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POLICIES AND SUPPORT IN RELATION TO LCA

Spillovers from production-based environmental reporting to product labelling

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Abstract

Purpose Although intuitively plausible, claims of causal links between corporate- and facility-level environmental reporting requirements and the rise of LCA-based labelling are not yet supported by explicit theoretical, empirical or historical analyses. Do production-based environmental monitoring and reporting have spillover effects and thus facilitate product-level disclosure of life cycle impacts? What is the evidence for different types of spillover effects?

Methods Thematic analysis of a dataset comprising qualitative statements made by a global set of hundreds of companies, as well as expert interviews and statements by industry associations and consultancies active in the area of product-based environmental disclosure.

Results The analysis demonstrates spillover mechanisms related to data, expertise and systems. Evidence is stronger for the role of expertise and systems than for data itself. However, data availability is closely linked to data expertise and the corresponding systems.

Conclusions Increasingly stringent corporate- and facility-level environmental reporting renders environmental life cycle labelling more feasible, thus enabling novel policy options.

Keywords Environmental Product Declarations · Product carbon footprints · Life cycle assessments · Environmental reporting · Carbon disclosure · Corporate reporting

1 Introduction

More and better information on the environmental harms associated with the production and circulation of goods has the potential to improve consumer choice (Edwards-Jones et al. 2009) and to enhance the regulation of ecological impacts embodied in global trade. For example, the state of California bases various procurement decisions on carbon efficiency benchmarks, and Denmark, France and the Netherlands have introduced building regulations targeting embodied emissions, with Environmental Product Declarations (EPDs) providing crucial data. Product carbon footprints (PCFs) can also inform border carbon adjustments, which aim to equalise the carbon price of domestic and foreign products, such as the European Union's Carbon Border Adjustment Mechanism (CBAM) (Grubb et al. 2022; Jordan 2024) and similar data will be required for the EU Ecodesign for Sustainable Products Regulation, specifically for Digital Product Passports (European Parliament and Council 2024).

EPDs present the results of life cycle assessments (LCA) of the environmental impacts associated with producing a good. Toniolo et al. (2019) found that between 2013 and 2016, the number of EPDs issued by European programme operators increased by 150% to a total of 4888. In March 2023, Anderson (2023) reported nearly 130,000 EPDs, in the construction products sector alone, globally. In addition, PCFs package LCAs that focus solely on global warming potential (Ormond 2015; Carbon Trust 2016; Van der Ven et al. 2017).

Companies around the world are increasingly subject to environmental reporting requirements. In 2015, Kareiva et al. (2015) suggested that "the same environmental indicators that inform corporate reports could ideally inform the labelling of products and in turn influence consumers" and

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that there may be *spillover effects* from corporate environmental disclosures to product labelling. While the scholarly literature has deployed the term "spillover" in multifarious ways (and Kareiva et al. do not fix its meaning), Jordan (2021, p. 694) offers a succinct definition, well-suited for this context: "[a] spillover occurs when improvements in activity *a* lower costs for or increase the productivity of activity *b*" (based on Pierson 2000b, p. 255).

Various authors have criticised corporate environmental management and reporting as largely symbolic, ineffective practices (Wright and Nyberg 2015; Vílchez 2017) and as part and parcel of a movement towards the privatisation of environmental regulation (Mason 2008). From their analysis of environmental disclosure initiatives, Gupta and Mason (2014, p. 336) conclude that "transparency has minimal market-restricting effects". Rather than having "substantive market-forcing effects", they argue that transparency is more likely to serve "environmental service valuation, commodification or market facilitation" (ibid, p. 336f.).

However, spillovers from corporate environmental management and reporting to the product level could unlock important policy options and thereby empower progressive political action. Product-level environmental data offers distinct opportunities for regulation and environmental pricing compared to facility- or corporate-level data, and the availability of complementary data at multiple levels is likely to enhance overall environmental policy and governance performance. A better understanding of such spillover effects is therefore crucial—not only for explaining and predicting but also for actively shaping the evolving informational conditions for environmental policy and governance options. Jordan (2021) provides an account of how policies that induce the sharing of environmental data at the sectoral level have helped to improve the conditions for the release of product-level data. However, a comparable account for spillovers from the firm to the product level is still lacking.

Building on and going beyond Kareiva et al., who do not specify the mechanisms through which spillovers from firm to product level may occur, I propose underlying mechanisms and present supporting evidence. First, I examine the build-up of data and capacities in response to production-based environmental monitoring requirements, by analysing statements made by hundreds of companies from around the world. Second, I investigate spillovers into the domain of product life cycle information, drawing on interview results, secondary literature and statements from industry associations and consultancies involved in product-based environmental disclosure.

Section 2 spells out the propositions and methodology. Section 3 examines how greenhouse gas (GHG) reporting requirements induce the build-up of capacities for environmental accounting within firms. Section 4 then assesses how the build-up of capacities for production-based accounting facilitates EPD/PCF production. Section 5 discusses the results.

2 Propositions and methods

Kareiva et al. (2015) suggest spillover effects from corporate environmental disclosures to product labelling. However, they do not clarify why they focus solely on annual corporate environmental disclosures rather than on production-based environmental reporting requirements more broadly. Intertwined as these are, it makes sense to look at both phenomena.

There are key differences not only between product-based environmental reporting and production-based environmental reporting but also among the different types of production-based reporting itself. The latter can be divided into corporate-level[1] reporting and location-specific reporting, which may focus on the installation, facility or site level. Corporate-level greenhouse gas reporting is conventionally differentiated into Scope 1 (emissions under *direct* control of the corporate entity), Scope 2 (*indirect* emissions associated with purchase of electricity, steam, heat, or cooling) and Scope 3 (*indirect* upstream and downstream emissions). While exigencies for accurate, verifiable primary data are the strongest for Scope 1 emissions, Scope 2 is already less transparent and there will be rarely, if at all, specific data available for all types of Scope 3 emissions. When primary data are unavailable from suppliers, companies may perform their own calculations or rely on secondary emissions factors—either generic or sector-specific—sourced from literature or databases (Greenhouse Gas Protocol 2011, 2018a, 2018b).

In contrast, the product-level reporting of environmental lifecycle impacts hardly concerns itself with the specific location, machinery or corporate entity associated with emissions but mostly deals with the overall impacts along the lifecycle of products (often limited in practice to cradle-to-gate data). However, product-level reporting does emphasise the importance of primary data when emissions are directly controlled by the reporting entity. For processes under a company's direct control, it is difficult to justify the absence of actual consumption or emissions data. By contrast, emissions or consumption data associated with upstream suppliers are more likely to rely on generic calculations or secondary data, similar to Scope 3 emissions (European Environment Agency 1997; PE International 2013; BSI Group 2014).

[1] This paper does not address sectoral reporting but see Jordan (2021).

Location-specific as well as corporate Scope 1 and Scope 2 environmental data are in fundamentally different formats than those of product LCAs. The former deals with the consumption and emissions associated with a particular location, machinery or corporate unit over a given amount of time. The latter deals with the overall or upstream lifecycle environmental impacts of a given product, independently of the time of their concrete manifestation. However, Scope 3 environmental data do have parallels with product LCAs, as the allocation of up- or downstream environmental impacts will depend on how many units of products a company consumes or sells as part of its activities.

Collecting and validating data for disclosing the lifecycle impacts of a product is costly. It can be even more challenging in less industrialised countries (Plassmann et al. 2010). Pierson (2000a) suggests that "[i]mprovements in a core activity can *spill over* by improving related parts of the economy (lowering costs or increasing productivity)" (emphasis added). Where the benefits then flow back from the "related parts" to also lower the costs for or increase the productivity of the core activity, we can speak of *complementarities* (ibid.). An examination of potential spillovers and complementarities between different types of activities therefore helps to elucidate how the dynamic co-development of ostensibly separate activities has brought about the emergence and maturation of the field of life cycle assessment.

It is important to distinguish between latent spillovers from activity *a*, which could potentially exert effects on activity *b*, and manifest spillover effects, which actually exert effects on activity *b*. A spillover is *latent* where it is "concealed, inactive, lying dormant or hidden until circumstances are suitable for its manifestation, or 'release'" (Stephenson 2012, p. 797). Where one is solely interested in explaining the past, attention will naturally gravitate to manifest spillover effects. Those who wish to engage in forward theorising—"to identify possible policy interventions and reason forward to how the problem and interventions might unfold over time" (Levin et al. 2012)—should also consider latent spillovers.

Do production-based environmental monitoring and reporting have spillover effects and thus drive down costs for the eventual product-level disclosure of life cycle impacts? The plausibility of catalytic spillovers from production-based monitoring and reporting requirements to the diffusion of lifecycle product data hinges on the existence of functional benefits. I propose the following mechanisms for these spillover effects:

- Proposition 1a: *External environmental monitoring and reporting requirements lead companies to acquire better data on environmentally relevant aspects of production activity*
- Propositions 1b: *Better data on environmentally relevant aspects of production activity can then be transformed into life cycle environmental data at the product level*
- Proposition 2a: *External environmental monitoring and reporting requirements lead companies to acquire more expertise on production-based monitoring and disclosure*
- Proposition 2b: *More expertise on production-based monitoring and disclosure then becomes available for creating life cycle environmental data at the product level*
- Proposition 3a: *External environmental monitoring and reporting requirements lead companies to acquire more organisational and technological resources for production-based environmental monitoring and disclosure*
- Proposition 3b: *More organisational and technological resources for production-based environmental monitoring and disclosure then become available for creating life cycle environmental data at the product level*.

Figure 1 illustrates the six propositions on the causal mechanisms that connect policies and initiatives targeted at increasing the information on the environmental impacts of firm activity to the availability of information on the emissions embodied in products. Propositions 1a, 2a and 3a concern the causal links from the institutional environment to the firm level. Subsequently, Propositions 1b, 2b and 3b cover how changes at the level of the firm improve conditions for the creation of lifecycle data at the level of the product.

Propositions 2b and 3b can be formulated not only for processes *within* but also for those *between* firms: As organisational and facility-level disclosure create a demand for external services and products, this gradually helps to develop a market for such skills or products, ultimately lowering costs for product-level disclosure.

Importantly, the functioning of these mechanisms should be time-*dependent*. They are more likely to be present at the early stages of developing regimes for environmental monitoring, verification and reporting. In contrast, at more advanced development stages—even with high synergies between production- and product-level data—the spillover effects gradually lose their force.

To empirically validate my propositions about the changes that environmental monitoring and reporting requirements induce in companies, I examined the CDP 2015 investor dataset, which provides company statements on responses to the risks and opportunities associated with different policies. It would not be fair to use current data to test Kareiva et al.'s (2015) claim about the presence of spillover effects; instead, the data chosen should correspond to the time when the claim was made. In this sense, this is a historical study.

In 2015, 1896 organisations participated in the flagship CDP survey, which collects climate-related company disclosures on behalf of investors. Of these, 650 organisations

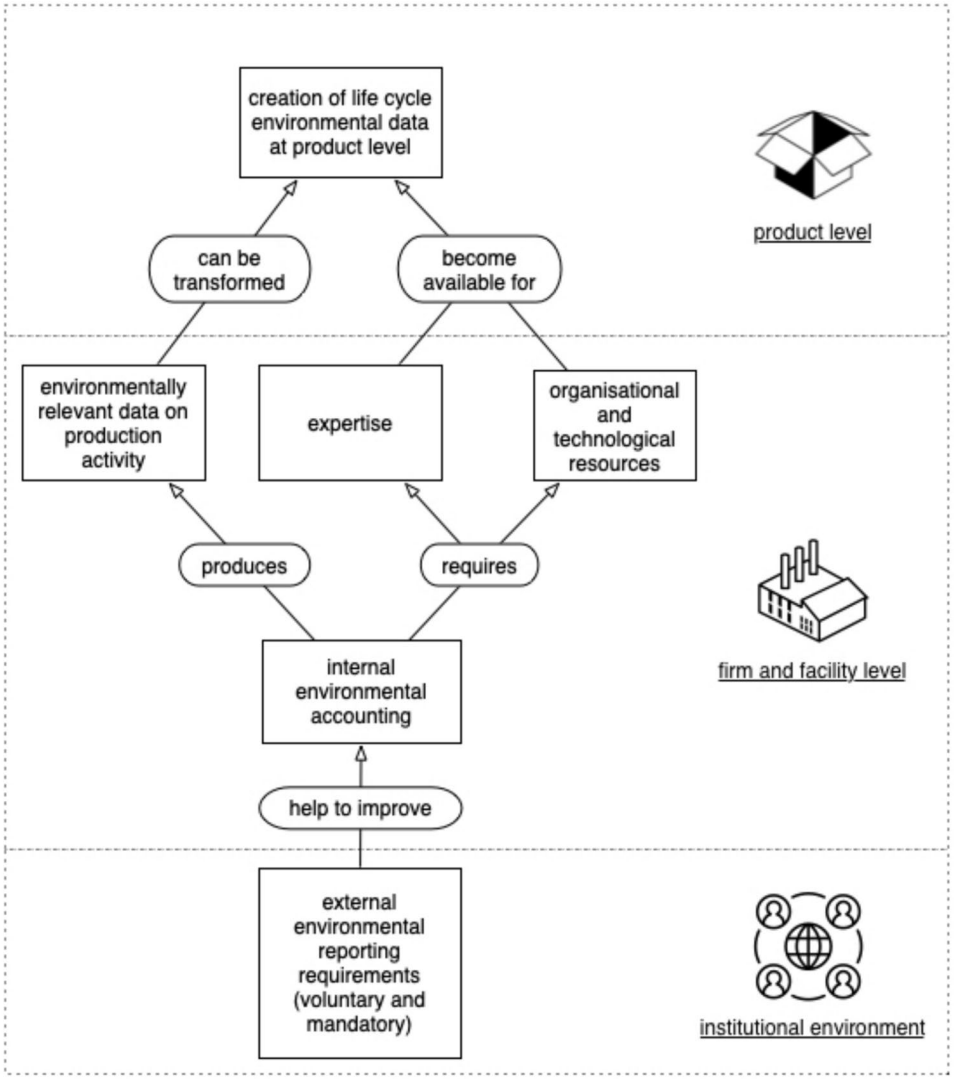

Fig. 1 Propositions on causal mechanisms leading from policies and initiatives targeted at increasing the information on the environmental impacts of firm activity to the availability of information on the emissions embodied in products

indicated regulatory risks (512) and/or opportunities (300) related to emission reporting obligations. These organisations were asked to describe the respective risks and opportunities and provide information on the management methods and their associated costs. The resulting free-form responses constitute a wealth of qualitative information on change processes within companies.

The analysis focused on whether companies need to undergo significant internal change processes to comply with external reporting requirements. If companies must allocate additional internal resources and modify procedures to accommodate environmental monitoring and reporting requirements, these adjustments may ultimately benefit product-level, LCA-style disclosures and thus constitute latent spillovers.

Thematic analysis enables the transformation of qualitative information into quantitatively measurable "codes" (Boyatzis 1998). I thematically coded statements indicating that climate-related reporting obligations have stimulated change processes across three categories:

a) Improvements in the availability of environmental data
b) Systems or technologies
c) Human resource allocation

As free-form survey responses do not imply that companies intended to signal the absence of a phenomenon by not mentioning it, the results indicate only the presence of the phenomena described, not their absence.

Analysing survey results, particularly when respondents are not anonymous, requires accounting for the tendency of respondents to highlight socially desirable traits and behaviours while downplaying those considered undesirable (Phillips and Clancy 1972; Krumpal 2013). Companies have an interest in presenting themselves in a positive light, aiming to "talk up" their prospects towards

investors and appear legitimate to stakeholders more generally. When companies simply state that they are better equipped to deal with regulations than their competitors, this can be deemed socially desirable but not necessarily trustworthy. However, when they provide details of their operational change processes, thereby acknowledging a less-than-optimal current or prior state, such statements are more trustworthy. Overall, the changes within organisations, on which I focus, are rather technical, and I report them as if we could expect them to be true. Nonetheless, companies have strong incentives to portray themselves in the best light possible.

To explore spillovers from the firm or facility level to the product level in environmental reporting, I conducted ten semi-structured interviews with LCA experts, most of whom have worked with leading organisations in the field. As part of a larger research project, I purposively sampled at least three senior experts on EPD and/or PCF creation processes in Germany, UK and USA, respectively, focusing on the building materials sector. Most of these experts have a comprehensive view of how developments in this area have unfolded over the past two decades (see Table 1). As most of them have worked with various companies, often as consultants, they are likely to have a more representative view than experts who have only experience with one company. I contrast and complement the interview findings with secondary literature as well as with statements from industry associations and consultancies active in product-based environmental disclosure.

I also draw on company statements and LinkedIn data to analyse the overlap of competencies required for production- and product-based environmental disclosure at both the individual and organisational levels.

3 From the institutional environment to the site and firm levels

To empirically evaluate Proposition 1a: *External environmental reporting requirements lead companies to acquire better data on environmentally relevant aspects of production activity*, I analysed the CDP 2015 survey and hand-coded whether companies indicated data improvements when describing risks or opportunities arising from reporting obligations, or the management methods adopted to mitigate risks or harness opportunities. Of the 650 companies declaring regulatory risks or opportunities from emission reporting obligations, 65 (10%) indicated the improvement of emissions data as a response. While 10% is a relatively low result, these responses nevertheless suggest a causal influence of external reporting demands on the emergence or improvement of internal environmental data. For example, South Korean chemicals company *LG Chem* states that it "developed GHG Inventories to cope with climate-change regulations and monitors energy consumption and GHG emissions every month" (CDP 2015). The U.S. multinational pharmaceutical company *Merck & Co.* observes that "Emissions reporting obligations result in careful analysis of the sources of emissions …" (CDP 2015).

To evaluate Proposition 2a: *External environmental reporting requirements lead companies to acquire more expertise on production-based monitoring and disclosure*, I analysed how many companies mentioned human resources allocation as a response to emissions reporting obligations. Of the 650 companies communicating regulatory risks or opportunities from emission reporting obligations, 168 (25.8%) indicated responding through human resource allocation. For example, the U.S. multinational energy corporation *Chevron* discloses that "the total expense with staff time costs [of implementing

Table 1 Interviews and correspondences drawn upon

Interviewees	Organisation	Position	Year	Region
Jane Anderson	Thinkstep, independent EPD verification company, formerly BRE	Consultant with Thinkstep	2017	UK
Anonymous	IBU	Senior representative	2017	*Germany*
Morgan Jones	Carbon Trust	Associate Director	2017	UK
Danny Püschel	Gebäude-Allianz and NABU	Coordinates the department responsible for EPDs in a company that produces LCAs for buildings and building materials	2017	Germany
Joep Meijer	Right Environment	President	2017	USA/Europe
Mark Goedkoop	PRé	Founder	2017	Netherlands/global
Anonymous	DGNB	Staff member	2016	Germany
Anonymous	PCA	Staff member	2017	USA
Anonymous	Major sustainability consultancy	Senior representative	2017	Western Europe and Americas
Isabela Butnar	UCL, former LCA consultant	Researcher	2018	UK

Chevron's GHG and Energy Reporting System.. and training over 200 data reporters and the development of tools and processes] can be estimated to have been several million dollars" (CDP 2015). The U.S. multinational conglomerate *United Technologies Corporation* declares: "Management of the mandatory emissions reporting quality program costs approximately $50,000 per year" (CDP 2015). Allocating human resources to complex, previously unaddressed tasks often builds cognitive capacity, contributing to expertise in these areas.

Some of this expertise is also sourced from external consultants. For example, Canadian oil and natural gas producer *Bonavista Energy Corporation* notes that "[m]anagement is completed by internal staff and third-party consultants …" (CDP 2015). The contracting of external consultants and auditors mobilises financial resources towards the building or maintenance of their capacities for sustainability accounting.

Of the 650 companies documenting regulatory risks or opportunities from emission reporting obligations, 125 (19.2%) mention systems or technologies as a response to emissions reporting obligations, supporting Proposition 3a: *External environmental reporting requirements lead companies to acquire more organisational and technological resources for production-based environmental monitoring and disclosure*. For example, the Korean construction company *Daewoo E&C* notes, "In 2012, 320 million KRW was used to build the greenhouse gas inventory system" (CDP 2015). Similarly, the multinational conglomerate *Johnson Controls* states, "These [reporting] obligations require more manpower and new systems to capture and report emissions and related data" (CDP 2015).

However, it is not always possible to clearly attribute the adoption of technologies and systems designed to capture production-based environmental data as the independent variable and the availability of such infrastructure for product-level information as the dependent variable. Describing regulatory opportunities from emissions reporting obligations, the packaging company Huhtamäki Oyj states that "The resources for LCA calculations (working hours, data management systems and software) … [costs] annually some …." (CDP 2015). I removed this statement from the overall count. While not all the statements on responses to emissions reporting obligations exclusively refer to production-based reporting—as illustrated by the example above—a close reading of the actual responses strongly suggests that they typically refer to the production level.

4 From the site and firm levels to the product level

Many companies have identified responses to production-based GHG reporting requirements in the form of change processes across the three domains of data, expertise and tools. The following analysis examines whether such change processes are likely to produce spillovers favourable to the diffusion of product-level environmental labels.

4.1 Data

Data availability and quality remain key challenges for LCA in environmental labelling (Erskine and Collins 1997; Wu et al. 2014). Is there a "recycling" of data from either the organisational or the site level to the product level? This section examines the evidence for Proposition 1b: *Better data on environmentally relevant aspects of production activity can then be transformed into life cycle environmental data at the product level*.

A number of sources with domain-specific epistemic authority suggest that such a "data recycling" is possible. For the organisational level, the European Commission (2013) states that the Organisation Environmental Footprint "… may be disaggregated to the product level using appropriate allocation keys". Ernst and Young (2012) (2012, p. 1) point out that the different reporting obligations, at the corporate and product level, are best addressed with a set of compatible indicators. An LCA expert with the German Sustainable Building Council suggested that corporate reporting requirements facilitate the availability of data for LCAs (interview in December 2016).

However, where do the "appropriate" allocation keys come from? Setting up such a quality model with credible allocation keys requires expertise and effort. Morgan Jones from the Carbon Trust thinks that "the two disciplines of product footprinting and organisational are still quite separate and the data used rarely crosses over between them" (interview in September 2017).

Site-level data on material, energy and—as a proxy—financial flows are more useful for LCA practitioners than the more aggregated corporate-level data (PE International 2013) (interviews with Jane Anderson and Danny Püschel). As external monitoring and reporting requirements help to improve the data basis at the site level, variations in such requirements result in significant differences in data availability (interviews with IBU and Joep Meijer). If the data is already available at the site level, it should be easier to retrieve the data necessary for LCAs. For example, in their methodology for a sector EPD for Italian cement, Strazza et al. (2010) identify compliance

with the "monitoring and reporting guidelines of the EU Emissions Trading Scheme" as a guarantor for the homogeneity of CO_2 emission estimation procedures between different cement plants.

However, LCA practitioners also conduct dedicated on-site measurements to obtain primary data (PE International 2013). In LCAs, breaking down the contributions of materials and energy from the site level to the individual products is often challenging (interviews with Danny Püschel and IBU). For this, LCA practitioners must disaggregate site-level data and correctly allocate material and energy flows to specific production lines within a manufacturing site. Given these challenges, it is often more practical to measure a specific production line directly for LCA purposes (interviews with Isabela Butnar and Morgan Jones).

Evidence for Proposition 1b that *better data on environmentally relevant aspects of production activity can then be transformed into life cycle environmental data at the product level* is mixed. A priori it seems clear that any additional measurements of hitherto unmeasured environmentally relevant flows translate into additional costs. However, where specific measurements are conducted anyway, the contribution of prior, less specific measurements, may be negligible.

4.2 Expertise

Concerning Proposition 2b that *once companies acquire more expertise on production-based monitoring and disclosure it then becomes available for creating life cycle environmental data at the product level*, it is important to differentiate between three kinds of expertise:

- How to conduct and verify LCAs ("compilation" knowledge)
- Knowledge on company or site-specific environmentally relevant flows ("flow" knowledge) that can be used to support LCA experts
- Awareness of EPDs and PCFs.

Substantial individual and organisational overlap between production-based monitoring and reporting skills and the ability to conduct LCAs makes it likely that production-based monitoring and reporting creates a demand for the skills of organisations and individuals who also have expertise in conducting LCA and creating EPDs and PCFs. First, there is an individual overlap in the capacity to offer services related to production-based monitoring and reporting, on the one hand, and LCA, on the other hand (interview with IBU). In 2018, three of the 14 skills "top skills" associated with the topic of LCA on the career website LinkedIn were closely related to firm-level GHG management skills. Companies employing such staff for production-based GHG monitoring and reporting benefit from spillover effects enhancing LCA capacities. While this does not mean that LCA is among the top skills of those who market themselves as suitable candidates for environmental compliance management and reporting, from the perspective of the self-identified LCA experts, there is a significant overlap of skills.

Second, there is an organisational overlap in the capacity to offer production-based and product-based environmental reporting services: According to 2018 LinkedIn data, Accenture, Ernst and Young as well as ERM and Thinkstep were among the five companies with the most self-declared LCA experts. The first two indicate that they see opportunities arising from emissions reporting obligations (see CDP 2015), Thinkstep (now part of Sphera) offered corporate environmental monitoring and reporting solutions and ERM has also acted as a GHG emissions verifier. In 2013, nearly three-quarters of the companies that responded to CDP had their emissions verified by a third party (Confino 2013), helping to create a market for verification services. Some companies offer both assurances for corporate GHG emissions as well as assurance for GHG emissions and consulting services in the areas of LCAs, EPDs and PCFs. At least three of the "big four" accounting and professional services firms have not only engaged with corporate reporting but also with LCA (CDP 2015; Cembureau 2015; Deloitte 2016; Ernst & Young 2018; PwC 2018).

At least seven out of nine EU ETS *Phase III Greenhouse Gas Verifiers* accredited in the UK also offer carbon footprinting services, at least as part of LCAs and EPDs (ERM 2009; BSI 2011; The International EPD System 2016; DNV GL n.d.; Kiwa n.d.; Lucideon n.d.; SGS n.d.; United Kingdom Accreditation Service n.d.). Major certification company Bureau Veritas acts as a GHG emissions verifier and also certifies EPDs (The International EPD System 2016). Its three top competitors (Hoovers n.d.) all offer LCA or product carbon footprinting services, either by themselves or through subsidiaries (Intertek n.d.; SGS). In 2016 the *Big Three* credit-rating agency S&P Global acquired the major sustainability and LCA consultancy Trucost, signalling the entry into the LCA business of an actor with major epistemic authority in the financial world, who is already involved with using firm-level environmental data for the Dow Jones Sustainability Indices (Robecosam 2018).

These overlaps indicate that production-based monitoring and reporting create a demand for the skills of organisations and individuals who also tend to have (a) expertise in conducting LCA and creating EPDs and PCFs ("compilation" knowledge) and (b) the ability to provide valuable advice, in the form of energy and material "flow" knowledge, to LCA practitioners.

Growth in the supply of LCA expertise (a) helps to reduce the costs for EPDs and PCFs, as suggested by Manzini et al. (2006). When more staff possess knowledge of

environmental flows (b), it becomes easier for external LCA consultants to obtain the necessary data (interview with Jane Anderson).

Individuals with expertise in production-based environmental reporting are also more likely to be aware of EPDs and PCFs, facilitating the diffusion of environmental life-cycle product information. Experts providing production-related consulting or verification services may point their customers to the possibility of obtaining EPDs or product carbon footprints. Companies that need to comply with corporate environmental reporting requirements have a higher demand for sustainability experts, who, in turn, have greater awareness of EPDs (interview with IBU). Ibáñez-Forés et al. (2016) surveyed all 130 companies with products certified in the International EPD System. Over 50% ($n = 55$) stated that they found "out about EPD tools through technical consultancy".

4.3 Systems

Let us now examine Proposition 3b: *when companies acquire more organisational and technological resources for production-based environmental monitoring and disclosure, more resources also become available for creating life cycle environmental data at the product level*. Manzini et al. (2006) hypothesise in rather general terms that "the greater the sophistication of the company's technological infrastructure, the lower the EPD costs". I will focus more specifically on the technological and organisational infrastructure dedicated explicitly to *environmental* purposes.

Historically, the lack of an integrated environmental database in companies has hindered efficient LCA production (interview with Jane Anderson, see also Pujari et al. 2003). When environmental data in a company is not centrally available but must be retrieved from various individuals rather than from a single source, gathering data for LCAs is more time-consuming (interviews with Danny Püschel and Jane Anderson).

In the late 1990s, LCA analysts often had to manage physical files and paper invoices. Many companies lacked data on volumes of resource consumption, such as water and electricity use, which required LCA consultants to extrapolate environmental flow data from financial information. Additionally, consultants needed to verify whether companies had used the correct nomenclature for environmentally relevant flows of energy and materials (interview with Anderson).

Data availability at the firm level has dramatically improved over the past two decades due to the rise of environmental management systems (EMS), which allow for easy retrieval of environmental data from IT systems (interview with Anderson). In 2005, the number of European ISO 14001 certificates approached the 50,000 mark, after having nearly doubled within 3 years (To and Lee 2014). The introduction of EMS required companies to establish systems for measuring environmentally relevant flows, prompting them to record actual quantities of material and energy consumption and waste production using standardised metrics. This significantly reduced the time LCA practitioners needed to spend verifying the correct use of metrics and reconstructing environmental flow data from financial data (interview with Anderson). Today, at least in a Western European corporate context, LCA analysts can draw data from centralised environmental management systems (Finkbeiner et al. 2003), which has improved data availability (interviews with IBU and Jane Anderson). In this sense, organisational, technical and data spillovers are interlinked.

LCA tools, such as Thinkstep's GaBi, integrate with electronic enterprise resource planning systems like SAP (Thinkstep n.d.). Some EPDs are directly produced from environmental management data (interview with Anderson). However, LCA software remains distinct from software for corporate-level environmental accounting.

While there is evidence supporting the proposition that organisation and technological resources acquired in response to production-based monitoring and disclosure can also be usefully drawn upon for creating life cycle data at the product level, the systems themselves remain distinct. Consequently, additional elements and skills are necessary to leverage these resources for LCA.

5 Results and discussion

Spillover effects from production-based environmental monitoring and reporting boost the diffusion of PCFs and EPDs by raising awareness of labelling opportunities and reducing the costs of LCAs. This article examines three mechanisms, or channels, through which the institutional environment induces firms to develop data on environmental emissions, as well as the expertise and systems needed to acquire, process and communicate this information.

For propositions P1a, P2a and P3a, which address the relationship between the institutional environment and firm-level outcomes, the analysis suggests that requirements for monitoring and reporting GHG emissions drive the development of data and capacity within companies. Figure 2 shows the percentage of companies that indicated improvements across the various categories in response to reporting obligations.

Company statements to CDP demonstrate that external reporting requirements drive internal GHG monitoring efforts. This, in turn, leads to the allocation of resources, which enhances technical, organisational and cognitive capacities for measuring environmental flows.

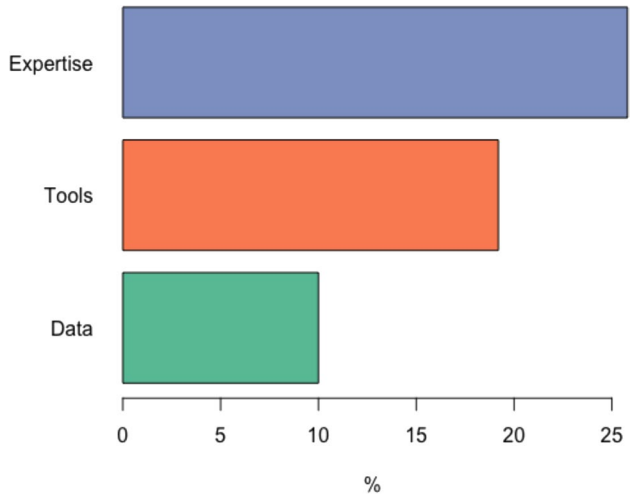

Fig. 2 Percentages of improvements in different categories as a response to reporting obligations

The CDP survey does not include standardised questions about the change processes I examined in-depth here, which reduces the likelihood of false positives. Respondents may have omitted reporting changes driven by emissions reporting obligations, even if such changes occurred. Consequently, there is substantial evidence that reporting obligations contribute to improvements in data, systems and expertise capacities.

If credible evidence shows that production-based reporting requirements have stimulated improvements in technical, organisational and cognitive capacities—resources that can be effectively utilised by creators of product-level life cycle environmental data—then these requirements can be seen as having produced at least *latent* spillover effects. The case for such spillover effects becomes even stronger if we can demonstrate that these effects have already begun to *manifest*.

The evaluation of evidence for Proposition 1b that *better data on environmentally relevant aspects of production activity can be transformed into life cycle environmental data at the product level* yielded ambiguous results. While prior monitoring and reporting of data often benefit LCAs, overly aggregated data may require additional measurements at the level of individual production lines. This limits the spillover of data from the production to the product level.

There is good evidence for Proposition 2b that *more expertise on production-based monitoring and disclosure becomes available for creating life cycle environmental data at the product level*. The substantial overlap between expertise in production-based monitoring and reporting and LCA suggests that demand for the former has likely facilitated the diffusion of the latter. Furthermore, spillover effects are evident when production-based monitoring experts assist LCA consultants during site visits.

Unfortunately, the LinkedIn data on individual-level skill overlaps is opaque, and it was not possible to archive a snapshot of the webpage in an internet archive. Further research is needed to better understand how relevant occupational fields have evolved. This could be achieved through surveys analysing the qualification profiles of sustainability experts, providing insights into the extent to which these professionals embody a convergence of environmental compliance, corporate reporting and LCA expertise.

There is good evidence for Proposition 3b that *more organisational and technological resources for production-based environmental monitoring and disclosure become available for creating life cycle environmental data at the product level*. This proposition is closely connected to the earlier propositions on *data* and *expertise*. A key component of environmental management systems is the assignment of responsibility for environmental flow accounting to individuals with relevant *expertise*, which helps LCA practitioners efficiently gather data within companies. As a result, organisational and technological *systems* act as mediating factors, fostering *expertise* and enhancing *data availability*, potentially lowering the costs of LCA production. However, corporate-level and LCA software systems remain largely separate, reflecting the distinct objectives of corporate- and product-level environmental accounting. This separation limits the extent of spillover effects.

The establishment of institutional responsibilities and procedures for environmental accounting in companies, alongside the installation of systems and measurement devices, has been more critical for supporting LCAs than the mere availability of firm-, facility-, or installation-level data. However, data availability remains closely connected to data expertise and the associated systems.

In principle, better life cycle data should be conducive to the development and diffusion of EPDs/PCFs (Del Borghi et al. 2020). Under conditions of subpar-quality information, it should take longer for the field to mature to a level that allows its outputs in the form of EPDs to be drawn upon as a basis for policy (keeping expectations towards quality constant). However, as long as the process remains insufficiently standardised and consultants and verifiers have incentives to pursue easier, less data-intensive routes towards EPDs/PCFs, it cannot be conclusively claimed that better data availability supports the diffusion of EPDs/PCFs.

Economic spillover effects in terms of costs represent only one form of spillover effects. There are probably other factors besides costs that limit the diffusion of LCAs and EPDs, and which production-based environmental monitoring and reporting could potentially mitigate. Specifically, *normative* and *institutional interest* spillovers are promising avenues for further research.

Normative spillover effects may arise when production-based environmental reporting triggers a *normalisation*

process, making it seem more appropriate to also engage in product-based reporting. As a result, companies that are already required to monitor and report environmental data—and share this data with third parties for verification—may become more willing to share product-based data as well.

Knowledge spillover effects are likely intertwined with the enhancement of qualification profiles and the development of organisations and intra-organisational units that ultimately benefit from the expansion of activities within their areas of expertise. Demand for skills related to environmental monitoring and reporting drives the proliferation of environmental expertise, with expert individuals and organisations likely to have an *institutional interest* in expanding the scope of their activities—by also offering and promoting product lifecycle assessments. For a theoretical rationale, see Downs (1965) and Voß and Simons (2014).

In principle, the results of this study could be corroborated by examining correlations between the proliferation of production-based environmental reporting and monitoring and product-based LCA disclosure across sectors, regions and over time. However, companies subject to a high degree of production-based environmental reporting and monitoring may be more exposed to other common exogenous factors, such as consumer demands. This would be an important limiting factor in drawing conclusions from such correlations, as it would make it difficult to attribute the observed effects solely to the endogenous spillover mechanisms I have proposed. For example, Manzini et al. (2006, p. 128) hypothesise that "the more the company's strategy is oriented toward a green approach, the more the benefits that can be obtained through the EPD".

Due to the complementarities between production-based monitoring and product-based disclosure, there may also be a reverse causal effect, where product-based disclosure strengthens the conditions for production-based monitoring and disclosure. While this effect may have been minimal or absent in the past, it could become more significant in the future.

The data used for the empirical analysis in the first part was much broader than in the second part. This difference reflects the greater maturity of the field and the availability of the CDP survey. In contrast, the emerging PCF/EPD field is smaller, and I conducted interviews with representatives from some of the leading organisations in this field. Further research could expand the number of interviews and provide a more in-depth focus on specific regions and sectors.

An alternative research strategy could involve tracking the CDP statements of selected companies over time, rather than using a cross-sectional approach. This longitudinal method could offer deeper insights into how companies have responded to earlier waves of monitoring and reporting obligations.

Further research could explore the spillover effects of environmental monitoring and reporting along supply chains. The similarity between life cycle inventories needed for calculating Scope 3 emissions and those required for creating EPDs makes Scope 3 data a valuable asset for EPD creation. Once a company accounts for Scope 3 emissions, it becomes easier to assess product-level life cycle emissions, too. Since the same third-party databases facilitate the collection of both "data for product life cycle and corporate value chain (scope 3) GHG inventories" (Greenhouse Gas Protocol 2018b), there can be synergies from developing both inventories in parallel (Greenhouse Gas Protocol 2011). When companies go beyond generic data for the calculation of their upstream emissions and request specific environmental data from suppliers, they may stimulate better environmental monitoring and reporting among supplier companies. In turn, supplier-provided, product-specific EPDs or PCFs enable more accurate assessments of corporate environmental impacts than reliance on third-party databases alone (Strazza et al. 2016).

This paper has focused on spillover effects between production-based environmental reporting and the disclosure of lifecycle impacts of products, highlighting the gaps, or "mismatch", between them, which are constitutive of the *non-identity* between these different types of environmental reporting. Without this non-identity, the notion of spillover effect would be meaningless. Nevertheless, there is a path forward that can help to significantly narrow the gap between corporate (not location-based) and product-level reporting while preserving their distinct scopes: consolidating Scope 3 reporting effectively moves towards an organisational life cycle assessment (O-LCA), as advocated by the Life Cycle Initiative (2017), or the organisation environmental footprint (OEF) (Damiani et al. 2022), as promoted by the European Commission. The synergies between product and organisational LCA are significantly greater than those between product LCA and conventional corporate reporting. Yet a historical account of the development of LCA as a field should be wary of simply portraying these different approaches as alternatives but should seek to work out how different practices have historically conditioned one another—and spillovers from one type of activity to another are a key variable explaining the institutional development of complex informational ecosystems.

Voluntary corporate environmental disclosure initiatives, such as CDP and the Global Reporting Initiative (GRI), benefit from companies being subjected to mandatory environmental monitoring and reporting requirements already, for instance in the context of environmental permitting (European Commission 2018), toxic release inventories (Hamilton 2005) or emissions trading (Grubb et al. 2022). Such existing mandatory reporting requirements reduce the costs and lower the stakes involved in subsequent voluntary

reporting. Voluntary disclosure under CDP and GRI could be—at least partly—seen as merely another outlet for data generated in response to government requirements for monitoring and reporting. Where this is the case, the critique that "transparency has minimal market-restricting effects" (Gupta and Mason 2014, p. 336) may be less relevant, as privately organised transparency would be an epiphenomenal development, with government regulation the prime mover. And while toxic release inventories may not have market-restricting effects by themselves, requirements for adherence to "best available techniques" for the purposes of environmental permitting, and carbon pricing through emissions trading, are certainly *market-restricting* activities (albeit ambitions levels may be insufficient). However, where privately organised transparency does, indeed, lead to *additional* measurements it may indirectly—via spillovers to the product level—aid more market restricting policies. Future research may provide more insight into the extent to which spillover effects from production to product level can be almost wholly attributed to mandatory monitoring and reporting obligations at the level of installation, facility and firm, or if voluntary transparency efforts have their own, independent role to play.

This study is limited to analysing spillover effects from *quantitative* environmental reporting at the corporate/facility level to *quantitative* reporting at the product level. Future research could explore whether *qualitative* environmental reporting at the corporate or facility level has similarly influenced the development of *quantitative* product-level reporting.

6 Conclusion

Corporate environmental management and reporting have faced sustained criticism for being largely symbolic and ineffective, viewed by some as contributing to the privatisation of environmental regulation. However, the co-evolution of public and private governance remains underappreciated. Corporate environmental management and reporting often already develop in response to—or anticipation of—government policy. In addition, changes in corporate practice can have knock-on effects, unlocking novel regulatory options for the government: my analysis provides strong evidence that production-based environmental reporting and disclosure create valuable spillover effects that support the diffusion of product-based environmental life cycle labels. LCA-based labels are more actionable for policymakers than corporate-level environmental data, serving as a basis for green public procurement, regulatory standard setting and border carbon adjustments. In this way, what may seem like soft, symbolic informational measures can ultimately support more robust public policy initiatives.

Spillover effects from production-based environmental monitoring and reporting reduce various costs associated with product-level life cycle impact disclosure. This paper presents a substantial body of evidence, quantifying hundreds of qualitative company statements and demonstrating that, in many companies, external reporting requirements drive significant changes in resource allocation, systems implementation and data availability. These changes increase the data on environmental flows that is available within companies, and the competences and capacities to work with this data. A comprehensive analysis—based on on-depth interviews with LCA practitioners, company service portfolios and expertise clusters on LinkedIn—reveals how this facilitates the availability of data, systems and competences for assessing the life cycle impacts of products. However, the transformation of production-based data into product life cycle data is not straight-forward but requires additional skills and different software, and sometimes, data may not be "recycled" but must be measured anew. Still, there are sufficient overlaps and functional benefits in terms of expertise, technologies and organisational structures to conclude that policies and initiatives that induce a greater engagement with environmentally relevant data at the level of the site or firm also help to reduce costs for producing life cycle information on the environmental impacts embodied in products. These findings offer partial yet systematic empirical support for theories suggesting that site- or firm-level monitoring and reporting can produce spillover effects into the documentation of product-level life cycle impacts.

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Data availability The CDP 2015 climate change data that support the findings of this study are available from CDP. Restrictions apply to the availability of these data, which were used under licence for this study.

Declarations

Conflict of interest The author has no competing interests to declare that are relevant to the content of this article. However, several of the author's former students have gone on to work for CDP, a staff member of CDP has presented the organisation in a postgraduate module led by the author and the UCL ISR is actively exploring collaboration opportunities with CDP.

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