accessed: 16/08/2024]

TypeScript with a React chart library[2]. The dashboard allows process analysts to assess the average environmental impacts of activity instances and process instances per environmental cost variant. Based on this, they can copy the existing simulation scenario into a new scenario, re-configure the process simulation, create new environmental cost drivers, and thereby compare and evaluate different process re-designs for their potential to reduce the environmental impact of the business process being analysed.

2.2. Structure

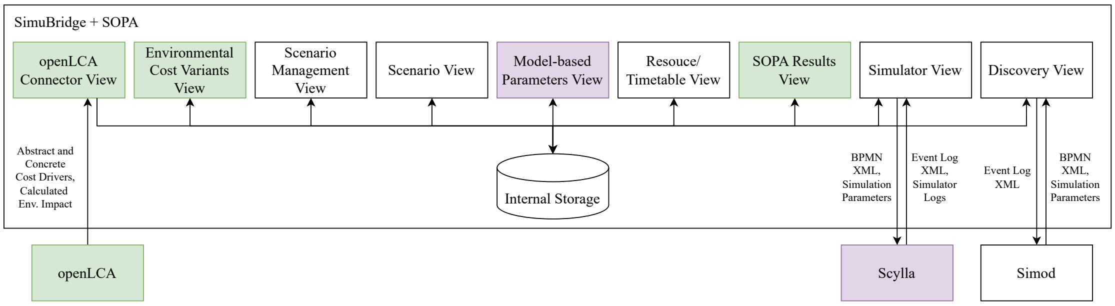

Figure 2: Extended architecture; newly introduced concepts shown in green, extended ones in purple

The integration of SOPA into SimuBridge extends the existing architecture and data schema of SimuBridge, which has been implemented as a web application, in several ways. The overall architecture is shown in Figure 2, where we highlight extended and newly added components.

In general, we extended the internal purpose-built data schema to accommodate environmental cost variants as well as abstract and concrete environmental cost drivers in simulation scenarios. We have integrated openLCA for creating and calculating abstract and concrete environmental cost drivers; we also extended the process simulation engine *Scylla*, written in Java, to make use of these concepts and assign concrete environmental cost drivers to activity instances based on the environmental cost variant. In Figure 3, we highlight the internal data schema of SimuBridge and the SOPA-specific concepts that we added. We also extended the user interface of SimuBridge to 1) configure openLCA and the environmental cost variants in the *openLCA Connector View* and *Environmental Cost Variants View*; 2) Assign abstract environmental cost drivers to process activities in the *Model-based Parameters View*; and to 3) view the resulting environmental costs across activities and process instances in the *SOPA Results View*.

For increased portability and independence of operating systems, we provide SimuBridge and the process simulation engine Scylla as *Docker* images, i.e., packaged in light-weight virtual containers. Only openLCA needs to be installed manually, although for Windows, a portable standalone version also exists.[3].

[2]https://mui.com/x/react-charts/ [Accesssed: 21/08/2024]
[3]See https://www.openlca.org/download/ [Accessed: 23/08/2024]

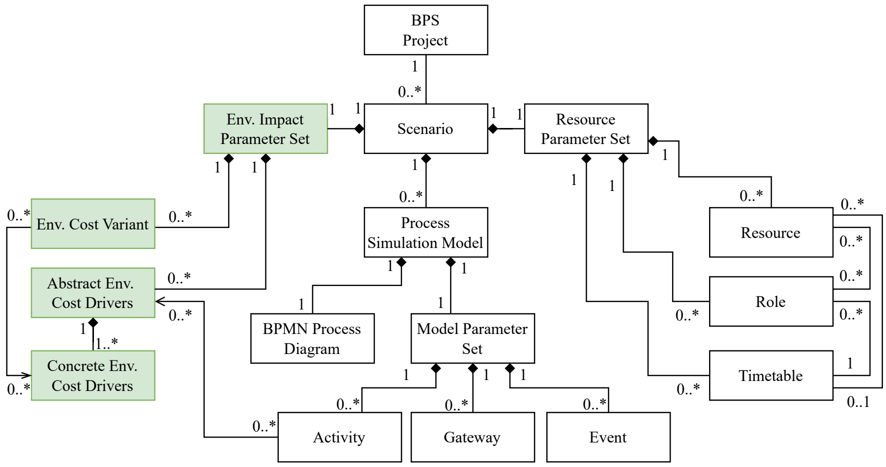

Figure 3: Internal data schema of SimuBridge, extended by SOPA concepts highlighted in green

3. Demonstration and Future Work

For demonstrating our implementation, we unfortunately cannot freely provide LCA datasets, since the underlying databases are bound to (educational) licences. Instead, we provide a synthetic dataset online[4] that can be loaded into openLCA – see the repository linked above for a description of how this can be achieved – and used for demonstration purposes. We additionally provide several BPMN diagrams (a logistics process, a hiring process of a university, and a pizza baking and delivery process) and describe scenarios that can be tested with our implementation and the synthetic dataset.

In the future, we plan to extend the integration of SOPA into SimuBridge: We want to include support so that event logs with annotated environmental cost driver information can serve as a basis for creating and configuring simulation scenarios and the corresponding environmental cost drivers. Doing so would allow process experts to even further reason about the environmental impact of process re-designs based on simulation scenarios derived from historic process data (something already possible with SimuBridge without considerations of environmental impact). We also want to make the simulation even more dynamic, so that the simulation engine uses *parametrised* environmental cost drivers and calculates the environmental impact *dynamically* by calling openLCA, instead of statically. Finally, we plan to conduct a case study with the SOPA-SimuBridge extension in a real-world organization, to further illustrate the benefit of holistic sustainability analyses of business processes with business process simulation.

Maturity We evaluated our work with several synthetic business processes and scenarios for which we derived LCA data from existing databases. We were able to quantify the environmental impact based on configured simulation scenarios and the underlying LCA data, and were able to reason about reductions in environmental impact based on process redesigns. Furthermore,

[4] https://github.com/INSM-TUM/SimuBridge--SOPA-Extension/tree/main/demo [Accessed: 28/08/2024]

we have presented the underlying SOPA framework to several industry experts with knowledge in the area of sustainability and BPM, who agreed that the combination of LCA-based holistic environmental assessments and business process simulation adds value and enables useful considerations of process redesigns.

Acknowledgments

We would like to thank the Bachelor students who contributed to incorporate the SOPA framework in SimuBridge and Scylla: Kareem Ali Abou-sena, Mihail Atansov, Alexey Bednik, Ilona Bogatinovska, Wen-Chun Chen, Jing Yao Seow, Orion Shkodra, Renis Shutina, Hui-Yu Yu and Zeynep Sude Yildirim.

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