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ncing Act? Aligning Product Innovation and Production Efficiency through Eco-stra

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Abstract

With an undifferentiated catchword ?eco-innovation? is a largely understudied area, but of high relevance to the society and companies given the strong focus especially by governments on grand challenges like climate change, green technologies and environmental challenges. The paper utilizes the 2009 European Manufacturing Survey for the Danish sub-sample including 335 manufacturing firms. Through factor analysis, the paper confirms three main focus areas of new product development in relation to production facilities: efficiency considerations, market attention and greening of innovation. Logistic regression analysis demonstrates that while market attention is important for new product development, green aspects of innovation and efficiency considerations for innovation are important for the energy efficiency of the production companies. Combining these models highlights that energy efficiency moderates the effect of market attention on new product development.

The paper therefore concludes that product innovation and energy efficiency is a balancing act, focusing on one will have detrimental effects on the other! These findings point to the conclusion that researchers and practitioners in innovation management have to take the specificities and interactions of different types of eco-innovation more carefully in consideration than so far and to formulate new managerial practices combining energy efficiency and product innovation.

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A Balancing Act?
Aligning Product Innovation and Production Efficiency through Eco-strategies

Abstract

With an undifferentiated catchword 'eco-innovation' is a largely understudied area, but of high relevance to the society and companies given the strong focus especially by governments on *grand challenges* like climate change, green technologies and environmental challenges. The paper uses the 2009 European Manufacturing Survey for the Danish sub-sample including 335 manufacturing firms. Through factor analysis, the paper confirms three main focus areas of new product development departing in the production facilities of the firm: efficiency considerations, market attention and greening of innovation. Logistic regression analysis demonstrates that while market attention is important for new product development, green aspects of innovation and efficiency considerations for innovation are important for the energy efficiency of the production companies. Combining these models highlights that energy efficiency moderates the effect of market attention on new product development.

The paper therefore concludes that product innovation and energy efficiency is a balancing act, focusing on one will have detrimental effects on the other! These findings point to the conclusion that researchers and practitioners in innovation management have to take the specificities and interactions of different types of eco-innovation more carefully in consideration than so far and to formulate new managerial practices combining energy efficiency and product innovation.

Key words: eco-innovation, sustainability, energy efficiency, innovative performance

1. INTRODUCTION

This paper demonstrates that environmental new product development (ENPD) and processes related to enhancing energy efficiency for production facilities are different, but connected parts of the same managerial puzzle. With an undifferentiated catchword 'eco-innovation' is a largely understudied area, but of high relevance to the society and companies given the strong political focus on *grand challenges* like climate change, green technologies and environmental challenges (EC, 2011, Arundel & Kemp, 2009, Nill & Kemp, 2009, Smith et al., 2010).

In a non-academic way, eco-innovations are new products, processes or services with one or more positive environmental effects associated with it. A green effect is for instance an attempt at diminishing the consumption of electricity in the consumer phase or avoidance of harmful substances in the product.

This paper studies product innovation activities, and in particular compares some "green" aspects with more ordinary aspects that can be taken into account jointly or alone in firms' product development activities, and examines whether these "green" aspects increase the probability of introducing new products. Additional indicators of "green" management e.g. environmental management systems (EMS) are introduced as well. The paper therefore specifies eco-innovation as "normal" innovations where environmental aspects can be added or not. Obviously, this is a rather simplistic view of the extent of "green" in a firm's innovation activities that theoretically range from "black" to entirely "green" (Dangelico & Pontrandolfo, 2010). The paper assumes that consideration of additional environmental contents in ordinary innovation activities requires additional managerial resources and time compared to an ordinary product innovation process. However, if a firm already focuses on energy efficiency (e.g. savings of energy in the firm's own production) this may relieve the need for additional resources, because resources are already invested in other parts of the firm's activities aiming at improvements in performance through cost savings.

Unfortunately, systematic knowledge of managerial practices and the link between product innovation, green aspects of new products, and energy efficiency remains scattered (Albino et al., 2009, Rennings & Rammer, 2009).

One reason for this lack of evidence lies in the openness and broadness of the eco-innovation concept. *The relevant criterion for determining whether an innovation is an eco-innovation is that its use is less environmentally harmful than the use of relevant alternatives* (Kemp & Pearson, 2008: 6). This open-ended criterion is hard to handle in practice, especially for SME often lacking management systems or working with management systems that are only developed on a basic level. Second, the definition of Kemp and Pearson (2008) implies that most innovations have both economic and environmental effects (Kemp & Pearson, 2008: 5). Kemp and Pearson's performance based definition leaves them unable, to establish a clear line of discrimination between 'ordinary' and 'environmental' innovations. Third, firms lack managerial and cross-functional understanding of the potential benefits in linking these aspects of innovation and energy efficiency. The paper assumes that there is a potential for cross-functional integration and explicates two scenarios for eco-innovation strategies:

(i) A firm may choose to concentrate on ENPD *or* on energy efficiency to bundle limited internal and external resources for innovation and production in a certain period of time.

(ii) A firm may choose to use resources simultaneously for *both* purposes by utilizing the similarity of the resources and competencies needed to support them. This simultaneous use requires cross-functional integration across production and innovation units within the firm.

These scenarios are investigated as enveloped in the following research questions:

1) *Which aspects of eco-strategies determine energy efficiency in production activities?*
2) *Which aspects of eco-strategies determine product innovation?*
3) *To what extent can firms' eco-strategies align product innovation with energy efficiency in production activities?*

The paper uses the data from the large-scale European Manufacturing Survey (2009) on 335 Danish manufacturing companies. The analyses demonstrate that product innovation is determined by market-related aspects, whereas energy efficiency in production activities is determined by green aspects of innovation ("intentions for eco-innovation"). The paper therefore concludes that scenario *one* appears the most common. The contributions of the paper are, (i) a more systematic structuring of the diffuse research and practice field eco-innovation focusing on eco-innovation and energy efficiency in production, (ii) survey-based quantitative evidence for the weighting and interactions of different aspects of innovation activities leading both towards "ordinary" and "green" aspects for product innovation in smaller and medium sized production facilities, and (iii) identification of detailed paths for future research on the measurement and management of eco-innovation activities.

Before the paper proceeds to the description of the applied methodology and data (*chapter 3*) and to the summary and discussion of the empirical findings (*chapter 4*), *chapter 2* uses the two scenarios to identify relevant literature on both ENPD and energy efficiency in production processes. The paper concludes (*chapter 5*) with some recommendations for managerial decision processes, which are derived from the discussion of findings and some implications for future research in the emerging area of eco-innovation.

2. INNOVATION, ECO-INNOVATION AND ENERGY EFFICIENCY – A REVIEW

Delimitation and definition of eco-innovation

The literature offers a range of definitions rather than one generally accepted definition for 'eco-innovation'. In general, these highlight diverse aspects, while being quite general (Carrillo-Hermosilla et al., 2009). Kemp and Pearson state that *the relevant criterion for determining whether an innovation is an eco-innovation is that its use is less environmentally harmful than the use of relevant alternatives* (2008: 6). In a similar way, Ottman et al. (2006: 24) define eco-innovations as those *products that strive to protect or enhance the natural environment by conserving energy and/or resources and reducing or eliminating use of toxic agents, pollution and wast*e. These definitions stress the types of environmental focus in green products regarding energy, resources, pollution and waste. Further papers focus on the actual environmental impact, from the relative improvement compared to other products (Peattie, 1995) to an absolute reduction in environmental effects (Young et al., 2000, Biesiot & Noorman, 1999), although recognizing that products always have an environmental impact regardless of the extent of green in the product (Dangelico & Pontrandolfo, 2010). Pujari (2006: 77) defines eco-innovation processes as a *NPD process wherein companies* *explicitly undertake activities to achieve higher environmental (green) performance as well as commercial performance*, and therefore underlines the perspective of improving the environmental performance of the product, while not ignoring the commercial or market performance. Therefore, eco-innovations should fulfill two goals simultaneously, namely improvement of environmental impact *and* obtaining commercial performance.

This paper is in line with the definition of Pujari (2006) in stating that *eco-innovations are new successful products, processes or services integrating one or more positive environmental dimensions. A positive environmental dimension can e.g. be attempts at diminishing the consumption of electricity in the consumer phase or avoidance of harmful substances in the product.* Consequently, a new product may contain one or more of such dimensions combined with more traditional characteristics like new design, new functionality, new form etc.

Eco-strategies and energy efficiency in production activities

Energy efficiency has become one of the most important topics in economic and political debates during the past few years. With rising energy prices, a more energy-efficient production could lead to lasting reductions of production costs, and a positive contribution to an overall increase in competitiveness of the firm (Pye & McKane, 2000). It would therefore be fair to assume that energy efficiency should be high on the managerial agenda, especially for manufacturing firms with high energy usage.

As mentioned above, eco-innovations may be characterized by a set of different characteristics such as reduction of harmful materials or the amount of energy used during manufacturing of a product. Dangelico and Pontrandolfo (2010: 1610) list characteristics of green products as they have identified them in the literature, and in eight of the nine identified papers energy efficiency is mentioned. However, despite these apparently obvious benefits, process innovations aiming at improving energy efficiency of production facilities are often analyzed separately without consideration for the possible integration into the ENPD process. Following Theyel (2000) and Belin et al. (2009), it would be reasonable for managers to consider interactions between processes and products carefully, when strategizing on adequate eco-innovation strategies for their firms, or even to consider how energy efficient process innovations can be engaged with new products in the first place.

Eco-strategies and product innovation

In the last two decades, research on ENPD in manufacturing firms primarily utilized case studies to achieve a better understanding of the ecological aspects of innovation management (e.g. Beise & Rennings, 2003, DeMendoca & Baxter, 2001, Florida & Davidson, 2001, Morrow and Rondinelli, 2002, Donnelly et al., 2006, Triebswetter & Wackerbauer, 2008, Smith, 2009). The findings of these case studies point to specific internal and external conditions of firms involved in ENPD practices. The identified *internal factors* of firms dedicated to ENPD can be summarized as: a certified EMS and use of additional managerial tools to foster ENPD (e.g. benchmarking, appointment of an environmental officer), a strong vision (environmental policy) and promoters supporting both, innovation management in general, and environmental management in particular, and specific business models and upfront proficiency for eco-markets. The literature further mentions some *external factors* that support ENPD like governmental legislation, the existence of lead markets, customer demand, supplier and (lead) user partnership, cooperation along the whole supply chain and participation in professional networks and associations (Brunnermeier and Cohen, 2003, Pujari, 2006, Rehfeld et al., 2007, Hornbach, 2008). However, this paper only investigates the internal factors and their links with ENPD and energy efficiency. Further research should include the external factors in a combined research setup.

Drivers of eco-innovation strategies

A review of the literature identifies a set of important drivers for eco-innovation. These drivers can be characterized as either internal factors like *environmental management systems* and internal cooperation (Donnelly et al., 2006) and *R&D investments* (Rennings & Rammer, 2009) or external factors like *supplier partnership* (Rennings & Rammer, 2009).

Donnelly et al. (2006) observe in their case study on a large US telecommunication technology provider that a new Product-based Environmental Management System (PBEMS) led to a 28 % improvement in environmental performance and a reduction of the energy consumption of 15-25 % in the production phase of two specific new products developed in 2004 (Donnelly et al., 2006: 1365). The paper further identifies as the most important supportive activities for the PBEMS the *embedding of its implementation in an overall reorganization of the company, enforced supplier partnership, third party certification* and the *alignment of environmental and quality management* (Donnelly et al., 2006: 1365f.).

With regards to internal factors that are supporting ENPD practices in production facilities, *environmental management systems* are described as the most important driving force of ENPD in firms. Especially, recent case studies by Triebswetter & Wackerbauer (2008) on automotive and commercial vehicle firms in the wider Munich region, and by Morrow and Rondinelli (2002) on smaller domestic energy and gas firms in Germany show that EMS strengthen both environmental performance and competitive advantages of the investigated firms.

Recent quantitative studies provide a more differentiated picture regarding interactions between EMS and ENPD practices in production facilities (Ziegler & Seijas Nogareda, 2009). Surveys by Bisbe and Otley (2004) on medium-sized manufacturing companies with headquarters in Spain, Rennings et al. (2006) on all EMAS-validated German manufacturing facilities, and Wagner (2007) using 'European Business Environment Barometer 2001/2002' data provide evidence for *both* negative correlations between EMS and ENPD practices (Bisbe & Otley, 2004), and positive effects of EMS on environmental process and product innovations (Rennings et al., 2006, Wagner, 2007). The maturity of the implemented EU 'Environmental Management and Auditing Scheme' (EMAS) is identified as the most important determinant of environmental process innovations in a recent study (Rennings et al., 2006).

Some managerial activities are often connected to the existence of an EMS and have a positive effect on either environmental product innovation or process innovation (Wagner, 2007). With regards to environmental product innovation this positive effect is shown for 'information of customers', ‘market research on green products’ and ‘eco-labeling’. For environmental process innovation only the market research variable shows a positive influence. Furthermore, Wagner (2007) observes a few and rather weak, but significant country and industry effects. In a second recent and related paper, Wagner (2008) relies additionally on patent data from German manufacturing firms dealing with environmental innovations (1999-2005). While Wagner (2008) confirms the positive effect of EMS on (‘subjective’) ‘self-evaluated environmental process innovations’ in this second study, he is unable to find a positive effect for patenting of environmental innovations as ‘objective’ measure (using eco-patents as independent variable) with this study.

Finally, the focus of the survey of Frondel et al. (2008) is on environmental policy tools and their effects on firms’ management practices in manufacturing comparing ‘cleaner production measures’ and ‘end-of-pipe technologies’. They find a significant positive effect of ‘cost saving strategies’, the use of EMS and other environmental management tools (‘process control systems’, ‘environmental audits’), and environmentally oriented R&D investments on ‘cleaner production measures’.

Rennings and Rammer (2009) analyzed German CISdata with a special focus on ‘energy and resource efficiency innovations’ (EREI). Using a matching procedure based on probit regression models, they compare firms with and without EREI and demonstrate that firms with EREI are significantly more productive, R&D-oriented (in terms of R&D expenses) and successful regarding cost savings from process innovations than firms without EREI. Further differences between the investigated groups refer to a broader search for innovation impulses (more and different information sources), stronger cooperation within the firm’s own enterprise group and with suppliers, and a more intense perception of innovation barriers. *Environmentally oriented R&D investments,* or R&D-intensity in general, are also used as controls for NPD in most of the other survey-based studies included in the literature review.

Summarizing, a firm focusing on saving energy to save cost in its own production phase may also strive to implement these energy saving technologies in the development of new products. Pye and McKane (2000: 175) stress that improved energy efficiency may be a byproduct of productivity gains or improved productivity may be a byproduct of better energy efficiency. No matter the direction, *management must understand all of the costs and benefits associated with an investment in energy efficiency* (Pye & McKane, 2000: 175). They continue to stress the potential benefits of improved energy efficiency, among which, one is improved product quality (e.g. improved customer satisfaction), and thereby establish a direct link to product innovation activities. Also Carrillo-Hermosilla et al. (2010) state that the reduction of production cost or even improved energy efficiency directly may occur as side effects to the actual innovation activities. No matter the direction of the causality, we expect that a firm’s investments in energy efficiency will lead to lower resource investments in product innovation compared to firms that are not involved in energy efficient processes for cost savings in manufacturing.

Alignment of product innovation with energy efficiency in production activities

With regards to an explicit alignment of product innovation with energy efficiency in production activities, Theyel (2000) performed a pioneering quantitative eco-innovation study investigating both ENPD practices and changes of production processes caused by environmental considerations. Theyel used data from 188 US manufacturing plants in the chemical industry to investigate the dependent variable 'environmental performance[1]' on five management practices, of which only two showed a significantly positive effect. These independent variables are 'employee pollution prevention training program' and 'requiring pollution prevention standards or prerequisites from suppliers'. In contrast to other survey-based studies dealing with eco-innovations, Theyel (2000) excluded the effect of an EMS on ENDP and production processes.

In contrast, Belin et al. (2009) consider not only ENPD *and* environmental effects in production activities, but also potential effects of an EMS. Based on CISdata for France and Germany they identify determinants and specificities of eco-innovations[2] (Belin et al., 2009: 1). They find that legal regulations and cost savings, especially material and energy savings, are the main drivers of eco-innovation in both countries. In neither of the countries, existence of an environmental management system has a significant effect on eco-innovation. Important country-specific findings are that eco-innovations in France are based more on process and organizational innovations regarding production facilities, while this hypothesis cannot be verified for German firms. A similar result is found for customer demand, which shows lower relevance for German than for French firms.

The findings of our literature review confirm that the research questions stated above are highly relevant, but have been discussed only partly or even marginally referring to larger quantitative samples so far. Especially hypotheses, which are explicitly combining ENPD and activities aiming at improving energy efficiency of production facilities are missing in the current literature.

3. METHODOLOGY AND DATA

Collection of data

As stressed in the summary of the literature review, there is a need for further quantitative evidence on eco-innovation. Accordingly, this topic was included as a theme in the multi-topic and multi-country *European Manufacturing Survey*. The project consists of a joint survey carried out in 12 European countries, Turkey and Russia. The current paper is based on project data from Denmark that were collected in 2009 (April through June) using a web survey tool.

The survey is constructed with a core set of questions that are used by all countries, and an additional set of self-selected questions added by the single countries. In Denmark, the global financial crisis, energy efficiency and eco-innovation questions were added to the survey. Since some of these country-specific questions are used for the present paper, it is not possible to make cross-country comparisons.

The population of firms was delimited to manufacturing companies (NACE 15 to 37) with more than 20 employees (N = 3068). The company names and addresses were drawn from a database building on national statistical information in February 2009. To identify the correct respondent in each firm, all firms in the population were contacted by telephone. During the phone call, the respondents accept of participation was retrieved and subsequently their personal email addresses were recorded. The phoners were instructed to identify the person responsible for production activities (i.e.

[1] Plant's percentage reduction of chemical waste generation during past three years.
[2] Reduction of environmental impact.

production manager, production director or executive production officer of the plant). In case this person could not be reached, the switchboard was asked to provide the email address of the correct respondent, and if this could not be provided, a general company email was requested.

The phone contacts resulted in 1291 email addresses, to which a personalized link was sent to the electronic survey. In total, three e-mail reminders were sent to the respondents with approximately 14 days apart. The final response rate (n = 335) calculated on the population is 10.9 % (335/3068), and of the number of accepts to receive the survey, the response rate is 25.9 % (335/1291). The sample has been tested for representativeness using sector, region and size (size was calculated on both, the number of employees and turnover in last year of accounting), and no significant differences were identified indicating that the study is representative of the population of firms in the Danish manufacturing industries.

Selection of variables

The first dependent variable and variable for test of moderation is *energy efficiency* (n=230). Energy efficiency is measured on a relative scale [values from 1 to 5] requesting that the firm estimates the efficiency of its own production in terms of actual material and energy consumption compared with other factories of its industry. The scale ranges from 1 equaling considerably less efficient (2.6 %) to considerably more efficient (6.1%). The value 3 indicates equally efficient (50, 4 %). In the analyses, the variable is coded 1 for those firms that are more efficient (values 4 and 5) versus the rest (value 0).

The second dependent variable is *product innovation* (n=334) and measured on a binary scale [yes (50.6 %)/no (49.4 %)] following the argument that every product innovation has a (non) ecological component. The question is framed as whether the firm has introduced new products (since 2006) that were completely new to the factory or incorporated major technical changes. This formulation enables us to interpret the dependent variable as real product innovations and not minor incremental changes.

The main independent variables are the *production aspects* that are important for product development. The survey investigated ten different production aspects: electrical consumption in the production phase, electrical consumption in the user phase (end user), possibility of recirculation (e.g. renewable raw materials relevant for ‘cradle to cradle’ product development), maximizing product lifetime, avoidance of harmful substances, fulfillment of quality standards, fulfillment of consumer wishes, expected earnings and profit, functionality and user friendliness, and costs of R&D. Each of these aspects are measured on a scale from not important (=1) to important (=5). These aspects are formulated in general terms, and as the following tests will show, future research should focus on strengthening the items for additional tests. Since the literature does not clearly specify an underlying structure, principal component analysis is used to explore the data to obtain a factor structure. To check the identified factors, principal axis factoring has also been tested resulting in the same factors. The item “electrical consumption in the user phase (end user)” was excluded because of substantial cross-loadings. In the following, we therefore continue with nine items.

The rotated factor solution results in three factors (total variance explained = 60 %):

- *Efficiency considerations for innovation* include compliance to quality standards, compliance to consumer wishes, and expected earnings and profits. Cronbach Alpha coefficient = 0,634.
- *Market related aspects* include functionality and user-friendliness, maximizing product lifetime and costs of R&D. Cronbach Alpha coefficient = 0,639.
- *Green aspects of innovation* include consumption of electricity in production phase, use of renewable materials, and avoiding harmful substances. Cronbach Alpha coefficient = 0,545.

The internal consistency for the green aspects of innovation is below the recommended level of 0,6 for new and exploratory scales. To further analyze the components, confirmatory factor analysis (CFA) was applied. The results of the CFA for the three components are (N>250 and number of items = 9): CFI = 0.930; RMSEA = 0.069 and CMIN/DF = 2.58. These values indicate that the model fit is not very good, but at an acceptable level (to assess model fit please consult Hair et al., 2006). Extracted variance for each of the components: green aspects of innovation = 0,351; market related aspects = 0,389; efficiency considerations for innovation = 0,367. Each of the standardized regression weights are highly significant (<0,0001), and are close, but not all above the threshold value of 0,5. Although the model fit is only moderate, we continue with the three factors, while also recommending that further scale development is carried out for eco-innovation in future research.

A key independent variable is the use of *environmental management systems*. The survey assessed whether the firm has adopted one or more of the following five environmental management systems: standardized system equivalent to EMAS II, equivalent to ISO 14000 or similar, lifecycle evaluation according to ISO 14044, environmental standards or environmental accounting and simplified tool for environmental management. The firm could respond [yes/no] to each of these in terms of adoption of the Environmental Management System For those systems that were adopted, we then asked for the extent of used potential [scale low, medium and high]. The adoption of environmental management systems is expected to be related to the firm's own usage of energy and its attention towards environmental aspects also for product development.

The independent variables are first representing the firms that have adopted at least one of the environmental management systems mentioned above (n = 122). This variable is included and has been tested with different specifications because the literature systematically uses implementation of EMS as indicator of eco-innovation. In the models, we used a dummy variable that was coded with "1" if the firm had implemented at least one of the EMS indicated in the questionnaire . The second option which we tested is the number of EMS that the firm had applied (range from 1 to 5), and the extent of use (1 if medium or high use). These two are interpreted as the breadth of use (the former) and the depth of use (the latter) of environmental management systems. 213 companies did not adopt any of the Environmental Management Systems and therefore are coded with breadth = 0, and 68 companies have applied at least one of the EMS. Since the results from the logistic regression models are insignificant for the second coding, we continue using the first version, whether the firm has adopted minimum one of the systems. An additional dummy was recorded (=1) if the firm has adopted one *environmental management system* with the *specific aim of product innovation*. This variable was introduced as an alternative to the above mentioned more general specifications of the EMS.

Control variables
The paper has tested a number of control variables:

- *Dummies for industries*. The OECD categorization of three levels of high, medium and low technology was coded to generate three dummies using low tech as baseline.
- Formulation of *clear and measurable energy reduction goals* for the firm. The variable is coded so that those firms with reduction goals are coded as "1". The main idea is that firms that have actually formulated goals (although they may not have achieved them) are more conscious about the environmental agenda and may therefore be more energy efficient as compared to their competitors.
- Adoption of new production technologies (*process innovation*). This variable is measured as "1" if just one of 13 pre-defined technologies were adopted, and that these were implemented in 2006 or later. It is our suggestion that introduction of process innovation for production purposes is closely connected to energy efficiency considerations.
- Adoption of new organizational concepts in the firm (*organizational innovation*). This variable is measured as "1" if just one of 15 pre-defined organizational concepts is implemented in the firm, and again these should be implemented in 2006 or later. Lenox and Ehrenfield (1997) find that ENPD is more likely to be hampered by organizational barriers than by technical barriers. Therefore if firms implement organizational innovations in parallel with the development of new products, we can assume that these organizational barriers are diminished.

	Mean	Std. deviation	n
New products introduced after 2006	1,51	0,50	334
Energy efficiency	1,35	0,48	230
Efficiency considerations for innovation (*factor 1*)	4,25	0,72	311
Market related aspects (*factor 2*)	3,35	0,88	308
Green aspects of innovation (*factor 3*)	2,92	0,94	312
Management systems	0,36	0,48	335
Formulation of goals for reduction of energy consumption	1,27	0,45	334
Organizational innovation	0,51	0,50	334
Process innovation	0,30	0,46	335

Table 1: Descriptive statistics for variables in models

Because the main dependent variables are binary, logistic regression models are used to estimate the main effects. The results for the dummies indicate that *goals for reduction of energy consumption* and a *high tech dummy* are the most important dummies for the final models (see interpretation in the following section). The firm's position in the value chain as either producer of finished goods, supplier or contract manufacturer was also considered. This variable was tested because the firms view on eco-innovation may be strongly influenced by its own position in the value chain and therefore it may act according to the type of its customer (a dummy was coded for each type; contract manufacturer as reference). None of the dummies were significant in the models and they are therefore excluded from the final analyses. Additional control variables were tested (company size, high energy usage industries, customer orientation, but excluded from the models due to their insignificance.

Descriptives

The following tables provide some basic descriptive evidence starting with the main variables for the regression models. The main independent variables are distributed on firm size (*table 2*). Small firms with less than 50 employees are less likely to introduce new products (54.7 % vs. 49.2 % on average), whereas the large firms are more innovative than the average (28.2 % vs. 49.2 %). This implies that the larger the firms grow in terms of number of employees the more likely it is that the firms introduce new products, which is entirely in line with earlier research.

			New products introduced since 2006		
			No	Yes	Total
Number of employees in 2008 (in intervals)	under 50 employees	Count	82	68	150
		% within group	54.7%	45.3%	100%
	50 to 249 employees	Count	67	72	139
		% within group	48.2%	51.8%	100%
	more than 250 employees	Count	9	23	32
		% within group	28.1%	71.9%	100%
Total		Count	158	163	321
		% within	49.2%	50.8%	100%

Table 2: Product innovation distributed on firm size

On average 65.3 % of the companies are less efficient than the firms in their own industry, whereas 34.7 % are more efficient than the firms they compare themselves to. Looking at the firm size it can be seen that the large firms with more than 250 employees have fewer firms that are less efficient than those they compare themselves to, whereas for the medium-sized firms the share is somewhat larger than the average for all firms. There is, however, not a direct relationship between company size and relative energy efficiency (*table 3*).

			Energy efficiency		
			As rest or less efficient	More efficient than others	Total
Number of employees in 2008 (in intervals)	under 50 employees	Count	66	35	101
		% within group	65.3%	34.7%	100%
	50 to 249 employees	Count	65	33	98
		% within group	66.3%	33.7%	100%
	more than 250 employees	Count	14	9	23
		% within group	60.9%	39.1%	100%
Total		Count	145	77	222
		% within	65.3%	34.7%	100%

Table 3: Energy efficiency distributed on firm size

A difference of means test demonstrates that there are no significant differences between the three factors on firm size, whereas firms in high tech industries score significantly higher than firms in other sector types (e.g. medium tech) on the efficiency factor and on the market factor (results not shown in tables). There are no significant differences in industry types on the green factor. Therefore, it is not possible to discern particular industries that are more prone to include environmental aspects in their innovation activities. The correlation table (*table 4*) does not identify any variables with correlations that are high enough to cause suspicion of multicollinarity.

Model building

Since the dependent variable is binary, the paper applies a hierarchical logistic regression analysis. Logistic regression is a special form of regression analysis formulated to predict and explain a binary categorical variable. The logistic regression analysis follows the best practices as suggested by Hoetker (2007) and the suggestions for testing moderator hypotheses formulated by Frazier et. al. (2004). The variables are entered stepwise starting with the independent variables, then the moderator variable and interaction effects follow and finally the controls. For the moderation effects, the moderator is first entered followed by the interaction terms (in a block). To test the robustness of the models, both forward, backward and enter are used as methods and none of these are found to affect the model fit and the significance of the single factors.

	Product inno	Energy eff.	Factor – effici.	Factor - market	Factor-green	EMS	Ener. Goals	Org. inno.	Proc. Inno.
Product inno.		-0,14	0,030	0,184	0,030	0,053	0,146	0,111	0,110
Energy eff.	0,839		0,200	0,094	0,215	0,120	0,125	-0,082	-0,093
Factor-efficien.	0,596	*0,003*		0,409	0,313	0,142	0,138	0,026	-0,043
Factor – market	*0,001*	0,168	*0,000*		0,335	0,043	0,126	0,141	-0,131
Factor – green	0,556	0,001	*0,000*	*0,000*		0,244	0,201	0,026	-0,057
EMS	0,333	0,069	*0,012*	0,452	*0,000*		0,388	-0,109	-0,019
Ener. Goals	*0,008*	0,059	*0,015*	*0,027*	*0,000*	*0,000*		0,001	0,099
Org. inno.	*0,043*	0,216	0,653	*0,014*	0,654	0,047	0,982		0,018
Process inno.	*0,045*	0,160	0,454	*0,022*	0,316	0,386	0,070	0,739	

Table 4: Correlation table (level of significance in lower half of the table)
Note: Significant levels of correlation (below 0.05) are marked with italics

4. INVESTIGATING THE RESEARCH QUESTIONS

Our findings are extracted from the hierarchical logistic regression model introduced above. Through the principal component analysis, three main focus areas of new product development were identified: market related aspects, efficiency considerations for innovation, and green aspects of innovation. Using these three factors as input together with environmental management systems, the regression models tested the dependent variable energy efficiency (*model 1*). Second, a separate model is analyzed for product innovation using the same independent variables combined with energy efficiency as a moderator (*model 2*).

The results of the table for energy efficiency (*table* 5) demonstrate that the overall model fit improves with the inclusion of the variables in the model raising Nagelkerkes R^2 from 4.0 to 15.3, and the classification table shows that overall percentage of correct classifications is 70.9 %. The omnibus test of the model fit using the Chi^2 is not significant for the first model (0.274), but since none of the control variables are significant this is as it could be expected (0.03). For the final model, including the independent variables, the Chi^2 is significant. Furthermore, the Hosmer & Lemeshow test for predictive accuracy based on a classification system behaves as expected and is insignificant (0.685).

The results in *table 6* demonstrate that the overall model fit improves significantly with the inclusion of the variables in the model using Nagelkerkes R^2 from 11.4 to 17.3 %, and the classification table shows that overall percentage of correct classifications is 63.8 %. The omnibus test of the model fit using the Chi^2 is significant for all the model steps (between 0.002 and 0.006). Furthermore, the Hosmer & Lemeshow test behaves as expected again (0.410).

	Control Variables			**Independent Variables**		
		Omnibus Chi^2	**0,274**		**Omnibus Chi^2**	**0,03**
Energy efficiency	**Unstd. coef.**	**Sig.**	**Exp (B)**	**Unstd. coef.**	**Sig.**	**Exp (B)**
Constant	-0,543	0,114	0,581	-0,825	0,034	0,438
Goals for energy efficiency	0,481	0,106	1,617	0,175	0,606	1,191
Organizational innovation	-0,404	0,171	0,668	-0,339	0,284	0,713
Process innovation	-0,46	0,169	0,631	-0,392	0,265	0,676
High tech	0,126	0,815	1,134	0,411	0,479	1,508
Medium tech	0,029	0,930	1,030	0,270	0,452	1,310
Low tech (Base)		0,973			0,687	
Efficiency considerations for innovation				0,357	0,004**	1,711
Market related aspects				0,048	0,777	1,049
Green aspects of innovation				0,520	0,004**	1,682
Management systems dummy				0,161	0,638	1,174
N		213			213	
Model fit (Nagelkerke $R^{2)}$		0,04			0,153	
Change R^2					0,113	

* * p< 0.05 level, *p<0.1

Table 5: Hierarchical regression model for energy efficiency

Model 1 examines research question 1: *Which aspects of eco-strategies determine energy efficiency in production activities?* The model specified that efficiency considerations including compliance to consumer wishes and quality standards combined with an outlook for earnings and profits is positively and significantly related to energy efficiency in production. The second factor on the green aspects of innovation including consumption of electricity in production phase, avoidance of harmful substances and use of renewable materials was also positively and significantly related to energy efficiency. The third factor on market-related aspects of innovation was not related to energy efficiency. The selected control variables are all insignificant in this model. The model therefore demonstrates that green aspects for product innovation do contribute to the determination of energy efficiency in combination with the efficiency considerations.

	Control Variables			**Independent Variables**			**Interaction**		
	Omnibus Chi²		**0,002**	**Omnibus Chi²**		**0,006**	**Omnibus Chi²**		**0,002**
New Products	**Unstd coef.**	**Sig.**	**Exp (B)**	**Unstd coef.**	**Sig.**	**Exp (B)**	**Unstd coef.**	**Sig.**	**Exp (B)**
Constant	-0,67	0,047**	0,512	-0,546	0,131	0,579	-0,446	0,432	0,64
Goals for energy efficiency	0,561	0,056*	1,752	0,456	0,162	1,578	0,495	0,136	1,641
Organizational innovation	0,482	0,095*	1,619	0,394	0,186	1,482	0,378	0,212	1,46
Process innovation	0,046	0,884	1,047	0,146	0,653	1,158	0,233	0,487	1,262
High tech	1,969	0,004**	7,165	1,798	0,01**	6,037	1,635	0,021**	5,129
Medium tech	0,225	0,484	1,252	0,105	0,753	1,111	-0,009	0,978	0,991
Low tech (Base)		0,015**			0,33			0,049	
Efficiency considerations for innovation				-0,037	0,797	0,963	-0,109	0,473	0,896
Market related aspects				0,314	0,051*	1,369	1,556	0,004**	4,74
Green aspects of innovation				-0,049	0,76	0,952	-0,09	0,592	0,914
Management systems dummy				0,123	0,711	1,131	0,122	0,718	1,13
Energy efficiency							-0,02	0,952	0,981
EE * Factor 2							-0,811	0,013**	0,444
N	213			213			213		
Model fit (Nagelkerke R^2)	0,114			0,137			0,173		
Change R^2				0,023			0,036		

* * p< 0.05 level, *p<0.1

Table 6: Hierarchical regression model for product innovation

Model 2 examines research question 2: *Which aspects of eco-strategies determine product innovation?* Contrary, to the model for energy efficiency, product innovation is only determined by the market-related aspects of innovation, and *not* the ecological aspects of innovation and the efficiency considerations of innovation. A first finding is therefore that eco-innovation strategies for innovation only contribute to the improvement of energy efficiency in production activities, but do not contribute to product innovation, whereas the market factor is significant in determining product innovation.

The implementation of environmental management systems that was used throughout the empirical literature as an indicator of eco-innovation was found insignificant in both models, and is therefore not assisting in determining either energy efficiency performance or product innovation. We further tested whether those firms that implemented EMS for the specific purpose of product innovation would contribute. However, the number of cases was extremely limited (4.5 % of the cases) and insignificant.

The controls demonstrate that firms, who set explicit and measurable goals for energy reductions, are more likely to introduce new products. The interpretation of the variable is similar to the arguments put forth regarding EMS, namely that explicit consideration of the environmental effects of production and operations is driving additional attention towards the development of eco-innovations. However, the development and implementation of organizational changes in the organization does not stimulate eco-innovation as suggested in the literature. Similarly, the control variable for process innovation is also insignificant. Finally, the industry dummies based on high/medium/low tech sectors showed a positive and significant effect for high-tech.

To address question 3, we analyze if energy efficiency and product innovation can be aligned. Energy efficiency is therefore added to the second model as independent variable and as a subsequent interaction term with the significant factor 2 for market orientation. The last column of *table 6* demonstrates that energy efficiency is a moderator of the relationship between the market aspects and product innovation. Since the moderator is in itself *not* a predictor of product innovation, energy efficiency is a pure moderator (MacKinnon, 2008: 276-278). Therefore, the self-reported comparative energy efficiency of the production companies has a moderating effect on the relationship between product innovation and market aspects. The exact effect of the moderator on the market aspects and product innovation is illustrated in *figure 1*. The two graphs illustrate that with increasing market orientation (increase in factor 2 – along the x-axis) the likelihood of introducing new products decreases if the firm is more energy efficient compared to other firms in the industry (illustrated by the graph “pi score for high EE”).

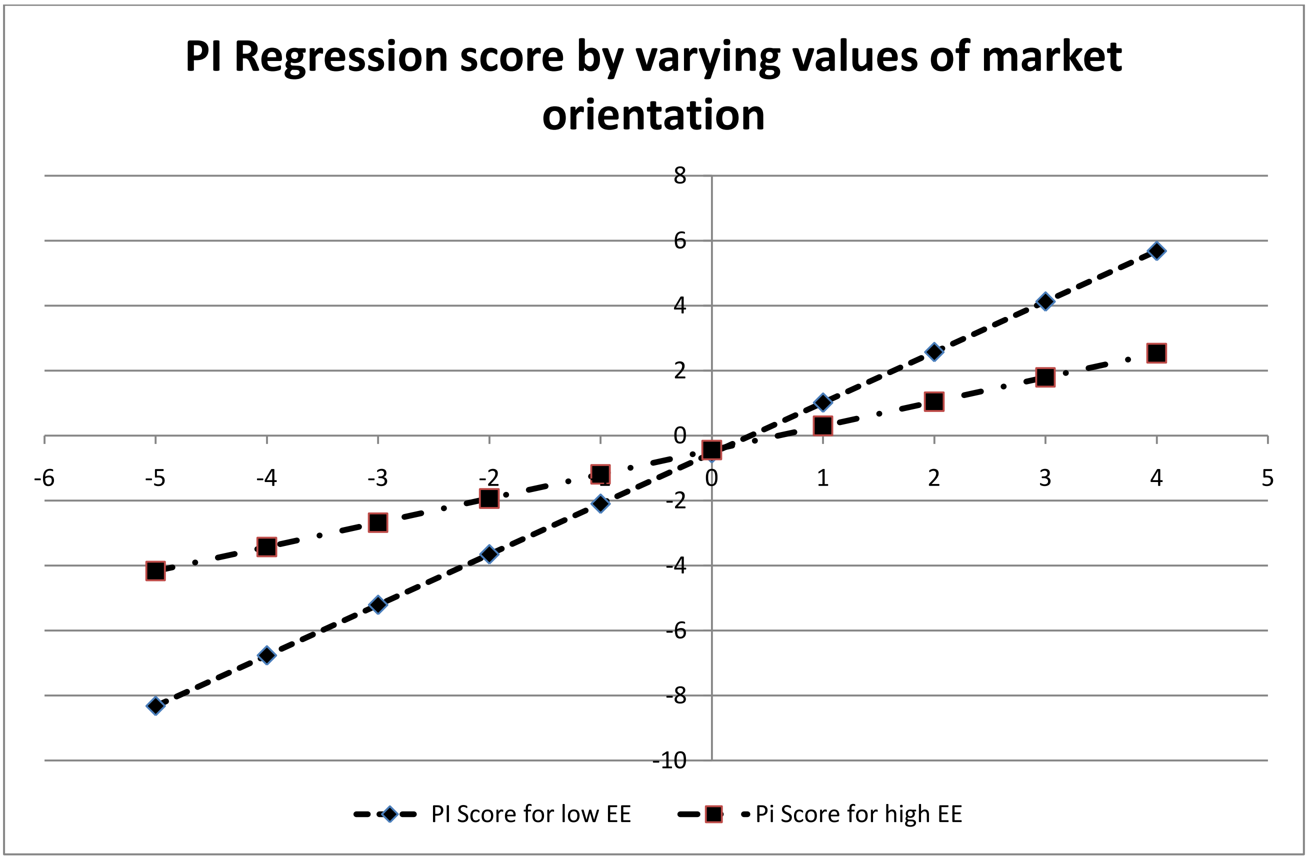

Figure 1: market orientation and product innovation – energy efficiency as a moderator

Similarly, for the firms that are low on energy efficient compared to the industry, an increase in market orientation results in a higher likelihood that the firm introduces new products.

In summary, the findings indicate that Danish manufacturing firms tend to focus on either energy efficiency *or* product innovation and that the eco-strategies do not link these aspects, which supports *scenario 1*. Furthermore, since we find evidence that different factors drive eco-innovation and energy efficiency our answer to research question 3 "*to what extent can firms' eco-strategies align product innovation with efficiency in production activities"* is that they are not directly aligned, actually the moderation effect directly show that if firms are more energy efficient than their competitors then being market oriented has less impact on the innovative capabilities of the firm than if the firm is low on energy efficiency. The results therefore point to a separation rather than linking of product innovation and energy efficiency.

5. CONCLUSION AND FURTHER RESEARCH!

This paper has analyzed three research questions using survey-based data from Danish manufacturing firms:

1) *Which aspects of eco-strategies determine energy efficiency in production activities?*
2) *Which aspects of eco-strategies determine product innovation?*
3) *To what extent can firms' eco-strategies align product innovation with efficiency in production activities?*

The analytical results demonstrate that the aspects for new products are separated in their ability to determine respectively product innovation and energy efficiency in production activities. Market-related aspects like focus on functionality, user-friendliness and cost of R&D has a positive effect on product innovation, but not on energy efficiency. Efficiency considerations for innovation and green aspects of innovation (leading potentially to product innovations) determine energy efficiency performance, but not product innovation. This implies that if firms focus on the green aspects for innovation this has no effect on their likelihood of introducing eco-innovations on the market, instead it will positively influence the firm's own energy efficiency efforts. More indirectly, the formulation of goals for energy consumption has a positive effect on product innovation. Therefore, *product innovation and energy efficiency is a balancing act, focusing on one will have detrimental effects on the other*!

Recommendations for managers

Our results therefore point to some clear points for managers to consider. Strategizing for eco-innovation is much more than reduction of harmful substances and reduction of energy consumption. Managers of firms need to ensure the cross-functional communication to formulate targets combining both innovation *and* energy efficiency realizing that different aspects carry tradeoffs between these areas. Our *first recommendation* for managers dealing with eco-innovations is that if the firms wish to benefit from their efforts on the production site in terms of improved energy efficiency then this can only be achieved through active cross-functional communication. Such communication must ensure that employees from both “silos” are coupled and communication on the benefits for both departments (energy efficiency and product development) is established.

One mechanism for establishing such communication is to impose specific, manageable, but quantitatively measurable goals for certain types of eco-innovation, while realizing the direct impact on the production activities. This can for example mean concrete (e.g. percentage or absolute) annual energy and/or material reduction goals for specific production facilities. Our *second recommendation* refers directly to the balancing act calling for firms that strategize on eco-innovation, product innovation and energy efficiency to formulate and motivate – *in detail* – a specified environmental strategy. However, further recommendations for managers require more in depth studies considering the main findings here that while some green aspects like goals for energy reduction may couple with product innovation, others like environmental management systems do not.

Future research based on the limitations in current empirical research

A barrier for development of further managerial recommendations is the lack of strong measures on eco-innovation. One important starting point is firms’ focus on particular aspects for new product development in relation to production facilities, especially efficiency considerations, market attention and greening of innovation. Our results provide only some first ideas about the managerial logic behind the formulation and implementation of firms’ innovation goals. Beside ‘objective’ reasons like sector-specific conditions (positive and significant effect for high-tech industry dummy in our study; table 6) or limited resources and time of responsible managers, there can be also ‘hidden’ respectively more ‘subjective’ barriers for setting balanced innovation goals. For example Schleich (2009) proposes ‘hidden costs’, ‘split incentives’, ‘imperfect information’ and ‘bounded rationality’ of managers as reasons for missing or insufficient goal-setting and -implementation regarding the greening of product and process innovations. Further research could combine the setting, implementation and balancing of different strategic goals with assumptions regarding ‘objective’ and ‘subjective’ barriers to eco-innovation.

Another relevant starting point for future research in the emerging field of eco-innovation is a more adequate and realistic operationalization of environmental management systems. So far they are operationalized in survey-based quantitative studies usually as a ‘yes/no’ dummy. This is also the case for our own study, although these are also combined with the primary aim of implementation. Such measures are rather rough offering an explication why there is no clear picture regarding environmental management systems in the eco-innovation literature. Both, the reviewed literature as well as our own findings provide some ideas how more complex and realistic measures of these management systems could look like. Some of the reviewed studies (e.g. Donnelly et al; 2006, Wagner, 2007) discuss that the introduction of environmental management systems is especially effective if it is embedded in a broader organizational innovation aiming at better environmental performance of a firm. In our own study, the environmental management systems show no significant effect on ENPD while energy efficiency goals do, although the two independent variables are closely connected conceptually. Putting these different observations together, a future measurement could be a more advanced scale for the measurement of the relevance of environmental management systems comprising items like e.g. ‘stand alone systems’, ‘systems embedded in firms overall re-organization strategy', 'systems linked to firms strategic performance goals' or 'systems including external market/customer perspectives'.

Therefore, there is plenty to do in future empirical research in the area of eco-innovation. This paper has only touched upon a few relevant and interesting elements like the interesting interaction between different aspects of innovations combined with the link between innovations as such and energy efficiency. Furthermore, new studies focusing on these interactions should also consider other types of eco-innovation than ENPD and innovations aiming at energy efficiency.

Finally, although we need general evidence on the link between production and innovation in terms of ecological aspects, we are particularly keen on advancing research on managerial decision practices concerning eco-innovation in small companies (with 20 or less employees) as these are widely neglected in the empirical literature.

REFERENCES

Albino, V., Balice, A. and Dangelico, R. M. (2009). Environmental strategies and green product development: an overview on sustainability-driven companies. Business Strategy and the Environment, 18, 83-96.

Arundel, A. and Kemp, R. (2009). Measuring eco-innovation. UNU-MERIT Working Paper Series, Maastricht (WP 2009-017).

Belin, J., Hornbach, J. and Oltra, V. (2009). Determinants and specificities of eco-innovations – An econometric analysis for France and Germany based on the Community Innovation Survey. DIME Working Papers on Environmental Innovation, Brussels (No 10, June 2009).

Beise, M. and Rennings, K. (2003). Lead Markets of Environmental Innovations: A Framework for Innovation and Environmental Economics. Centre for European Economic Research, Mannheim (Discussion Paper No. 03-01).

Biesiot, W. and Noorman, K. J. (1999). Energy requirements of household consumption: a case study of the Netherlands. Ecological Economics, 28, 367-383.

Bisbe, J. and Otley, D. (2004). The effects of the interactive use of management control systems on product innovations. Accounting, Organizations and Society, 29, 709-737.

Brunnermeier, S. B. and Cohen, M. A. (2003). Determinants of environmental innovation in US manufacturing industries. Journal of Environmental Economics and Management, 45, 287-293.

Carrillo-Hermosilla, J. C., del Rio Gonzalez, P. and Könnöla, T. (2009). Eco-Innovation: When sustainability and competitiveness shake hands, New York.

Carrillo-Hermosilla, J., Río, P. d., & Könnölä, T. (2010). Diversity of eco-innovations: Reflections from selected case studies. Journal of Cleaner Production, 18: 1073-1083.

Dangelico, R. M. & Pontrandolfo, P. (2010). From green product definitions and classifications to the green option matrix. Journal of Cleaner Production, 18: 1608-1628.

De Mendoca, M. and Baxter, T. E. (2001). Design for the environment (DFE): An approach to achieve the ISO 14000 international standardization. Environmental Management and Health, 12, 51-52.

Donnelly, K., Beckett-Furnell, Z., Traeger, S., Okrasinski, T. and Holman, S. (2006). Eco-design implemented through a product-based management system. Journal of Cleaner Production, 14, 1357-1367.

Florida, R. and Davidson, D. (2001). Gaining from green management: environmental management systems inside and outside the factory. California Management Review, 43, 64-84.

Fraizer, P.A., Tix, A.P. and Barron K.E. (2004). Testing moderator and mediator effects in counseling psychology research. Journal of Counseling Psychology, 51, 1, 115-134.

Frondel, M., Hornbach, J. and Rennings, K. (2008). End-of-pipe or cleaner production? An empirical comparison of environmental innovation decisions across OECD countries. Centre for European Economic Research, Mannheim (Discussion Paper No. 04-82).

Hair, J. F, Black, W. C., Babin, B. J, and Anderson, R. E. (2006). Multivariate data analysis (7th Edition), Upper Saddle River (NJ).

Hoetker G. (2007). The use of logit and probit models in strategic management research: Critical issues. Strategic Management Journal, 28, 331-343.

Hornbach, J. (2008). Determinants of environmental innovation – New evidence from German panel data sources. Research Policy, 37, 163-173.

Kemp, R. and Pearson, P. (2008). MEI project about Measuring Eco-Innovation, Final report, Maastricht. Available at: http://www.merit.unu.edu/MEI/papers/Final%20report%20MEI%20project%20DRAFT%20version%20March%2026%202008.pdf, 06 April 2010.
Lenox, M. and Ehrenfield, J. (1997). Organizing for effective environmental design. Business Strategy and the Environment, 6, 187-196.
MacKinnon D.P. (2008). Introduction to statistical mediation analysis. Multivariate Applications Series. Taylor & Francis Group, New York.
Morrow, D. and D. Rondinelli, D. (2002). Adopting corporate environmental management systems: Motivations and results of ISO 14001 and EMAS certification. European Management Journal, 20, 159-171
Nill, J., and Kemp, R.. (2009). Evolutionary approaches for sustainable innovation policies: From niche to paradigm? Research Policy, 38, 668-680.
Ottman, J. A., Stafford, E. R. and Hartman, C. L. (2006). Avoiding green marketing myopia: Ways to improve consumer appeal for environmentally preferable products. Environment: Science and Policy for Sustainable Development, 48, 22-36.
Peattie, K. (1995). Environmental marketing management – Meeting the green challenge, London.
Pujari, D. 2006. Eco-innovation and new product development: Understanding the influences on market performance. Technovation, 26: 76-85.
Pye, M. & McKane, A. (2000). Making a stronger case for industrial energy efficiency by quantifying non-energy benefits. Resources, Conservation and Recycling, 28: 171-183.
Rehfeld, K.-M., Rennings, K. and Ziegler, A. (2007). Integrated product policy and environmental product innovations: An empirical analysis. Centre for European Economic Research, Mannheim (Discussion Paper No. 04-71).
Rennings, K., Hoffmann, E. and Ankele, K. (2006). Product innovation impacts of EMAS: results of case studies and a survey of German firms validated according to the EU environmental management and auditing scheme. The Journal of Sustainable Product Design, 3, 93-100.
Rennings, K. and Rammer, C. (2009). Increasing energy and resource efficiency through innovation – an explorative analysis using innovation survey data. Czech Journal of Economics and Finance (CJEF), 59, 442-459.
Schleich, J. (2009). Barriers to energy efficiency: A comparison across the German commercial and services sector. Ecological Economics 68, 2150-2159.
Smith, A., Voß, J.-P. and Grin, J. (2010). Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges. Research Policy, 38, 435-448.
Smith, M. T. (2009). Eco-design Innovation in Small and Medium Sized Enterprises; some early conclusions. Paper presented at the 7th Greening of Industry Conference, Partnership and Leadership. Building Alliances for a Sustainable Future, Rome.
Theyel, G. (2000). Management practices for environmental innovation and performance. International Journal of Operations & Production Management, 20, 249-266.
Triebswetter, U. and Wackerbauer, J. (2008). Integrated environmental product innovation in the region of Munich and its impact on company competitiveness. Journal of Cleaner Production, 16, 1484-1493.
Wagner, M. (2007). On the relationship between environmental management, environmental innovation and patenting: Evidence from German manufacturing firms. Research Policy, 36, 1587-1602.
Wagner, M. (2008). Empirical influence of environmental management on innovation: Evidence from Europe. Ecological Economics, 66, 392-402.
Young, D., Scharp, R., and Cabezas, H. (2000). The waste reduction (WAR) algorithm: Environmental impacts, energy consumption, an engineering economics. Waste Management, 20, 605-615.
Ziegler, A., and Seijas Nogareda, J. (2009). Environmental management systems and technological environmental innovations: Exploring the causal relationship. Research Policy, 38, 885-893.