TOWARDS A DOMAIN SPECIFIC LANGUAGE FOR DESCRIPTION OF LONGITUDINAL BUSINESS PROCESSES RELATED TO DIGITAL AND GREEN TRANSFORMATION

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We investigate abstract common traits of longitudinal processes related to digital and green transformation of business processes, such as LCA analysis, CO_2 footprint evaluation, and production cost analysis. The common abstraction allows to develop general tools and joint understanding of the three most relevant analytical processes significant to economic entities: production cost allows the undertaking to stay competitive, while conforming to forthcoming regulation involving either calculation of CO_2 footprint (relevant to most value chains in European economy) or LCA analysis of products (relevant to major undertakings that are subject to sustainability reporting regulations). The result is an idea for a domain specific language that describes the concepts to calculate the stated process indicators and describe the data required in these calculations.

Keywords:
LCA analysis, CO_2 footprint, production cost, longitudinal process, domain specific language, mathematical modelling, evaluation, analysis

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1 Introduction

In digital transformation, organizations or companies leverage digital technologies to change how they conduct their business activities, communicate with customers, develop products and services, and manage their internal processes. Green transformation signifies a shift towards a more sustainable and environmentally friendly way of conducting business. It entails organizations' efforts to reduce their negative impact on the environment, focus more on sustainable development, and employ environmentally friendly practices, products, and technologies. This transformation includes taking measures to reduce carbon footprint, efficient use of resources, recycling, utilization of renewable energy sources, development of eco-friendly products, and waste reduction. The aim of green transformation is to create a more sustainable, environmentally friendly, and socially responsible business approach. The integration of digital and green transformations enables the creation of a more sustainable and innovative business model. Our investigation focuses on key elements of digital and green transformation, such as Life Cycle Assessment (LCA), CO_2 footprint evaluation, and production cost analysis. Through identifying common mathematical abstractions of these processes, we aim to develop comprehensive tools and foster a collective comprehension of the most crucial analytical procedures pertinent to economic entities. This achieves synergy between progress, efficiency, and environmental responsibility, resulting in better outcomes for humankind and the environment.[2]

In subsequent sections, we undertake a comprehensive review of concepts and learning space used. Then we explore the mathematical basis concerning CO_2 calculation, production cost analysis, and Life Cycle Assessment (LCA). Following the development of the mathematical model, an innovative Domain-Specific Language (DSL) is conceptualized and expounded upon, with detailed explanation provided in the subsequent illustrative example, focusing on the well known process of baking a pizza. To establish a foundational understanding, the discourse initiates with background research on LCA, PCA, and carbon footprint.

2 Background research on LCA, PCA, and Carbon Footprint

LCA began as an approach to assess the environmental implications of products and evolved into a standardized method for systematically evaluating the potential environmental impacts of products, services, and technologies. Recent efforts have also focused on expanding the LCA methodology to capture indirect effects through the use of economic techniques and models (consequential LCA) and broadening the traditional LCA framework to integrate environmental, social, and economic aspects into the analysis, referred to as life cycle sustainability assessment (LCSA) (Ciambrone, 1997, Nuss, 2014).

The significance of the growing number of carbon footprint reports is a response to both legislative requirements and the business environment, leading to global acceptance and adoption of the Greenhouse Gas Protocol (GHG Protocol) set by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) (GHG Protocol, 2004). Sources emphasize the importance of proper measurement and reduction of greenhouse gas emissions, as well as the significance of conducting appropriate analyses for understanding and taking action in an environment constrained by carbon production (Franchetti & Apul, 2012, Onat et al., 2013).

We first review the structure of the data that will serve as the basis for developing general tools and a shared understanding of the mentioned most relevant analytical processes. Data for life cycle costing analysis, life cycle assessment, and carbon footprint analysis are interconnected and vital for understanding the impact of operations on the economy, environment, and social responsibility. These analyses provide insights into various aspects of business processes and products. Life cycle costing analysis (PCA - Production Cost Analysis) assesses the total costs of a product or service throughout its entire life cycle, including acquisition, use, maintenance, and final disposal. This information aids in evaluating the economic consequences and profitability of a product or service and in decision-making. Life cycle assessment (LCA) provides a systematic overview of the environmental impacts of a product or service from its beginning to end, encompassing production, use, and final disposal. This analysis evaluates greenhouse gas emissions, resource consumption, and other environmental aspects, contributing to improving environmental sustainability. Carbon footprint analysis focuses on assessing the quantity of greenhouse gasses produced by a specific product, service, or organization. This analysis assists in measuring and managing carbon emissions and adjusting business practices to reduce the carbon footprint. The common denominator among these analyses is the emphasis on a comprehensive understanding of the impact of activities on the economy, environment, and social responsibility, enabling informed decisions for sustainable business practices.

The data for production cost analysis (PCA) includes various types of costs that are collected and analyzed throughout the entire life cycle of a product or service. The data structure for PCA analysis typically encompasses the following types of costs: cost of acquisition (costs related to the acquisition of a product or service, such as, purchase price, transportation costs, installation, licensing fees, and similar) and operating costs (costs incurred during the actual use of a product or service, including maintenance costs, repairs, operational expenses (e.g., fuel, electricity, water), labor costs, upgrades, and similar).

Structured data for Life Cycle Assessment (LCA) typically includes information and data describing the environmental aspects of a product or service throughout its entire life cycle. These details are organized to enable a comprehensive assessment of environmental impacts. The data structure for LCA can include the following: lifecycle stages (data concerning individual stages of the life cycle, such as raw material acquisition, production, distribution, use, maintenance, final disposal, recycling, etc.), resource consumption (information about the use of raw materials, energy, water, and other natural resources in each life cycle phase) and emissions (data on emissions of various pollutants in each life cycle phase, such as greenhouse gasses, water, air, and soil emissions, and other pollutants), environmental impact assessment (analysis of the product or service's impact on ecosystems, biodiversity, climate change, and similar).

Data required for carbon footprint analysis includes energy consumption (details about energy use such as electricity, heating fuel, use of engines or machinery, including energy sources), material consumption (including their origin, production, transportation, and final use or disposal), transportation and distribution (data concerning product or service transportation from suppliers to end-users or consumers, including modes of transport, distances, and fuel types), product or service usage (impact of final usage on emissions, such as energy consumption, waste generation, product sustainability, and duration of use), waste disposal (quantity and type of waste generated, along with emissions of waste treatment or disposal methods), business travel, existing and outgoing production processes, linked business processes and end-of-life product disposal.

Life Cycle Assessment (LCA), production cost analysis (PCA), and carbon dioxide (CO_2) footprint evaluation are closely linked, providing a comprehensive approach to assessing the sustainability and financial aspects of products or services. LCA carefully studies the environmental impact of a product or service from its beginning to end, covering stages like acquiring raw materials, production, distribution, use, maintenance, and end-of-life. This assessment includes detailed information about resource use, emissions, and environmental effects, particularly focusing on CO_2 emissions. Concurrently, PCA looks at the costs associated with the entire life cycle, including acquisition, operation, maintenance, and end-of-life. The financial data reflects the material and energy aspects studied in LCA. Importantly, the production and usage phases, central to PCA, significantly contribute to the carbon footprint, aligning with the emissions evaluation in LCA. In essence, the shared ground among LCA, PCA, and CO_2 emissions lies in their combined role in assessing the overall sustainability of a product or service, where environmental considerations, economic factors, and carbon footprint are intricately connected throughout the entire life cycle.

3 Concepts and learning space

A learning space is a mathematical structure for modeling the process of learning and understanding new concepts. Learning spaces are intended for modeling the intellectual space, knowledge that individuals already possess and can still acquire (Falmange, 2011, Bokal, Jerebic, 2023, Jerebic et al., 2023). In our research, we applied the learning space concept within the framework of mathematical modeling for sustainable process analysis. Table 1 comprises four columns, with the first column outlining variables necessary for the mathematical model. A comprehensive exploration of this topic is presented in the following sections. A brief overview follows, "i" denotes the index of a specific step of the process elaborated upon in the columns, "A_i" denotes the technological matrix utilized at corresponding step in the process, "d_i" serves as the decision vector specifying the desired resource quantities at each step. The "y_i" column represents the state of the world after each step in relation to the utilized or produced resources. The remaining three columns each pertain to a specific aspect of the central problem we aim to calculate. The "CO_2" column informs us of the emissions generated at each step of the process. "LCA" represents the environmental impact deriving from a chosen process step. Finally, "PCA" encapsulates the economic information about a step in the given process.

Table 1: Table of elements in corresponding model

	CO_2	LCA	PCA
i	step of production process	step of product life cycle	Step of product manufacture
A_i	Technological matrix of the i-th step		
x_i	Desired amounts to be produced during i-th step of the process		
y_0	Carbon footprint generated by the first step source	Environmental indicator value	Costs of the first step depending on resource consumption, normally zero
y_i i=1…n	Carbon footprint generated by the i-th step source	State of resources and products after the i-th step	

4 Mathematical models and algorithms

The base model we apply is a linear cost and linear production model that is also used in a parallel contribution Brun et al., 2023. Aligned with Table 1, the model denotes the state of the world at the *i*-th step of the process with $y_i \in R^m$. The decision vector of the same step is a m-dimensional vector $x_i \in R^m$, and it specifies all the desiderata of the production process that can be controlled. For simplicity, we may assume all monitored quantities can be controlled, implying x_i and y_i have the same dimension. The dimensions therefore constitute amounts of products, byproducts, pollutants, as well as amount of resources such as (raw) materials, partial products, energy, labor, time, money. The latter are usually reduced in quantity and the former are produced by the vector of change at each step of the process, $A_i\, x_i$. The (linear) technology producing this change of the state of the world given decision x_i is described by technology matrix A_i. This matrix is a square matrix by assumptions and its coefficients represent specific constants of the process, such as prices, densities or relative densities and ingredient amounts in products, energy requirements and similar. Having specified the initial state of the world y_0, the model of the process is then completely described by the following recurrence equation $y_i = A_i x_i + y_{i-1}$. Note that recurrence is elementary: the previous state of the world is linearly augmented by the vector of change produced by multiplying the decision vector with the technology matrix.

This iterative process continues throughout the entire sequence of steps, ensuring that the state vector at each stage comprehensively represents the cumulative effects of decisions and technological processes. Positive and negative values in the result vector respectively denote the creation or acquisition and consumption or utilization of resources, products, or byproducts. The final state vector, y_{final}, encapsulates the overall final state of the system, incorporating products, byproducts, and incurred costs from the entire process.

5 A Domain-Specific Programming Language

A domain-specific language (DSL) is a specialized programming or specification language designed for specific problem domains, representation techniques, or solution approaches, enhancing precision and efficiency in data interpretation for various applications (Fowler, M., 2010). In this section, we describe an innovative idea of a domain specific language for description of longitudinal processes that streamlines the method of sustainable process modeling and life cycle analysis, ensuring users can effortlessly navigate the complexities of mathematical modeling without requiring in-depth knowledge of matrices. Embracing a declarative approach to process definition, users articulate relationships between components without delving into procedural complexities. This abstraction prioritizes readability, making the language accessible to a wider audience by focusing on expressing the "what" rather than the "how" (Fowler, M., 2010).

At the core of the language lies the technological matrix, a dynamic representation of interdependencies within a process. Rows in the matrix correspond to process steps, while columns represent resources, emissions, costs, and other variables. This matrix enables users to analyze resource flows and environmental impacts, with costs and emissions dynamically calculated during the multiplication of the decision vector. This ensures a realistic representation of the environmental and economic impact of each step in a chosen process, eliminating the need for users to manually delve into matrix calculations.

Users of programming language define objectives using decision vectors expressing desired resource quantities. The language dynamically generates the matrix and vector required by the mathematical model, calculating emissions and costs during the multiplication of the decision vector with the technological matrix. This feature enables the exploration of diverse scenarios, allowing evaluation of decision-making trade-offs, providing a holistic understanding of process impacts.

Facilitating multi-dimensional analysis, the language empowers users to assess the implications of decisions across various dimensions simultaneously. Whether evaluating resource consumption, emissions, energy usage, or economic costs, users gain a comprehensive understanding, crucial for informed decision-making aligned with sustainability goals. For instance, users can clearly see how each step of the chosen process impacts the environment and economic standpoint and take measures to reduce the emissions or cost of a certain step.

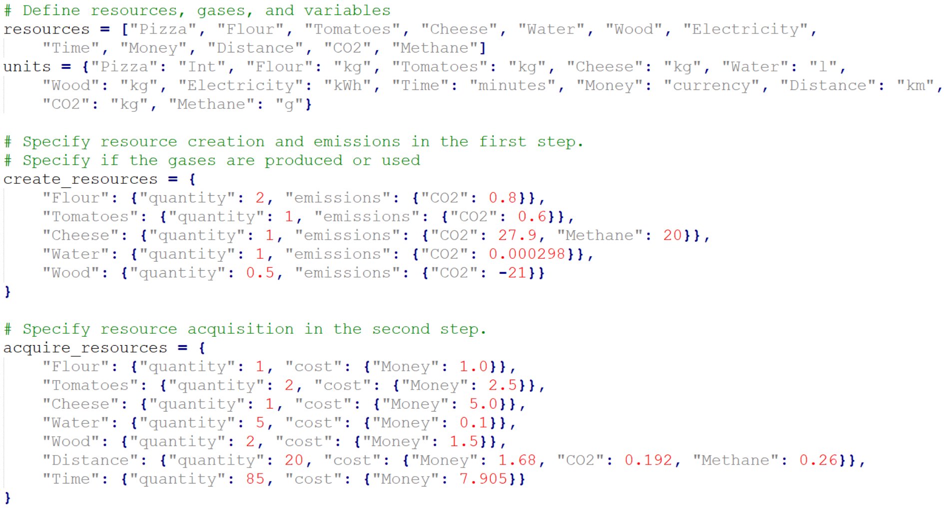
The language introduces a dynamic state evolution mechanism that empowers users to simulate the life cycle of processes, capturing temporal variations and system responses to changing conditions. Additionally, it recognizes diverse environmental impacts by enabling the customization of environmental coefficients within the technological matrix at the end of the chosen process. This adaptability ensures alignment with specific sustainability metrics or industry standards, enhancing the relevance and accuracy of the model.

The following image (Figure 1) illustrates a representation of the language syntax.

6 Illustrative example

In this section, we elucidate the practical application of the formula and domain-specific language through a detailed illustrative example, delving into the intricacies of assessing carbon dioxide (CO_2) emissions, life cycle analysis, and production costs. In the following illustrative example, we employ the designed DSL to assess carbon dioxide (CO_2) emissions, life cycle analysis, and life production cost analysis of a sketch of a pizza-making process. We navigate through four integral phases: production, procurement, baking, and consumption.

Commencing with production, the focus is on evaluating the environmental impact associated with the cultivation and manufacturing of raw ingredients. Shifting to the procurement phase, the focus broadens to encompass both environmental and financial considerations, incorporating factors like transportation distance, gas expenditure, and worker costs in the overall analysis. Transitioning to the baking stage, further divided into dough preparation, topping addition, and baking, the DSL allows for the specification of the cost of electricity and its corresponding environmental implications at each juncture. Finally, we address the consumption stage, completing the life cycle analysis within the boundaries of interest. Consequently, as a result we get a vector representing the state of the world after the entire pizza-making process. Every phase is represented as a separate entity within the DSL, facilitating a nuanced examination of environmental and cost dimensions across the entire process.



```
# Define resources, gases, and variables
resources = ["Pizza", "Flour", "Tomatoes", "Cheese", "Water", "Wood", "Electricity",
    "Time", "Money", "Distance", "CO2", "Methane"]
units = {"Pizza": "Int", "Flour": "kg", "Tomatoes": "kg", "Cheese": "kg", "Water": "l",
    "Wood": "kg", "Electricity": "kWh", "Time": "minutes", "Money": "currency", "Distance": "km",
    "CO2": "kg", "Methane": "g"}

# Specify resource creation and emissions in the first step.
# Specify if the gases are produced or used
create_resources = {
    "Flour": {"quantity": 2, "emissions": {"CO2": 0.8}},
    "Tomatoes": {"quantity": 1, "emissions": {"CO2": 0.6}},
    "Cheese": {"quantity": 1, "emissions": {"CO2": 27.9, "Methane": 20}},
    "Water": {"quantity": 1, "emissions": {"CO2": 0.000298}},
    "Wood": {"quantity": 0.5, "emissions": {"CO2": -21}}
}

# Specify resource acquisition in the second step.
acquire_resources = {
    "Flour": {"quantity": 1, "cost": {"Money": 1.0}},
    "Tomatoes": {"quantity": 2, "cost": {"Money": 2.5}},
    "Cheese": {"quantity": 1, "cost": {"Money": 5.0}},
    "Water": {"quantity": 5, "cost": {"Money": 0.1}},
    "Wood": {"quantity": 2, "cost": {"Money": 1.5}},
    "Distance": {"quantity": 20, "cost": {"Money": 1.68, "CO2": 0.192, "Methane": 0.26}},
    "Time": {"quantity": 85, "cost": {"Money": 7.905}}
}
```

Figure 1: Possible syntax of a domain-specific programming language

The comprehensive evaluation of the pizza making lifecycle, considering factors from CO_2 production during ingredient growth to vehicular methane emissions, reveals a total emission of 14,5 kg of CO_2 used and 89 g of methane produced. The associated cost amounts to 24 EUR, reflecting the estimated price for an average individual to bake one pizza outside of the regular food production value chains. However, it is important to note that the actual material cost of the pizza excluding individual's work (but accounting for retail rather than wholesale prices) is 5 EUR, rendering it comparable to the actual pizza cost. Within the pizza-making example, the domain-specific language employs matrix calculations to generate vectors at each stage, allowing users to access detailed insights into environmental impact and production costs for every step of the process. Additionally, the DSL facilitates a comprehensive overview by combining these individual vectors, enabling users to obtain the state of the world not only at the conclusion of the entire process but also at every intermediate step throughout the pizza production lifecycle. An in depth analysis of this example including all the data and sources will be covered in a submitted paper Alif et al, 2024.

7 Conclusions and further research

Production cost, life cycle analysis (LCA), and carbon footprint all share common domain in being methods or concepts crucial to various aspects of business operations and sustainable development. Despite serving different purposes, they exhibit a common mathematical model implying several common characteristics. All three concepts are pivotal for sustainable business practices in assessing a company's impact on the environment and society. Production cost, LCA, and carbon footprint all involve measuring or assessing a company's impact on the environment. Production cost focuses on determining the actual production costs, LCA assesses the overall environmental impact of a product or service throughout its life cycle, while carbon footprint evaluates greenhouse gas emissions across the entire supply and use chain of a product or service. All three concepts are also crucial in sustainability reporting for companies, enabling the evaluation and reporting of the environmental impact of their operations, products, or services. While each concept employs different approaches, all are indispensable for sustainable business practices and improving companies' environmental footprint.

As we delve into the realm of environmental sustainability and corporate responsibility, there remain promising avenues for further research in this dynamic field. Future investigations could explore the refinement and expansion of the formulated approach and domain-specific language (DSL) to accommodate evolving industry standards, emerging technologies, and shifting global priorities. Additionally, researchers might delve into comparative studies assessing the effectiveness of the DSL in diverse sectors and industries, providing valuable insights into its adaptability and scalability. Another approach could also focus on the development of standardized metrics and benchmarks within the DSL, fostering a common language for companies to benchmark their environmental performance against industry peers. Exploring the integration of artificial intelligence and machine learning algorithms within the DSL could enhance predictive capabilities, enabling companies to proactively identify potential environmental impacts and optimize resource usage. Collaborative efforts between academia, industry stakeholders, and policymakers could contribute to the creation of a robust and universally accepted framework, fostering a more sustainable and resilient global business landscape. Continued exploration of these aspects is essential for advancing our understanding of the interplay between business operations, environmental impact, and sustainable development, paving the way for informed decision-making and significant contributions to a sustainable future.

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