Research Article

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Sustainability-oriented cross-functional collaboration to manage trade-offs and interdependencies

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Abstract: Despite a consensus view in the literature about the importance of cross-functional collaboration (CFC) for corporate environmental performance improvement, there is a dearth of studies that explain how exactly sustainability-oriented CFC can foster this objective. The purpose of this paper is to explain the role of CFC in corporate environmental performance improvement. We do this by undertaking two rounds of literature review, developing a proposition after the first round and by collecting illuminative real-life examples that illustrate our arguments in the second round. We propose and illustrate that CFC can effectively address two systemic properties of corporate environmental performance: trade-offs and interdependencies among different aspects of corporate environmental sustainability. If left unaddressed, these systemic specifics would result in organizational, managerial, and behavioral outcomes, such as inertia, opposition to change, lack of information, and so on, which would turn into effective barriers to corporate environmental performance improvement. put CFC addresses these barriers through information sharing, knowledge building, and interest reconciliation.

Keywords: environmental sustainability, cross-functional collaboration, knowledge management, trade-off, interdependence

JEL codes: Q56, O32, M19, L21

"*Without appropriate organizational structure and management systems, corporations may not reap all the benefits associated with sustainability performance.*" *[Epstein and Roy, 2001: p. 593]*

1 Introduction

It is generally acknowledged that cross-functional knowledge management (KM) and integration strategies are indispensable for maintaining proper alignment with the complex and dynamically changing technological and contextual factors of value creation. One instrument of organizational knowledge integration is the practice of cross-functional collaboration (CFC). CFC is defined as a process of interaction and collaboration among team members representing different functional departments of an organization, so that they can exchange information and work together in a cooperative manner to arrive at mutually acceptable outcomes [Kahn, 1996].

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CFC, enabled by relevant organizational and technological solutions, is shown to contribute to the following: (a) generating new knowledge by recombining existing knowledge components; (b) converting tacit, individual-level knowledge into explicit, organization-level knowledge; (c) achieving goal congruence across different departments of an organization; and (d) improving organizations' adaptive capacity so as to cope with a complex and dynamically changing business environment [Hart, 1995; Gold et al., 2001; Galbraith, 2010].

One of the challenges that organizations are expected to address is the environmental sustainability of their activities. Integrating environmental considerations into firms' production systems requires technological, managerial, organizational, and behavioral changes, as well as competence accumulation [Trianni et al., 2017], since it considerably increases the complexity of the system and the number of intertwined operational and business constraints. It is no surprise that KM for sustainability in general, CFC in particular, has received increased attention among scholars investigating how management practices can support the improvement of corporate environmental performance [e.g., Michelon et al., 2013; De Medeiros et al., 2014].

Our initial review of this literature (detailed in the following section) has, however, revealed that beyond asserting, again and again, the importance of CFC, there is a dearth of studies that explain how exactly collaboration across different functional departments can foster corporate environmental performance improvement. Most papers discussing sustainability-oriented collaboration focus on collaboration with external stakeholders, for instance, across-company environmental partnerships and collaboration with suppliers or customers [e.g., Handfield et al., 2005; De Marchi, 2012; Grekova et al., 2016; Wassmer et al., 2017]. Conversely, the issue of building down organizational silos to connect environmental sustainability with other dimensions of corporate strategy – in particular, the way in which the ensuing new management practices can foster corporate environmental performance – has received much less attention. The purpose of this paper is to fill this gap in the literature by addressing the following research question (RQ).

RQ: What is the role of CFC in corporate environmental performance improvement?

We define corporate environmental performance improvement as the outcome of efforts aimed at economizing on resources and reducing the environmental harm associated with corporate activities from a life cycle perspective.

This RQ clearly delimits the topics covered. This study focuses on environmental sustainability-oriented (ESO) intraorganizational collaboration. Consequently, although it is a commonplace ever since Elkington [1997] stated that in addition to the environmental dimension, corporate sustainability needs to be evaluated also from the perspective of social justice, without subordinating the traditional economic criteria that enable sustaining the business itself, this paper focuses only on the environmental dimension of corporate sustainability performance. On the other hand, although obviously a broad range of external stakeholders influence corporate environmental performance, we take a narrow perspective, centering our attention only on collaboration across functional departments.

To answer the RQ, we undertake two rounds of literature review. Reviewing the vast literature on corporate environmental sustainability, which adopts an *organizational approach* and calls for CFC and KM, we make a proposition about the ways in which CFC can contribute to environmental performance improvement. In the second round of the literature review, we collect illuminative real-life examples to illustrate our arguments.

The paper is structured as follows. Next, we briefly review some of the diverse strands in the literature to which our RQ is related (first round of literature review). This is followed by the presentation of our proposition about the role of CFC and the description of the research design and data collection method. Subsequently, we present the findings of the data collection, i.e., the examples that illustrate our arguments. To conclude, we provide a few summary remarks and elaborate on the managerial implications of our research.

2 Literature review

Our research is related to multiple strands in the literature, including the literature on corporate environmental strategy and sustainability management practices, barriers to improving corporate environmental sustainability, green (dynamic) capabilities, and KM for sustainability. As it is beyond the scope of this paper to review each of these strands in detail, only a couple of messages will be picked and presented in this section – takeaways from the literature that are closely related to our RQ. These bits and pieces will be complemented in the subsequent sections with the results of our data collection exercise: we summarize some findings from environmental management papers that discuss real-life challenges encountered by manufacturing companies when implementing ESO changes in processes and practices.

One of the most influential – albeit heavily debated – assertions of the environmental management literature is that *it pays to be green*: investments in improving environmental performance improve firms' economic and financial performance [Porter and Van der Linde, 1995]. Nevertheless, a substantial proportion of firms fail to adopt measures that would improve their environmental performance. This fact is ascribed to the presence of a variety of barriers to environmental performance improvement [Trianni et al., 2017]. Some of these barriers are economic, market-related, and technological (e.g., lack of resources, long payback time, technological lock-in, and risks of production disruption); others – more related to the focus of this paper – are managerial, behavioral, and organizational. Examples include lack of awareness, resistance to change, risk aversion, and lack of knowledge and technical skills [Trianni et al., 2017]. The organizational and managerial barriers closest related to our study are lack of information (e.g., about costs, risks, impact, returns, and so on), vested or split interests [e.g., Rohdin and Thollander, 2006], silo thinking and low organizational power of the environmental department, decision-makers' bounded rationality [Simon, 1957] and short-term priorities, and an exclusively technocentric focus on sustainability issues that neglects the necessary organizational changes [Lozano 2012a, 2012b].

Considering the issue of barriers to corporate environmental performance improvement from the perspective of another research strand closely related to this study, namely, that of (dynamic) green capabilities [Teece et al., 1997; Rugman and Verbeke, 1998; Chen and Chang, 2013], it seems obvious that in addition to *functional green capabilities*, such as green innovation capability, ecodesign capability, green supply chain management capability, energy management capability, and so forth, other types of green capabilities are also indispensable. Examples include the capability to plan, orchestrate, and institutionalize ESO changes, i.e., to drive the necessary organizational change management process [Lozano et al., 2016] and integrate the related knowledge that is scattered across various departments of the organization.

These latter components of green capabilities are referred to as *architectural components* [Teece et al., 1997]; as opposed to the functional components of green capabilities. The architectural components of green capabilities are necessary for the integration of sustainability-specific knowledge into broader contexts of corporate strategy.

This leads us to the third, closely related strand of the literature: KM for sustainability. The point of departure of the literature on KM is that in response to the increasing complexity of both value-adding activities and the environment of operations, global firms usually modify their structures and processes [Schneider et al., 2017], e.g., they establish new organizational divisions or departments. Employees in the new units build up specialized knowledge to solve the problems assigned to them and manage all the relevant issues. The outcome is increased functional specialization, which, in turn, may inhibit the effective management of knowledge, e.g., its intraorganizational transfer and recombination.

As the capability of bundling and recombining knowledge resources has been regarded one of the key explanatory factors of competitive advantage at least since Penrose [1959], much research has been dedicated to KM within global companies. Effective KM is regarded an essential organizational capability enabling organizational learning [Nelson and Winter, 1982]. Gold et al. [2001] emphasize that KM needs to go beyond intraorganizational *information management*, i.e., beyond consolidating data as well as allow for smooth information flows. Effective KM also involves *organizational adaptation* and the development of organizational structures and routines that allow the firm to recognize, create and mobilize, as well as combine and transform knowledge. Hence, KM is closely related to the literature on dynamic capabilities [Teece et al., 1997; Eisenhardt and Martin, 2000].

KM also requires governance mechanisms to coordinate, integrate, and reconfigure routines across intraorganizational boundaries, as well as reconcile potentially conflicting interests and incentives [Birkinshaw et al., 2017]. Consequently, KM also requires *boundary spanning* activities within an organization, i.e., integration of activities across multiple organizational contexts [Schotter et al., 2017].

KM for sustainability is a rapidly growing subfield within the KM literature. Here, the point of departure is that the inherent complexity and the multidimensional and systemic nature of corporate environmental performance necessitate cross-disciplinary, cross-sectoral, and cross-functional collaboration [Harms, 2011; Ketata et al., 2015].[1] Collaboration across different functional departments is regarded as a means of integrating environmental methods and tools in the overall business strategy of the company [De Medeiros et al., 2014; Ketata et al., 2015; Mårtensson and Westerberg, 2016].

These papers emphasize that environmental strategy will deliver if, and only if, integrated in the broader context of the firm's competitive strategy, throughout their business processes, and at all corporate hierarchical levels [Hallstedt et al., 2010; Zhang et al., 2013].

One of the main organizational barriers to this integration is the *silo* mentality, when excessive structural (functional) differentiation is accompanied by rigid intraorganizational boundaries. Organizational decentralization and the creation of cross-functional teams with shared responsibilities are regarded adequate means to breaking through organizational silos [Stock and Seliger, 2016].

Some contributions discussing sustainability management practices provide details about the functions that need to be aligned through CFC. The majority of papers focus on collaboration between the specialized environmental unit and other functional departments, for instance, between environmental management on the one hand and product-and-process design or new product development on the other [Byggeth and Hochschorner, 2006; Dangelico et al., 2017], between environmental management and quality management [Curkovic et al., 2000], between environmental management and marketing [Hart, 1995; McDonagh and Prothero, 2014], or between environmental management and supply chain management [Handfield et al., 2005; Seuring and Müller, 2008].

Other papers take a more systemic view and propose multifunctional integration. Walton et al. [1998], e.g., underscore that greening requires product design, procurement, supplier evaluation, and logistics to be addressed simultaneously. Hajmohammad et al. [2013] discuss the requisite alignment of lean and green operations management and supply chain management for enhanced environmental performance. According to Harms [2011], sustainable supply chain management is a cross-functional undertaking integrating several functional areas in a business enterprise, including research and development (R&D), marketing and sales, public relations, procurement, and environmental management. Zhang et al. [2013] assert that an integrated sustainability perspective needs to span (a) the strategic level (enabling the top management to contextualize environmental strategy, define strategic targets, and harmonize them with organizational resources and capabilities), (b) the tactical level (supporting departmental managers in formulating a roadmap), and (c) the operational level.

However, when emphasizing the need for CFC as a means of integrating sustainability issues into company activities and adapting the organizational structure to the systemic nature of the sustainability concept, there are few papers that provide insights into precisely how ESO CFC can foster corporate environmental sustainability [notable exceptions are the papers by Harms (2011) and Székely and Strebel (2013)].

1 As mentioned previously, environmental partnerships and collaboration with external stakeholders so as to tap into geographically dispersed knowledge will not be discussed in this paper.

3 Proposition development, research design, and data collection

Following our initial review of the literature, which helped us to identify the research gap that needs to be addressed, we formulate a proposition regarding the role of CFC in corporate environmental performance improvement.

Our point of departure is that the sustainability imperative has added to the technological and contextual complexity of firms' external and internal business environments, i.e., to the number of aspects that need to be dealt with simultaneously. Consequently, firms need to deal with new operational and business constraints. Moreover, many of the new items that organizations need to address are interconnected in a synergistic, conflicting (trade-off laden), or conditional manner.

Trade-offs are situations requiring a sacrifice in one area to obtain benefit in another, related area [Byggeth and Hochschorner, 2006]. In the specific case of corporate environmental performance improvement, trade-offs refer to the situations when improvement in one aspect of environmental performance may come at the expense of another [Hahn et al., 2010].

In the context of this paper, conditional interconnections or interdependencies refer to the fact that some aspects *jointly* determine corporate environmental performance: if addressed in isolation, the related efforts will fail to deliver the expected results.

Firms respond to the ever-increasing complexity in their environment by *adaptation* and *innovation*. In accordance with the tenets of the strategy–structure–performance literature [Chandler, 1962], it can be asserted that these strategic actions involve *changes in the organizational structure*. Organizations become more segmented and specialized.

However, organizational silos may become an effective barrier to addressing, or even recognizing, interconnections (e.g., trade-offs) and conditionalities (e.g., interdependencies). Consequently, trade-offs and interdependencies – the systemic specifics of corporate environmental performance (together with various other factors not discussed here) – pose formidable challenges to intraorganizational goal congruence and cause uncertainties about priorities and ESO intervention-related risks. These specifics are behind several organizational, managemental, and behavioral barriers to environmental performance improvement.

In order to manage complexity and address newly emerging trade-offs and interdependencies, it is indispensable to establish organizational procedures and routines that facilitate coordination, enable information sharing, and foster knowledge integration. This leads us to advance the following proposition.

> CFC is an organizational routine and management practice that enables the identification and addressing of two systemic specifics of corporate environmental performance, namely, trade-offs and interdependencies, among the various aspects of environmental sustainability.

If left unaddressed, these systemic specifics would not only weaken the effectiveness of ESO interventions, but they would result in organizational, managerial, and behavioral outcomes, such as inertia, opposition to change, lack of information, and so on, which could even impede the adoption of ESO measures. CFC enables to recognize the practical consequences of these systemic specifics. It addresses them through information sharing, knowledge building, and interest reconciliation, which enables the management of change. In this way, CFC can mitigate organizational, informational, and behavioral barriers to corporate environmental performance improvement. Figure 1 provides a graphic summary of our arguments.

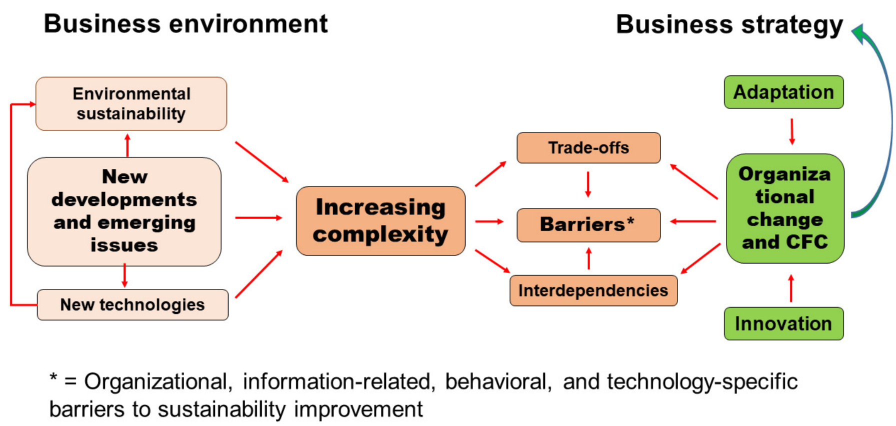

Figure 1. Conceptual framework.

The proposition we developed has guided our data collection. We conducted a review of the literature using the concepts therein as search strings. To make our search as broad and inclusive as possible, we conducted a search through Google Scholar, searching for peer-reviewed academic publications, written in English, from 1995[2] up to the present, using *trade-off* AND *corporate sustainability*/*trade-off* AND *environmental management*, and conversely, interdependen*/interconnect* AND *corporate sustainability/environmental management* as search strings.

Since Google Scholar ranks the hits in terms of their relevance, we decided to check the first 100 papers from the hits of both searches. These hits were filtered by checking their titles and the content of the abstracts for relevance. The relevant papers were read in full, and applying a snowball sampling technique [Fink, 2012], the citations therein were also checked and read in full if found to correspond to our research topic.

While this method worked well in the case of trade-offs, yielding several highly relevant papers, it turned to be useless in the case of interdependencies. Most of the hits proved irrelevant, since the papers suggested by the search engine discussed interconnections among business, environmental, and social considerations or were concerned with the interconnectedness of stakeholders. Conversely, when considering the notion of interdependence (interconnection) as a not-to-be-neglected property of corporate environmental sustainability, we were interested rather in interdependence (interconnections) *among aspects of environmental sustainability*, which originate rather in the systemic nature of sustainability.

Consequently, we decided to use the search strings *environmental sustainability/environmental management* AND *system interaction/functional interfaces*. These searches had already produced an acceptable number of hits, so we could undertake a similar sampling, filtering, and snowball-type sample expansion exercise as in the case of papers on trade-offs.

Finally, 36 papers were selected to be read in full.[3] The selected papers pertain either to the *business and the environment* literature or to the environmental science and technology literature. The initially collected sample was later complemented with 11 additional papers that had been brought in by focused searches for studies that highlight particular subtopics or clarify technical questions that emerged over the course of the analysis.

2 We decided to use 1995 as a temporal boundary for our search because two salient papers, by Hart [1995] and Porter and Van der Linde [1995], marking the beginning of a new era in sustainability theory and environmental management thinking, were published that year.

3 Note that not all papers have been included among the references of this paper, only the ones that were eventually used in the analysis are cited.

All in all, the objectives of our data collection and the subsequent analysis were as follows:

1. to collect illuminative real-life examples of problems and challenges associated with trade-offs and interdependencies among aspects of environmental sustainability;
2. to check whether practitioners encountering these problems could, in principle, mitigate them through CFC; and
3. to illustrate our proposition regarding the twin roles of CFC.

4 Addressing trade-offs in sustainability management – the second round of literature review

Traditional trade-off issues, such as trade-off between environmental performance and financial performance, are addressed, albeit implicitly, by the extensive *pays-to-be-green* literature [e.g., Ambec and Lanoie, 2008] and, more explicitly, by the critics of the win–win paradigm [see review by Hahn et al. (2010)].

Contesting the dominant view of the win–win paradigm, Hahn et al. [2010] argue that trade-offs and conflicts in corporate sustainability are the rule rather than the exception. The concept of trade-offs has become deeply embedded in the corporate sustainability literature and is utilized at a variety of levels (e.g., individual, organizational, industrial, and societal), contexts, and dimensions [Van der Byl and Slawinski, 2015; Haffar and Searcy, 2017].

As regards our proposition, three specific dimensions of trade-offs have proved relevant. The first one is the strategic choice perspective in the context of resource constraints: here, trade-offs become manifested when selecting among ESO investment objectives. This is an area that deserves proper scrutiny, since most sustainability-related issues are trade-off-laden ones, involving hard choices with respect to strategic orientation, technology, process, or supply chain. An example of this dimension is the trade-off concerning the timing of investment in ESO technological solutions. First-movers face a trade-off between contingent high benefits and higher-than-the-average uncertainties.

Another example is the trade-off between scope and depth, described by Csutora [2011]. Investigating firm-level strategies based on a survey by the Organisation for Economic Co-operation and Development (OECD) on environmental policy tools and firm-level management practices, she found that increasing the number of dimensions targeted by firms' ESO initiatives counters the degree of their sustainability performance improvement.

The second relevant dimension includes trade-offs between competing implementation approaches that would produce different ESO outcomes, i.e., where alternative solutions emphasize different domains of environmental performance; consequently, these domains have to be balanced against each other [Byggeth and Hochschorner, 2006; Haffar and Searcy, 2017].

The third, often-encountered trade-off is a situation when individual ESO solutions compromise other ESO targets, i.e., when a favorable outcome in one environmental respect may result in an adverse outcome in another [Robèrt, 2000].

The surveyed *environmental science and technology* literature abounds in details about each of these three kinds of trade-off. They are listed in Table 1, complemented with suggestions regarding the functions required to collaborate and integrate function-specific knowledge to address the given trade-off.

The trade-offs in Table 1 are ordered from relatively simple to increasingly complex ones. They demonstrate that environmental sustainability is not a straightforward, but rather a trade-off-laden, issue. It seems obvious that even the simplest trade-off issues require systems thinking [Williams et al., 2017] and CFC, involving the representatives of a range of corporate functions. Trying to explain how CFC can improve corporate environmental performance, the foregoing discussion focused on the interrelated, conflicting dimensions of environmental sustainability. Next, we turn to the issue of interdependencies. Similarly to trade-offs, interdependencies among aspects of environmental sustainability may also weaken the effectiveness of environmental performance improvement efforts, in addition to causing uncertainties about risks and returns on investments.

Table 1 Examples of trade-off-laden sustainability issues requiring CFC

Trade-off	Description	CFC	Source
Trade-offs between particular process parameters and sustainability	Shift to high-speed cutting (e.g., to achieve better-quality surfaces) increases the energy demand of processing. Moreover, high-speed cutting enhances tool wear. Reducing tool wear requires the application of special coating or the use of cooling lubricants, which, however, implies environmental concerns. Energy consumption is higher with a worn tool. However, early replacement of tools increases not only costs but also waste of resources.	Process design, operations, R&D, quality, and environmental management	Vijayaraghavan et al. [2013]
Trade-off between the environmental impact of particular product parameters	Strength-to-weight ratio and energy density: some materials considered for automotive components, e.g., carbon-fiber-reinforced polymer composites (or magnesium, aluminum, and other alloys) feature a better strength-to-weight ratio than pure steel. They would effectively reduce vehicle mass and thus contribute to fuel efficiency. However, the production of these alternatives to steel-based components requires more energy and produces more greenhouse gas emissions per unit of mass than what conventional steel would. The catalytic-converter problem: catalytic converters reduce toxic exhausts but increase the consumption of precious metals.	Strategic planning, product and process design, supply chain management, and environmental management	Robèrt [2000]; Kirchain et al. [2017]
Design for product longevity or for remanufacturing vs. technology development for improved environmental performance of new products	Against intuitive ESO considerations, improvement in the environmental performance of products would call for shorter product life, as the benefits associated with new models featuring superior environmental performance may outweigh the environmental costs related to early product replacement. New-generation consumer goods, e.g., refrigerators or vacuum cleaners, consume less energy in use. Ozone-depleting chlorofluorocarbon (Freon) emission by old vintage refrigerators is eliminated in newer vintage pieces. This calls for replacing inefficient products before their designed lifetime. However, the disposal of old models is associated with high environmental burden. However, an opposite trend is observed in the case of successive generations of smartphones (of identical companies, e.g., Apple). Life cycle assessments of successive product models show a consistent increase in greenhouse gas emissions, as new product families become increasingly complex.	Strategic management, innovation management, R&D, marketing, and& environmental management	Gutowski et al. [2011]; Suckling and Lee [2015]
Different stages in the product life cycle would require different and contradictory product design attributes	The use of low-impact, e.g., recycled, material (design phase) may be in contradiction with product life span and remanufacturing considerations (end-of-life phase), as these latter would require durable and often relatively high-impact material. Notice that the early stages of the design process have the greatest impact on the environmental performance of the products. However, designers in this stage have limited information about environmental properties of the product and thus concentrate rather on aesthetic and functional aspects.	New product development, process design, operations, marketing, and environmental management	Lagerstedt et al. [2003]

Trade-off	Description	CFC	Source
Trade-offs with respect to moving to a paperless manufacturing environment	Shifting to paperless shop floors as well as warehousing operations eliminates (reduces) the costs related to printing and paper disposal. Paperless manufacturing and warehouse picking may also improve the productivity of both the core and the support functions, which, in turn, can have beneficial resource efficiency implications. However, paperless manufacturing and warehousing may have nonnegligible energy costs and implications for WEEE.[4]	Strategic planning, production planning, operations, IT, logistics, and environmental management	Mleczko [2014]
Lean vs. green	Just-in-time management practices reduce waste (e.g., excessive inventory), eliminate inefficiencies along the supply chain, and contribute to more effective use of resources. However, this practice requires more transportation, resulting in more emissions. A similar trade-off can be observed between excessive work in progress (inventory), which may lead to late recognition and, thus, to the propagation of defects between subsequent processing stages. The outcome is wasted production capacity (processing parts that are already defective) and reduced resource efficiency. However, the reduction of this type of inventory through lean practices can increase lead time, because without buffers, bottlenecks in the system are more difficult to be prevented. This causes higher overall (in particular, standby) energy consumption.	Strategic planning, process design, operations, logistics, quality, and environmental management.	Colledani et al. [2014]; Carvalho et al., [2017]
Scope vs. depth	There is a trade-off between the scope and depth of sustainability agendas: if companies try to achieve improvement along a wide variety of sustainability dimensions, they may fail to have breakthrough achievements in areas of primary importance. They need to set priorities in terms of aspects with the greatest impact on environmental sustainability (e.g., prioritize a selected life cycle stage).	Strategic planning, product and process design, operations, logistics, R&D, communication, and environmental management	Csutora [2011]
Proactive vs. reactive	In the context of resource constraints, ESO firms usually need to make a strategic choice between investing in innovation for sustainability or scaling up (or extending) existing green technologies (the latter choice promises immediate and less-uncertain environmental performance improvements but may not resolve specific environmental problems). Similarly, firms usually need to select between complex pollution prevention technologies and pollution control technologies (a reactive strategy with immediate tangible benefits). Despite the immediate, low-risk, easy-to-measure benefits of the reactive strategies, firms choosing this latter option may, over time, face rising abatement costs.	Strategic planning, product and process design, operations, R&D, and environmental management	Klassen and Whybark [1999]; Pinkse and Kolk [2010]

4 Notable in this respect is the warning by Bull and Kozak [2014] that comparative life cycle assessments regarding paper and digital media are problematic, contingent on a series of assumptions. For example, the energy intensity of enhanced Internet use and of the storage, retrieval, and processing of orders of magnitude more data is also hard to calculate [Coroama and Hilty, 2014].

Trade-off	Description	CFC	Source
R&D targeting product stewardship vs. clean technology	While product stewardship innovations envisage incremental product improvements and development of products with lower-than-before life cycle costs, clean technology innovations leapfrog existing products and processes to achieve radical reorientation toward ecologically sustainable directions. Decision-makers face complex trade-offs because of competing product stewardship solutions (e.g., advanced, internal combustion engines with turbocharging systems in the automotive industry, or flexible fuel vehicles) and competing clean technology solutions (electric battery vehicles, hybrid electric vehicles [EVs], and so on), featuring different ecological impacts and unpredictable development trajectories.	Strategic planning, R&D, product and process design, marketing, and environmental management	Penna and Geels [2015]; De Stefano et al. [2016]
R&D targeting electric drivetrain technologies of automotive companies vs. vehicle weight reduction	A complex trade-off situation for ESO automotive companies. According to the results of the referred paper, vehicle weight reduction (in traditional vehicles) promises higher cumulative emission savings than shifting to EVs or hybrid vehicles. Strategic managers need to consider, however, the substantial government support targeting EV technologies, the evolution of consumer preferences, competition in the EV market, and the opportunity for changes in the incentive structure. R&D and product design staff need to consider weight reduction-related safety concerns.	Strategic planning, R&D, product and process design, marketing, communication and government relations, and environmental management	Serrenho et al. [2017]
Trade-offs related to manufacturing strategy selection: additive (3DP) vs. conventional manufacturing	The 3DP paradigm is associated with less waste, reduced inventory, higher resource efficiency, less transportation, easier inclusion of lightweight structures (improving, e.g., fuel efficiency); but the drawbacks include higher energy use in production partly because of low throughput; adverse impact on the environment because of the powder elaboration process; toxicological hazards related to the materials used in the 3DP process; unresolved quality problems (higher defect rate) because of the low maturity of the 3DP process.	Strategic planning, product design, operations, R&D, and environmental management	Chen et al., [2015]; Paris et al. [2016]

Abbreviations: 3DP = three-dimensional printing; CFC = cross-functional collaboration; ESO = environmental sustainability-oriented; IT = information technology; R&D = research and development; WEEE = waste electrical and electronic equipment.

5 Linking CFC and interdependencies in sustainability management

The point of departure of the literature discussing interdependencies in sustainability management is that environmental performance improvement initiatives cannot be considered as isolated projects. Every ESO initiative is part of the technological, infrastructural, and organizational systems of the firms in question [Williams et al., 2017]. ESO changes in products, production processes, and corporate practices are therefore bound to spill over to interconnected corporate subsystems and trigger related changes within the system itself. If these changes do not take place or are not addressed adequately, ESO investments and initiatives will fail to deliver or, at least, will not bring the expected results.

Considered from a systems perspective, it can be asserted that individual ESO interventions do not necessarily lead to a *cumulative* improvement in the production system: interventions may have *synergistic* or – as illustrated in the previous section – *antagonistic* effects. Further, the beneficial impact of certain ESO interventions may be *conditional* on other (complementary) actions.

This section considers this latter dimension of interdependencies among the aspects of environmental sustainability. We argue that the challenges to corporate environmental performance improvement generated by within-system interactions can be mitigated through CFC.

Most papers linking ESO CFC and interdependencies are concerned with product life cycle management[5] as a salient example of ESO activities involving practically all functional areas [Pujari, 2006; Umeda et al., 2012; Mårtensson and Westerberg, 2016].

Compared to life cycle management, the concept of sustainable supply chain management represents a somewhat narrower view of interdependencies. This concept takes into account interdependencies along the supply chain of the focal firm and calls for collaboration across functions responsible for the environmental performance of operations, procurement, supplier management, and logistics [Walton et al., 1998; Hajmohammad et al., 2013].[6]

A recurring aspect in the literature concerned with interdependencies in sustainability management is that environmental performance improvement necessitates a range of complementary assets that are developed by firms not necessarily as part of their environmental strategy but rather throughout their other value-creating activities [Christmann, 2000], for instance, when accumulating firm-specific human capital, or information and communication technology (ICT) capital.

When companies decide to initiate ESO activities, they need to consider the wide variety of interdependencies that these activities may entail, ranging from pure technological and infrastructural to strategic interdependencies. ESO initiatives involve new practices and require new technologies; hence, companies need to train existing – and hire new – employees and make investments. The effective implementation of ESO initiatives requires *building new* and *synthesizing* existing know-how.

One example illustrating both the interdependencies among and the conditional effects of ESO interventions is materials substitution in automotive components. Materials substitution is an extensively researched means of reducing vehicle mass, resulting in improved fuel efficiency. If implemented effectively, i.e., if significant mass reduction is achieved, this will require also the optimization of the vehicle engine, the transmission, the drive shafts, and the drive wheels for the lighter vehicle [Kirchain et al., 2017] to achieve the intended improvement in fuel efficiency. Further, material substitution will obviously necessitate synthesizing the expertise of not only the product and process design and the R&D departments but also that of operations, procurement, logistics, and enterprise resource planning.[7]

The diversity of interdependencies to be considered when implementing specific ESO initiatives is best illustrated by the case of remanufacturing.[8] When companies decide to engage in remanufacturing activities, they need to consider a multiplicity of connected issues [Priyono, 2016].[9] They need to evaluate whether they possess capabilities, infrastructure, and equipment for reverse logistics, disassembly, diagnostics, and testing (to evaluate the physical condition of the disassembled parts and components), cleaning, repair, and reconditioning or upgrading. All these critical activities in the

5 Product life cycle management is an approach that considers the environmental impact of products in a holistic manner: "from cradle to grave", i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair, and maintenance, to disposal or recycling [see review by Finnveden et al. (2009)].

6 Notice that both life cycle management and green supply chain management require not only intraorganizational collaboration across functions but also collaboration with external stakeholders, an issue that is beyond the scope of this paper.

7 Similarly, ESO changes in product architecture or in components require changes in processes, tooling, and plant logistics and, additionally, may also have supply chain repercussions.

8 Remanufacturing is defined as restoring used products to a like-new functional state, by disassembling, cleaning, and rebuilding them, as well as by replacing defective components, to ensure that the products meet or exceed the standards of a newly manufactured product [Sundin and Bras, 2005].

9 Considerations that affect business performance exclusively, such as positioning the remanufactured products in relation to new ones in terms of price, brand image, market niches, and so on, or the issue of outsourcing remanufacturing vs. retaining it as an in-house process are not analyzed here.

remanufacturing process require assets and capabilities that may not exist in firms specialized in new product manufacture.

This far–from-exhaustive list of complementarities and interconnections demonstrates that CFC encompassing environmental management, strategic planning, product and process design, operations, financial management, brand management, logistics, quality management, and human resources management is indispensable to lay the groundwork for the remanufacturing decision and, later, to implement it.

6 Conclusion and implications

The purpose of this paper was to explain why CFC is considered important for corporate environmental sustainability: to highlight how CFC can foster the improvement of corporate environmental performance. Illuminative real-life examples were collected to illustrate our arguments.

We argued that the systemic nature of and interdependencies in corporate environmental sustainability call for an integrated approach when designing and implementing ESO interventions. An integrated approach allows for consideration of a variety of possible domains that may be influenced by the given ESO initiative. CFC is a management practice that facilitates transferring and integrating function-specific components of knowledge. Accordingly, CFC fosters the *architectural components of green capabilities*: it strengthens the capabilities necessary for the integration of environmental sustainability-specific knowledge both in the corporate strategy and in the individual functional constituents of corporate strategy (this integration is represented by the green arrow in Figure 1).

Altogether, this study provides support for arguments asserting the importance of CFC in integrating the sustainability agenda in overall business strategy and extends our understanding of the specific ways in which ESO CFC fosters corporate environmental performance improvement.

It needs to be emphasized, however, that CFC is not a panacea: new management practices cannot change the existing trade-offs and they do not mitigate technological, financial, skill-related, or market-related barriers to corporate environmental performance improvement. CFC simply enables recognizing the complexity of the system and contributes to identifying some interrelated and potentially conflicting issues. This is the first step in coping with the behavioral, managerial, and organizational barriers that originate in the systemic features of sustainability. As a second step, CFC contributes to learning and to the management of change, since it institutionalizes communication and knowledge sharing and facilitates the reconciliation of conflicting interests.

Regarding the managerial implications, a key lesson for both the corporate C-suite and the functional officers is that in order to recognize and take care of trade-offs and interdependencies, sustainability-related issues should not be addressed from a narrow operational perspective. Efforts need to be devoted to designing and institutionalizing organizational practices that facilitate and routinize CFC.

In accordance with the paper by Madhavan and Grover [1998], it can be asserted that the collective knowledge of functional units constitutes only potential knowledge. In the case of corporate-level systemic issues such as environmental sustainability, CFC is indispensable for mobilizing the isolated components of knowledge and directing them toward suprafunctional objectives.

While helping to clarify these issues, this study has raised some points requiring further scrutiny. Further theoretical refinements are needed to reveal the specific mechanisms that govern CFC, e.g., whether the dominance of selected functions (e.g., environmental management) in collaborative projects should be preferred over a perfectly decentralized governance or not. Another issue is the extent of autonomy to be granted to ESO cross-functional teams: whether CFC should be limited to information exchange and to laying the groundwork for strategic decisions made by the top management or, instead, cross-functional teams should set priorities and implement actions autonomously.

An important direction of further research is to validate the conceptual framework outlined in this paper through case studies. Empirical evidence will add flesh to the bones of the framework presented.

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