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Citation for the original published paper (version of record):
Böckin, D., Goffetti, G., Baumann, H. et al (2022). Business model life cycle assessment: A method for analysing the environmental performance of business. Sustainable Production and Consumption, 32: 112-124.
http://dx.doi.org/10.1016/j.spc.2022.04.014

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Sustainable Production and Consumption 32 (2022) 112–124

Contents lists available at ScienceDirect

Sustainable Production and Consumption

journal homepage: www.elsevier.com/locate/spc

Business model life cycle assessment: A method for analysing the environmental performance of business

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ARTICLE INFO

Article history:
Received 30 November 2021
Received in revised form 5 April 2022
Accepted 9 April 2022
Available online 11 April 2022

Editor: Prof. Piera Centobelli

Keywords:
Life cycle assessment
Business model
Decoupling
Sustainable production and consumption
Functional unit
Method

ABSTRACT

This paper introduces business model life cycle assessment (BM-LCA), a new method for quantifying the environmental impacts of business models. Such a method is needed to guide business decisions towards decoupling economic activity from environmental impact. BM-LCA takes the business model itself as the unit of analysis and its economic performance as the basis of comparison. It can be applied to any type of business model involving material or resource use. In BM-LCA, monetary flows are coupled to material and energy flows. The methodology expands on conventional life cycle assessment (LCA) by elaborating the goal and scope definition and dividing it into two phases. The first descriptive phase details the business models to be compared. It includes a mapping of product chain actors and identifying business operations and transactions related to the product. The second coupling phase defines a profit-based functional unit and sets up the coupling equations expressing the economic relations to the product. Thereafter, conventional LCA procedures are followed to assess environmental impacts. The key innovation on LCA methodology is the development of a functional unit that captures the economic performance of a business model and links it to a product system. BM-LCA provides thus an important link between LCA and business competitive advantage.

1. Introduction

Following increased interest in sustainable business and circular economy, there has been numerous calls for methods that can analyse the environmental performance of business models (e.g., Das et al., 2022; De Giacomo and Bleischwitz, 2020; van Loon et al., 2021) and that can guide business decisions towards the decoupling of economic activity from environmental impact (e.g., Harris et al., 2021; Kjaer et al., 2019; Urbinati et al., 2017).

The interest in business models and their environmental performance stems from the observation that economic activity is tightly coupled with environmental impact — a growing economy has come with an increasing environmental footprint. This was perhaps first shown by Meadows et al. (1972) and more recently by Rockström et al. (2009). While decoupling (Jackson, 2009) offers a solution, it is often discussed on a macroeconomic level, for example, carbon emissions in relation to nation's gross domestic product (International Resource Panel, 2011; EC, 2015), therefore offering little guidance to business practice. On the firm-level, the literature instead points to the role of business models for shaping production and consumption systems (e.g., Lüdeke-Freund, 2010; Urbinati et al., 2017; Wells, 2013) and for bringing sustainability innovations to the market (Boons and Lüdeke-Freund, 2013; Wells, 2013). Many different types of sustainable business models have been proposed, but there is limited empirical support from environmental assessments as to whether their environmental performance is better and when these lead to decoupling (Kjaer et al., 2019; Pieroni et al., 2019; Zink and Geyer, 2017). Hence, there is a need for a systematic methodology for assessing the environmental consequences of business models and the different ways these create and capture value (Bocken et al., 2016; Harris et al., 2021; Kravchenko et al., 2019; van Loon et al., 2021).

There is thus a pressing research gap regarding a systematic approach for evaluating business model environmental performance. This paper seeks to fill that gap by presenting business model life cycle assessment (BM-LCA), a new form of life cycle assessment (LCA) for the environmental assessment of business.

The BM-LCA method is the result of a realisation that mainstream LCAs, with their usual product focus, fail to capture the impacts of business models themselves. Typically, an LCA takes a product as the object of analysis and models the associated technical system. No matter how low the environmental footprint of a product, the overall environmental outcome is uncertain if mass production and sales are required for the business model to be economically viable. This means that a business-

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https://doi.org/10.1016/j.spc.2022.04.014

oriented LCA method must account for socio-technical and economic dimensions of a business model, dimensions that are seldom included in LCA (Bocken et al., 2016; Costa et al., 2019). Incorporating such dimensions into an LCA method would also make it more relevant to businesses, according to Hoffman et al. (2014).

Considering this, we innovated on conventional LCA methodology so that the business itself becomes the object of analysis and its economic performance the basis of comparison — this led to the development of business model LCA (BM-LCA). The method enables quantitative environmental assessment of business models and can be used for comparing the environmental performance of different business models to see if decoupling is achieved. The aim of the paper is to introduce BM-LCA methodology.

The methodological innovation took place within a project on comparing the environmental sustainability of two business models of a Swedish company. While the business model analysis of the project has been described in a technical report (Böckin et al., 2020), the present paper has the purpose of providing a systematised and generalised account of BM-LCA methodology applicable to any business model. To illustrate key novel features of the methodology, we have devised and presented a simplified comparative case in the present paper. (See Goffetti et al. (2022) for an account of the application of BM-LCA to the empirical comparative case and an analysis of the method's usefulness for business model innovation.)

2. Literature review

Looking into the literature on business models and the existing methods for improving their environmental performance, we find that methods either fail to focus on business or offer inadequate assessment of business environmental performance.

2.1. Business models

The concept of a 'business model' has many interpretations, often diverging (De Angelis, 2018). A basic dictionary definition states that a business model is 'a description of the different parts of a business or organization showing how they will work together successfully to make money' (Cambridge Business English Dictionary, 2011). Since the widespread adoption of the business model concept, it has primarily been used to support profit generation (Bocken et al., 2014; Dentchev et al., 2016; Magretta, 2002). There are arguments for an expanded view of the purpose of businesses (Geissdoerfer et al., 2018). However, as indicated by the definition above, from the perspective of a business company, its owners and shareholders, the purpose might indeed be a viable business in terms of sustained economic performance.

Elaborating on the basic definition, BMs can be described as how a company makes money, often around a particular product or service and for a particular market; the profit formula includes the costs and the revenue streams for this (Ovans, 2015). This identifies the product being one means to business alongside other means such as pricing, marketing, production and distribution networks (c.f., Reim et al., 2015). Therefore, an environmental assessment method centring on the product system is insufficient to determine the environmental performance of a business model.

In a so-called linear business model, a business generates profit via the continuous sale of products. Alternative business models have been put forward for reducing the environmental impacts of businesses (Boons and Lüdeke-Freund, 2013), including sustainable business models (SBM), product-service systems (PSS) and circular business models (CBM). SBMs are 'business models that incorporate pro-active multi-stakeholder management, the creation of monetary and non-monetary value for a broad range of stakeholders, and hold a long-term perspective' (Geissdoerfer et al., 2018). PSS is a subset of this and is defined as 'a mix of tangible products and intangible services, designed and combined so that they are jointly capable of fulfilling final customer needs' (Tukker and Tischner, 2006). Examples include so-called use-based PSS, for example, in the form of rental models. Finally, CBMs are another subset of SBMs, partially overlapping with PSS. CBMs lack a universally agreed upon definition (Geissdoerfer et al., 2018), but one states that a CBM is 'a business model in which the conceptual logic for value creation is based on utilizing economic value retained in products after use in the production of new offerings' (Linder and Williander, 2017). Characteristics of these definitions are the conditioning of the business model in the basic definition with various ecodesign strategies and sustainability principles for ecological and social value. Nevertheless, a sustainable business model, just like a linear one, 'structures' the value process so that it provides value to customers and collects a portion of this in revenues to the company.

To conclude, regardless of the business model, their purpose is business. Any assessment of their environmental performance needs to analyse business itself, more particularly, the business around its products.

2.2. Environmental assessments

A life cycle perspective is crucial for attaining a holistic view of the potential environmental impacts of all parts of a product system. A common method for such assessments is LCA, defined as 'a technique for assessing the environmental aspects and potential impact associated with a product' (ISO 14040, 2006). Generally, LCA is applied in four phases, namely 1) goal and scope definition, 2) life cycle inventory analysis, 3) life cycle impact assessment and 4) interpretation. Baumann and Tillman (2004) offer detailed descriptions of these phases.

A central problem in LCA is the establishment of a relevant basis of comparison for the objects under consideration, typically reflecting the function of the studied system (commonly a product or service) from a user's perspective. This is used to define a functional unit to which all environmental impacts are scaled. The functional unit is typically defined in terms of the physical characteristics describing the function of the product for a user. For example, for packaging, 1 l, for transporting goods, 1 tonne ∗ km, and for surface materials such as paint or flooring, 1 m^2 ∗ year. Such functional units do not reflect the function of business, which is why a different form of functional unit is necessary when the object of analysis is a business model. For the method presented here, we need to consider how the functional unit could reflect the function of a business model (see Section 3).

2.3. Environmental assessments of business models

A variety of studies have been carried out relating to the environmental assessment of business models. However, we have not found any of these to centre the evaluation on the environmental consequences of different ways of making money. The way these studies relate a business model and attempt to account its environmental performance differs (see overview in Table 1).

Some studies labelled as environmental assessments of business models use conventional LCA to compare product alternatives that represent different business scenarios. More specifically, we found that the comparison of products for the different business models are comparisons of differences in product designs or in user behaviour assumed to reflect some physical consequences of the business model in the analysed product. Thus, the majority of these studies take the product function as the basis of comparison and exclude a quantified business economic perspective. Consequently, there is no way of analysing the actual consequences of business with each business model, the environmental performance of a business model. Examples of studies in this category include environmental LCAs of renting next-to-skin garments (Bech et al., 2019), water purifiers (Chun and Lee, 2017), heavy-duty trucks (Diener et al., 2015), strollers (Kerdlap et al., 2021), rental clothing (Johnson and Plepys, 2021), power-tools (Martin et al., 2021) as well as clothing libraries (Zamani et al., 2017). The same is true of LCAs that are complemented by qualitative business considerations,

Table 1
Examples of quantified environmental assessments of business models from literature, grouped according to their object of analysis and whether economic data is used in modelling or not.

	Object of analysis (basis of comparison)		
	Product (function of product)		Business model (economic performance)
No economic data in modelling	Environmental LCA: - Bech et al. (2019) - Chun and Lee (2017) - Diener et al. (2015) - Johnson and Plepys (2021) - Kerdlap et al. (2021) - Martin et al. (2021) - Zamani et al. (2017)	LCA with qualitative economic perspective: - Barbieri and Santos (2020) - Hoffmann et al. (2020) - Tschiggerl et al. (2018)	–
Economic data in modelling	Parallel LCA and LCC: - Kaddoura et al. (2019) - Zhang et al. (2018) - Bi et al. (2015) - Bi et al. (2017)	Simulation-based tools: - Asif et al. (2016) Eco-efficiency: - Mendoza et al. (2019)	(Place for BM-LCA, present method)

for example, assessments of cloth diapers (Hoffmann et al., 2020), energy storage technologies (Tschiggerl et al., 2018) and veterinary pharmaceutical products (Barbieri and Santos, 2020).

A limited number of studies have attempted to add economic considerations to environmental assessments, either in modelling or in later impact assessment stages. The work by Asif et al. (2016) is an example of attempting to integrate modelling of environmental and economic effects. They developed a tool based on system dynamics and agent-based modelling to assess leasing of washing machines. Again, the basis of comparison is the product function rather than that of business itself. Further studies that base their assessment on product comparisons include those that apply LCA and life cycle costing (LCC) in parallel. Examples include studies comparing plug-in and wireless charging for electric buses (Bi et al., 2017; Bi et al., 2015), studies on PSS models for passive durable products like furniture and exhibition equipment (Kaddoura et al., 2019), energy-using equipment for separating air into its constituents (Zhang et al., 2018) and eco-efficiency calculations for disposable diapers (Mendoza et al., 2019).

Within impact assessment in LCA, some methods have been developed that monetise environmental impacts, such as the environmental priority strategies method (EPS) (Steen, 2015), the life cycle impact assessment method (LIME) (Itsubo and Inaba, 2004) and a method developed in a study by Tsai et al. (2014) who monetise carbon emissions etc. to calculate the profit of a manufacturing facility. Nevertheless, the monetised flows are not directly relevant to the performance of a business model, since these are mainly negative externalities, that is, costs not incurred by business unless forcibly internalised via, say, a carbon tax.

Although multiple LCA studies are labelled as environmental assessment of business models, their object of analysis remains on the product function. A few of these studies bring in some economic data on costs or externalities but do so without addressing business model performance. Together, this means that there is a place for a business-oriented LCA method which integrates economic in the modelling and for which the object of analysis is the business model itself (see Table 1).

2.4. Tools for improving the environmental performance of business models

The business model canvas (BMC) is a popular tool for guiding business model innovation. It aids in mapping the value proposition, creation, delivery and capture of a business model (Osterwalder and Pigneur, 2010). However, the BMC lacks an environmental perspective. As a result, variants have been developed like the triple layered BMC (Joyce and Paquin, 2016), the Ecocanvas (Daou et al., 2020), the circular BMC (Lewandowski, 2016), the circular business model mapping tool (Nußholz, 2018) and the typology of circular economy business model patterns (Lüdeke-Freund et al., 2018). These add qualitative considerations such as reverse logistics and potential environmental effects. Furthermore, Pieroni et al. (2019) found that 93% of 92 reviewed approaches for sustainable business model innovation built on qualitative data. A recent practice review (Das et al., 2022) identified most companies do not forecast the environmental impact of their new business ideas and that there is a great need for environmental impact assessment tools that assist business analysts and designers. There is thus a lack of systematic and quantitative tools to guide decision making towards more environmentally sustainable business models.

3. Methods and conceptualisations

The development of the method stemmed from a few key ideas. The first is the need to (re)contextualise product-centred LCA into a business setting. The second is to base it in a socio-material understanding of the materials and energy flows modelled in LCA (Baumann and Lindkvist, 2021). Such a socio-material view supports the identification of actors along the product chain and business operations interacting with the physical life cycle and allows for connecting the monetary streams of the business model to the material and energy flows of the product system. These two principles result, first, in a different basis of comparison, one based on the economic performance of business models rather than the physical function of a product or service, and second, to a set of coupling equations that connect business and product systems.

Since there are many companies (and other actors) along a life cycle, to distinguish the company whose business model is being analysed, it is here called ‘business company’.

3.1. Object of analysis: from a product to a business perspective in LCA

The crucial innovation of BM-LCA is the shift from taking a product or service as its object of analysis, as is typical in LCA. Since a product is a means for business, alongside pricing, marketing, production and distribution networks (c.f., Boons and Lüdeke-Freund, 2013; Reim et al., 2015), it is not enough to centre an LCA on the product system if business models are to be analysed (Baumann et al., 2022). This leads instead to that the object of analysis is the business model employed for delivering that product or service. In turn, this allows us to map and compare the environmental consequences of different ways of business to make money from their products or services. Moreover, the focus here is on the business system for making money from a particular (set of) product(s), as opposed to viewing a business model as encompassing, for example, an entire company with several product portfolios and activities.

For BM-LCA it is necessary to understand how a business model is related to the technical life cycle system of a product. To begin, it is necessary to understand what parts of the product system belong to the business company, its relations to the surrounding network of actors, including suppliers and customers, and its different business operations around the product. For this, an analysis of the actors shaping the product chain organization (PCO) is made (Baumann, 2008, 2012), as is depicted in Fig. 1, and the technical steps belonging to the business company are identified. Next, the 'socio-material interaction points' (Baumann and Lindkvist, 2021) within the business company are identified — here, it is where the business activities take place that handle and relate to the product material flows. This results in a set of business operations and transactions that make up the business system around the product. Some operations are associated with costs (e.g., procurement and wages) and others with incomes (e.g., from sales). A transaction between two actors implies the exchange of money for goods and/or services as seen in the simple schematic in Fig. 1 (in the case of services, there is almost always some associated use of materials and energy). Stated otherwise, the identification of socio-material interaction points along the product flow corresponds to identifying the points at which revenue and costs occur for the business company. The transactions between the business company and other actors in the value chain (e.g., customers and suppliers) are those that make up the profit formula for a business model (Ovans, 2015) and are therefore of particular importance for BM-LCA.

In order to analyse a business model and its environmental consequences quantitatively, the business needs to be coupled with the associated physical product system in a systematic way. For this, the monetary flows of the business model are coupled with the material and energy flows of the product system. Each business operation can be described with an equation that expresses the economic relation to the product, for example, as the price of the product or the costs of distribution for the product. This means that each equation expresses both business-related and product-related aspects and formalises their relationship as an equation. Expressing each socio-material business operation in this way results in a set of coupling equations that links the business model to the product system. This enables a quantitative description of the environmental impacts of the business model.

For comparability between different business models around a product, an economic basis of comparison is necessary. Whereas conventional LCA is based on functional equivalency in physical terms, the focus on business leads to a functional unit expressing economic equivalency. This means that business models are compared on basis of achieving the same level of economic performance. Various indicators can be used, including profit margin and rate of return, cf. Schmidlin (2014). However, here, we choose a simple indicator, profit (revenues minus costs). Consequently, the functional unit in an BM-LCA is expressed as a certain level of profit that the business models should achieve. Such profit levels are usually stated for a given accounting period, such as 'profit per year'.

To summarise, a socio-material perspective on material flows adds actors to the technical system of the product, and allows the identification of those socio-material interactions in the product system that pertain to the business; the relationship of the physical flows of the product system to the monetary flows of the business model can be expressed through a set of coupling equations. With a profit-based functional unit related to profit calculations from business transactions and together with the coupling equation linking business transactions to the product system, it becomes possible to conduct a quantitative environmental analysis and comparison of different business models around a product.

3.2. Empirical study for methodological development

The development of BM-LCA took place within a project consisting of comparing a sales model for jackets and a rental model for the same jackets for a Swedish apparel company. The project is presented in a technical report (Böckin et al., 2020). The methodological development followed an iterative process, alternating between applying the principles (i.e., business-in-focus and socio-materiality) and empirically working out the monetary and material flow relationships for two business models for a real company.

The notions to shift from a product focus to a business focus for the LCA as to use a profit-based functional unit and the application of a socio-material perspective on the product chain were realised before the empirical investigation and were used as starting points when outlining the modelling of the system. The research process went from delineating to detailing the modelling based on insights from the two studied cases and documenting the work procedure. The cases provided us with concrete socio-material interactions that we could model as coupling equations between the physical flows and money flows and define a profit-based functional unit. Learnings from the comparison of the business models thus informed the methodological articulation, which in turn informed the environmental assessments of the two cases. At the same time, performing the analyses of the cases provided insights on the practical feasibility of the methodology.

The method was made functional and consistent for the particular empirical case and later systematised and generalised into a methodology to enable its application to any other business model. The systematised methodology, BM-LCA, is presented in this paper and detailed in Section 4. In order to demonstrate the key novel steps in BM-LCA (compared to mainstream LCA), we have devised a simple comparative case, here presented in Section 5. The devised case shows the computational procedure with a limited number of parameters for the sake of simplification. The application of BM-LCA to real business models in an empirical study is described in full in another paper

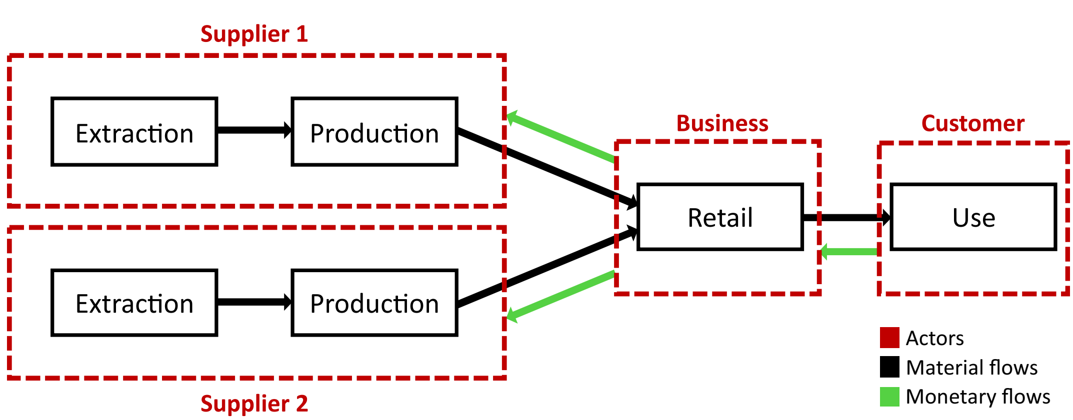

Fig. 1. Simplified life cycle flowchart identifying the actors in a value chain. The transactions between the business company and other value-chain actors are associated with material flows in one direction and monetary flows in the other. In this example, the business company in focus is a retail company, but analysis of other companies business models is also possible with BM-LCA.

(Goffetti et al., 2022). In this, a more complex cost structure is present, a broader environmental assessment and sensitivity analysis are conducted, and the findings from the BM-LCAs are analysed and discussed in relation to the method's usefulness for business model innovation for environmental sustainability.

4. Business model life cycle assessment – the methodology

BM-LCA is based on the principles described in Section 3. With the key innovation being made on the functional unit, this places the methodological innovation mainly in the goal and scoping phase of the LCA procedure. The method still builds on LCA but expands the goal and scope stage into two phases. The first phase describes the key features of each business model under consideration as well as the related product system, including how the amount of production depends on the number of customer transactions. The second phase defines a profit-based functional unit, thereby establishing a quantitative basis for comparison between business models. Equations are then set up to couple monetary flows and physical flows. The number of transactions required to achieve the desired profit level in each business model is then calculated and the associated amount of production is derived. Finally, standard LCA procedure is followed for the life cycle inventory (LCI) analysis, life cycle impact assessment (LCIA) and the interpretation of results.

Below we detail each phase of BM-LCA, as intended for a generic business comparing two business models, and summarise the method at the end of this section. The method allows for any number of business models to be compared.

4.1. Goal and scope: descriptive phase

The goal and scope definition involves defining the purpose of the study, the business models considered, environmental impact categories and system boundaries. Whereas conventional LCA compares product systems based on product function, BM-LCA compares the contribution of products to business. The purpose is thus to assess and compare the environmental effects of at least two different business models. The system boundaries should at least cover the life cycle of the products involved from cradle to grave. The time period, geographic limitations and environmental impact categories are defined according to the case in question. Data sources and quality should reflect the real situation of the business to the largest extent possible, particularly as regards economic data.

The business models under consideration are described in terms of the type of customer transactions that take place, whether the business retains or sells ownership of the products, and how product stocks (if any) are maintained. The product(s) associated with the business models must also be defined and described in terms of their most relevant characteristics (such as function, lifetime, and material composition).

Furthermore, a connection must be established regarding how the amount of production, q, depends on the number of transactions, t. This can be done by applying a PCO approach (see Section 3.1). This involves mapping the actors in the product chain to find the life cycle steps belonging to the business company and those belonging to suppliers and clients in order to identify which transactions take place and what exchange of goods and material are associated with each transaction. For instance, in a linear sales model every customer transaction implies the sale of a product (which first has to be produced or acquired from a supplier), and consequently t and q will be equal. In a rental model, however, q will depend on the rate at which products are worn out and replaced, which in turn depends on the number of rental transactions. For a pure service model, there is no exchange of goods or materials between business and customer. However, even pure services usually depend on material flows: hair salons require premises, shampoo and water, and IT services require physical networks, servers and electricity.

4.2. Goal and scope: coupling phase

The next phase follows the procedure in Fig. 2. It starts by defining a functional unit that will serve as the basis of comparison between the business models. This will then allow for setting up the equations that couple the material and monetary flows in the business model. With these, the number of transactions and associated production to reach the defined profit level can be calculated. This process is then repeated for each business model to be compared.

In more detail, a functional unit is defined in step 1. As established in Section 3.1, the function of a business model is interpreted as its economic performance, which should be equal for each compared model. Consequently, the functional unit is defined as the following:

- A certain amount of profit, π, over a business period, T, from customer transactions for a particular set of products from a particular business

The profit level chosen may be based on either the stated goals of the business, if the aim is to support business model innovation, or average historical profits, if the aim is to assess current business models.

In step 2 an equation is set up to couple the monetary and material flows for each of the compared business models in order to find the number of customer transactions, t. This in turn determines the necessary number of products, q. Start by finding all revenues and costs related to operating the business model during the period T depending on the transactions, t. The cost categories chosen should be relevant to the business under consideration. The choice also depends on whether the analysis will be static (disregarding the time-value of money) or dynamic (in which case, e.g., interest rates and discounted future costs can be taken into account). Importantly, only costs carried by the business itself should be included (i.e., not external or customer costs). Throughout this paper we will use a generic cost structure adapted from Norris (2001) to represent different types of costs:[1]

- Direct costs (e.g. cost of production, labour, capital investment and waste disposal)
- Indirect costs (costs that cannot be allocated directly to a product or process, e.g. administrative overhead costs)
- Contingent costs (e.g. fines, penalties and liabilities)

An equation can then be set up for the profit (π), as the revenues (R) minus the costs (C) of the business model:

$$\pi = R - C_{direct} - C_{indirect} - C_{contingent} \quad (1)$$

In order to solve this equation for the number of transactions, t, the revenues and costs must be expressed in terms of t. For this purpose, we introduce a coupling factor, f, that allows revenues and costs to be written as in Table 2. The coupling factor will be different for each cost or revenue stream and for each business context, and will couple the money flows to the customer transactions in each case.

Eq. (1) can now be written in terms of transactions and coupling factors:

$$\pi = f_{revenue} * t - f_{direct} * t - f_{indirect} * t - f_{contingent} * t \quad (2)$$

[1] Note that intangible and external costs are excluded as they do not directly determine the costs and revenues of a business.

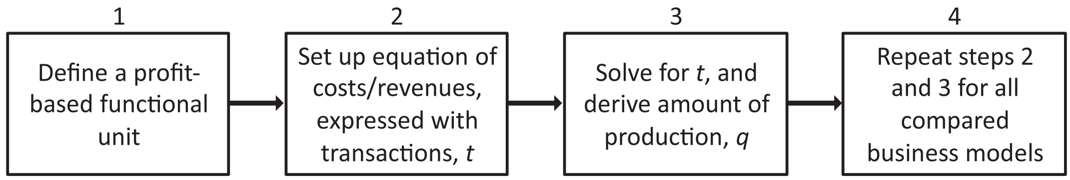

Fig. 2. Procedure for coupling monetary and physical flows and finding the number of customer transactions and associated amount of production.

A coupling factor must be found for each cost and revenue. To illustrate what the factors f could be, $f_{revenue}$ could for example depend on the price of one transaction, so the revenues would be:

$$R = transaction\ price * t$$

Hence, the coupling factor, $f_{revenue}$, in this example is equal to the transaction price.

A less straightforward example involves connecting indirect costs to the number of transactions. Indirect costs are often semi-fixed, such as the costs for office space, which are not directly dependent on transaction or production volumes. This needs to be solved for each individual case, but one example could be to express how the indirect costs depend on the amount of real estate that the business uses. Indirect costs would then be:

$$C_{indirect} = indirect\ cost\ per\ unit\ of\ real\ estate * amount\ of\ real\ estate$$

We can then estimate how much real estate is needed to sustain a certain number of transactions during a specific period. Then the amount of real estate can be expressed as follows:

$$amount\ of\ real\ estate = \frac{t}{\#transactions\ sustained\ per\ unit\ of\ real\ estate}$$

The indirect costs can now be written as:

$$C_{indirect} = \frac{indirect\ cost\ per\ unit\ of\ real\ estate * t}{\#transactions\ sustained\ per\ unit\ of\ real\ estate}$$

Hence, in this example, the coupling factor is:

$$f_{indirect} = \frac{indirect\ cost\ per\ unit\ of\ real\ estate}{\#transactions\ sustained\ per\ unit\ of\ real\ estate}$$

In other cases, indirect costs will be truly independent of customer transactions, there is no coupling factor. The corresponding cost in Table 2 will then be a fixed number, independent of transactions (see example in Section 5.2).

In step 3, the known profit, π, and coupling factors can be used to solve Eq. (2) for the transactions, t, required to reach the profit in the functional unit.:

$$t = \frac{\pi}{f_{revenue} - f_{direct} - f_{indirect} - f_{contingent}} \quad (3)$$

Table 2
Revenues and costs in the first business model, expressed in terms of the number of customer transactions.

Revenue or cost	Expression in terms of number of transactions, t
$R=$	$f_{revenue} * t$
$C_{direct}=$	$f_{direct} * t$
$C_{indirect}=$	$f_{indirect} * t$
$C_{contingent}=$	$f_{contingent} * t$

Once t is calculated, the required amount of production, q, associated with that level of transactions can be derived based on the connection between the t and q established in the descriptive phase.

Lastly, steps 2 and 3 are repeated for each of the business models to be compared. In other words, set up an equation, solve it for t by finding the corresponding coupling factors, and finally find the necessary amount of production, q, depending on the business model in question.

4.3. Life cycle inventory, impact assessment and interpretation

The calculations with the number of customer transactions and number of associated products needed to reach the same profit in each business model provide the reference flows for the product system, which makes it possible to feed these parameters into the LCA and calculate the environmental impacts. This is done by applying conventional LCA methodology for building an LCI, carrying out LCIA and interpreting the results.

LCI analysis entails constructing a product system model, quantifying all environmentally relevant flows, and scaling the flows according to the functional unit. Subsequently, in LCIA, the flows in the LCI are aggregated and their effects on the chosen environmental impact categories quantified. Finally, interpretation is the process of reaching conclusions and recommendations by analysing the results, scrutinising their robustness, and considering the pros and cons of each business model compared.

4.4. Method summary

All phases and detailed steps of BM-LCA are summarised in Fig. 3.

5. BM-LCA: a simplified, illustrative case

To illustrate the use of BM-LCA, we have here devised a simple comparative case in an imaginary company, purposely formulated to be brief and general. For an account of BM-LCA applied in full to a real empirical case, see Goffetti et al. (2022). In the devised case, the company aims to reduce its environmental impact by adopting a new business model for their product, jackets. Given that each business model should have the same economic performance, which one has the best environmental performance and should be chosen in order to minimise the environmental consequences of the business company's economic activities?

5.1. Goal and scope: descriptive phase

The business company in question is choosing to compare three business models for making money from jackets over a period of one month ($T = 30$ days):

1) In the first business model, the company sells a quality product at a high price. Every jacket is produced and then sold to a customer who takes ownership of the product. Consequently, the number of customer transactions during any period equals the number of jackets that should be produced.
2) The second business model is a fast fashion model, where high volumes of lower quality jackets with lower production costs are sold

Business Model LCA

Phase	Description of each step
Goal and Scope: Descriptive phase	Give general description of the setup of each business model to be compared and of the related product(s) and state the relevant time period.
	Define system boundaries and environmental impact categories of the assessment. Map actors in the product chain.
	Find the connection of how the amount of production, q, depends on the number of transactions, t, for each business model.
Goal and Scope: Coupling phase	Step 1: Define the functional unit as the profit, π, that each business model must achieve.
	Step 2: Identify all of the business' costs and revenues associated with running one of the business models for the stated period. Find conversion factors, f, to couple costs and revenues to customer transactions, t. Set up an equation for the profit as revenues minus costs: $\pi = f_{revenue} * t - f_{direct} * t - f_{indirect} * t - f_{contingent} * t$
	Step 3: Solve the equation to find the transactions, t, required to reach the profit. Derive the required amount of production, q.
	Step 4: Repeat steps 2 and 3 for every business model to be compared.
Life Cycle Inventory	Construct a system model and quantify all environmentally relevant flows, scaled according to the functional unit.
Life Cycle Impact Assessment	Aggregate all flows from LCI and quantify their effects on the chosen environmental impact categories.
Interpretation	Analyse the results and scrutinise their robustness to identify pros and cons of compared business models.

Fig. 3. A summary of each phase of BM-LCA, along with a description of how to carry out each step.

at a lower price. Here too, customer transactions equal the number of produced jackets.

3) The third is a rental model, where the company retains ownership of the jackets (same type of jackets as in the first business model) and charges a fee every time a customer rents one. Hence, the company maintains a stock of jackets that are repeatedly rented and cleaned between each customer. The only new production required is replacing jackets that reach their end of life. Because the number of rental transactions does not equal the number of jackets produced, their relation must be established. For simplicity, we assume that 5% of all rental transactions result in a jacket being replaced by a new one, while the rest are carried over to the next month and continue to be rented.[2]

Monetary and material flows are calculated with respect to the company's business models. For the environmental flows, the whole life cycle of a jacket is considered, divided into production, use and end-of-life, as conventional in LCA (Fig. 4). Production includes textile and garment production, and production impacts thus depend on the number of jackets produced. The use phase in the rental model includes laundry and customer transports back and forth to the stores, and thus depends on the number of transactions. End-of-life is assumed to include collection and disposal of jackets by landfilling. Consequently, the impacts from end-of-life are, like production, dependent on the number of jackets produced. Of all the potential environmental impacts, we will here in this devised case only consider climate change due to CO_2 emissions.

[2] In a real rental model, this connection between transactions and production of replacement jackets will depend on details of the rental model, such as rental efficiency and replacement rate (Goffetti et al., 2022).

5.2. Goal and scope: coupling phase

The four-step procedure in Section 4.2 is followed to set up all the coupling equations linking monetary flows and physical flows and which are solved for the number of transactions, t.

Starting with step 1, the functional unit is defined as the following, according to the company's goals:

- 100,000€ profit per month, from customer transactions of jackets

In step 2, an equation is set up to find the number of transactions, t_{sales}, and the number of produced jackets, q_{sales}, required to reach the defined profit (according to Eq. (2) in Section 4.2). We begin with analysing the first business model in Fig. 1, the sales model. Costs and revenues from running the sales model for one month must be found and, wherever possible, coupled to the transactions, t_{sales}, by finding the corresponding coupling factors, f:

$$€100,000 = f_{revenue} * t_{sales} - f_{direct} * t_{sales} - f_{indirect} * t_{sales} - f_{direct} * t_{sales} \tag{4}$$

Here, for the sake of example in the devised case, we assume that the sales price and direct cost of one jacket are €100 and €60 respectively, and that indirect and contingent costs are €5000 per month each. The revenues are then the number of transactions times the price, $R_{sales} = t_{sales} * €100/\text{jacket}$. Consequently, the corresponding coupling factor is $f_{sales,\ revenue} = €100/\text{jacket}$. Further, the direct costs can be expressed as the number of produced jackets times the production costs, $C_{sales,\ direct} = q_{sales} * €60/\text{jacket}$. Since, in a linear business model, every customer transaction implies a product sold that must first be produced, then $q_{sales} = t_{sales}$. Consequently, the direct costs are $C_{sales,\ direct} = t_{sales} * €60/\text{jacket}$, and the coupling factor is simply $f_{sales,\ direct} = €60/\text{jacket}$.

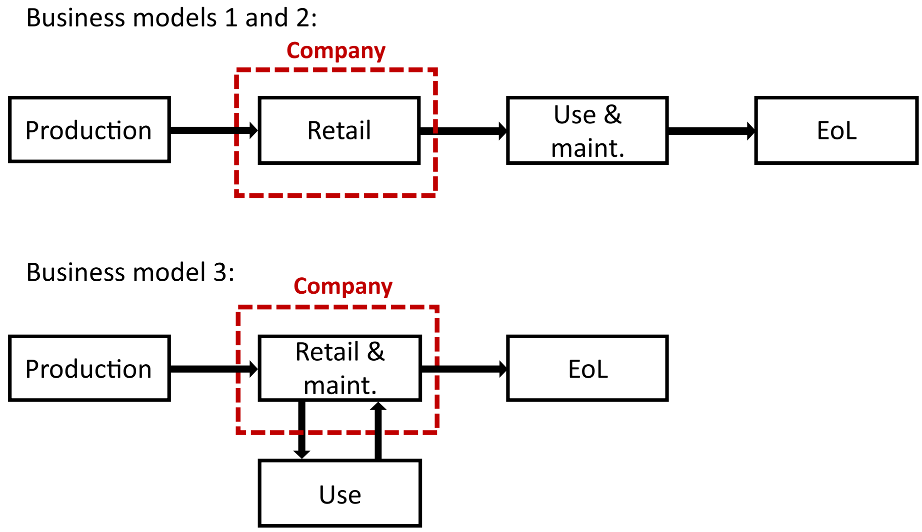

Fig. 4. Life cycle flowcharts for a sales model (business model 1), a fast fashion model (business model 2) and a rental model (business model 3) for the devised case.

Indirect costs can be assumed to depend on the number of stores where the company conducts its business, and the stores being large and flexible enough to accommodate however many transactions take place. This is independent of the number of customer transactions, meaning that a coupling factor cannot be found in this instance. In this simple case, we assume that contingent costs are also independent of transactions, without a coupling factor. Table 3 summarises revenues, costs and coupling factors.

In step 3, Eq. (4) is solved for t_{sales}:

$$€100,000 = €100/jacket * t_{sales} - €60/jacket * t_{sales} - €5000 - €5000$$
$$\Leftrightarrow t_{sales} = \frac{€100,000 + €5000 + €5000}{€100/jacket - €60/jacket} = 2750\ transactions \quad (5)$$

After finding the number of transactions in the sales model for one month, it follows that the number of jackets produced must be $q_{sales} = 2750$ jackets.

In step 4, the same procedure is followed to find the transactions (t_{fast}, t_{rental}) and associated number of produced jackets (q_{fast}, q_{rental}) for the fast fashion and rental business models. Like the sales model, the fast fashion model is also linear, so setting up the corresponding equation is straightforward. For the fast fashion business model, we here assume that production costs are €5/jacket, the sales price €20/jacket, and that the model is otherwise similar to the sales model. The summary in Table 4 shows that the coupling factors are €20/jacket for revenues and €5/jacket for direct costs.

According to the functional unit, the profit should be €100,000, meaning that the following equation for the fast fashion model can be set up and solved:

$$€100,000 = €20/jacket * t_{fast} - €5/jacket * t_{fast} - €5000 - €5000$$
$$\Leftrightarrow t_{fast} = \frac{€100,000 + €5000 + €5000}{€20/jacket - €5/jacket} \approx 7333\ transactions \quad (6)$$

In order to reach the same profit level with the fast fashion as with the sales model, 7333 sales transactions are required, which in turn requires $q_{fast} = 7333$ produced jackets.

Unlike the sales and the fast fashion models, the rental model is not linear. Setting up the equation thus requires more effort. Here, we assume a rental price of €10 per rental transaction and that each customer rents a jacket for one day. Hence, the period's revenues can be expressed as $R_{rental} = t_{rental} * €10/rent$, meaning that the corresponding coupling factor is: $f_{rental,\ revenue} = €10/rent$.

For the direct costs, the production cost of €60 per jacket remains the same as in the sales model (assuming here that there are no design changes) and thus $C_{rental,\ direct} = q_{rental} * €60/jacket$. To derive the coupling factor, $f_{rental,\ direct}$, the number of produced jackets q_{rental} needs to be expressed in terms of the number of rental transactions t_{rental}. Section 5.1 states that 5% of rental transactions result in a replaced jacket, i.e., $q_{rental} = t_{rental} * 0.05$. Hence, the direct costs can be written as $C_{rental,\ direct} = t_{rental} * 0.05 * €60/jacket$. Thus, the coupling factor becomes $f_{rental,\ direct} = 0.05 * €60/jacket = €3/rent$. The indirect and contingent costs are again assumed to be unchanged.

In summary, the revenues and costs in the rental model are presented in Table 5.

Again, using the profit of €100,000 from the functional unit, the following equation can be set up and solved:

$$€100,000 = €10/rent * t_{rental} - €3/rent * t_{rental} - €5000 - €5000$$
$$\Leftrightarrow t_{rental} = \frac{€100,000 + €5000 + €5000}{€10/rent - €3/rent} \approx 15,714\ transactions \quad (7)$$

To achieve the same profit level with the rental business model, around 15,700 rental transactions are needed, however, fewer jackets need producing. The required number of replacement jackets to be produced can be derived by again using $q_{rental} = t_{rental} * 0.05$. Hence the rental model entails the production of $q_{rental} \approx 786$ jackets.

Table 3
Costs, revenues and coupling factors (when applicable) in the sales model.

Sales model	
$R_{sales}=$	€100/jacket $* t_{sales}$
$C_{sales,\ direct}=$	€60/jacket $* t_{sales}$
$C_{sales,\ indirect}=$	€5000
$C_{sales,\ contingent}=$	€5000

Table 4
Costs, revenues and coupling factors (when applicable) in the fast fashion model.

Fast fashion model	
$R=$	€20/jacket $* t_{fast}$
$C_{direct}=$	€5/jacket $* t_{fast}$
$C_{indirect}=$	€5000
$C_{contingent}=$	€5000

Table 5
Costs, revenues and coupling factors (when applicable) in the rental model.

Rental model	
$R=$	€10/rent $* t_{rental}$
$C_{direct}=$	€3/rent $* t_{rental}$
$C_{indirect}=$	€5000
$C_{contingent}=$	€5000

Table 6 summarises the calculated physical flows and number of transactions.

5.3. Life cycle inventory, impact assessment and interpretation

After establishing the number of customer transactions and the associated number of jackets in each business model, it is time to calculate the environmental impact. Here, for sake of simplicity, we only calculate the CO_2 emissions for each business model.

For the LCI, CO_2 emissions from the jacket life cycle must be quantified. Emissions from production and end-of-life are the same in the sales and rental models, amounting to 30 kg CO_2 per jacket in total. In the fast fashion model, the lighter and lower quality jackets can be expected to emit less, say, 20 kg CO_2 per jacket.

For the use phase, in the sales and fast fashion models, a customer travels back and forth to the store to purchase a jacket, and then the jacket is used until it is discarded. Assume that this emits 0.9 kg CO_2 per transaction. The jacket is assumed to be laundered once in its lifetime, emitting 0.1 kg CO_2. Every transaction in the sales and fast fashion models thus generates a total of 1 kg CO_2 emissions. In the rental model, each transaction entails two roundtrips to the store (pick-up and return), which means that the emissions are 1.8 kg CO_2 per transaction. The jackets will also be laundered between each customer, with emissions of 0.1 kg CO_2 per transaction. The total emissions per transaction in the rental model are thus approximately 2 kg CO_2.

The LCI is summarised in Table 7 (with only CO_2 emissions for sake of simplicity, we can here omit the LCIA). The LCI results show that the rental model emits 36% less CO_2 than the sales model for the same profit, while the fast fashion model emits 81% more. Hence, BM-LCA applied to this test case indicates that the rental model represents a more decoupled business than the sales model – the same economic performance is achieved with a lower environmental impact. While use phase impacts in the rental model increased significantly in comparison to the sales business model, the impacts from production are decreased to an even greater extent. The results for the fast fashion model showed the least environmentally beneficial way of making money because of the need to produce a large number of jackets.

The last step is interpretation of the results. It can be noted that the method allows for a sensitivity analysis in which the altering of economic parameters to investigate their influence on environmental performance is possible. This is possible thanks to the coupling equations linking monetary flows of the business to the material and energy flow in the product system. For instance, increasing the rental price to €20 (from €10) makes the rental model 73% better than the sales model (instead of 36%), while a sales price of €30 in the fast fashion model (instead of €20) makes it only 8% worse than the sales model (instead of 81% worse). The reason is that a higher price allows the same profit to be achieved with fewer transactions, thus generating lower environmental impacts. Conversely, if the cost of production is €40 per jacket (instead of €60) then the rental model is only 15% better than the sales model. Because production costs are lower, the sales model's profits are higher, and the number of rental transactions needs to increase to reach the same profit.

Table 6
Number of transactions and jackets produced in the sales, fast fashion and rental business models during one month.

	Sales model	Fast fashion model	Rental model
Number of transactions	$t_{sales} = 2750$	$t_{fast} = 7333$	$t_{rental} = 15,714$
Number of jackets produced	$q_{sales} = 2750$	$q_{fast} = 7333$	$q_{\mathrm{rental}} = 786$

6. Discussion

This paper provides a starting point for a new line of inquiry into quantitative environmental assessment of business models by presenting a new variant of LCA, here named BM-LCA. There is a plethora of topics to discuss for any new method, but we will focus the discussion on what makes the method unique, and its feasibility and application.

6.1. The novelty of BM-LCA

The novel contributions of BM-LCA can be described in different ways.

In comparison to LCA, the key methodological contribution is that BM-LCA provides a way to quantify the environmental consequences of different ways of making money and can thus be used for analysing the environmental performance of business models. This is made possible through an innovation on the functional unit.

Whereas the functional unit in mainstream LCA expresses equivalence in physical terms for a product (or service) from the perspective of a user, it expresses economic equivalence in BM-LCA from the perspective of the business company. When mainstream LCA is applied for the study of business models, it can therefore not directly describe the environmental consequences of different ways of making money. Instead, for such studies, one must estimate or assume how the business model will affect physical aspects of the product life cycle. Only through such estimates and assumptions can the environmental impacts eventually be calculated. The resulting environmental impact is therefore not directly indicative of the business model. In contrast, thanks to the coupling equations in BM-LCA, it becomes possible to couple the business model to the product system and an environmental impact measure of the business model can be calculated. In other words, BM-LCA brings to light the environmental burdens related to value creation. The difference in relationships between business model, product system and environmental impacts for BM-LCA and mainstream LCA is illustrated in Fig. 5. The assumptions translating business model implications into physical differences that can be modelled with LCA are replaced with the coupling equations in BM-LCA.

The found examples of mainstream LCA applied for the study of business models (summarised in Table 1) all rely on estimates or assumptions about physical factors such as design, product lifetime, and user behaviour to estimate the environmental performance of a new business model. Such an approach is unhelpful when different business models use identical product designs (as in the first and third business models in the illustrative case). Since BM-LCA takes the business model per se as the object of analysis and integrates business parameters (e.g., price levels), it becomes possible to also directly pinpoint the business parameters with greatest influence on environmental impact, not just differences in product designs or user behaviour. Altering an economic factor such as product price has direct effects on the number of customer transactions required and consequently on the environmental performance of the business model, as shown by the sensitivity analysis in the devised illustrative case. This places BM-LCA in a category of its own in relation to mainstream LCA when it comes to analysis of business models (see Table 1). BM-LCA thus represents an important contribution for the investigation and understanding of environmental effects of different business models without confusing the analysis with the effect of assumptions about the use or durability of products.

Furthermore, BM-LCA overcomes the inherent scale-related limitations of mainstream LCA. In LCA, the compared alternatives might imply vastly different scales, for example, when comparing a business

Table 7
Simple life cycle inventory showing CO_2 emissions per functional unit.

Life cycle phases	Sales model	Fast fashion model	Rental model
Production and end-of-life	30 kg $CO_2 * q_{sales}$ = 82,500 kg CO_2	20 kg $CO_2 * q_{fast}$ = 146,667 kg CO_2	30 kg $CO_2 * q_{rental}$ = 23,571 kg CO_2
Use phase	1 kg $CO_2 * t_{sales}$ = 2750 kg CO_2	1 kg $CO_2 * t_{fast}$ = 7333 kg CO_2	2 kg $CO_2 * t_{rental}$ = 31,428 kg CO_2
Total	85,250 kg CO_2	154,000 kg CO_2	55,000 kg CO_2

model of mass-produced fast-fashion shirts with a business model around recycled shirts that will operate on a smaller scale. In contrast, differences in scale are captured by BM-LCA, since each compared business model implies a different number of transactions, thus affecting costs and revenues. Thanks to the economic basis of comparison in BM-LCA and the coupling equations, the product system and its impacts are scaled to the required level of economic performance level in the functional unit for compared business model(s) should achieve.

BM-LCA also has the potential to provide a valuable addition to the business model innovation toolbox. So far, the many tools that build on the business model canvas, such as those by Lewandowski (2016), Lüdeke-Freund et al. (2018) and Daou et al. (2020), can be useful to identify and/or design different features of a new business model. However, they are not capable of quantitative environmental assessment, and many have called for methods that can quantitatively measure the environmental performance of business models (e.g., Das et al., 2022; De Giacomo and Bleischwitz, 2020; Harris et al., 2021; Kjaer et al., 2019; van Loon et al., 2021). Such a quantitative assessment is possible with BM-LCA and shown in the present paper, albeit for a simple case.

6.2. Application and feasibility in different contexts

To understand if application of BM-LCA is meaningful and feasible, it is important to understand what the method represents and what its limitations are. However, given the novelty of the method, applicability, feasibility and related methodological and practical limitations are here examined only through a reasoned approach. Further needs of methodological development and research can be envisaged and are outlined in Section 6.3. Given the scope of BM-LCA, business-related applications are considered here, whereas policy-relevant applications are left for future research and considerations.

Because BM-LCA compares business models on the basis of economic performance, it is suited for identifying the business model whose economic activity contributes less to resource use and environmental impacts. In other words, BM-LCA can guide business decisions towards decoupling. The development BM-LCA is therefore an important contribution that addresses calls for research on decoupling in a business practice, for example, from Hoffman et al. (2014) and Kjaer et al. (2019).

The developed methodology can be applied to any type of business model where a customer is provided with a product or service, as long as there is material or energy use that can be related to the transaction between the business and its customers and expressed as coupling equations. Such reliance on a physical input is a limitation inherited from the underlying LCA methodology. Examples of sectors where the method would be more difficult to apply are pure services as in finance or insurance. Nevertheless, many, if not most, other services do depend on physical input, such as a hair salon's use of water, heating and shampoo, which makes application of BM-LCA possible for such services.

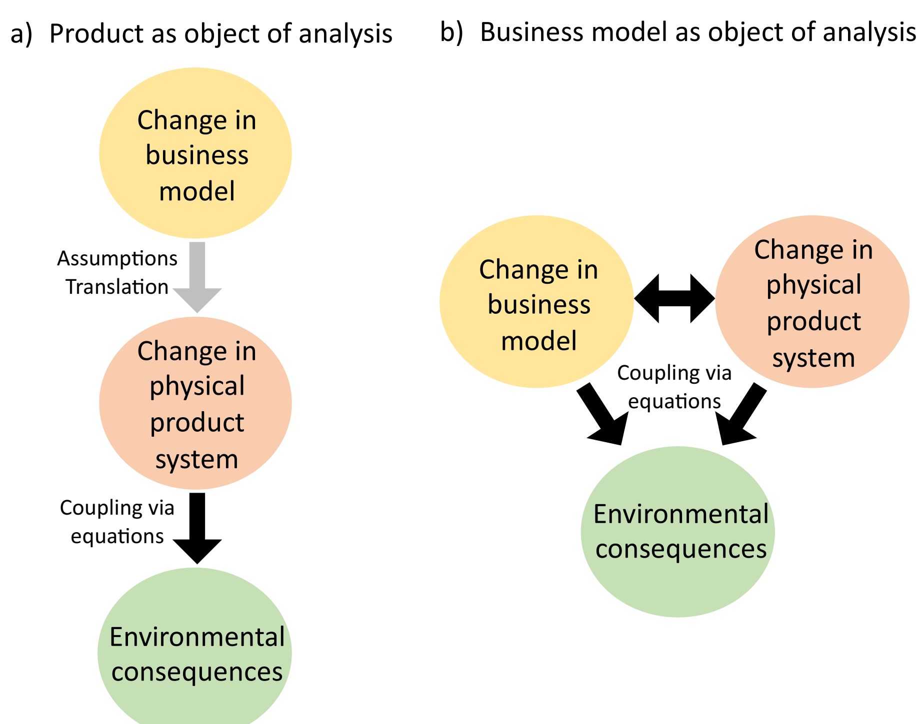

Fig. 5. Schematic of how business model changes are connected to their environmental consequences, depending on the object of analysis. In the product-oriented model (a) the environmental consequences of business must be translated via assumptions (grey arrow) about how business affects the physical product system, which in turn directly affects the environmental impacts (black arrow). In the business-oriented model (b) by coupling monetary and physical flows in the model equations, BM-LCA provides a way to directly see the effects of business on the environmental impacts.

The method can also be particularly relevant in fulfilling the need for critically evaluating the environmental performance of alternative business models like SBM, PSS and CBM. This could be important for a business company competing with green claims on basis of a sustainable business model to check that it is not making excessively green claims.

The comparative approach is important in a BM-LCA study. It is important to understand that the environmental performance is calculated for a stated level of profit and time period for the analysed business models in order to identify their relative environmental performance, not of business as such in real time. Since profitability can be greatly influenced by revenue and cost variables, it becomes important to analyse how these might affect business model environmental performance. For this, a sensitivity analysis during the interpretation phase is of particular importance. For analysis of a stand-alone business model to be meaningful, it is necessary to achieve some form of comparison. A simple way to do this is by modifying business and/or product variables to identify the environmentally significant elements of the business model. This results in a comparison of versions of the same business model.

The situation with a mutable parameter (profit level) as denominator in the functional unit in BM-LCA is cause for special attention. More specifically, improved environmental performance of a business model can seemingly be achieved when environmental impacts are kept at the same level while profits are increased. Even though such a situation would imply relative decoupling, it is also important to also ensure that environmental impacts are reduced in an absolute sense. While BM-LCA can support decoupling efforts within a business practice, we do not claim that BM-LCA can handle all environmental and sustainability challenges of economies. For example, excessiveness of profit levels and justice of economic distribution in societies are not evaluated with BM-LCA.

Unlike life cycle costing (LCC), which deals with cost parameters for all companies and actors along the entire life cycle (Steen, 2005; Swarr et al., 2011), BM-LCA considers the economic parameters related to business models in one of the companies in the life cycle. While LCC can be used to identify cost hotspots in a product system, BM-LCA can be used to identify environmental hotspots for a business model and its value creation. This also means that current BM-LCA methodology is not applicable for aggregate analysis of the business models of the companies within a value network.

BM-LCA can be useful in business model innovation processes when aiming for improved business model environmental performance. More specifically, since both business parameters and physical parameters can be varied in the sensitivity analysis, this can identify business model elements with significant impact on the environmental performance of the business model. This is further described and discussed in a related empirical paper (Goffetti et al., 2022).

Business complexities that are too difficult to model in BM-LCA can to some extent be handled through the sensitivity analysis. Since companies continuously make strategic business choices to seek increased profits, they will also have different success with different business models on different markets. Representing such complexities in BM-LCA would require such a multitude of coupling equations that it would probably seem impractical, if not unfeasible. Instead, some of these business aspects could be explored through representative modification of business and physical variables in the sensitivity analysis.

Another benefit of the possibility to modify both business parameters and physical parameters in the sensitivity analysis is that the method also can support product design decisions. However, there is a special case when a particular physical change is not captured, namely when comparing two linear business models. In the fast fashion example in Section 5, the designed life-length of the offered product does not factor into the results,[3] why BM-LCA is not suited for guiding product design in such a case.

[3] For business models where product ownership is retained, however, product lifetime does enter the equation as it is likely to affect the replacement rate of products (Goffetti et al., 2022).

It is important to note that, from a customer's perspective, BM-LCA does not answer which of the offerings of a business are environmentally preferable. For example, in the fast fashion case in Section 5, the jacket's shorter lifetime does not affect the results. However, a mainstream LCA would show that a customer will have to buy several cheap jackets to make them last as long as the expensive one in the sales model. In other words, BM-LCA is designed to inform business decisions, not customer choices, since the economic performance of a business is not relevant to the customer. BM-LCA and mainstream LCA could be related to the two different framings on production and consumption discussed by Boons (2021), where the former relates to business models and the latter to modes of provisioning.

Bocken et al. (2016) argue that since LCA is time-consuming, it is not worthwhile to modify LCA methodology to support business model innovation. Instead, they opt to guide business via a simplified typology based on ‘slowing, narrowing and closing loops’, or for simple tools (cf., Das et al., 2022). BM-LCA is probably not considered the simple tool these authors call for. The goal and scope phase in BM-LCA requires multi-disciplinary competences to establish an economic basis of comparison and couple monetary flows with material and energy flows. Only future application of BM-LCA will reveal whether it will be considered worthwhile to be adopted as a tool for business model innovation. Nevertheless, the completion of an empirical comparison for a real company was possible (cf., Böckin et al., 2020). Furthermore, a BM-LCA study could in principle be conducted by building on an existing conventional LCA, by adding the coupling equations to the product system(s) of the conventional LCA. This could perhaps be achieved through the constructive collaboration of LCA analysts and business analysts.

6.3. Further development of the method

This paper presents a first version of a methodological description of BM-LCA. While the method as presented here is ready to use, there is scope for further development, for example, by going into more detail on costs that are relevant for a business to include in profit calculations. These could include capital investments, risks, interest on financing loans and discounted future costs and revenues. The basis of comparison was here expressed as equal profit for each compared business model. In reality, however, businesses use different indicators for economic performance, such as profit margin or rate of return. In principle, the method allows for any economic key performance indicator, as long as monetary flows can be connected to physical flows via transactions. Additionally, other types of impact besides environmental impacts can be included in future iterations of the method, such as social impacts. Conversely, the method could also be developed for simpler assessment, for example, of carbon footprint or rules of thumb.

This method analyses the business model of a company offering one (or a limited set) of products/services. In principle, multiple products can be included in the assessment, with the advantage of allowing a business to consider product portfolios. This would give a more complete picture of the business model at the cost of higher complexity and collecting and analysing more data.

Concerning the practical feasibility and usefulness of the method, studies of the work required for conducting a BM-LCA study in a company would be useful. Analysis of if and how an existing LCA study could practically be added upon with coupling equations to attach a business model to it would help companies with LCA experience determine how their efforts could be re-used and developed. It would also be interesting to explore how the multidisciplinarity of BM-LCA contributes to cross-functional communication and sense-making on business and environmental sustainability in a company.

BM-LCA should also be applied, tested and validated on real cases of various types of business models in addition to the application in Goffetti et al. (2022). Further empirical studies will be needed to see if the use of BM-LCA leads to decoupling in practice. In the devised case, relative decoupling (Jackson, 2009) was obtained with the rental model since it resulted in a lower environmental footprint than the sales model for the same economic performance, but whether absolute decoupling will be achieved depends on business decisions in relation to the market at large.

7. Conclusions

This paper has presented business model life cycle assessment, a quantitative methodology for assessing and comparing the environmental impact of business models, in which the business model itself is taken as the object of analysis. The methodology was originally developed through a real case (presented in full by Goffetti et al., 2022) and illustrated here using a simple devised case. BM-LCA couples the monetary flows of the business model to physical flows of the product system so that the environmental performance of a business model can be described and evaluated. For this, economic business performance is used as the basis of comparison rather than product function from a user perspective as in conventional LCA.

The key contribution of BM-LCA is that it brings business aspects into LCA, thereby enabling environmental assessment of business models and with the potential to support business model innovation towards environmental sustainability. It therefore provides an important bridge between LCA and business competitive advantage. This opens up an important avenue of research and discussion around quantitative methods that are useful and relevant for guiding green business decisions and for understanding the environmental properties of different types of business models.

Future research should apply BM-LCA to real cases of different business models. This will further validate the method, develop the generalisation of the methodology and investigate its feasibility and usefulness in different contexts, both for environmentally assessing existing business models and for business model innovation towards decoupling.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research was supported by the Mistra REES (Resource-Efficient and Effective Solutions) Programme, funded by MISTRA (the Swedish Foundation for Strategic Environmental Research), and the Circularis Project, funded by Vinnova (the Swedish Innovation Agency) as well as by Chalmers University of Technology via the Area of Advance Production and the Kamprad Family Foundation for Entrepreneurship, Research & Charity.

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