What is Green Innovation? – A quantitative literature review

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Abstract: The importance of green innovation management is growing in practice and academia likewise. To our knowledge, a recent and comprehensive literature review is lacking. In this paper we contribute to a clarification of the concept "green innovation" and provide an overview of the existing body of literature in the field of green innovations identifying the most active scholars, institutions and relevant publications.

We find that the three different notions of green, eco/ecological and environmental innovation are used largely synonymously while the notion of sustainable innovation broadens the concept and includes a social dimension. We find further that the most active scholars are situated in Europe (i.e. Netherlands, Italy and Germany) and identified three innovation management journals leading the field.

Keywords: Innovation management; green innovations; eco innovations; environmental innovations; sustainable innovations; literature review

1 Introduction

Since a number of years the importance of the management of green innovations is growing in practice and academia likewise. Although major engineering disciplines already dedicate significant research to sustainable solutions (e.g. for renewable energy such as solar and wind power), recently the German federal ministry for Education and Research stated that despite promising concepts sufficient research is hardly ongoing in the management discipline (BMBF, 2010). Andersen (2008: 3) states that "environmental innovation research is still in its early phase, and there are worldwide very few actual innovation researchers working with environmental issues." Particularly in the innovation management field we are aware of only a few scholars who conduct research dedicated to new product/service development of green innovations.

To our knowledge, a recent and comprehensive literature review of the status quo is lacking. Confusion exists particularly with regards to different notions that describe innovations with a reduced negative impact on the environment. The most prominent notions used in the literature are "green", "eco", "environmental" and "sustainable" to describe this innovation type.

With a focus on innovation management this paper has two objectives. First, we aim to contribute to a clarification of the concept "green innovation". Second, we aim to provide an overview of the existing body of literature in the field of green innovations and identify the most active scholars, institutions and relevant publications in the field.

Our research is divided into two sections: First, we present different definitions for the four notions around the concept of green innovation including eco/ ecological innovation, sustainable innovation, environmental innovation. We discuss and compare those definitions to create an understanding of differences and similarities in these conceptualizations. Second, we provide results from a quantitative analysis of the available literature under the four notions. For this analysis we compiled a publication data set from the Google Scholar database. We present the findings from a three level analysis, i.e. on an aggregate level, then narrow it to the field of "Business, Administration, Economics and Finance" and finally focus on the scientific area of innovation management.

The remainder of this paper is structured as follows: The second section is dedicated to definitions of the different notions describing innovations with a reduced negative

environmental impact and their discussion. The third section describes our research approach to compile and analyze the publication data for our literature review. In the fourth section we present our findings. The fifth section discusses our findings and the sixth section concludes the paper including recommendations for future research.

2 Clarifying the concept of "green innovation"

Before reviewing the literature a clarification of the concept of "green innovation" was needed to understand which literature must be included in our analysis. We quickly realized that other notions (i.e. ecological innovation, environmental innovation, and sustainable innovation) are used on similar topics by other scholars. Therefore, we dedicated at first more attention to the discussion of the different notions contributing to a better understanding how "green" innovation is defined and which notions can be used as synonyms but which notions have different meanings. In the following we briefly review a number of widely cited definitions.

According to Church, Hecox et al. (2008: 3) citing Dresner (2008: 30), the term "sustainable development" was first used in 1980 by the International Union for Conservation of Nature and Natural Resources in their World Conservation Strategy report. The report defines sustainable development as "the integration of conservation and development to ensure that modifications to the planet do indeed secure the survival and well-being of all people." As stated in several publications (e.g. Mebratu (1998), Dixon and Fallon (1989)), the notion of "sustainable development" was essentially coined by the Brundtland report, commissioned by the UN where it is defined as meeting "the needs of the present without compromising the ability of future generations to meet their own needs. The concept of sustainable development does imply limits - not absolute limits but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities" (Brundtland, 1987: 24).

A number of definitions exist for the notion 'eco-innovation'. One of the first, Fussler and James (1996) define eco-innovations as "new products and processes which provide customer and business value but significantly decrease environmental impacts" (cited from Bartlett and Trifilova (2010: 2)). In a similar manner Kemp and Pearson (2007: 3) define eco-innovation as "the production, assimilation or exploitation of a product,

production process, service or management or business method that is novel to the organisation (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives". The Europe INNOVA panel concludes that "eco-innovation means the creation of novel and competitively priced goods, processes, systems, services, and procedures that can satisfy human needs and bring quality of life to all people with a life-cycle-wide minimal use of natural resources (material including energy carriers, and surface area) per unit output, and a minimal release of toxic substances" (cited from Reid and Miedzinski (2008: 7)). Based on the industrial dynamics perspective Andersen (2008: 5) defines eco-innovation "as innovations which are able to attract green rents on the market. […] The concept is closely related to competitiveness and makes no claim on the "greenness" of varies innovations. The focus of eco-innovation research should be on the degree to which environmental issues are becoming integrated into the economic process." In line with this argumentation is the definition from the OECD (2009: 19). Accordingly eco-innovation is defined as "the creation or implementation of new, or significantly improved, products (goods and services), processes, marketing methods, organisational structures and institutional arrangements which - with or without intent - lead to environmental improvements compared to relevant alternatives". Building on these two definitions Arundel and Kemp (2009: 34) conclude that eco-innovation is "a new concept of great importance to business and policy makers. It is about innovations with lower environmental impact than relevant alternatives. The innovations may be technological or non-technological (organizational, institutional or marketing-based). Eco-innovations can be motivated by economic or environmental considerations. The former includes objectives to reduce resource, pollution control, or waste management costs, or to sell into the world market for eco-products".

In comparison to the eco-innovation definitions, Oltra and Saint Jean (2009: 567) define environmental innovation "as innovations that consist of new or modified processes, practices, systems and products which benefit the environment and so contribute to environmental sustainability".

To define the notion 'green innovation' Driessen and Hillebrand (2002: 344) apply "a rather pragmatic definition" stating that it "does not have to be developed with the goal of reducing the environmental burden. [...] It does however, yield significant environmental

benefits". Chen, Lai et al. (2006: 534) define green innovation "as hardware or software innovation that is related to green products or processes, including the innovation in technologies that are involved in energy-saving, pollution-prevention, waste recycling, green product designs, or corporate environmental management".

To summarize, the above mentioned definitions of the four notions sustainable, eco, environmental and green innovation show minor differences in their descriptive precision. With regards to content they seem to examine the same topic and can be used largely interchangeably. Nevertheless, we identified six important aspects in the different definitions:

1. Innovation object: Product, process, service, method
2. Market orientation: Satisfy needs/ be competitive on the market
3. Environmental aspect: Reduce negative impact (optimum = zero impact)
4. Phase: Full life cycle must be considered (for material flow reduction)
5. Impulse: Intention for reduction may be economical or ecological
6. Level: Setting a new innovation/ green standard to the firm

The first two aspects have a general character and apply to nearly all innovation definitions, stating that the innovation object may be a product, process, service or method (e.g. business model) and that a innovation should satisfy a user`s need or solve a problem and therefore be competitive on the market. Concerning the environmental aspect all cited definitions agree that the innovation should have a reduced negative impact (i.e. lower negative externalities). The optimum would be an innovation without any negative impact on the environment at all. This aspect requires the comparison to existing intra- or inter-organizational alternatives and may therefore only be specified relatively and temporary. The fourth aspect appears only in two of the definitions by Kemp and Pearson (2007) and Reid and Miedzinski (2008). The authors call explicitly for a full life cycle analysis and a thorough analysis of all input- and output factors. The aim is a reduction of resource consumption. In this point there may well be a differentiation between the notions, as mainly scholars of the notion eco-innovation call for precise impact analysis whereas scholars using the term green innovation remain at a shallow level. Fifth, the definitions emphasize that the intention for the reduction may be economical or ecological, stating that for example the reduction of material usage in a new product development could have different causes. The last aspect covers problems related to the definition of innovation and environment-friendly as the two notions are

both relative and have no absolute value (e.g. any innovation could be new to the world, industry or the firm). To our understanding the notions are interpreted as setting a new innovation/green standard to firm.

The last two aspects are the main reasons for a scientific discussion as they impede researchers to clearly separate green and non-green innovations and determine their degree of "greenness". Due to the numerous types of innovation, these fuzzy aspects allow nearly all firms to be included into the definition of a green innovator (see also Andersen (2008)). Comparing the UN Brundtland definition for sustainability with the other three notions, the most important difference in this definition is the consideration of the ecological AND social dimension. The development of sustainable innovations therefore implements economical, ecological and social aspects. This is to our understanding the main difference between "sustainable" and the other three notions which only include the former two aspects.

Having discussed the four different notions based on existing definitions and concluded that they are often used synonymously we decided to include all of them in our literature review. In the following we outline our research approach before we report our findings to understand the development of the field in recent years and to identify the most active scholars, institutions and important contributions.

3 Research Approach

For the literature review data was collected from the Google Scholar (GS) database in November 2010. Publications were collected using the search strings "green innovation", "eco innovation", "environmental innovation" and "sustainable innovation". With this approach we decided to search by topic and not by (top) journal to include "all" published articles in this field as suggested by Webster and Watson (2002). Our total dataset includes 8,516 publications. The extracted publication types include journals, conference proceedings, book(-chapters), additional journals and working publications. The data was extracted with the software "Publish or Parish" (v3.1.3926).

Instead of using the Thomson ISI Web of Knowledge database, which is considered the "most commonly used source of bibliometric data", we decided for the GS database due to its broader data coverage (e.g. including conference proceedings, working papers, books) than the strict ISI criteria; although taken into account the disadvantage that the

GS database coverage is not as strictly methodological than the ISI database (Harzing and Wal, 2007: 1). Harzing and Wal (2007) however show that an analysis based on GS data results in more comprehensive citation coverage, particularly in the field of management and international business. To verify whether the data we extracted from the GS database covers the relevant literature, we compared our results with those extracted from the Thomson ISI Web of Knowledge database on an aggregated level. The comparison of the GS data (8,516 results) with the data extracted from the ISI database (176 results) results reveals that depending on the different notions between 67-86% of the ISI publications are included in our dataset.

The extracted publications were analyzed in a three level analysis using bibliographic information of the authors, publication years, journal names and citation frequency. A first level analysis provides an overview investigating the development of publications using the four notions on an aggregated level but also for seven scientific areas as available from GS. The second level of our analysis narrows and deepens the analysis to the specific discipline "business, administration, finance, economics". The third level of our analysis focuses on publications published in selected journals associated with innovation management. In this analysis we included 10 journals listed in the 'sub-discipline' "Management of Technology and Innovation" of the 2009 VHB ranking of the German Academic Association for Business Research (Schrader and Hennig-Thurau, 2009) and 15 journals listed in the 'subject area' "innovation" of the 2011 Harzing meta-ranking that is based on 19 international rankings (Harzing, 2011).

4 Findings of the quantitative analysis

The first level of our analysis focuses on the aggregated number of publications and the four different notions. Among the total number of 8,516 publications in our dataset, 40.7% (3,469) apply the notion "environmental innovation", 31.9% (2,716) the notion "sustainable innovation", 17.6% (1,495) "eco-innovation" and 9.8% (836) the notion "green innovation". It appears that more than 80% of the publications use only one notion indicating that the notions are used consistently within individual publications. Only in a limited number of publications (between 1.6 – 6.2%) the authors use multiple notions, with the notions "green-" and "eco-innovation" representing the highest value. Figure 1

reveals the chronological development of the publications using the four different notions.

Figure 1 Development of annual publications

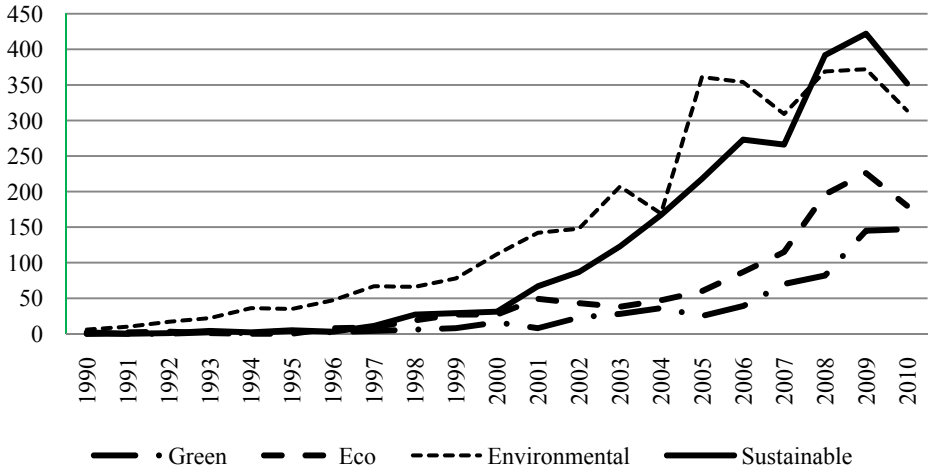

Figure 1 reveals that prior to 1990 little research was conducted as indicated by the low number of annual publications (i.e. less than 10 per year)[1]. Until 1997, research favored the notion "environmental innovation". Since 2000, the notion "sustainable innovation" became 'fashionable', which is also predominantly used currently with more than 400 publications in 2009. Since 2005, the notions "green" and "eco innovation" become increasingly used in scientific publications with an average of 150, respectively 230 publications per year.

GS clusters publications in seven disciplines. With 62.6% the majority of the publications in our data set relates to the field "business, administration, finance, economics" (BAFE). 25.0% of all publications relate to the field "social sciences, arts, humanities" (SAH) followed by 7.9% of the publications that are related to the field "engineering, computer sciences and mathematics" (ECSM). Publications in the fields "biology, life science, environmental science" (2.0%), "chemistry and material science" (1.4%), "physics, astronomy, planetary science" (1.0%) and "medicine, pharmacology, veterinary science" (0.3%) play only minor roles. Our results show that the usage of the four notions is

[1] Please note that not all papers published prior to 1990 may be digitalized and therefore can hardly be included in the GS database.

almost similarly distributed across the seven scientific disciplines. Our results indicate that the notion "sustainable" is preferably used in publications related to the "ECSM" and "SAH" disciplines, while the notion "environmental" is associated primarily with the fields "SAH" and "BAFE".

Table 1 Top Journals with 10 or more BAFE papers

Rank	*Journal name*	*Number of papers*	*Share of total*	*Cum share of total*
1	Journal of Cleaner Production	135	2.88%	2.88%
2	Business Strategy and the Environment	74	1.58%	4.45%
3	Energy Policy	43	0.92%	5.37%
4	Ecological economics	38	0.81%	6.18%
5	Environmental Quality Management	36	0.77%	6.94%
6	Journal of business ethics	25	0.53%	7.48%
7	Research Policy	22	0.47%	7.94%
8	Technovation	20	0.43%	8.37%
9	Environmental and resource economics	17	0.36%	8.73%
9	Futures	17	0.36%	9.09%
10	The Journal of Sustainable Product Design	16	0.34%	9.44%
11	Science	15	0.32%	9.76%
12	Journal of Industrial Ecology	14	0.30%	10.05%
12	Journal of environmental Management	14	0.30%	10.35%
13	European Environment	12	0.26%	10.61%
13	Technology Analysis & Strategic Management	12	0.26%	10.86%
14	Commercial Research	11	0.23%	11.10%
14	Energy Economics	11	0.23%	11.33%
15	Energy & Environment	10	0.21%	11.54%
	Others	4,153	88.46%	100.00%
	Total	4,695		

The second level of our analysis focuses on the BAFE field. In total, 4,695 publications were identified related to this discipline. Papers published in the BAFE field are scattered across several hundred journals. Table 1 reveals that 15 journals have published ten or more articles included in our sample. Together these journals published 542 articles, equivalent to 11.5% of the BAFE publications. With 135 articles the by far top ranking journal in the "Journal of Cleaner Production" followed by "Business Strategy and the Environment" with 74 articles, hence about half of the number of the top ranked journal. Six journals have published 20 or more but less than 50 papers. Research Policy and Technovation, two prominent journals in the innovation management field appear on rank seven and eight.

Table 2 BAFE articles with 20 or more annual citations

Rank	*Cites*	*Cites/year*	*Pub year*	*1st author name*	*Title*	*Journal*
1	8775	626.79	1997	DJ Teece	Dynamic capabilities and strategic management	Strategic Management Journal
2	1548	119.08	1998	J Elkington	Partnerships from cannibals with forks: The triple bottom line of 21st-century business	Environmental Quality Management
3	1780	111.25	1995	ME Porter	Toward a new conception of the environment-competitiveness relationship	The Journal of Economic Perspectives
4	488	54.22	2002	BÅ Lundvall	National systems of production, innovation and competence building	Research Policy
5	588	53.45	2000	P Bansal	Why companies go green: a model of ecological responsiveness	Academy of Management Journal
6	47	47.00	2010	N Johnstone	Renewable energy policies and technological innovation: Evidence based on patent counts	Environmental and Resource Economics
7	598	46.00	1998	D Revelt	Mixed logit with repeated choices: households' choices of appliance efficiency level	Review of Economics and Statistics
8	559	43.00	1998	S Sharma	Proactive corporate environmental strategy and the development of competitively valuable organizational capabilities	Strategic Management Journal
9	343	42.88	2003	AB Jaffe	Technological change and the environment	Handbook of environmental economics
10	693	40.76	1994	RA Wolfe	Organizational Innovation: Review, Critique and Suggested Research Directions	Journal of management studies
11	307	38.38	2003	DG Hoopes	Guest editors' introduction to the special issue: why is there a resource-based view? Toward a theory of competitive heterogeneity	Strategic Management Journal
12	325	36.11	2002	T Dyllick	Beyond the business case for corporate sustainability	Business strategy and the environment
13	213	35.50	2005	A Smith	The governance of sustainable socio-technical transitions	Research Policy
14	205	34.17	2005	AB Jaffe	A tale of two market failures: Technology and environmental policy	Ecological Economics
15	255	31.88	2003	K Buysse	Proactive environmental strategies: a stakeholder management perspective	Strategic Management Journal
16	274	30.44	2002	AB Jaffe	Environmental policy and technological change	Environmental and Resource Economics
17	310	28.18	2000	RK Chandy	The incumbent's curse? Incumbency, size, and radical product innovation	The Journal of Marketing
18	84	28.00	2008	J Markard	Technological innovation systems and the multi-level perspective: Towards an integrated framework	Research Policy
19	193	27.57	2004	D Popp	ENTICE: endogenous technological change in the DICE model of global warming	Journal of Environmental Economics and Management
20	215	26.88	2003	C Fischer	Instrument choice for environmental protection when technological innovation is endogenous	Journal of Environmental Economics and Management
21	78	26.00	2008	S Seuring	From a literature review to a conceptual framework for sustainable supply chain management	Journal of Cleaner Production
22	571	25.95	1989	SR Milliman	Firm incentives to promote technological change in pollution control	Journal of Environmental Economics and Management
23	355	25.36	1997	AB Jaffe	Environmental regulation and innovation: A panel data study	Review of Economics and Statistics
24	76	25.33	2008	S Ambec	Does it pay to be green? A systematic overview	Academy of Management Perspectives
25	290	24.17	1999	A Gerybadze	Globalization of R&D: recent changes in the management of innovation in transnational corporations	Research Policy
26	382	23.88	1995	P Shrivastava	Environmental technologies and competitive advantage	Strategic Management Journal
27	191	23.88	2003	J Sarkis	A strategic decision framework for green supply chain management	Journal of Cleaner Production
28	128	21.33	2005	R Kemp	The management of the co-evolution of technical, environmental and social systems	Towards environmental innovation systems
29	234	21.27	2000	K Rennings	Redefining innovation--eco-innovation research and the contribution from ecological economics	Ecological economics

Looking more closely at the most cited articles, Table 2 lists the BAFE related articles with 20 or more annual citations. From these 29 papers, three articles appear to have more than 100 annual citations which were all originally published in the mid / end of the 1990s. While the most cited paper by David J. Teece, Gary Pisano and Amy Shuen (1997) is not specifically dedicated to an environmental topic, the papers of John Elkington (1998) and Michael E. Porter and Claas van der Linde (1995) which rank second and third are. Three authors have multiple papers either as first or co-authors among these 29 papers.[2] Four papers were published by Adam B. Jaffe, three by Richard G. Newell and two by Adrian Smith. The earliest paper appeared in 1989 by Scott R. Milliman, a US scholar affiliated with the Department of Economics at James Madison University, Virginia.

From the top cited articles, five publications appeared in the Strategic Management Journal, four papers among were published in Research Policy and three in the Journal of Environmental Economics and Management.

Table 3 Top 10 BAFE authors and institutions

Rank	*Author name*	*Number of papers*	*Institution*
1	FEE Mattei	159	Fondazione Eni Enrico Mattei - Climate Modelling Institute, Italy
2	René Kemp	42	Professor of Innovation and Sustainable Development, International Centre for Integrated assessment and Sustainable development (ICIS), Maastricht University, The Netherlands
3	Massimiliano Mazzanti	27	Dipartimento di Economia Istituzioni Territorio, Faculty of Economics, University of Ferrara, Italy
4	Klaus Rennings	23	Vice-head of the department "Environmental and Resource Economics, Environmental Management", Centre for European Economic Research (ZEW), Germany
5	Carlo Carraro	22	President of and Professor of Environmental Economics and Econometrics, University of Venice, Italy
6	Richard MacLean	20	Director of Richard MacLean & Associates, LLC, Flagstaff, AZ
7	Jens Horbach	17	Former ZEW, since 2010 Professor at the Faculty of Business, University of Applied Sciences Augsburg, Germany
7	M Wagner	17	Julius Maximilian University of Würzburg, Professor of the Chair for Entrepreneurship and Corporate Growth, Germany
7	Nick Johnstone	17	Empirical Policy Analysis Unit, National Policies Division, OECD Environment Directorate
10	Marko Hekkert	15	Professor of Dynamics of Innovation Systems, Department of Innovation and Environmental Science, Utrecht University, The Netherlands

Table 3 reveals the most active scholars in the BAFE field. Leading by number of publications is FEE Mattei representing an Italien foundation dedicated to climate change research publishing papers in the name of the foundation. Among the top 5 active scholars are two further Italian researchers. Massimiliano Mazzanti from University of

[2] Please note that Table 2 lists only the first authors.

Ferrara ranks third and Carlo Carraro from University of Venice on the fifth rank. Three German institutions are present: The Centre from European Economic Research (ZEW) on rank four, the University of Applied Sciences in Augsburg ranked on place seven with a similar number of publications as the researcher from Julius Maximilian University of Würzburg. Among the top 10 list are also two Dutch researchers from Maastricht University ranked second and Utrecht University on the tenth place. A researcher of the OECD is also present, sharing rank seven with the two German researchers. Only one non-European researcher is present on this list from the USA who is primarily affiliated with his own consulting firm ranked on place six.

The third level of our analysis focuses on publications particularly related to the field of innovation management. Selecting only papers published in the 25 innovation management journals that are included in the two rankings (VHB, Harzing), we identified 136 papers equivalent to 2% of the total number publications in our dataset. After a pioneering publication by Harwood (1977) not much research was published in the innovation management field until the late 1990s, similar to the general publication development pattern depicted in Figure 1. Just around the start of the new century annual publication numbers started to increase to about 25 in 2010. We analyzed the 136 publications with regard to the journals in which they were published, the authors and their affiliated institutions as well as the articles' citations as impact measure.

Table 4 Top innovation management journals with at least three publications

Rank	*Journal name*	*Number of papers*	*Share of total*	*Cum share of total*
1	Technological Forecasting and Social Change	32	23.53%	23.53%
2	Research policy	24	17.65%	41.18%
3	Technovation	18	13.24%	54.41%
4	Journal of Business Venturing	8	5.88%	60.29%
4	R&D Management	8	5.88%	66.18%
5	International Journal of Technology Management	7	5.15%	71.32%
6	Journal of Product Innovation Management	5	3.68%	75.00%
6	Science and Public Policy	5	3.68%	78.68%
7	European Journal of Innovation	4	2.94%	81.62%
7	Creativity and Innovation Management	4	2.94%	84.56%
8	European Journal of Innovation Management	3	2.21%	86.76%
	Others	18	13.24%	100.00%
	Total	136		

The 136 were published in 23 different journals. Table 4 shows the journals in which at least three publications appeared. In these 11 journals 118 papers were published accounting for 86.8% of all innovation management publications. Table 4 reveals further that the three most active journals in the field are Technological Forecasting and Social

Change with 32 publications (23.5%), Research Policy with 24 publications (17.7%) and Technovation with 18 publications (13.2%). In total, the publications in these three journals account for 54.4% of all innovation management related publications.

When analyzing the 136 papers with regard to papers published by the same author (independent whether they appear as first or co-author), we identified only five scholars who published multiple articles (i.e. more than one). Together these authors published 12 articles, with only two of them publishing three articles. With seven papers, the majority of the 12 papers was published by scholars of the Department of Innovation and Environmental Science at Utrecht University in the Netherlands.

Marko P Hekkert is professor for Dynamics of Innovation Systems at this department since 2007. He published one article as first author in Technological Forecasting and Social Change in 2009 ("Functions of innovation systems as a framework to understand sustainable technological change: Empirical evidence for earlier claims") and two articles as second author in the same journal in 2007 ("How perceived uncertainties influence transitions; the case of micro-CHP in the Netherlands") and one paper in Science and Public Policy in 2008 ("Stimulating renewable energy technologies by innovation policy"). Simona O. Negro, an assistant professor at the same department, published two articles as first author. The paper published in Science and Public Policy in 2008 ("Stimulating renewable energy technologies by innovation policy") was co-authored by Marko P Hekkert. The second article appeared in Technological Forecasting and Social Change in 2008 ("The bumpy road of biomass gasification in the Netherlands: Explaining the rise and fall of an emerging innovation system") with Roald A.A. Suurs as co-author. Roald A.A. Suurs is a PhD student of Marko P Hekkert and also published two papers, one as first author in Technological Forecasting and Social Change in 2009 ("Cumulative causation in the formation of a technological innovation system: The case of biofuels in the Netherlands") and one article as second author in the same journal in 2008 ("The bumpy road of biomass gasification in the Netherlands: Explaining the rise and fall of an emerging innovation system").

Adrian Smith also published three articles. He is a senior fellow at the Environment and Energy Programme, SPRU (Science and Technology Policy Research), Freeman Centre, University of Sussex. He published two articles in Research Policy, one in 2005 ("The governance of sustainable socio-technical transitions") and the other in 2010 ("Innovation

studies and sustainability transitions: The allure of the multi-level perspective and its challenges") as well as one article in Science and Public Policy in 2003 ("Transforming technological regimes for sustainable development: a role for alternative technology niches?"). His 2005 Research Policy paper appears among the top cited papers listed in Table 2.

Stefan Kuhlmann is professor of Foundations of Science, Technology and Society at the University of Twente, The Netherlands. During his position at the Department of Technology Analysis and Innovation Strategies, Fraunhofer Institute for Systems and Innovation Research (ISI) in Germany he published two articles as first author. One article appeared in Research policy in 2001 ("Future governance of innovation policy in Europe--three scenarios") and one article in Technological Forecasting and Social Change in 2003 ("Scenarios of technology and innovation policies in Europe: Investigating future governance").

When analyzing the citations of the 136 papers, we found that five papers have more than 100 total citations, nine papers have 50 or more citations but less than 100 citations and 44 papers have between 10 and 50 citations. 21 papers have zero citations. When analyzing the annual citations, only one paper has more than 50 annual citations. 12 papers have 10 or more annual citations, but less than 50 citations. These papers are listed in Table 5. Furthermore, 44 papers have annual citations below one.

Table 5 Innovation Management articles with 10 or more annual citations

Rank	*Cites*	*Cites/year*	*Pub year*	*1st author name*	*Title*	*Journal*
1	488	54.2	2002	BÅ Lundvall	National systems of production, innovation and competence building	Research policy
2	213	35.5	2005	A Smith	The governance of sustainable socio-technical transitions	Research Policy
3	84	28.0	2008	J Markard	Technological innovation systems and the multi-level perspective: Towards an integrated framework	Research Policy
4	290	24.2	1999	A Gerybadze	Globalization of R&D: recent changes in the management of innovation in transnational corporations	Research Policy
5	58	19.3	2008	J Horbach	Determinants of environmental innovation-New evidence from German panel data sources	Research Policy
6	64	16.0	2007	J Edler	Public procurement and innovation-Resurrecting the demand	Research Policy
7	218	14.5	1996	JO Lanjouw	Innovation and the international diffusion of environmentally responsive technology	Research Policy
8	72	14.4	2006	S Thornhill	Knowledge, innovation and firm performance in high-and low-technology regimes	Journal of Business Venturing
9	14	14.0	2010	TJ Foxon	Developing transition pathways for a low carbon electricity system in the UK	Technological Forecasting and Social Change
10	125	12.5	2001	S Kuhlmann	Future governance of innovation policy in Europe-three	Research Policy
11	36	12.0	2008	EA Eriksson	Adaptive foresight: navigating the complex landscape of policy strategies	Technological Forecasting and Social Change
12	50	10.0	2006	JA Siguaw	Conceptualizing Innovation Orientation: A Framework for Study	Journal of Product Innovation Management
12	20	10.0	2009	A Faber	Models in evolutionary economics and environmental policy: Towards an evolutionary environmental economics	Technological Forecasting and Social Change

It appears that not all of the highly cited articles listed in Table 5 are closely related to the topic of green innovation and particularly managerial issues. Only the titles of the four articles by Horbach (2008), Lanjouw and Mody (1996), Foxon, Hammond et al. (2010) and Faber and Frenken (2009) clearly indicate a relation to green innovation, although not even on a managerial, intra-firm level, but rather on a national, policy level. The title of the paper by Smith, Stirling et al.(2005) rather indicates a relation to the social dimension of innovations.

5 Discussion

In this paper we showed that the concept of green innovation is closely related to three other notions. When comparing various definitions of the four notions "green innovation", "sustainable innovation", "environmental innovation" and "ecological innovation" we found only minor conceptual differences. We identified six aspects that are incorporated in the different definitions and found one key aspect that differentiates the conceptualization of sustainable innovation from the other three notions. In its original meaning sustainable innovations include also a social dimension in addition to the ecological dimension (i.e. social innovations). Nevertheless several scholars such as Scherhorn, Reisch et al.(1997: 16) eradicate this boarder. Concerning the three other largely ecological-based notions, eco-innovation seems to be the most precise and well developed concept, whereas green innovation remains rather shallow. In most of the publications the notions are however used interchangeably. We identified various scholars that contributed to defining green innovation, such as René Kemp from Maastricht University. Further advances in this area are impeded by the problem of measuring and comparing the environmental benefit of different innovations precisely. This problem recently led to several attempts to categorize innovations, e.g. differentiate them by technology, degree of novelty or application area. Discussing all available measurement approaches would go beyond the scope of this paper as a wide accepted consensus has not been found to date. An overview of different categorization is provided by Arundel (2009).

The findings of our quantitative analysis support the impression of interchangeable usage of the four notions. The results from the quantitative literature analyses further revealed that little research was conducted on the topic prior to 1990. The majority of publications in our dataset relate to the field "business, administration, finance, economics" (BAFE).

Within this field the majority of publications focus evidently on economic topics on meso- or macro-level of innovation science (i.e. industry, national policy level) instead of managerial topics (i.e. intra-firm level).

Among several journals that publish results of green innovation research, the Journal of Cleaner Production clearly stands out. With a total of 135 publications it ranks first and hence appears to have a central hub function for green innovation research. Furthermore, the journal Research Policy plays a central role for publications in the wider BAFE field as well as the innovation management research. In this particular research stream two further journals play important roles (i.e. Technological Forecasting and Social Change, Technovation). It appears that most influential publications originate from European research centers in the Netherlands, Italy and Germany. However, we can conclude that the field of ecological innovation management plays a minor role in scientific research with only 136 publications so far. From our research it appears that hardly any institution evolved with a clear research focus dedicated to green innovation management.

6 Conclusions and future research

We found that different notions of innovations with reduced environmental impact are used mainly interchangeable. Our research identified relevant journals and prominent scholars in the broader discipline of business administration, finance and economics, but more specifically in the innovation management field. We showed that the research focus in the field of "green innovation" in the past has been on industry or national level, which is a highly complex area associated with numerous problems (e.g. measurement of economical benefit, comparison of alternatives, etc.).

For future research we suggest placing an emphasis on firm level first to describe and analyze the related problems thoroughly on a smaller scale. In a second step the comparison of well-described ecological innovations from different firms and sectors will contribute to theory building on meso- or macro-level.

Furthermore most available definitions in the field of green innovations include economical AND ecological intended innovations. We suggest pursuing further research to create an advanced understanding of the coexistence/ interaction of the two intentions in managerial praxis as many recent innovations are not purely policy-driven any more. Another problem exists in the classification of green innovations where further research is needed.

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