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Achieving sustainable new product development by integrating product life-cycle management capabilities

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ABSTRACT

Concerns about sustainability matters have been growing significantly during the last decades. The triple bottom line approach – an often applied operationalization of sustainability integrating the economic, social, and ecologic aspects of sustainable development – has gained attention in companies, especially with regard to sustainable products. Nevertheless, the integration of sustainability in new product development is still in an early stage. Hence, the purpose of this paper is to elaborate on the impact of the three product life-cycle management pillars, i.e. product data management, process management, and engineering project management, on facilitating the integration of new product development and sustainability. An explorative multi-case study with a total of 23 interviews in six automotive companies has been conducted. The case studies show that sustainability requirements increase complexity in new product development, in which globally-dispersed design teams, product variation, and time-to-market pressure already have to be managed. In order to mitigate these challenges in new product development, the incorporation of the three product life-cycle management pillars may be beneficial. By doing so, globally-dispersed processes become streamlined across departments and companies, development accuracy due to a joint database is enhanced, and the utilization of cross-company capabilities focusing on sustainable product development is established. This research provides practical implications and argues for integrating product life-cycle management into sustainable new product development.

1. Introduction

Product complexity and globally dispersed product design activities challenge today's companies in high technology industries (Grieves, 2006). These challenges impact whole product life-cycles – at least in theory (Mascle and Zhao, 2008). Thus, companies are forced to invest in concepts like product life-cycle management (PLM) supporting their operations management in reducing managerial complexity in new product development (Stark, 2005). PLM expresses the engineering point of view of the product life-cycle concept and integrates the aspects of people, processes, and data (Stark, 2005). For example, the lack of a well-defined PLM process is seen as a key factor in companies missing targets in new product introduction and therefore causing delayed market entry, as was the case of the Airbus A380 (TechDrummer, 2008). Similarly, Toyota's massive vehicle recalls were caused due to the cars' complexity and might have been avoided by implementing a thorough PLM concept (Gu, 2010).

Sustainability activities demanded by customers, non-governmental organizations, and legislation are increasing the complexity of product design (Bevilacqua et al., 2007; Hu and Bidanda, 2009). Influencing a product's sustainability characteristics is prevalent in the design phase (Evans et al., 2007). This can also be seen in the case of Airbus trying to reduce weight for economic and environmental reasons. Less weight of a plane enables designing bigger planes with more capacities and less environmental-impacting exhausts. Although research on green new product development (Polonsky and Ottman, 1998; Baumann et al., 2002; Lee and Kim, 2011) has emerged, it is not sufficient as social aspects also require attention as reflected in growing research activities and requests for sustainable approaches in supply chain management (Seuring and Müller, 2008), operations (Kleindorfer et al., 2005), engineering (Allenby and Allen, 2007), and sourcing (Pagell et al., 2010), as well as the request for sustainable products (Bevilacqua et al., 2007). Consequently, green new product development (NPD) needs to move to the next step toward a sustainable new product development. Sustainable development is grounded in the Brundtland Commission's definition as "*a development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (WCED, 1987, p. 42). This definition is the first in which a sustainable development had been expressed and noted. Henceforth, it can be considered as the root for all concepts and

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recent research in the today's vast field of sustainability. The Brundtland Commission focused on two key points. On the one hand the 'needs' of generations are addressed, which are mainly concentrating on the desires of poor people of the world. On the other hand the thought of timeliness was of interest. Future generations should not be impacted negatively by current developments. This means that it is not sustainable to fulfill the needs of the current generation when impairing the situation of future generations. This includes especially the exploitation of natural resources which are hard or not at all to replenish. Processes or activities that use resources now without providing them to future generations are not in line with a sustainable development. The Brundtland Commission also stated that a sustainable development has to be initiated today in order to give future generations a realistic chance to fulfill their needs. Nevertheless, it is also mentioned that these actions require governmental support to guide companies on a sustainable development path. Sustainable development needs to be done on a regional, national, and global level. The rather vague definition (Callens and Tyteca, 1999) of sustainable development by the Brundtland Commission (WCED, 1987) is difficult to infer for companies and has been specified by the triple bottom line approach into integrating economic, social, and ecologic aspects (Elkington, 1997; Dyllick and Hockerts, 2002). The link of the triple bottom line to new product development must be achieved in order to design and produce sustainable products. From an engineering point of view, products pass through a life cycle with different characteristics of processes and data and involve many people and companies. Henceforth, product life-cycle management, i.e. product data management, process management, and engineering project management, becomes the focal point when dealing with NPD.

Combining the challenges of sustainability, NPD, and the advantages of PLM leads to the research question addressed: how do the product life-cycle management pillars support a successful sustainable new product development? This paper seeks to answer this question by drawing on insights from six case studies in the automotive industry. The automotive industry is known for complex products and processes (Thun and Hoenig, 2011) as well as for strong sustainability requirements (Orsato and Wells, 2007). In addition, the automotive industry is seen as a pioneer in product life-cycle management activities (Grieves, 2006), allowing valuable and reliable insights to be expected.

The remainder of the paper is structured as follows. Section 2 introduces the literature on NPD, sustainability, and PLM. It provides a table connecting new product development success factors with the PLM pillars and sustainable activities. In Section 3, the case study methodology is described and justified. Section 4 presents the findings from the cases, while Section 5 gives the discussion. The conclusion and further research opportunities are drawn in Section 6.

2. From terminology to a basic conceptualization

In order to address the research question the theoretical background provides the basic comprehension of the three concepts: sustainability management, new product development and the product life-cycle management pillars. This is represented in the following four sections. The fifth section explains the integrative approach of all concepts.

2.1. Sustainability management

Research within the area of sustainability attracts a large community in academic literature (e.g. Huang and Rust, 2010; Schneider and Meins, 2012; Caniato et al., 2012; Lee and Farzipoor Saen, 2012). The concept of the triple bottom line is mainly in used in connection with companies (Wiedmann et al., 2009). The definition of the triple bottom line integrates economic profitability, environmental protection, and social responsibility (Elkington, 1997; Dyllick and Hockerts, 2002; Kleindorfer et al., 2005). The comprehension of each triple bottom line aspect is shown in Table 1 and is followed in this study. The triple bottom line is seen as an adequate guidance for organizations specifying the Brundtland Commission's definition of sustainable development (Naslund and Williamson, 2010).

The Brundtland Commission defined sustainable development as "a development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). The advantage of the triple bottom line lies in a supply chain wide focus. The development of sustainable products aims at fulfilling the users' needs with the purpose of reducing environmental and social impacts of products while providing economic value to the company during the whole product's life cycle (Hsueh, 2011). Accordingly, companies are able to gain competitive advantages through sustainability (Campbell, 2007). The competitive advantage can also affect the whole supply chain because corporate sustainability does not solely impact the company but also the whole supply chain (Vachon and Mao, 2008; Seuring, 2011; Caniato et al., 2012). Shrivastava (1995, p. 955) provides a further definition of sustainability with a strong environmental focus, referring to "the potential for reducing long-term risks associated with resource depletion, fluctuations in energy costs, product liabilities, and pollution and waste management". However, the interpretation does not include aspects of a social performance. The often-mentioned statement that the social dimension of sustainability has been neglected becomes evident here (Aguilera et al., 2007; Mu et al., 2011).

2.2. New product development

Research in new product development (NPD) has been of interest for several decades (e.g. Leonard-Barton, 1992; Muffato, 1998; Kleinschmidt et al., 2007; Afonso et al., 2008), attracting researchers in engineering services (e.g. Perrone et al., 2010), collaboration aspects (e.g. Ramesh and Tiwana, 1999), and global teams (e.g. Rauniar and Rawski, 2012). New product development focuses on the transformation of a market opportunity into a product available for sale with short development cycles (Krishnan and Ulrich, 2001; Atuahene-Gima and Murray, 2007). Short development cycles enable companies to react quickly to changed market demands (Hu and Bidanda, 2009). Following a market opportunity is a vital aspect to remain competitive. Today this

Table 1
The triple bottom line (based on Elkington (1997), Dyllick and Hockerts (2002) and Kleindorfer et al. (2005)).

Triple bottom line	Description
Social	Skills, motivation, and loyalty of employees and business partners Value is added to the community which a company operates in
Environmental	Reduction of the consumption of natural resources below the natural reproduction
Economic	Guaranteed cash-flow at any time while producing return to shareholders

requires focusing on the development of sustainable products (Bevilacqua et al., 2007). In order to gratify customers, product developers are urged to follow these requests for sustainable products in implementing sustainability aspects in new product development (Kaebernick et al., 2003). This is caused by NPD defining the success of a product across the entire life cycle and laying the foundation of a company's success (Zhang and Dhaliwal, 2009; Hult and Tomas, 2010).

Since new product development is significant for a company, NPD-specific factors have been developed. A considerable amount of empirical research for new product development success factors is available (Montoya-Weiss and Calantone, 1994). These factors have been condensed and justified over time by thorough NPD research, leading to the following commonly established ones (Griffin, 1997; Cooper, 2001; Marion et al., 2012): cross-functional work, top-management support, market planning, and formalized processes. These success factors hence cover the two fundamental aspects for mitigating successful products of (1) doing the project right and (2) doing the right project as indicated by Cooper (2001). Cross-functional work and formalized processes support doing the project right, and top-management support and market planning focus on doing the right project (Marion et al., 2012). Based on Cooper (2001) and Marion et al. (2012) it can be said that all relevant success factors for a NPD are covered in this study on the one hand and on the other hand they are distinctive from each other.

These success factors, their description, and research examples are summarized in Table 2. Being examined and tested by several researchers, it can be assumed to have the most relevant success factors for this study. Based on these NPD success factors, the relevance of product life-cycle management for a sustainable new product development will be justified. This shall be done by reflecting the interconnection of each PLM pillar with each mentioned NPD success factor.

The current literature on NPD is mostly dominated by a marketing perspective (Hines et al., 2006), whereas the connection to sustainability and the engineering-driven product life-cycle management is rather rare (Bras, 2009).

2.3. Collaborative product development

Collaboration across departments and companies enables the management to identify and evaluate a greater selection of options in a sustainable NPD in order to reach the best solution (Klassen and Vachon, 2003). Consequently, collaboration is critical for product improvement, the reduction of cycle times, and reducing costs (Johnson et al., 2010). However, companies still fail to capitalize from collaboration, which may result from poor communication or lack of process harmonization (Barratt, 2004). In a collaborative environment, tools, interoperability standards, architectures, etc. have to be coordinated so that barriers do not prevent collaboration (Heuer, 2011). Product development projects are dependent on applications that provide data and process steps supporting the developers and even restricting access to certain areas. A successful collaboration is dependent on technology and organized processes (Johnson et al., 2010). Thus, the collaboration partners need to be organized around these requirements and related processes (Cooper et al., 1997). In this respect, it is important that the actors within the development team know their roles and functions in detail, so that collaboration between functions and companies is possible without barriers (Zhang, 2011). Barriers induce silo thinking, consequently hindering NPD. As a first effort towards collaboration, firms must overcome their own functional silos and adopt a process/product-focused approach (Lambert et al., 1998; Childerhouse and Towill, 2011) in order to be able to achieve a sustainable product development and thus a competitive advantage (Chen and Paulraj, 2004).

Besides barriers the aspects of strategicity and relationability of the partners in a collaborative NPD play an important role (Mazzola et al., 2008; Mazzola and Perrone, 2013). This calls for the concept of resource based view due to the importance of bringing resources in to the collaboration. The resource-based-view explains that inter-firm resources are valuable for competitiveness (Wernerfelt, 1984; Barney, 1991). In addition to the RBV, the presence of trust and reliability that makes the relationship between the partners less exposed to opportunism risks. Thus, the relational view adds that interfirm resources are sources of competitive advantage (Dyer and Singh, 1998; Petersen et al., 2005).

2.4. Product life-cycle management

Product-oriented companies realize that a suitable approach for product complexity management is product life-cycle management (PLM) (Young et al., 2007). “PLM is an integrated, information-driven approach comprised of *people*, *processes/practices*, and *technology [data]* to all aspects of a product's life, […]. By trading product information for wasted time, energy, and material across the entire organization and in the supply chain,” (Grieves, 2006). The importance of trading information has been ignored with regard to new product development (Liker and Morgan, 2006). Products have to be developed quicker because product life cycles are getting shorter. The market requests new products frequently; therefore, short development cycles are of interest (Hu and Bidanda, 2009). This trend also results from the growing operational globalization and the pressure for market share, resulting in higher revenues to satisfy shareholders (Rao and Holt, 2005). As a result, the focus of a company is obliged to be on the product's success even more than it used to be (Cooper, 2001). PLM offers this

Table 2
New product development success factors (based on Griffin (1997), Cooper (2001), Marion et al. (2012)).

Success factor	Description	Examples
Cross-functional work	People from different functional areas work jointly toward a new product	Pagell and Wu (2009), Wang et al. (2009), Rauniar and Rawski (2012)
Top-management support	Sponsorship by company's senior staff to enable NPD activities	Sarin and McDermott (2003), Salomo et al. (2010), Slotegraaf and Atuahene-Gima (2011)
Market planning	Evaluation of the current market needs with the company's capabilities to fulfill these needs	Lambert (1998), Hult (2011), Esslinger (2011)
Formalized processes	Well defined routines toward a dedicated output being agreed by all development partners	Singhal and Singhal (2002), Grieves and Tanniru (2008), Bergsjo et al. (2008)

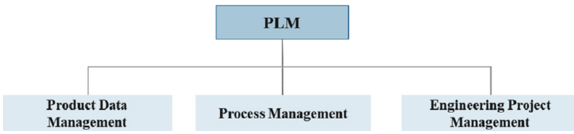

Fig. 1. Three pillars of PLM (based on Saaksvuori (2004), Stark (2005), Chiang and Trappey (2007) and Grieves and Tanniru (2008)).

product-centric approach in Product Data Management (product/data), Process Management (processes/practices), and Engineering Project Management (people) (Saaksvuori, 2004; Stark, 2005; Chiang and Trappey, 2007; Grieves and Tanniru, 2008). The three product life-cycle management pillars are displayed in Fig. 1 and are briefly explained.

(1) Global teams in NPD require suitable applications supporting communication and collaboration to enable teams to work at different locations (Klassen and Vachon, 2003). Collaboration can be facilitated by PLM through central data provisioning with product data management (Cao et al., 2009) representing the first product life-cycle management pillar. Data is managed and stored centrally so that data duplication and herewith connected data inconsistencies are hampered.
(2) The second PLM pillar of process management supports the implementation of cross-functional and cross-company, product-focused processes. Processes need to be designed according to the product and material flow in order to facilitate and accelerate product development.
(3) The third pillar of engineering project management covers the management of the other two columns through organizing product-focused resources (Terzi et al., 2010), managing the approach in product changes, product-related issue management, and also the higher-level program management.

2.5. Toward a life cycle focused sustainable NPD

The interface of NPD, sustainability, and PLM is currently not elaborated hence a literature review in a narrower sense is infeasible. This supports the necessity of this study, to explore the impact of product life-cycle management on a sustainable new product development, thus, to connect NPD, PLM, and sustainability.

This leads to the following framework elaborating on the interconnection of NPD and PLM with a central focus on sustainability, see Fig. 2.

In order to elaborate on the framework the mentioned NPD success factors of Table 2 are put in relation to the introduced PLM pillars in Fig. 1. By doing so, the same level of analysis of both concepts is achieved. The intersections of the resulting table are enriched with the triple bottom line aspects of Table 1. Consequently, the resulting table provides details on the way in which the product life-cycle management pillars support the NPD success factors with a TBL focus (see Table 3). The content of each intersection has been developed based on the extant literature available on each concept.

Table 3 provides the sustainable characteristics of the NPD–PLM intersections. The intention is not only to provide the table but also empirical exploration and evidence in a case study format. The selection of the most relevant fields appeared to be difficult regarding justification parameters. In order to avoid a random or author-biased selection, the case study results of Section 4 have been taken as the basis. On the one hand cases were taken in which all companies can provide common insights. On the other hand it is interesting to look at these cases in which only few companies can provide data, i.e. extreme cases. This approach is following Voss et al. (2002) indicating that extreme cases provide the most insightful findings (Voss et al., 2002). Consequently, the following intersections will be explained:

(1) *Cross-functional work* and *product data management* forming the first intersection in the table has the intention to have one data management strategy and one source storing environmental and ecological product facts across departments and companies (Choi et al., 2010). Information and product data flow across companies is important (Schmenner and Swink, 1998; Chen and Paulraj, 2004) to successfully establish a joint product development with suppliers toward sustainable products (Wang et al., 2009; Pagell and Wu, 2009). In joint product development collaborations the product data management is in control of the joint venture. Communication and interoperability strategies can be planned ex-ante (Mazzola and Perrone, 2013). Each component needs to be estimated and evaluated against their environmental and social impacts. Product developers have to rely on up-to-date information from one single data source (Grebici et al., 2006). The reliance on up-to-date data from all development partners provides the chance to reduce product development time (Lee et al., 2006) and henceforth development costs. Nevertheless, confidentiality issues still prevail across the supply chain with regard to data. This can also be seen in the relational view, that trust and reliability foster a relationship (Petersen et al., 2005; Mazzola et al., 2008; Childerhouse and Towill, 2011). However, PLM tries to address this issue based on confidentiality restrictions.
Experts in sustainability as well as PLM are scarcely available. These experts need to be managed thoroughly (Slotegraaf and Atuahene-Gima, 2011). *Engineering project management* provides procedures in resource management (Rose et al., 2007) to support *cross-functional work* managing experts (Bunduchi, 2009). Global design activities require global-acting experts being managed from global program management teams (Salomo et al., 2010). The implementation of these teams being responsible for several projects provides advantages in standardization and expert-resource utilization. Cross-functional teams therefore reflect the core of a sustainable new product development approach (Sarin and McDermott, 2003).

Proposition 1. *Product data management enables a cross-company common sustainable product development by managing and providing data according to the triple bottom line.*

(2) *Product data management* supports the idea of a single source of product data and product sharing (Li et al., 2008) intending to enhance and facilitate collaboration activities across companies. However, these systems are so expensive (Xie et al., 2008) that the investment in such a system can solely be done by *top-management*. Aside from the high investment costs, product data management applications are able to reduce development costs, shorten the time-to-market, as well as improve consistency and flexibility of data (Sackett and Bryan, 1998). Thus, the use of such an application may pay-off.
(3) PLM offers with its *process management* pillar the capabilities to support development processes, demanding the incorporation of multi-regional teams with different expertise (Hahn et al., 2008). Development partners in different regions must be aligned. Therefore, *top-management* needs to be closely involved in process management in order to establish processes with development partners so that the design teams can work without competence or process issues. Without top-management support, it would hardly be possible to implement new, company-wide processes (Ellram et al., 2007) since a powerful driver and decision taker would be missing.

Table 3
NPD success factors being supported by PLM pillars with a TBL focus.

	Product data management	Process management	Engineering project management
Cross-functional work	Cross-functional environmental and social data provisioning	Cross-company sustainable process alignment	Management of sustainability key resources/experts with sustainability capabilities
	Cross-company environmental and social data provisioning Common product development platform toward economic product development	Cross-functional sustainable process alignment Silo thinking avoidance toward economic development	
Top-management involvement	Economic investment in one data management application	Process alignment with development partners	Program and project management toward a standardized sustainable product development
	Strategy alignment toward sustainable products		
Market planning	Virtual evaluation of product safety for end-users	Requirements management to detect market needs for new ecological or social demands/restrictions	Evaluation of market changes to comply with company goals, resources and capabilities Market analysis for sustainable needs and capabilities
Formalized processes	Product-focused sustainable data handling processes	Workflow management for economic process execution	Common change management processes for economic and environmental success
	Process flexibility improvement		

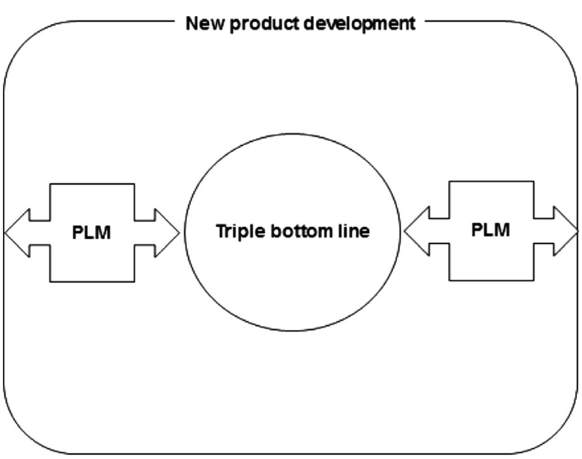

Fig. 2. PLM to facilitate a sustainable NPD.

(4) Detecting and following the requirements of customers is necessary to fulfill their needs regarding a product. In order to be able to fulfill customers' requirements, these requirements must be correctly understood, which often is not the case (Kerr et al., 2006). In order to minimize these misunderstandings, a structured requirements management is used within *process management* and *market planning*. Especially for high-technology products, the requirements management is necessary (Chen and Sackett, 2007) to support the clear definition of products within product development (Schuh et al., 2008).

(5) In *market planning* and *engineering project management*, the program management has to evaluate if changes demanded in the market are feasible for the company. Feasible in the sense of having the knowledge, the resources, and financial matters to execute the necessary changes. On the one hand, the risk of losing competitive advantages has to be evaluated (Lambert et al., 1998). On the other hand, it is evident to evaluate if the company is capable of following new market needs like sustainability (Esslinger, 2011). Respectively, whether the company already has the capabilities to comply for the market needs or whether new – often costly – experts need to be engaged must be evaluated (Hult and Tomas, 2010). Based on the product focus of PLM, customer feed-back for future products can be incorporated through web-based applications, being able to automatically extract relevant data (Schulte, 2008).

(6) *Product data management* enables reliable and flexible product design (Sackett and Bryan, 1998) through providing one data source across functionalities and companies avoiding data duplicates. Flexibility is given because product specific data are available in one source and thus can be used easily for component replacement without having to access further data applications. Due to this aspect, it is essential for companies to have product-focused oriented processes being established in NPD across departments and companies in *formalized processes* (Stark, 2005; Grieves, 2006). This process/product orientation – instead of pure functional orientation – avoids unneeded process steps not being environmentally, socially, and economically sustainable. Furthermore, they are better focused on the core aspect of the company (Stecke and Raman, 1995).

(7) The process of changing components in one product is a cross-functional or even cross-company activity (Bergsjo et al., 2008) requiring streamlined processes and coordination among the stakeholders. Changes can impact all development partners, requiring them to be defined and aligned (Singhal and Singhal, 2002). *Formalized processes* being executed with an *engineering project management* approach facilitate the association. This alignment is important to ensure components phase-in and phase-out without risking the product success or development. Components need to be changed in order to be more ecological or economical.

The conceptualization in Table 3 is rather a representation of pre-theory that would need further theoretical and empirical research. The following propositions can be stated based on the framework and the NPD-PLM matrix development:

Proposition 2. *Process management has the ability to achieve cost reduction based on the cross company process definition to establish product-focused development processes.*

Proposition 3. *Engineering project management facilitates the use of resources leading to sustainable results across the entire product development process.*

3. Methodology

3.1. Research design

The intention of this study is to explore the interconnection of NPD, sustainability, and PLM. The use of case studies has been encouraged as the method of choice when studying a phenomenon in the real life context (Yin, 2009), which is given here. Case studies are well-suited for complex structures because they allow for intense interaction with the informants which is not possible for e.g. surveys (Eisenhardt and Graebner, 2007). Besides they draw on multiple sources of information leading to robust data and information-rich cases. Interaction with an informant helps to reduce misunderstandings and antagonizes social-desirability bias in the sustainability topic. The intention of the research directs toward exploring the interconnection of sustainability and new product development and herewith to drive NPD and sustainability theory (Marion et al., 2012). Validity and reliability aspects (Gibbert et al., 2008) are summarized in Table 4.

3.2. Case selection

The study is focused on the automotive industry. First, product development is of strategic relevance in this industry because it impacts the success of a car (Quesada et al., 2006). Second, green approaches have been of interest in this industry due to the high amount of users and the herewith connected pollution potential. Third, to remain competitive in this highly competitive market, companies are forced to establish a positive sustainability image and innovation. Thus, they need to incorporate sustainability aspects holistically. Fourth, the automotive industry has been in focus for product development studies recently (Quesada et al., 2006; Townsend et al., 2010; Perrone et al., 2010; Thun and Hoenig, 2011).

A multilevel case selection process was followed in order to get robust case information to gain sufficient insights while minimizing the number of cases (Perry, 1998). Based on the reviewed literature and expert information, a sampling frame was developed. Companies were selected that were recorded in the Dow Jones Sustainability Group Index (DJSI) or FTS4Good (López et al., 2007) in order to comply for sustainability. Following the sampling criteria, six companies agreed to take part in the study. They provide access to the relevant interview partners within product development and sustainability, as well as in further departments, like controlling, to receive multiple points of view. The characteristics of the participating firms and informants are summarized in Table 5. It has to be mentioned that the case companies asked for confidentiality; therefore, no exact numbers can be provided in the table. Yin (2009) argues that data collection can be stopped when no significant new insights can be taken. This, however, is a qualitative criterion and cannot be pinned down by a certain number of cases. Other researchers argue that a multi-case analysis providing 4–10 cases provides a good research basis (Gibbert et al., 2008). Eisenhardt (1989) suggests that seven cases are the maximum a person can mentally process.

3.3. Data collection

A theoretical sampling approach was followed (Eisenhardt, 1989; Miles and Huberman, 1994). Primary data – new data collected specifically for this study (Calantone et al., 1995) – collection was executed in two phases. Foremost, the interviewees were asked to complete a pre-interview informative questionnaire on their role, tasks, and structure of the product development and sustainability departments. This approach allowed assessing the characteristics of the potential interviewees, for example, their hierarchical position within the organization, their experience on the job and with sustainability-related, PLM-related, and NPD-related processes. Subsequent to the self-administered questionnaire, guiding questions for the semi-structured interviews were developed based on the interviewees' responses as suggested by Perry (1998), Yin (2009) and Miles and Huberman (1994). The information retrieved from the firms' sustainability reports were also taken into account (Eisenhardt, 1989; Pagell and Wu, 2009). At least three semi-structured interviews were conducted per case with a maximum of five, with a total of 23 interviews forming the basis for the research (see Table 5). The interviews were conducted on site in order to gain deeper insights of survey results and lasted between 60 and 90 min.

Notes of the answers and presented documents were taken during the interviews and were immediately compiled. A case database was established with interview notes, questionnaires, content from the company's websites, annual reports, and sustainability reports to account for reliability (Gibbert et al., 2008). This approach is based on the recommendations of Yin (2009) to use primary and secondary data in order to comply for data triangulation (Gibbert et al., 2008). The incorporation of secondary data – data that was already existing for other purposes than this study (Calantone and Vickery, 2010) – is important because it is more objective and not biased by the interviewees (Busse, 2010). The use of multiple data types and respondents helps to mitigate social-desirability bias and single-informant bias (Eisenhardt, 1989).

4. Findings

Once all primary and secondary data were collected, the available information was structured according to the framework.

Table 4
Validity and reliability details (based on Gibbert et al. (2008) and Yin (2009)).

Criteria	Case research phase			
	Design	**Selection**	**Collection**	**Analysis**
Reliability	Develop case study protocol	Selection based on notation in DJSI and FTS4Good	Questionnaire and semi-structured interview	Involvement of researchers who did not gather data
Internal validity	Theoretical research framework	Sampling criteria recorded in case study protocol	Recording of interview details	Triangulation of multiple data sources
Construct validity	Adaption of constructs from previous works in PLM, NPD, and sustainability	NA	Multiple sources of information	Chain of evidence
External validity	Sampling within automotive industry	Description of case firms and context	NA	Cross-case analysis

Table 5
Case characteristics.

Firm	Alpha	Beta	Gamma	Delta	Epsilon	Zeta
Firm size[a] [employees]	~30.000	~100.000	~250.000	~8.000	~100.000	~45.000
Informant job title	Product data manager Project manager Sustainability manager	Process manager Controlling manager Product data Manager Project manager Sustainability manager	Product data manager Product development manager Sustainability manager Process manager	Sustainability manager Process manager Project manager Product data manager	Process manager Product and process manager Sustainability manager	Portfolio manager Sustainability manager Product manager Process manager
Executed interviews	3	5	4	4	3	4
Company type	OEM[b]	OEM[b]	OEM[b]	OEM[b]	OEM[b]	OEM[b]
Company's PLM experience	1 year	> 3 years	> 3 years	1–3 years	> 3 years	1–3 years

[a] Approximated figures due to confidential restrictions.
[b] Original equipment manufacturer.

Table 6
Case studies in the PLM-product development matrix toward sustainable products.

	Product data management	Process management	Engineering project management
Cross-functional work	α β γ δ ε ζ	α β γ δ ε	β γ ε
Top-management involvement	α β γ δ ε ζ	α β γ δ ε ζ	α β γ δ ε
Market planning	β γ δ ζ	β γ	β γ
Formalized processes	Special case: product-focused vs. functional approach α β γ ε vs. δ ζ	α β γ ε	α β γ ε

The same procedure was executed for all cases. The overall data analysis was accomplished in two phases. First, within-case analyses were conducted to develop individual profiles in order to become acquainted with each case. Second, it was proceeded with a cross-case analysis to detect communalities and differences in sustainable new product development and PLM behavior across the studied cases (Eisenhardt and Graebner, 2007).

Table 6 shows the results from the case study research based on the previously elaborated NPD–PLM matrix for sustainable activities. The table contributes to current research by providing an exploration of the impact of the three product life-cycle management pillars toward a sustainable new product development in the automotive industry. These results are leading the choice for the detailed elaboration on the case results. All case companies are present in the connection of: product data management and cross-functional work, product data management and top-management involvement, as well as process management and top-management involvement. The intersection of product data management and formalized processes has an exceptional position since divergent strategies are followed. Relevant cases are extreme cases (Voss et al., 2002) that provide solid information. Extreme results are provided by either intersections that provide data from all case companies or only by few. The analysis is structured per NPD success factor across the three PLM pillars. This facilitates readability and the analysis approach:

(1) Cross-functional work.
(2) Top-management involvement.
(3) Market planning.
(4) Formalized planning.

4.1. *Cross-functional work*

Product data management is the core pillar of PLM based on the interviews with the case companies. The interviews showed that PLM and product data management are often used synonymously. The distinction between both has only been clear for *Beta's* and *Gamma's* interviewees. They realized that PLM is more than just data. However, the management of product-related data takes a central role for all case companies in striving for sustainable products and product development. *Gamma's* product data manager explains that it is already challenging to gather sufficient product-related data of all functions within the company to achieve reliable environmental evaluations. The advantages of one single data source are fundamental in the interviewee's opinion. Time-consuming data adjustments due to multi-data storage are avoided. Data inconsistencies do not occur anymore and do not cause product development delays. In respect to sustainability, acquiring data on environmental performance and social sourcing is enabled by product data management. Reaching consistent data and having one database requires careful actions in collaborative development projects with suppliers was posited by *Alpha's* product data manager. The interviewees raised the problem that supplying data to another company causes barriers. Both sides are concerned if the provided data is secure. The collaborative product development process with sustainable materials is much faster after the first years when the uncertainty of data security is replaced through mutual trust in his opinion. Nevertheless, extensive data collaboration with the suppliers provides the chance to create supply-chain-wide master data, facilitating cross-functional work. *Gamma's* and *Epsilon's* product data managers justify that the potential for sustainable production lies in collaboration and data management since the product components require environmental measures in order to evaluate their environmental impact. Engineers can only make a sustainable component selection if data on quality, cost, and sustainability impact are available was expressed by *Delta's* product manager.

The management – and herewith the third PLM pillar – of key resources with special sustainability and PLM knowledge is important as reflected by *Beta* and *Gamma*. It often happens that experts can be found at the collaborating company so that costly external experts do not need to be hired. Nevertheless, as *Epsilon's* process manager states: "these resources need to be managed carefully". A thorough management of resources with sustainable expertise is vital for not setting a wrong focus.

4.2. Top-management involvement

"The importance of a product data management application is clearly visible in having one data source for the product across functions", states *Gammas* product data manager. All functions are herewith able to access all necessary data on the product and its components without having to look in different systems. However, the establishment of such a system is costly and therefore cannot be done without top management support, which was emphasized by the product data managers of *Alpha*, *Beta*, and *Delta. Beta's* data manager expresses that a thorough product data management requires time and resources in addition to a good application. At *Zeta* it has been mentioned that the aim of having a cross-company data application necessitates top-management support to negotiate the capabilities of that application. Especially capabilities like data security are seen as a major issue in order to set rules for the level of necessary data availability.

Epsilon's product and process manager stated that PLM's engineering collaboration across companies is now essential to develop innovative and sustainable products. If several collaboration partners are involved, the processes to design a product need to be aligned. This alignment however, is solely possible when being initiated and aligned by the top-management of each development partner. "This process adjustment", claims *Gamma's* process manager, "has to ensure the incorporation of equal sustainability understanding and measures across the departments." The vision of sustainability in product development has to be initiated by top management since it impacts the company's operations. If processes are not directed toward sustainability, it quickly gets forgotten. "The priority of sustainability has to be implemented in all company processes across all functions as well as across the supply chain", highlights *Alpha's* sustainability manager. In order to be able to execute these processes across the whole company, top-management support and guidance are vital to overcome internal political discussions and blocking points.

4.3. Market planning

The case companies are all thoroughly observing the market for changed needs or specific requirements. "Not following the market requirements would be fatal," says *Zeta's* portfolio manager. *Epsilon's* product and process manager explained in addition, that the market requirements build one important source for the next product concepts. Therefore, structured PLM processes of product-related requirements management are executed. At *Beta*, specific PLM workshops are done with customers in order to receive feedback on current products and future requirements. Similar feedback forums are done at *Gamma* and *Epsilon. Alpha* and *Delta* mainly rely on market analyses being executed by specialized external companies. However, all of them have a PLM-driven process to support sustainable integration in NPD.

Most case companies (*Alpha*, *Delta*, *Zeta*, and partly *Epsilon*) do not connect engineering project management directly with PLM. This means that the functionalities of engineering project management are, however, not always executed with a PLM intention or from a PLM point of view. Otherwise, *Beta* and *Gamma* enforced that efficient data and process management calls for a dedicated institution controlling the activities. Both punctuate the importance of changes in the market place. Changes in the market need to be evaluated with respect to sensuousness of the product development, capability for introduction, and resource skills. On the one hand, the management needs to know what additional costs occur when changing a component to a more sustainable one. On the other hand, engineers are obliged to evaluate if they are able to execute these changes. Environmental requirements e.g. ask for specific knowledge in design and material evaluation. Often new materials, e.g. carbon, or production processes (lightweight) are used to reduce environmental as well as social impacts. *Beta's* sustainability manager proceeds that these skills often need to be established or bought-in externally. *Gamma's* product manager explains that variations in the market have a high impact on the company. The market shift from big, powerful cars to smaller environmental-friendly ones forced R&D teams to rethink their strategy. On the one hand, environmental changes are evaluated and, on the other hand, even more important the economic impacts need to be calculated.

4.4. Formalized processes

Epsilon's product data manager explains that product changes often must occur without stopping production or design. Hence, if a component was detected that needs to be changed due to sustainability reasons a formalized process is triggered to smoothly phase-out the old component and phase-in the new one. This is necessary for implementing environmental-friendly components without risking a successful product. "If these actions would not be executed by previously defined processes among all departments and development partners, it would take very long to change components impacting the development costs," states *Alpha's* product manager.

It is noticeable that the companies still have divergent set-ups in the case of product-focused vs. functional-focused processes. Product-oriented work processes facilitate the use of PLM application and enable its entire spectrum. Some case companies even argue that a real PLM benefit can only occur with a product-focused process (*Beta* and *Gamma*). Others claim that this orientation is helpful (*Epsilon*) whereas a third group still uses functional work organizations (*Alpha*, *Delta*, and *Zeta*). *Alpha*, though, already mentioned to change their processes toward a product-focused one while after one year of experience with PLM they already realized that functional approaches require double-work and hinder smooth material and information flows. This is in line with an argument from *Gamma's* sustainability manager that the processes of a company striving for sustainable products need to be product-oriented. During the analyses of the interviews and secondary data it was realized that the companies with product-focused processes have a PLM organization, thus, an entity within the company focusing only on product-focused aspects along the whole life cycle. This organization covers activities of all PLM pillars. This seems to help defining standardized, company-wide approaches. However, in this research it could not unambiguously be specified if the PLM organization correlates with product-focused processes or if a PLM organization is dependent on the size and portfolio complexity of a company. *Epsilon* argues that their product range is rather small; therefore, a product-focused orientation is not yet needed. Nevertheless, based on the data from the research, the triggers for a functional- or process-related structure cannot be defined.

5. Discussion

This paper links research at the interface of sustainable new product development and PLM by extending current literature based on an explorative multi-case research design. The framework investigates how the PLM pillars support a successful sustainable new product development.

The contribution of the paper is twofold. First, it elaborates on the connection of sustainability, NPD, and product life-cycle management by integrating the three PLM pillars with the NPD success factors from a sustainability point of view. The aspects of data, processes, and people are evident to reach a NPD with sustainable characteristics. Second, on grounds of multiple case studies in the automotive industry, it contributes to existing engineering and management literature by providing explanations for sustainability in new product development with the support of product life-cycle management.

The first PLM pillar of product data management provides the main benefits for sustainability activities due to the strong capability of data management across functions, companies, and regions among the collaboration partners (Choi et al., 2010). Table 6 shows that the case companies currently do most activities in product data management. Data on environmental impacts or social sourcing can be provided and controlled with product data management. This central data provisioning (Cao et al., 2009) facilitates the evident cross-functional work in NPD in which people from different functional areas and companies work jointly together (Wang, 2009). The development process can be accelerated to save development costs without lacking quality, as explained by Grieves (2006). However, effective product data management applications require top-management support because a thoroughly defined and established product data management creates major costs a priori. Thus, top management needs to be involved in NPD and PLM from a cost perspective on the one hand since the implementation of PLM initially causes high costs. On the other hand, top management needs to be involved from a strategic point of view, because product life-cycle management and changes in NPD impact the whole operations management of a company. Without a driving top management the necessary changes toward a sustainable PLM being supported by the product life-cycle management pillars would not be possible (Griffin, 1997; Stark, 2005).

Drawing on the strategic point in connection with the RBV and the relational view, it can be said that product data management is based on trust and reliability to ensure an inter-firm relation. Hence, the inter-firm relation is influenced (McIvor, 2009; Mazzola and Perrone, 2013). In strong collaborative relationships the data management is defined and controlled jointly. Thus, communication and interoperability problems can be mitigated ex ante. This is different for contract based alliances (Mazzola and Perrone, 2013). Anyhow, this is one of the biggest organizational challenges to integrate sustainability into the NPD process. As discussed the organizational form of collaborative partners plays a significant role.

Besides product data management, the aspect of product-focused process management (the second PLM pillar) contributes to a sustainable new product development. Cross-functional work within the company and also with external development partners is important, because costs can be reduced by common processes with a sustainability focus. Establishing processes across functions surely requires top-management involvement to provide executive power. On a cross-company level, top-management has to be the driving factor owing to the fact that process changes might have an impact on the entire company. The power to change these processes lies only in the top-management hands (Ellram et al., 2007) and herewith impacts PLM and NPD. Streamlined processes in a joint product development are essential for not losing time and money due to poorly defined process steps (Slotegraaf and Atuahene-Gima, 2011). Consequently, the more the partners trust each other, the higher the quality of communication and interoperability. Thus is supported by the relational view in trust and reliability to minimize opportunism risks (Mazzola et al., 2008). Nevertheless, it is unclear if the supplier or the focal company is the driver of common practices. Both companies will either have several suppliers or customers. Therefore, the question arises which actions will be done if interfering processes or routines appear? This implies that discussions and issues may arise when the supplier and the main company do not have the same sustainability processes and routines. This triggers questions for future research: will the main company overrule the processes of the supplier or will both companies find a common solution? Can a supplier only collaborate with customers having the same sustainability standards? Or will suppliers also be able to work with customers having different sustainability vision? Nevertheless, this might request a large amount of flexibility. However, this may be caused due to not perfectly defined sustainability standards on an international level. Further research with supplier/customer networks is therefore necessary.

Engineering project management seems to be the least connected PLM pillar with sustainable new product development. Companies do not see the need to directly manage resources across the life cycle or in new product development to reach a good sustainable performance. Resource management is still seen more as a functional-oriented task than a product-/process-focused one. However, if product-focused processes are established, why is it advantageous to manage resources on a functional level? Nevertheless, to make a clear statement on this question, further research is encouraged.

However, from a top-management perspective, it can be said that process alignment and management is easier in collaborative engagements like Joint Ventures than in contractual based ones (Mazzola et al., 2009; Mazzola and Perrone, 2013). The more the partners trust each other the higher the quality and intensiveness of information exchange.

The research unfolds that little research regarding the social component of the triple bottom line is available and is hard to connect with PLM. Environmental and economic aspects are well-represented and also well-supported by the PLM pillars. However, the social dimension and the impact of PLM on a social NPD are scarce in research. On the one hand, the social aspect itself requires further research (Mu et al., 2011) and it can be questioned, on the other hand, if a social NPD is explored at all. Besides the needed further effort in social research it is also necessary to analyze possible trade-offs in integrating sustainability in NPD or PLM. Hence, trade-offs are found between economic efficiency, social and environmental considerations (Hahn et al., 2010). Such trade-offs in sustainability also impact PLM and NPD when being integrated with each other. Nevertheless, a thorough analysis concentrating on such trade-offs needs to be done to gain reliable and robust research results.

On the theoretical side, there are also a number of suggestions for future research. Particularly the question of trade-offs among the sustainability dimensions would be highly relevant. This would warrant future research on how this could be addressed regarding NPD.

With regard to the research question and research design, case study research was found well-suited to investigate how the product life-cycle management pillars support or facilitate the implementation of a sustainable new product development. However, limitations exist and further research is therefore encouraged. The case studies were focusing on one industry only, which limits the generalizability of the findings. Researchers are strongly encouraged to extend this exploration of sustainability and PLM through investigations in other life-cycle stages and with larger samples in order to support or refute the findings.

6. Conclusion

In this paper, the approaches of six global automotive manufacturing companies continuously meeting the challenge of satisfying sustainability requirements in new product development have been presented. In particular, based on the multiple case studies it was examined how automotive companies realize the impact of the PLM pillars on facilitating the implementation of a sustainable new product development. The interviews showed that the meaning of PLM is not the same in all companies. The development of product data management to a holistic product life-cycle management approach seems not to have arrived fully in the industry.

The social aspect is currently rather scarcely supported in the product development part of PLM. It is noticeable that in nearly all interviews, the social aspect with regard to product data management did not play a significant role. Some argue that the safety of a product affects social impacts, and the amount of emissions influences the society's health. Furthermore, the design influences the production process and the way it must be manufactured. Thus, the social dimension on grounds of employees is impacted. However, most interviewees were not sure if this is due to PLM. Neither the case studies not theory can provide a clear proof.

The case companies were aware that merely data collaboration is not sufficient but also requires processes for working together. Security concerns still prevail as sensitive data is often not shared as it should be in order to receive full collaboration benefits. This shows that trust in the access control capabilities of PLM applications still needs to be improved.

This study clearly indicates the importance of the PLM pillars for a collaborative new product development with a sustainable character so that managers can benefit from it, too. They gain insights how product life-cycle management supports reaching a sustainable NPD.

In the end, it can be stated that a sustainable new product development is dependent on cost awareness, quality, flexibility, and environmental issues plus the awareness of social attributes and the use of the PLM pillars. Nevertheless, the integration of sustainability in the NPD process is a challenging and long-lasting activity for the entire company.

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