Environmental Innovation and Societal Transitions 38 (2021) 34–51

Contents lists available at ScienceDirect

Environmental Innovation and Societal Transitions

journal homepage: www.elsevier.com/locate/eist

Research article

Diffusion of environmental innovations: Sector differences and explanation range of factors

Klaus Fichter [a,b,*], Jens Clausen [a]

[a] Borderstep Institute for Innovation and Sustainability, Clayallee 323, 14169 Berlin, Germany
[b] Department of Business Administration, Economics and Law, Innovation Management and Sustainability, Carl von Ossietzky University of Oldenburg, Ammerländer Heerstr, 114-118, 26111 Oldenburg, Germany

ARTICLE INFO

JEL classification:
O32
O33
O38
Q55
Q56
Q58

Keywords:
Diffusion
Environmental innovation
Product and service innovation
Sector
Transition
Diffusion policy

ABSTRACT

Empirical research on the diffusion of environmental product and service innovations has significant limits: almost all investigations focus on just a single sector or technology, usually energy, and concern a small number of diffusion cases. Therefore, it is hardly possible to generalize across sectors and to identify potential differences between sectors. We address this research gap with an investigation of a large sample of 130 diffusion cases from 11 different sectors. We apply a new mixed-method approach of statistical analysis and qualitative extreme case analysis. We provide insights on the differences in dissemination rates and knowledge on sector-specific factors. This helps to explain diffusion processes and design effective sector-specific transition policies. The concept of explanation range of factors clarifies the role and relevance of different diffusion factors and opens up avenues for further research on environmental innovation. Based on our findings, it can be concluded that some factors explain diffusion in (almost) all cases (high explanatory range), some only in specific sectors (medium explanatory range), and some merely in individual cases (low explanatory range).

1. Introduction

Many product and service innovations that contribute to environmental sustainability have been introduced to the market in recent decades (Hojnik and Ruzzier, 2016). Recent empirical investigations reveal that about two-thirds of them remain in small market niches (Clausen and Fichter, 2019). This is a key problem for transitions to enhance an environmentally sustainable economy because any possible environmental benefits only occur to a limited extent.

If diffusion of environmental innovations is ultimately to bring about a successful transformation of dominant forms of consumption and/or production, it is necessary to implement policies which give rise to this diffusion (Kivimaa and Kern, 2016). The need for policy support for the diffusion of environmental innovation can also be justified by market failures (Jaffe et al., 2005) and system failures (Bleda and del Río, 2013; Mignon and Bergek, 2016). Policy interventions are shown to be more powerful for inducing 'the adoption and development of new clean technologies when designed in a policy mix and time consistently' (Veugelers, 2012, p. 1770). The econometric results by Costantini et al. (2017) 'suggest that when the policy mix is characterized by a more balanced use of demand-pull and technology-push instruments, its positive effects on environmental innovation tend to be greater' (Costantini et al., 2017, p. 799). They also show plausible connections between environmental regulation and innovation. Lanjouw and Mody (1996)

* Corresponding author at: Borderstep Institute for Innovation and Sustainability, Clayallee 323, 14169 Berlin, Germany.
E-mail addresses: klaus.fichter@uni-oldenburg.de (K. Fichter), clausen@borderstep.de (J. Clausen).

https://doi.org/10.1016/j.eist.2020.10.005
Received 29 February 2020; Received in revised form 27 August 2020; Accepted 22 October 2020
Available online 26 November 2020

provide empirical evidence that innovation responds to pollution abatement expenditures, an indicator of the severity of environmental regulations. Lead market arguments for the export potential of environmental innovations can provide an argument for policy support for environmental niches. Walz and Köhler (2014) found evidence that 'international policy diffusion and learning across countries on the level of niche–regime interaction can improve the legitimacy of supporting policies' (Walz and Köhler, 2014, p. 20). Further improvement of the performance and characteristics of environmental product innovations also seem necessary to reduce important barriers and establish a solid driving force for dissemination. Menanteau and Lefebvre (2000) underline the importance of public programmes for creating initial niche markets and enabling a technological learning process to become established.

While innovation policy is often related to specific fields of technology and cross-sectoral challenges, diffusion policy is usually created for specific sectors (Quitzow et al., 2014). An agriculture ministry might create policies for agriculture and food consumption (Läpple and Rensburg, 2011), an energy ministry policies for energy production and consumption (Quitzow, 2015a), and a transportation ministry policies for different forms of mobility (Barbarossa et al., 2017; Mazur et al., 2015). There has been an ongoing debate as to finding the right balance between general and sector-specific diffusion policies (Azar and Sandén, 2011). For example, there are arguments to the effect that sector-based policy initiatives are more effective in supporting diffusion while broad, cross-sector initiatives are more cost-efficient, but not as effective in pushing diffusion. In order to give targeted advice for the transformation of specific sectors, it seems appropriate to analyse diffusion with regard to the characteristics and differences between sectors (Bohnsack et al., 2016; Cainelli and Mazzanti, 2013). As most recent systematic literature reviews reveal, diffusion research on environmental product and service innovations has until now been limited to studies that focus on only one sector or technology, usually energy, and on a small number of diffusion cases in individual sectors (Clausen and Fichter, 2019). This confirms findings from earlier investigations (Calleja et al., 2004; del Río González, 2009). It remains unclear to what extent the diffusion of environmental product and service innovations differs between sectors and to what extent potential differences have to be taken into consideration when designing sector-related diffusion policies. Furthermore, there is also a clear research gap in regard to the factors that influence the diffusion of environmental innovations in different sectors. While there is quite a bit of knowledge which factors are potentially relevant for diffusion (see Section 2), it is unclear which of them are valid for all sectors and which ones only have an influence in some sectors but not in others. An investigation of this topic would contribute to new research which has begun to analyse the strengths of lock-in mechanisms, and how they vary over time or between sectors (Klitkou et al., 2015).

Filling this research and knowledge gap would help explain why some transformational policies are successful and others are not and help answer the increasingly interesting question about 'how we can explain the varied progress with transitions in different sectors and countries' (Köhler et al., 2019, p. 7 f.). It might further explain singular success stories which are widely known, e.g. the German Renewable Energy Act (Die Bundesregierung, 2017), the development of the renewable heat sector in Denmark (Tappeser and Fromm, 2018), and the development of a market for battery electric cars in Norway (Clausen, 2017). Finally,

Based on theories from evolutionary economics (Nill and Kemp, 2009) and concepts such as the diffusion path concept (Fichter and Clausen, 2016), we address the above-mentioned research gap by investigating the differences in the diffusion of environmental product and service innovations between different sectors and by studying the role and explanatory range of potential factors which determine diffusion processes in different sectors. To this end, we use a large sample of 130 diffusion cases and apply a multi-step and mixed-method approach of statistical analysis and a qualitative multi-case research design.

The data we use in this article was collected in earlier research projects. We clearly indicate this by referencing the sources (Clausen and Fichter, 2019; Fichter and Clausen, 2016). These studies are related to the diffusion of environmental product and service innovations in general and did not analyse sector-specific diffusion patterns, nor did they compare sectors. The two analytical steps applied in this paper (measuring sector-specific dissemination rates by diffusion path analysis and extreme case analysis) are new and are intended to investigate to what extent the diffusion of environmental product and service innovations differs between sectors. This is the first application of the mixed-method approach.

In this article, we first take stock of the current state of research and develop guiding research questions (Section 2). We then introduce the method of our investigation (Section 3) and subsequently present and discuss the results of our empirical study (Section 4). In the final Section 5, we summarize our findings and draw conclusions with respect to diffusion policies and future research.

The contribution of this article to ongoing research into the diffusion of environmental product and service innovations is fourfold: first, we provide insights on the differences in dissemination rates and diffusion dynamics between different sectors. Second, we provide knowledge on sector-specific factors. This helps explain diffusion processes and design sector-specific diffusion policies. Third, we introduce the concept of 'explanation range' of factors to diffusion research, which might help clarify the role and relevance of different diffusion factors and open up an avenue for further research on environmental innovation. Fourth, while empirical diffusion research until now has mostly either applied quantitative (statistical) methods or qualitative (case-study-based) research designs, we use a new mixed-method approach of statistical analysis and qualitative extreme case analysis, which seems suitable for our research purpose and an interesting option for further diffusion research in general.

2. State of research

The importance of environmental innovation management is growing both in practice and in academia (Hojnik and Ruzzier, 2016; Schiederig et al., 2012). Based on an extensive body of literature (Barbieri et al., 2016; Horbach, 2016; Kemp and Pearson, 2007; Schiederig et al., 2012) and the political activities of the Eco-Innovation Action Plan of the European Union (European Commission, 2011), we define 'environmental innovation' as any form of innovation that brings about or seeks to make significant and demonstrable progress towards the goal of sustainable development that reduces environmental impact, increases resilience to environmental pressures, or achieves more efficient and responsible use of natural resources.

While product and service ‘innovation’ is the process of developing and implementing a radically new or significantly improved product or service, we define ‘diffusion’ as the purchase, use, imitation, or adaptation of an innovation by a growing number of persons or organizations as adopters. It involves the period after the first successful implementation or after market introduction (Fichter and Clausen, 2016). Research offers a wide range of concepts and empirical studies that provide and investigate factors that influence diffusion processes in general as well as the adoption rate of environmental innovation in particular (Karakaya, Hidalgo & Nuur, 2014). On the basis of these studies, six main areas of influence on the diffusion rate can be distinguished (Clausen and Fichter, 2019; Fichter and Clausen, 2013, 2016):

(1) *Product-related factors*: First, the possible factors directly related to the innovation object (product or service) have to considered. In his seminal studies, Rogers (2003, p. 219 ff.) indicates that the relative advantage, the perceptibility, compatibility, complexity, and trialability of an innovation are important variables that can influence the speed of adoption. When these attributes are applied to the diffusion of environmental product innovations, they can be considered to be relevant product-related variables.
(2) The adopter-related factors describe the course of the adoption of an innovation by an individual or an organization (e.g. a company) and deal with the question which factors influence the adoption process. Here, the ‘presence’ and participation of user-innovators as well as their early involvement in the innovation process plays an important role (Baldwin et al., 2006; Lüthje and Herstatt, 2004). The necessity of behaviour changes and the requirement to develop new (consumption) routines inhibit the diffusion of innovations (Barbarossa et al., 2017). Uncertainties concerning the function and the quality of the product, but also the regulatory environment of an innovation, delay the adoption process in the case of individuals as well as businesses (Iyer et al., 2015; Morton et al., 2018). In businesses, decisions are usually made collectively, and companies tend to value function, quality, and cost-effectiveness more highly (Mukoyama, 2003). In the case of consumers, on the other hand, a high price is often a constraint even independently of cost-effectiveness because of limited liquidity (Andrews and DeVault, 2009; Bottomley and Fildes, 1998)
(3) Diffusion research has identified the influence of the innovation supplier as an important field to explain the dissemination of innovative products and services (Hintemann, 2002; Hockerts and Wüstenhagen, 2010; Kivimaa and Kern, 2016). A number of characteristics of the suppliers play a role in their behaviour in the diffusion process. Concerning *supplier-related factors*, suppliers’ sizes and reputations are important, besides the availability of relevant products and services on the market (Fombrun, 1996; Iyer et al., 2015; Shapiro and Varian, 1999).
(4) Looking at the development of an industry has considerable potential to explain the diffusion of its products and services, so *sector-related factors* are relevant for the analysis as well. An important aspect for example is the number and economic strength of the innovative manufacturers and suppliers, including the retail trade, present in the industry (Hockerts and Wüstenhagen, 2012; Iyer et al., 2015). The emerging industry associations and niche actors with their lobbying activities changing the boundary conditions are also of importance (Scherrer et al., 2020). Nelson (1994) stresses the development of supporting structures within the sector. The existence and activities of industry trade associations appears to be relevant especially in the context of obtaining financial support from the government, reducing regulatory obstacles, and developing exnovation tools for phasing out predecessor products (Bruns et al., 2008). The role of market leaders also appears to be relevant for diffusion (Johnson and Silveira, 2014). Intermediaries as change agents should also be taken into consideration as a possible supporting factor (Bergek, 2020; Kanda et al., 2020).
(5) *Policy-related factors* of government intervention play a special role in the development and diffusion of environmental innovations because of their double externality problem (Jänicke, 2008; Quitzow, 2015b; Veugelers, 2012). The diverse political instruments used by governments to support the diffusion of environmental innovations (Jänicke, 2008; Kivimaa and Kern, 2016) as well as the societal forces impacting innovation and diffusion processes can be grouped in four different factors: governmental push and pull activities as well as institutional obstacles (Andersen and Liefferink, 1997; Droste et al., 2016; Kivimaa and Kern, 2016), lead market policies (Beise and Rennings, 2005; Walz and Köhler, 2014), media reporting, and campaigns by non-governmental organizations (Brunner and Marxt, 2013)
(6) *Path-related factors*: Diffusion research based on evolutionary economics also stresses the fact that there is an inherent dynamic in the diffusion path because of path dependencies, competing industry standards, and dominant designs (Geels, 2002; Köhler et al., 2019; Rip and Kemp, 1998) as well as self-reinforcing effects such as the critical mass phenomenon (Lehmann-Waffenschmidt and Reichel, 2000; Zeppini et al., 2014) and network effects (Geroski, 2000; Rogers et al., 2005; Vollebergh and Kemfert, 2005). Against this background, three path-specific factors can be distinguished: path dependencies due to historical ties, interactions between competing diffusion paths, and self-reinforcing effects within the diffusion path itself.

Based on two systematic literature reviews (SLR), which we conducted in 2011 (Clausen et al., 2011) and 2018 (Clausen and Fichter, 2019), it can be concluded that empirical research on the diffusion of environmental innovation is limited in three ways:

1 Almost all studies are limited to one industry or technology, usually energy.
2 Most studies reduce the complexity of the diffusion process significantly and focus on a small number of factors from up to three out of six potentially relevant areas of influence mentioned above.
3 Almost all studies concentrate on a small number of diffusion cases in individual sectors.

Against this backdrop, it can be argued that there is a clear research gap with regard to empirical diffusion studies on environmental innovation which are based on a large number of sectors and a large number of cases and therefore enable cross-sectoral generalizations and the identification of potential differences in diffusion dynamics between different sectors. To the best of our knowledge, our earlier investigations (Clausen and Fichter, 2019; Fichter and Clausen, 2016) are the only studies that cover a large number of diffusion cases of environmental innovations (100 and 130, respectively) from a broad variety of sectors. The findings of these studies suggest that only a limited number of factors are suitable for explaining the diffusion of environmental product and service innovations in general, meaning in all sectors. Out of the 22 investigated independent variables[1], the highest significant correlations with the independent variable dissemination rate was observed with low need of behaviour modification, completeness and availability of service, renown and reputation of suppliers, and price development of product/service innovations.[2] Here, it remains unclear whether the other factors are not suitable to explain the diffusion of environmental innovation at all or whether they are sector-specific and valid only in some sectors, but not in others.

It might by hypothesized that at least three of these six areas of influence are strongly related to economic sectors: these are 'sector-related factors', but also 'supplier-related factors' since products in different sectors are typically produced by different sector-related firms, and 'policy-related factors' because in many cases policies for different sectors are developed by different governmental bodies and with different strategies and policy involvement. The importance of these areas of influence on diffusion processes has been demonstrated by many scholars; the following paragraphs outline these areas briefly.

Nelson (1994) and Kanda et al. (2018) highlight the importance of the development of sector structures. In later stages of diffusion, the work of (green) sector associations is relevant to organize lobbying, achieve beneficial regulatory framework conditions, and prepare exnovation strategies to remove predecessor products from the marketplace (Bruns et al., 2008; Iyer et al., 2015; Jacobsson and Lauber, 2006; Nelson, 1994). Because of their influence on sector associations, market leaders also play a central role. It is of central importance that market leaders do not use all their power to prevent the diffusion of new products. Instead, they may have an impact on the speed of diffusion when they enter into the innovation (Geels, 2013, 2014; Penna and Geels, 2012). Intermediaries are also of importance to support diffusion (Kanda et al., 2015; Nolden et al., 2016).

Some authors highlight the role of pioneer-suppliers for diffusion of innovations (Hockerts and Wüstenhagen, 2010; Wüstenhagen et al., 2008) and others emphasize the importance of the size of suppliers: although small firms may be innovative, they may have problems regarding warranty claims (Barney, 1991; Fombrun, 1996; Shapiro and Varian, 1999).

The availability of relevant products and services on the market is also a precondition for successful diffusion (Fabrizio and Hawn, 2013). In service sectors the necessary training efforts for staff might also be a factor; if there is substantial need for training, this might prevent service firms from engaging in the dissemination of an innovative service.

Politics is of central importance for diffusion as well. The effective use of political instruments is crucial for the diffusion of innovations (Jänicke, 2005, 2008; Rennings, 1998). Political instruments must be combined in the most effective way (Kern et al., 2017; Kivimaa and Kern, 2016) and can be grouped in four different factors: (1) governmental push and pull activities, (2) institutional obstacles (Andersen and Liefferink, 1997; Horbach et al., 2012; Jaffe and Stavins, 1995), (3) lead market policies (Beise and Rennings, 2005), and (4) media reporting and campaigns (Brunner and Marxt, 2013). Crespi et al. (2015) argue that information mechanisms such as eco-labels can prove to be key in the diffusion process of environmental innovations.

Summarizing the impact of these factors on diffusion, it can quite possibly be the case that diffusion varies between sectors and that the role and influence of specific factors differ between sectors. It would therefore be quite probable that diffusion research had already explored differences between product or service diffusion across sectors. But if we examine recent publications on diffusion research, we find an overwhelming number of articles dealing with the energy sector. Energy was the singular focus of 19 out of a sample of 25 articles exploring diffusion of environmental innovations (Clausen and Fichter, 2019) and at least an important element in four more studies. Only two articles were identified which study the diffusion of non-energy innovations. Also, we did not find research comparing diffusion processes across sectors.

Against this backdrop, we will investigate the following research questions:

1 To what extent does the diffusion of environmental product and service innovations differ between sectors?
2 Which of the 22 independent variables potentially influencing the diffusion of environmental product and service innovation are relevant in which sectors?

3. Method

In this paper, we focus on the diffusion of environmental product and service innovations as the unit of analysis. Diffusion processes are highly complex fields of investigation. For this reason, we limited the scope of the study in three ways. (1) We focused on product and service innovations. (2) We investigated the diffusion process in a specific geographical region or country. We decided to choose a

[1] The 22 investigated independent variables are listed in column 2 of Table 5. We carried out a comprehensive evaluation of the literature in 2011. In this systematic literature review (SLR) (Clausen et al., 2011), we identified 22 potential factors influencing the diffusion trajectories of environmental innovations in six fields of influence (see Table 1) (Fichter and Clausen, 2016). In a second SLR in 2018 we could not identify additional fields of influence or significant new factors. For this reason, we investigated the 22 independent variables (Clausen and Fichter, 2019).

[2] Additionally to the 22 variables, we controlled for other potential influences such as the time since market introduction (Clausen and Fichter, 2019). In order to study the diffusion process sufficiently, we defined that the duration between market introduction and the time of investigation had to be at least three years. We could not find any correlation between the time since market introduction and the dissemination rate.

European country and selected Germany as the largest national market in Europe and because Germany represents a lead market for many environmental innovations, which provides valuable insights on diffusion dynamics. (3) We focused the analysis on the period between market introduction and the time of investigation (2016).

In order to investigate our guiding research questions, we had to select sectors and cases relevant from an economic and environmental point of view. We introduce the selection of sectors and cases in Section 3.1.

In order to generate generalizable results and detailed insights on differences between sectors and on factors influencing the diffusion of environmental product and service innovations, we had to devise a suitable research design and decided to use a large sample of 130 diffusion cases for which we had generated data in former research projects (Clausen and Fichter, 2019; Fichter and Clausen, 2016). The case profiles of this sample provide detailed information on all relevant factors. They were generated according to a consistent data collection and assessment procedure which permits statistical analysis and sector comparison. We applied a multi-step and mixed-method approach of statistical analysis and a qualitative multi-case research design.

The investigation of our first research question requires a large sample of diffusion cases in order to generate generalizable results. We took stock of the above-mentioned dataset of 130 diffusion cases and applied a diffusion path analysis approach in order to generate insights on sector-specific dissemination rates of environmental product and service innovations. The approach is introduced in Section 3.2.

In a second step, we investigated diffusion patterns and the role and relevance of different factors by applying a qualitative multi-case research design and decided to use an extreme case analyses approach. This is presented in Section 3.3. While the data was collected in earlier research projects, the two analytical steps presented here are new, and the mixed-method approach was applied for the first time.

3.1. *Selection of sectors and cases*

Those products, services and product-service systems were selected for the analysis which are expected to have a high impact on the development towards a green economy and which can effectively contribute to sustainability goals at national or international level (BMU, 2014; BMUB (Hrsg.), 2016). Both national and international studies were examined to identify these products, services, and product-service systems. Germany was chosen as the geographical location for the analysis, taking into account ecological lead markets already identified as relevant for Germany (Fichter and Clausen, 2016).

Additionally, we conducted a literature search and compiled a large number of suitable innovations. A total of 130 innovative, environmentally friendly products and services suitable for the study were selected. Each product or service with its particular diffusion path constitutes a ‘case’ for the analysis. This approach provided a comprehensive overview of environmentally friendly product and service innovations that are relevant from the experts’ point of view. A detailed description of the 130 selected environmental innovations and their classification into sectors is given in Clausen and Fichter (2019). The final classification into sectors followed the Statistical Classification of Products by Activity in the European Community (Commission of the European Communities (Statistical Office/Eurostat), 2008), but had to be adjusted to achieve sufficient functional homogeneity of the 130 products and services and to have a sufficient number of cases in each sector. Furthermore, the sector classification focuses on environmental impacts and is similar to the sector classification used for political target setting (BMU, 2014; BMUB (Hrsg.), 2016). Thus, the term ‘sector’ in this article is used in the sense of fields of products or services with functional similarity and homogeneity. We classified the 130 environmental product and service innovations into 11 sectors (see Table 1).

3.2. *Diffusion path analysis: measuring sector-specific dissemination rates*

Diffusion path analysis is based on evolutionary economics and was applied in previous empirical investigations (Clausen and

Table 1
Environmental product and service innovations broken down by sector and by degree of dissemination*.

Sectors	Degree of Dissemination*				Total
	up to 1%	up to 10 %	up to 50 %	up to 100 %	
Agriculture, food, and hospitality	2	10	2	1	15
Renewable energy	7	1	3	4	15
Renewable raw materials	2	5	2		9
Construction and building products		5	4		9
Transport and mobility	5	5	3	1	14
Internet and computing		3	6	10	19
Energy-efficient products and services	4	4	8	5	21
Trade		3	1		4
Green scientific-technical services	2	5	1	1	9
Rental services	1	4	4		9
Financial services	4	2			6
Total	**27**	**47**	**34**	**22**	**130**

*The ‘degree of dissemination’ is used as dependent metric variable and as an indicator for the diffusion of marketable goods and services. For more details see Section 3.2.

Fichter, 2019; Fichter and Clausen, 2016). It was used to measure the 22 independent variables displayed in column 2 of Table 5 as well as two dependent variables: (1) dissemination rate and (2) diffusion dynamics. In this investigation we took stock of a dataset of 130 diffusion cases which was generated in earlier investigations (Clausen and Fichter, 2019; Fichter and Clausen, 2016) and used the data to measure sector-specific dissemination rates and diffusion dynamics. In this way, we expanded our analysis and investigated differences between sectors.

3.2.1. Measuring independent variables

In our earlier investigations (Clausen and Fichter, 2019; Fichter and Clausen, 2016), we prepared a qualitative profile for each case using secondary information. The secondary information used came from market studies, life-cycle analyses, suppliers' websites, as well as information related directly to the products or services in question. The description of the cases followed a template, and an existing coding system was used. Key data on the product or service as well as the diffusion process were collected. The coding system allowed us to convert qualitative data into quantitative data, and the template ensured that we collected and analysed the same types of information in all cases.

Using the 22 potential factors as independent variables for the empirical study, we developed a coding system for each factor in order to assess the value of the variable between +2 and -2 (see Clausen and Fichter (2019)). We surveyed the variables using 3-point scales (2, 1, 0 or 0, -1, -2) and 5-point scales (-2 to +2). The reason why we used different scales is that some factors can have positive, neutral and negative effects on diffusion (e.g. the factor 'role of the industry trade association'), some can have only positive or neutral effects (e.g. the factor 'relative advantage of the innovation'), and some can have only negative or neutral effects (e.g. the factor 'institutional obstacles').

A coding team evaluated the independent variables and assigned a value to each factor in each case. For example, we coded the case 'carsharing' with the positive value of +2 for the variable 'perceptibility', since the innovation is clearly visible to the public and perceptibility may be assigned an effect promoting diffusion. The coding team comprised nine researchers with specific expertise in the particular service and market. At least two persons reviewed and evaluated each of the 130 profiles. The result of the survey was a dataset including key data about 130 cases of sustainable innovations as well as values for the 22 independent variables.

A comprehensive description of the method can be found in Fichter and Clausen (2016) and Clausen and Fichter (2019).

3.2.2. Dependent variable 1: dissemination rate

A metric variable, the dissemination rate, was chosen as the indicator for the diffusion of marketable goods and services. The dissemination rate can be considered a synonym for market penetration. In order to determine the dissemination rate, the following information must be available:

- information on the number of products and services currently in use or the number of products or service units sold in one year,
- information on the size of a suitable reference market.

For each product and service, reference markets were defined and the size of the respective dissemination rate was determined. In principle, if data were available, inventory data were selected (e.g. absorption chiller: the reference value is the share of total refrigeration generation for buildings and industry). If such data were not available, shares of sales in the current market were determined. In the case of products that exist only in a few demonstration projects, a dissemination rate of 0.1 % was entered as the reminder value in order to enable quantitative evaluation.

In the case of a number of renewable energy technologies (hydropower, wind power, pellet heating, CHP), the sustainable national potential was chosen as the reference value. If a high percentage has been achieved here, only a small proportion of the total potential remains untapped, and further promotion of diffusion in such cases will only make limited sense. A detailed description of the information sources and estimations of dissemination rates for each case is provided in Clausen and Fichter (2019).

3.2.3. Dependent variable 2: diffusion dynamics

In addition to the dependent variable dissemination rate, the indicator 'diffusion dynamics' was constructed as a sum of the values coded for the 22 variables for each product or service. Given the fact that we used 3-point scales (2, 1, 0 or 0, -1, -2) and 5-point scales (-2 to +2) (Clausen and Fichter, 2019), the maximum value for the indicator diffusion dynamics is 34 and the minimum value is -30. While the dissemination rate is viewed as an indicator of the actual present state of diffusion, the dependent variable diffusion dynamics is considered to be an indicator of the potentiality to diffuse. Diffusion dynamics bundles the influence of the 22 independent variables (drivers and barriers) and is intended to be a measure of the latent diffusion potential, which is hypothesized to be higher if all variables have high values. For the coding and the values see Clausen and Fichter (2019). The results were analysed quantitatively using SPSS software.

The data on each of the 130 cases and the detailed results of the case analysis of services and product services systems have been documented in separate publications for 11 sectors. The detailed results for products are published by Fichter and Clausen (2016). Detailed information on the analysis of the dissemination rate of all cases is documented by Clausen and Fichter (2019).

3.3. Extreme case analysis: comparison of 'stars' and 'poor dogs'

While the approach of diffusion path analysis described in the previous section is suitable for investigating general differences between sectors with regard to dissemination rates and diffusion dynamics of environmental product and service innovations (research question 1), the approach does not generate reliable insights with regard to the role of individual independent variables in different sectors and the question to what extent these factors are sector-specific (research question 2). Despite the fact that we use a large sample of cases (130) for our investigation, the sector subgroups (ranging from 4 to 21 cases) are too small to apply statistical methods to analyse potential differences of individual factors and their interaction in various sectors. Given the early stage in cross-case and cross-sector diffusion research on environmental product and service innovations, we decided to use an explorative qualitative case study approach to shed light on the role and explanatory range of different factors in describing and explaining diffusion in different sectors. Therefore, based on the results of diffusion path analysis (step 1), we used a multi-case study design and conducted an extreme case analysis (Seawright and Gerring, 2008, p. 300) to identify common factors and characteristics (step 2). Based on steps 1 and 2, we try to identify the explanatory range of the 22 independent variables and to clarify which factors are sector-specific (step 3).

The extreme case method selects a case because of its extreme value on the independent or dependent variable of interest (Seawright and Gerring, 2008, p. 300). For an extreme case analysis, one or more cases are needed that exemplify extreme values of the variable of interest. We chose the dissemination rate as the relevant variable and selected three diffusion cases from the group with the lowest dissemination rates of all cases investigated in the sector (poor dogs) and from the group with the highest dissemination rate in the sector (stars). Choosing from this univariate distribution allows for an explanatory approach. Since the extreme case method only generates useful insights with a larger sample of cases, we decided to select only those sectors for analysis with 10 cases or more. Five sectors provided sufficiently large samples, ranging from 14 cases in the transport and mobility sector to 21 cases in the energy-efficient products and services sector (see Table 2). Three cases from the group with the lowest dissemination rates and three cases from the group with the highest dissemination rates of all cases investigated in the sector were selected and are shown in Table 2.

The comparison is contextualized by an overview of the dissemination rate and diffusion dynamics of all innovations examined in the particular sector.

3.4. Assessing the effect of factors in extreme case analysis

The purpose of extreme case analysis is to identify relevant factors and characteristics of poor dogs and stars. While identifying factors (independent variables) is a first step in case analysis, the second step is to assess the influence of these factors on the dissemination rate as our dependent variable. In order to provide a clear and consistent assessment methodology of the influence of individual factors, we decided to use a binary coding scheme. Both, the independent variable (factor) as well as the dependent variable (dissemination rate) are either assessed to be ‘High’ (H) or ‘Low’ (L). For example, if we identified a factor such as ‘relative advantage of innovation’ to be relevant in the sample of the three poor-dog cases or the three star cases in one sector, we assessed whether the value of ‘relative advantage of innovation’ was ‘High’ or ‘Low’. Furthermore, we classified the poor-dog cases to have a ‘Low’ dissemination rate and the star cases to have a ‘High’ dissemination rate. According to this coding scheme, four combinations are possible:

Furthermore, we assume that a factor is useful for explaining the diffusion of an innovation if there is a consistent combination. We consider an LL or HH combination to be consistent because if the value of the factor is low, it is consistent if the dissemination rate is low too. The same holds true for the HH combination. It is inconsistent if the combination is HL or LH. We use this coding and classification scheme (Table 3) in the analysis and discussion of the cases. When we refer to poor-dog cases we use the abbreviation ‘P’, and when we refer to star cases we indicate this by an ‘S’. Thus, in poor-dog cases the possible combinations are PLL, PLH, PHL, and PHH, and in star cases SLL, SLH, SHL, and SHH. We use these abbreviations in the following section.

Table 2
Extreme case analysis by high and low dissemination rates in each sector.

Sectors	Poor dogs (three cases from the group with the lowest dissemination rates of all cases investigated in the sector)	Stars (three cases from the group with the highest dissemination rates of all cases investigated in the sector)
Agriculture, food, and hospitality	Community-supported agriculture (0.033 %)	Free range eggs (33 %)
	Organic hotels (2%)	MSC fish (46 %)
	Organic canteens and catering (4.1 %)	Organic baby food (60 %)
Renewable energies	Deep geothermal energy (0.08 %)	Wind power (onshore) (32 %)
	Geothermal and hydrothermal cooling (0.1 %)	Large- and small-scale hydropower (55–63%)
	Solar thermal power plants (0.1 %)	Biogas plants (80 %)
Transport and mobility	Private car-sharing (0.17 %)	Electronic tickets (20 %)
	Electric cars (0.5 %)	Mobility consulting (30 %)
	(Professional) Car-sharing (1.7 %)	Mobile navigation systems with TMC (90 %)
Energy efficiency products and services	Energy-saving contracting (0.5 %)	LED light bulbs (45 %)
	Smart metering (1.1 %)	Panel heating (70 %)
	Electricity contracting (2%)	Highly efficient washing machine (100 %)
Internet und computing	E-book reader (4.8 %)	Digital camera (75 %)
	Video conferencing (8%)	E-mail (80 %)
	Thin client (8.8 %)	LCD monitor (95 %)

Table 3
Possible combinations of the value of a factor and the dissemination rate.

		Dissemination rate	
		Low	High
Value of factor	High	High-Low (HL)	High-High (HH)
	Low	Low-Low (LL)	Low-High (LH)

4. Results and discussion

The following analysis has a focus on the selected five sectors and uses findings from diffusion path analysis (Section 4.1) and a comparison of 'poor dog' and 'star' innovations in five sectors to search for differences (Section 4.2 to 4.4). We conclude with cross-sector findings (Section 4.5).

4.1. Differences in dissemination rate between different sectors

Diffusion path analysis indicates significant differences between sectors with regard to the dependent variable dissemination rate (see Table 4). While the average dissemination rates of environmental product and service innovations in the catering and food sector as well as in the transportation and mobility sector are only slightly above ten per cent (12.2 %), diffusion of the innovations in the renewable energies and energy efficiency sector is much stronger. The highest average dissemination rate can be observed in the Internet and computing sector. Here, the average dissemination rate is almost fifty per cent (49.1 %), and 84 % of all cases investigated in this sector reach a dissemination rate of 10 % or higher.

Based on the diffusion path analysis and the extreme case analysis, we identified three types of sectors which show significant differences in the diffusion of environmental products and services:

- The agriculture, food and hospitality, and transport and mobility sectors do not show high dissemination rates, neither in general nor for key innovations, which are important for achieving positive environmental change. These sectors have only very few stars (cf. e.g. Fig. 1).
- The renewable energies and energy-efficient products and services sectors show moderate dissemination rates in general, but also a significant number of quite successful cases of diffusion which were driven by instruments of environmental policy (cf. e.g. Fig. 2).
- The Internet and computing sector reveals an overall significant market-driven dynamic of diffusion, but comprises innovations with rather small environmental benefits that do not seem to lead to a high level of positive environmental change (cf. Fig. 3).

We will discuss these three types of sectors in the following.

4.2. Sectors with low dissemination rates and very few stars

4.2.1. Agriculture, food, and hospitality

In the agriculture, food, and hospitality sector, it was possible to determine both the diffusion dynamics and the dissemination rate for 15 products and product service systems. The distribution of cases according to these indicators as well as the three stars and the three poor dogs investigated are shown in Fig. 1. Based on the values of diffusion dynamics and dissemination rate, three groups of cases can be distinguished:

Table 4
Differences in dissemination rates between different sectors.

Sector	Lowest dissemination rate in sample	Highest dissemination rate in sample	Average dissemination rate in sample	Percentage of cases with a dissemination rate of 10 % or higher	Number of cases investigated
Agriculture, food, and hospitality	0.03 %	60 %	12.2 %	20 %	15
Transport and mobility	0.01 %	90 %	12.2 %	29 %	14
Renewables energies	0.08 %	87 %	26.3 %	47 %	15
Energy-efficient products / services	0.1 %	100 %	31.6 %	62 %	21
Internet and computing	4.8 %	100 %	49.1 %	84 %	19
All sectors investigated	0.01 %	100 %	**21.7 %**	45 %	**130***

*This is the total number of cases investigated in 11 sectors.

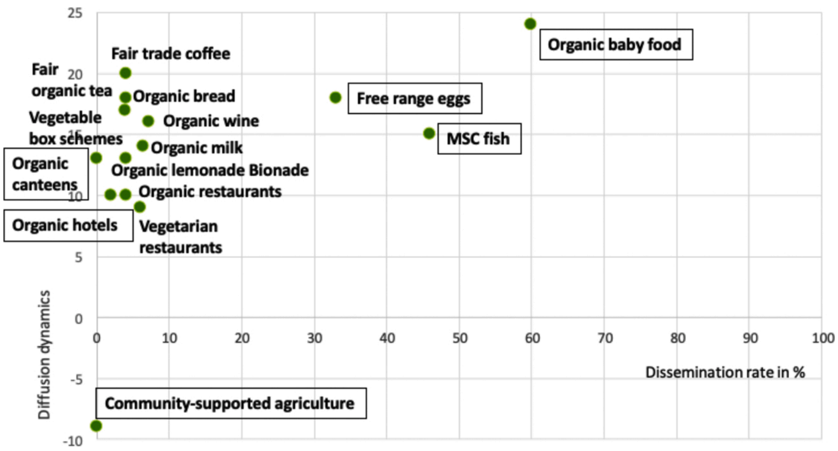

Fig. 1. Cases investigated in the agriculture, food, and hospitality sector.

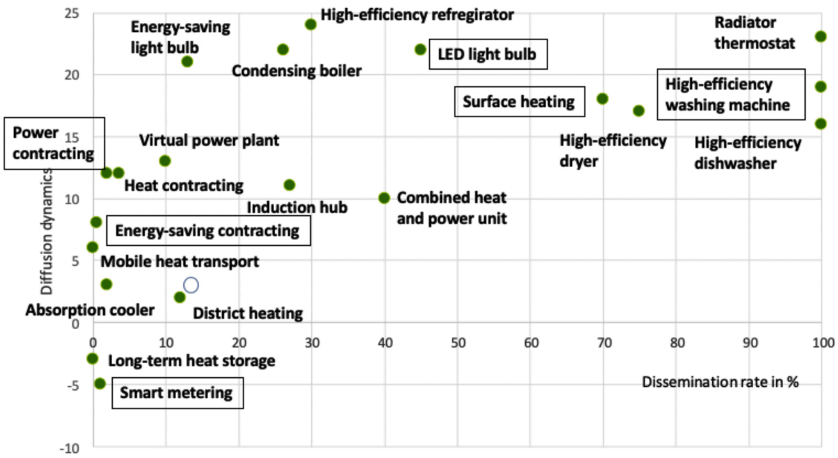

Fig. 2. Cases investigated in the sector energy-efficient products and services.

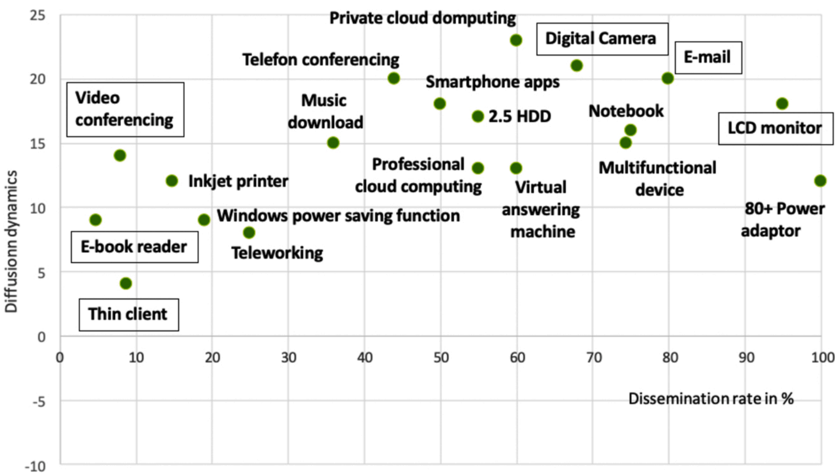

Fig. 3. Cases investigated in the Internet and computing sector.

- Community-supported agriculture (0.03 %) and vegetable box schemes (0.1 %) have extremely limited diffusion.
- 10 products and product service systems of the organic sector have been established in small market niches with dissemination rates between 2 and 7%.
- Free-range eggs, MSC fish, and organic baby food show high dissemination rates. These three are the stars in the sector.

The extreme case analysis provided the following insights with regard to the 22 factors that potentially influence diffusion:

- The compatibility of the three successful products with traditional shopping and food consumption is high (SHH); no change of behaviour on the user side is necessary at all (SHH).
- Successful diffusion is more likely to occur with products whose additional costs remain manageable from the customer's viewpoint. Free-range eggs and MSC fish are not much more costly than conventional products (SHH), and in the case of the more expensive organic baby food, willingness to pay is high, and both the amount of food and the length of time it is consumed are limited.
- The successful products are offered nationwide by incumbent firms with a high reputation (SHH), including the major market leaders in production and retail (SHH).
- Political support (PLL) - except in the form of labels and the ban on caging hens - and path-related factors play little role in diffusion processes in the catering and food sector (PLL).

However, these observations only explain to a limited extent why a number of other organic products still remain in the niche market. Organic bread, organic wine, and organic milk do not require users to change their behaviour at all and are also widely available. The suppliers are as well-known as in the cases of free-range eggs, MSC fish, and organic baby food. However, the actual additional costs of buying organic products are significantly higher in the long term than in the case of the organic baby food, which is purchased only temporarily. Many organic food products are sold at a price premium of between 34 % (alcoholic beverages) and 145 % (sugar, jam, etc.) (Haubach and Held, 2015, p. 51) (PLL).

Von Koerber (2000) argues plausibly that the additional expenditure for organic farming can best be reduced through economies of scale and larger volumes in logistics and distribution. And a recent consumer survey shows that for 63 % of respondents, the high price is the most important reason for not buying organic food (PricewaterhouseCoopers, 2017, p. 5). Possible savings from different dietary habits do not dampen this effect because the necessary changes in habits and behaviour are another major barrier to diffusion. The fact that established suppliers already have organic food in their product ranges has a strong impact on diffusion only where the purchase decision does not lead to high additional costs. As long as the price framework cannot be changed to the detriment of conventional farming, it will be necessary to improve the competitiveness of organic farming through additional support programmes.

Taking into account that in order to achieve environmental targets relating to biodiversity as well as phosphorus and nitrogen flows, organic farming must be expanded to a high percentage of farmland, it can be observed that the instruments of information and communication alone are not sufficiently effective (PLL). The very limited diffusion impact of the 'Council Regulation (EEC) No 2092/91 of 24 June 1991 on organic production of agricultural products and indications referring thereto on agricultural products and foodstuffs', which introduced the organic food label 27 years ago, may serve as an example.

4.2.2. Transport and mobility

In the sector of transport and mobility, the diffusion dynamics and the degree of diffusion were determined for 14 products and product service systems. Based on the values of diffusion dynamics and the dissemination rate, three groups of cases in the field of mobility can be distinguished:

- Bicycle taxis, bicycle rental, natural gas cars, private car-sharing and, electric cars have very low dissemination rates under 1% to date.
- Various mobility services as well as the energy-efficient car (3-litre car, A + car) remain in market niches with small degrees of dissemination ranging between 1.7 % at present for car-sharing and 11 % for conventionally fuelled energy-efficient cars.
- Only three out of 14 innovations have reached dissemination rates of 20 % or higher. These comprise IT-based offers in the mobility sector such as electronic tickets, (online) mobility consultation, and mobile navigation systems with TMC.

The extreme case analysis provided the following insights with regard to the 22 factors that potentially influence diffusion:

- The more disruptive innovations in car-sharing promise economic benefits, but require significant changes in user behaviour (PLL). Electric mobility is currently still associated with high costs (PLL) and significant uncertainties about range and charging (PLL).
- Similar to users, providers act cautiously and offer innovations that do not lead to disruptive changes. An exception to this is organized car-sharing; although all the major car manufacturers have entered this market, the dissemination rates were still limited in 2016 (time of investigation).
- Self-reinforcing effects are not pronounced (PLL), but they support the three IT-based innovations electronic tickets, (online) mobility consultation, and mobile navigation systems with TMC (SHH).

In addition to these factors, a lack of infrastructure is also likely to be the cause for slow diffusion in some cases, such as lack of car-sharing or rental bicycle stations or lack of charging infrastructure for electric vehicles. In some sectors (e.g. mobility, energy), it could be necessary to consider 'availability of infrastructure' as an additional factor influencing the diffusion process in future research.

4.2.3. Comparing the two sectors with low dissemination rates and very few stars

In both sectors the German policy relies on information and communication instruments and generally does not make use of financial instruments or regulatory law (PLL). An exception is a limited subsidy for electric cars, which as of early 2019 are a slowly growing market suffering from a shortage of available products.

It can be observed in both sectors that central innovations which could contribute to achieving environmental targets exist in market niches, but do not diffuse into the mass market without strong political support (PLL), which is available e.g. for electric cars in Norway (Clausen, 2017). Just waiting for self-sustaining market dynamics which brings sustainable products and services out of the niche without changes of the market framework has not brought about success over the last 25 years.

With regard to the role of infrastructure for diffusion, there is a clear difference between the agriculture, food, and hospitality sector and the transport and mobility sector. This indicates that additionally to the 22 factors which we have investigated, the role of infrastructure is a relevant factor in some sectors, but not in others. Therefore, this additional factor can be classified as sector-specific.

4.3. Sectors with partial transformation driven by instruments of environmental policy

4.3.1. Renewable energies

In the field of renewable energies, we determined both the diffusion dynamics and the dissemination rate for 15 products and product service systems. Three groups of cases can be distinguished based on the values of diffusion dynamics and the dissemination rate:

- Cases with extremely small dissemination rates of less than 1%: deep geothermal energy, geothermal and hydrothermal cooling, sails for commercial ships (Skysails), solar thermal power plants, and offshore wind power.
- Cases with dissemination rates of 1%–7%: energy cooperatives, bioenergy villages, and biodiesel.
- Cases with dissemination rates of 17%–87%: Green electricity trading, wind power (onshore), pellet heaters, large- and small-scale hydropower, biogas plants, and renewable energy project planning.

The extreme case analysis provided the following insights with regard to the 22 factors that potentially influence diffusion:

- Successful innovations are based on less complex business models (SHH) and therefore entail fewer economic risks and uncertainties (SHH).
- The successful innovations are considerably more economical (SHH) than the less successful ones due to the long-term and occasionally quite high funding provided by the German Renewable Energy Sources Act of the year 2000 (SHH), which has resulted in a rapid expansion of renewables and additional cost-reducing economies of scale.
- After numerous takeovers, wind power and hydropower in particular are today often in the hands of large technology groups (SHH), which are well networked in their sectors and receive a great deal of support; worldwide supply and service are ensured (SHH).
- Although the strong media presence and perceptibility of wind power and biogas plants promoted their diffusion (SHH), this does not always have a positive effect since resistance is also becoming increasingly established as they become more widespread.

4.3.2. Energy-efficient products and services

Both the diffusion dynamics and the dissemination rate for 21 products and product service systems were determined in the field of energy-efficient products and services. The distribution of cases according to these indicators as well as the three stars and poor dogs investigated are shown in Fig. 2. Three groups of cases can be distinguished based on the values of diffusion dynamics and dissemination rate:

- Cases with extremely small dissemination rates of up to 1%: Long-term heat storage, mobile heat transport, energy-saving contracting, and smart metering.
- Cases with dissemination rates of 2%–13%: absorption coolers, electricity contracting, heat contracting, virtual power plants, energy-saving lightbulbs, and district heating networks.
- Cases with dissemination rates of 26%–100%: condensing boilers, induction hubs, high-efficiency refrigerators, co-generation plants, LEDs light bulbs, panel heating, high-efficiency dryers, radiator thermostats, high-efficiency washing machines, and high-efficiency dishwashers.

The extreme case analysis provided the following insights with regard to the 22 factors that potentially influence diffusion:

- The successful innovations are products that are directly functionally equivalent to a less efficient alternative (SHH) (e.g. LED vs. conventional light bulbs, efficient vs. inefficient washing machines) and are therefore fully compatible (SHH) and technically not complex (SHH). This limits the extent of necessary behavioural change (SHH) and the uncertainties on the part of the adopters are very low (SHH).

- Successful innovations usually provide clear economic benefits for the end user (SHH), whereas this is only partly the case with less successful innovations.
- The legal enforcement of the diffusion of successful innovations is consistently strong (SHH). Eco-design minimum standards (the best-known example being the EU ban on incandescent lamps) effectively push inefficient technologies out of the market. Political support for less successful innovations is weaker (PLL).
- In the case of successful innovations, considerable price reductions (SHH) have been possible as a result of higher sales figures thanks to economies of scale, which cannot be seen in the case of less successful innovations (PLL).

4.4. High market-driven diffusion dynamics with low environmental benefits

The diffusion dynamics and dissemination rates of 19 products and product service systems were determined in the field of Internet and computing. The distribution of cases according to these indicators as well as the three stars and poor dogs investigated are shown in Fig. 3.

A comparatively large share of the environmental product and service innovations in the Internet and computing sector are characterized by rather small environmental benefits. Based on the values of diffusion dynamics and dissemination rate, four groups of cases can be distinguished:

3 E-book readers, video conferencing,[3] and thin clients, which all require certain behavioural changes, have a comparatively low dissemination rate under 10 %.
4 Inkjet printers, the Windows power saving function, and teleworking, reach only very moderate dissemination rates between 15 % and 25 %.
5 10 products and product service systems reach high dissemination rates between 35 and 80 %.
6 The LCD monitor (95 %) and the 80+ power supply (100 %), whose high market share make them the dominant designs, has led to the at least proportionate disappearance of former competitors from the market.

The extreme case analysis provided the following insights with regard to the 22 factors that potentially influence diffusion:

- The relative advantage of the successful products has been consistently rated as high (SHH), whereas this was true of only one out of three of the less successful cases.
- The media presence[4] of successful products was consistently rated as very beneficial (SHH); all three less successful cases had a significantly lower media presence (PLL).
- All three successful cases were not inhibited by path dependencies (SHH), but benefited from price reductions (SHH) and self-reinforcing effects (SHH). The less successful cases had to overcome path dependencies (PLL) and benefited less from price reductions (PLL) and self-reinforcing effects (PLL).
- Financial advantages (price, costs, cost-effectiveness) significantly promote the diffusion of many Internet and computing innovations (SHH). Established providers (SHH) and high availability (SHH) also have a very positive effect on diffusion.
- Political factors hardly play a role in the diffusion of Internet and computing innovations (SLH).

4.5. Cross-sector findings

Pulling together the empirical findings provided by the diffusion path analysis of the entire sample of 130 diffusion cases of environmental product and service innovations (Table 1), the diffusion path analysis of selected sectors (Section 4.1), and the extreme case analysis (Sections 4.3 and 4.4) allowed us to generate insights regarding our second research question: *Which of the 22 independent variables potentially influencing the diffusion of environmental product and service innovation are relevant in which sectors?*

When investigating this question, we build on concepts that differentiate the explanation range of factors influencing the implementation and diffusion of environmental innovations (Fichter and Clausen, 2013, p. 97 ff.) Here, the explanation range of factors is divided into three categories:

1 *Factors with a high explanation range*: These factors are suitable for explaining the diffusion of all or at least most innovations in all sectors.
2 *Factors with a medium explanation range*: These factors explain the process and speed of diffusion very well for some sectors or specific groups of innovations, but not for others.

[3] It may be noted that since data collection in 2016 the dissemination rate of videoconferences on PCs and notebooks has increased intensively, but less so the use of videoconferencing rooms, which imply high costs and require a change of location in order to take part in the conference.

[4] Media presence it is not limited to paid advertising, but includes all types of media coverage. In our coding system, the factor 'Media and campaigns' is defined as follows: To what extent did the media (press, radio, TV, etc.) and NGO campaigns accelerate or inhibit the diffusion trajectory? This factor is categorized as a policy-related factor, because it relates to public visibility and communication which we consider to be part of the larger political process.

Table 5
Assessment of 22 factors regarding their explanation range.

Area of influence	Factors influencing the diffusion process	Relation to dissemination rate (Kendall's tau-b and approximate significance) (n = 130)	Consistent influence in extreme case analyses of five selected sectors (n = 30)					Explanation range of factor		
			Agriculture, food, and hospitality	Transport and mobility	Renewable energies	Energy-efficient products, services	Internet and computing	High	Medium	Low
Product-related factors	Relative advantage of innovation	0.177*				SHH	SHH	X		
	Perceptibility									X
	Compatibility	0.159*	SHH			SHH		X		
	Low complexity				SHH	SHH			X	
	Trialability									X
Adopter-related factors	Involvement of user innovators	−0.203**							X	
	Low need for behaviour modification	0.329**	SHH	PLL		SHH		X		
	No/low uncertainties on the part of adopters	0.199**		PLL	SHH	SHH		X		
	Financial (dis-)advantage (price, costs, cost-effectiveness)	0.130*	SHH, PLL	PLL	SHH	SHH	SHH	X		
	Necessary training efforts for staff	not analysed								
Supplier-related factors	Renown and reputation of suppliers	0.332**	SHH		SHH		SHH	X		
	Completeness and availability of product or service	0.349**			SHH		SHH	X		
Sector-related factors	Degree of support by industry trade association	0.234**							X	
	Degree of support by market leaders	0.214**	SHH						X	
	Degree of support by intermediaries as change agents									X
Policy-related factors	Institutional obstacles	0.145*							X	
	Degree of governmental push and pull activities		PLL	PLL	SHH	SHH, PLL			X	
	Role of lead market policies	0.177*							X	
	Coverage by media and campaigns						SHH, PLL			X
Path-related factors	Role of path dependencies		PLL				SHH, PLL		X	
	Price development of product/service innovation	0.336**			SHH	SHH, PLL	SHH, PLL	X		
	Level of self-reinforcing effects	0.278**		PLL, SHH			SHH, PLL	X		

Characteristics of Kendall's Tau-b: 0 to 0.05: no correlation; up to 0.2: weak correlation; up to 0.5: medium correlation; above 0.5: strong correlation. Only statistically significant correlations are shown.
*significant at 0.05 level; **significant at 0.01 level; n = 130.
PLL = Poor-dog cases (P) with a low value of the factor (L) and with low dissemination rates (L).
SHH = Star cases (S) with a high value of the factor (H) and with high dissemination rates (H).
Source: The first three columns are taken from earlier work by Clausen and Fichter (2019). The consistent factors identified in extreme case analyses of five selected sectors (columns four to eight) and the explanation range of factors (column nine to eleven) are original work by the authors in this paper.

3 *Factors with a low explanation range*: These factors are relevant in some individual diffusion cases, but do not explain the diffusion of all or most cases in a sector or a specific group of innovations.

Table 5 provides a summary of findings from the previous analytical steps and assesses the explanation range of the 22 factors that potentially influence the diffusion of environmental product and service innovations. We combine research step 1 (statistical diffusion dynamics analysis) (see columns 2 and 3 in Table 5) with research step 2 (extreme case analysis) (see columns 4–8 in Table 5).

A factor was rated as having a 'high' explanation range if there was a significant correlation between the factor and the independent variable dissemination rate in the entire sample of 130 diffusion cases (research step 1) and, additionally, if the variable had a consistent influence on the dissemination rate in the extreme case analysis (research step 2) in at least two sectors.

A factor was rated to have a 'medium' explanation range if either a significant correlation was identified in the entire sample of the 130 diffusion cases or if a consistent influence on the dissemination rate was found in the extreme case analysis in at least two sectors.

If neither of the two was the case, the factor was rated as having a 'low' explanation range.

Our results suggest that nine of the 22 variables investigated have a high explanatory range and seem to be suitable for explaining the diffusion of environmental product and service innovations in all sectors. Eight factors (medium explanatory range) help to explain the process and speed of diffusion in some sectors or for specific groups of innovations very well, but not in others. Additionally, the factor 'role of infrastructure', which was not part of the 22 variables investigated, was identified as relevant in the transport and mobility sector. This factor can also be considered to have a medium explanatory range. Finally, four factors may be relevant in some individual diffusion cases, but do not explain the diffusion of all or most cases in a sector or specific group of innovations.

We found differences in the explanatory range of the factors in all six areas of influence (product-, adopter-, supplier-, sector-, policy-, and path-related factors). As hypothesized in Section 2, we assumed that at least three of these six areas of influence are strongly related to economic sectors: sector-related factors, supplier-related factors, and policy-related factors. Our findings support this assumption for sector-related factors and policy-related factors, but not for supplier-related factors. Here, we identified two factors (renown and reputation of suppliers, completeness and availability of product or service) with a high explanatory range. They seem to be helpful to explain the process and speed of diffusion in all sectors.

It is worth mentioning that none of the policy-related factors has a high explanatory range. At least our investigation does not support this. It seems that these factors are helpful for explaining the diffusion of environmental product and service innovations in some sectors, but not in others. This is consistent with the observation (see Section 2) that in many cases policies for different sectors are developed by different governmental bodies and with different strategies and policy involvement.

5. Conclusion

While empirical research on the diffusion of environmental product and service innovations has to date almost always been limited to a small number of cases in individual sector studies, our sample (130 cases from 11 sectors) and research findings allow for generalizable insights and comparisons between different sectors. With regard to our first research question, we can clearly conclude that the extent of diffusion of environmental product and service innovations differs considerably between sectors. We used two indicators in research step 1 (statistical diffusion path analysis) to measure the differences and generated new data on sector-specific dissemination rates and diffusion dynamics. The first indicator is the average dissemination rate across all diffusion cases in one sector. While the average dissemination rate of innovative environmental products and services in the Internet and computing sector is almost 50 %, it is 32 % with energy-efficiency products and services and 26 % in the renewable energies sector. We found the lowest average dissemination rates in the transport and mobility and the agriculture, food, and hospitality sectors (12 % each). Another indicator is the percentage of cases in each sector that range below a dissemination threshold of 10 % market share. While 16 out of the 19 environmental product and service innovations in the Internet and computing sector investigated exceed this threshold, this is only true for three out of 15 cases investigated in the agriculture, food, and hospitality sector.

Against the background of these findings, it is striking that up until today most research on the diffusion of environmental innovation is focussed on the two more successful sectors, namely renewable energy and energy efficiency (Clausen and Fichter, 2019). Even the studies which compare sectors focus only on case studies or subsectors with climate impacts (Bergek and Berggren, 2014; Droste et al., 2016; Iyer et al., 2015; Kivimaa and Kern, 2016). Yet the problems of non-diffusion of environmental innovation are also severe in the sectors of agriculture, food, and hospitality as well as in transport and mobility. With the exception of electric cars (Barbarossa et al., 2017) and a very special case of the spread of organic farming amongst farmers in Ireland (Läpple and Rensburg, 2011), these sectors remain largely unexplored. It might be concluded that significantly more multi-sector studies are needed to gain real understanding of diffusion processes in general. This would indicate a clear research gap in diffusion research. Furthermore, it can be concluded that more research on the less successful diffusion processes in the agriculture, food, and hospitality sector as well as in the transport and mobility sector are needed. This might help understand specific obstacles and path-dependencies in these sectors.

We introduced the concept of 'explanation range' of factors to diffusion research in order to investigate our second research question. Furthermore, we developed a new mixed-method approach by combining quantitative techniques (statistical diffusion path analysis) with qualitative extreme case analysis. Also, we elaborated a new methodology for assessing the effect of factors in extreme case analysis (see Section 3.4). Our findings support the assumption that these methodological developments are suitable and help to clarify the role and relevance of different diffusion factors in different sectors. This might open up an interesting new methodological avenue for further research on the diffusion of environmental innovation specifically and on innovation in general.

Our results suggest that nine of the 22 variables investigated have a high explanatory range and seem to be suitable to explain the diffusion of environmental product and service innovations in all sectors. This seems true for the factors relative advantage of an innovation, compatibility, low need for behaviour modification and, no/low uncertainties on the part of adopters. We found also a high explanatory range for the factors financial advantages for adopters, renown and reputation of suppliers, completeness and availability of products and services, price development of product/service innovation, and self-reinforcing effects. In our sample, these factors influenced diffusion in all sectors. Especially the need for behavioural change appears to be a central barrier to diffusion across all areas of demand which is hard to overcome. Even positive economic effects do not always seem to overcome the obstacle of a necessary change of behaviour. Compared to the 25 most recent empirical studies on the diffusion of environmental innovation (Clausen and Fichter, 2019, p. 67 f.), these findings provide support, but also new insights in regard to relevant diffusion factors. Our findings support the relevance of adopter-related factors (e.g. Barbarossa et al., 2017; Morton et al., 2018) and path-related factors (e.g. Timma et al., 2015; Zhang et al., 2011). While product-related and supplier-related factors have hardly been examined or identified in previous diffusion studies (Clausen and Fichter, 2019, p. 67 f.), our findings reveal the relevance of product-related factors (relative advantage, compatibility) and supplier-related factors (renown and reputation of suppliers, completeness and availability of products and services) for the explanation of dissemination rates and diffusion dynamics in all sectors.

Perhaps the most interesting finding is that none of the sector-related and none of the policy-related factors have a high explanatory range, at least not for our sample. Most of them only have a medium explanatory range. This means that these factors help to explain the process and speed of diffusion in some, but not all, sectors or specific groups of innovations very well. Policy-related factors in particular play a prominent role in the renewable energy sector and the sector for energy-efficient products and services. This supports findings by earlier investigations (Bonilla et al., 2015; Grafström and Lindman, 2017; Kivimaa and Kern, 2016; Morton et al., 2018), but also shows the limitations of single-sector studies. While most recent studies highlight the relevance of policy-related factors, almost all of them are limited to energy (Clausen and Fichter, 2019) and cannot make cross-sector comparisons. Our findings clearly suggest that policy-related factors are very helpful for explaining the diffusion of renewable energies or energy-efficient products and services, but do not have the same relevance and explanatory power in other sectors. A factor was rated as having a ‘high’ explanation range if there was a significant correlation between the factor and the independent variable dissemination rate in the entire sample of 130 diffusion cases and, additionally, if the variable had a consistent influence on the dissemination rate in the extreme case analysis in at least two sectors. This was not the case for any political factor. This finding is of crucial relevance for policy strategies.

With regard to policy strategies, our findings provide another important result. It relates to the type of policy instrument used to accelerate diffusion. Earlier studies showed that ‘policy interventions are more powerful to induce the adoption and development of new clean technologies when designed as a policy mix’ (Veugelers, 2012, p. 1770) and when used in a more balanced combination of demand-pull and technology-push instruments (Costantini et al., 2017). Our finding suggests that the effect of policy interventions also depends very largely on the type of policy instrument used, or to be more precise, on the severity of the instrument (Lanjouw and Mody, 1996). While soft instruments such as information-based interventions (e.g. public labelling schemes) can be very helpful in accompanying hard interventions (strong regulations, economic incentives etc.) in a policy mix, they are not at all sufficient as stand-alone measures. Our extreme case analysis made this very clear e.g. for the agriculture, food, and hospitality sector and the transport and mobility sector. Our findings evidently support the assumption that soft governmental instruments (information) and hard governmental interventions (regulation, taxes, subsidies) have very different impacts on diffusion. This is supported by the case of the diffusion of electric cars in Norway, where high economic incentives had a strong impact on diffusion (Figenbaum, 2017) and indicated that behavioural changes by large groups can be brought about by strong economic instruments, also in the sector of mobility. The case of the Indian state of Sikkim underpins that strong regulation can also move a nation towards organic farming (Avasthe et al., 2019).

The political implication of this analysis is simply that as long as the political community does not do anything significant to transform specific sectors, transformation will not happen, at least in certain sectors such as agriculture and mobility. If an unsuitable political framework giving incentives to unsustainable products is in place, which is evidently the fact in the agriculture, food, and hospitality sector, market forces will restrict better products in the niche since they are more expensive than conventional, unsustainable products. Thus, one key managerial implication for entrepreneurs and businesses is to jointly push for a level playing field for environmental innovations, making sure that subsidies for competing non-sustainable products and services are reduced and that their external costs are internalized in the market mechanism.

Based on the combination of findings in research steps 1 (statistical diffusion path analysis) and 2 (extreme case analysis), we identified eight factors with a medium explanatory range. These help to explain the process and speed of diffusion very well in some, but not all, sectors or for specific groups of innovations. Additionally, the factor ‘role of infrastructure’, which was not included in the 22 variables investigated, was identified as relevant in the transport and mobility sector. Even though not part of the analysis, this factor can also be considered to have a medium explanatory range. We found support for our assumption (see Section 2) that sector- and policy-related factors are strongly related to specific economic sectors. This is not the case with supplier-related factors. Here, we identified two factors (renown and reputation of suppliers, completeness and availability of products or services) with a high explanatory range. They seem to be helpful to explain the process and speed of diffusion in all sectors.

Finally, four factors (perceptibility, low complexity, degree of support by intermediaries as change agents, coverage by media and campaigns) can be relevant in some individual diffusion cases, but do not explain the diffusion of all or most cases in a sector or a specific group of innovations.

6. Limitations and further research

The validity of the results is limited to environmental product and service innovations and cannot be transferred to other types of non-marketable innovations. e.g. social or process innovations. The analysis was also limited to Germany and is based solely on secondary information. Measured against many diffusion studies, the analysis of 130 cases appears high, but is still a low figure for statistical analysis.

Therefore, we had to use an exploratory qualitative approach (multi-case study design) to investigate key drivers in different sectors. The extreme case analysis does not permit generalizations. Therefore, our assumptions with regard to the explanatory range of different factors has to be investigated more deeply and should employ a broader empirical basis. Our findings are a good start for hypothesis generation and then subsequent testing. Also, there is a clear demand for expanding the investigation beyond the five sectors in the focus of this article.

The quantitative part of our analysis is highly dependent on the qualitative evaluation of diffusion paths by a number of experts. Despite the fact that the assessment of experts was guided by a clear coding system and was controlled for by interrater reliability tests, this type of data generation might be considered a limit and needs to be implemented and controlled thoroughly in the future.

As stated in footnote 2, we controlled for the time since market introduction and did not find any influence. Nevertheless, the variation in the amount of time since market introduction among diffusion cases should be a topic in further research.

In our research, we focussed on the factors influencing the diffusion of environmental product and service innovations. Thus, we focussed on the diffusion processes on the market level and not on the level of single companies. Nevertheless, it could be worthwhile to connect insights from market level analysis and firm level analysis (Kiefer et al., 2019) in explaining diffusion dynamics.

Declaration of Competing Interest

The authors report no declarations of interest.

Acknowledgements

The investigation presented in this paper was part of the research project “"Environmental innovations and their diffusion as drivers of the Green Economy" that has been carried out on behalf of the German Environment Agency (Umweltbundesamt, UBA) (Forschungskennzahl FKZ 37 1414 1000). We are grateful for the funding and support of the German Environment Agency. We also thank two anonymous reviewers whose comments have greatly improved the manuscript.

References

Andersen, M.S., Liefferink, D., 1997. European Environmental Policy: The Pioneers. Manchester University.

Andrews, C., DeVault, D., 2009. Green niche market development. J. Ind. Ecol. 13 (2), 326–345. https://doi.org/10.1111/j.1530-9290.2009.00112.x.

Avasthe, R., Singh, R., Babu, S., Pashte, V., Sharma, P., 2019. Organic farming for doubling farmers income by 2022: Sikkim model, Pathway and strategies. Technological Interventions in Organic Farming for Doubling Farmers’ IncomePublisher. https://www.researchgate.net/publication/330900370_Organic_farming_for_doubling_farmers_income_by_2022_Sikkim_model_Pathway_and_strategies.

Azar, C., Sandén, B.A., 2011. The elusive quest for technology-neutral policies. Environ. Innov. Soc. Transit. 1 (1), 135–139. https://doi.org/10.1016/j.eist.2011.03.003.

Baldwin, C., Hienerth, C., von Hippel, E., 2006. How user innovations become commercial products: a theoretical investigation and case study. Res. Policy 35 (9), 1291–1313. https://doi.org/10.1016/j.respol.2006.04.012.

Barbarossa, C., De Pelsmacker, P., Moons, I., 2017. Personal values, green self-identity and electric Car adoption. Ecol. Econ. 140, 190–200. https://doi.org/10.1016/j.ecolecon.2017.05.015.

Barbieri, N., Ghisetti, C., Gilli, M., Marin, G., Nicolli, F., 2016. A survey of the literature on Environmental Innovation based on Main Path Analysis: a survey of the literature on Environmental Innovation. J. Econ. Surv. 30 (3), 596–623. https://doi.org/10.1111/joes.12149.

Barney, J., 1991. Firm resources and sustained competitive advantage. J. Manage. 17 (1), 99–120. https://doi.org/10.1177/014920639101700108.

Beise, M., Rennings, K., 2005. Lead markets and regulation: a framework for analyzing the international diffusion of environmental innovations. Ecol. Econ. 52 (1), 5–17. https://doi.org/10.1016/j.ecolecon.2004.06.007.

Bergek, A., 2020. Diffusion intermediaries: a taxonomy based on renewable electricity technology in Sweden. Environ. Innov. Soc. Transit., S2210422419302813 https://doi.org/10.1016/j.eist.2019.11.004.

Bergek, A., Berggren, C., 2014. The impact of environmental policy instruments on innovation: A review of energy and automotive industry studies. Ecol. Econ. 106, 112–123. https://doi.org/10.1016/j.ecolecon.2014.07.016.

Bleda, M., del Río, P., 2013. The market failure and the systemic failure rationales in technological innovation systems. Res. Policy 42 (5), 1039–1052. https://doi.org/10.1016/j.respol.2013.02.008.

BMU, 2014. GreenTech Made in Germany 4.0 Umwelttechnologie-atlas Für Deutschland (p. 222). Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU). http://www.greentech-made-in-germany.de/fileadmin/user_upload/greentech_atlas_4_0_bf.pdf.

BMUB (Hrsg.), 2016. Klimaschutzplan 2050. Klimaschutzpolitische Grundsätze und Ziele der Bundesregierung (p. 92). Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB). http://www.bmub.bund.de/fileadmin/Daten_BMU/Download_PDF/Klimaschutz/klimaschutzplan_2050_bf.pdf.

Bohnsack, R., Pinkse, J., Waelpoel, A., 2016. The institutional evolution process of the global solar industry: the role of public and private actors in creating institutional shifts. Environ. Innov. Soc. Transit. 20, 16–32. https://doi.org/10.1016/j.eist.2015.10.006.

Bonilla, J., Coria, J., Mohlin, K., Sterner, T., 2015. Refunded emission payments and diffusion of NOx abatement technologies in Sweden. Ecol. Econ. 116, 132–145. https://doi.org/10.1016/j.ecolecon.2015.03.030.

Bottomley, P.A., Fildes, R., 1998. The role of prices in models of innovation diffusion. J. Forecast. 17 (7), 539–555. https://doi.org/10.1002/(SICI)1099-131X(199812)17:7<539::AID-FOR684>3.0.CO;2-S.

Brunner, C., Marxt, C., 2013. Non–governmental organisations (NGO) and businesses in joint product innovation: development of a theoretical framework for “green” products. Int. J. Innov. Sustain. Dev. 7 (2), 192–211. https://doi.org/10.1504/IJISD.2013.053341.

Bruns, E., Köppel, J., Ohlhorst, D., Schön, S. (Eds.), 2008. Die Innovationsbiographie der Windenergie: Absichten und Wirkungen von Steuerungsimpulsen. LIT.

Cainelli, G., Mazzanti, M., 2013. Environmental innovations in services: manufacturing–services integration and policy transmissions. Res. Policy 42 (9), 1595–1604. https://doi.org/10.1016/j.respol.2013.05.010.

Calleja, I., Delgado, L., Eder, P., Kroll, A., Lindblom, J., van Wunnik, C., Wolf, O., Gouarderes, F., Langendorff, J., 2004. Promoting Environmental Technologies: Sectoral Analyses, Barriers and Measures. A Report from the Sustainable Production and Consumption Issue Group as a Contribution to the Environmental Technologies Action Plan. European Commission, Joint Research Center, Institute for Prospecitve Technological Studies.

Clausen, J., 2017. Elektromobilität in Norwegen. Fallstudie im Rahmen des Projekts Evolution2Green – Transformationspfade zu einer Green Economy. Borderstep Institut für Innovation und Nachhaltigkeit. https://evolution2green.de/sites/evolution2green.de/files/documents/2017-03-e2g-fallstudie_emobilitaet_norwegen_borderstep.pdf.
Clausen, J., Fichter, K., 2019. The diffusion of environmental product and service innovations: driving and inhibiting factors. Environ. Innov. Soc. Transit. 31, 64–95. https://doi.org/10.1016/j.eist.2019.01.003.
Clausen, J., Fichter, K., Winter, W., 2011. Theoretische Grundlagen für die Erklärung von Diffusionsverläufen von Nachhaltigkeitsinnovationen. Borderstep Institut für Innovation und Nachhaltigkeit.
Commission of the European Communities (Statistical Office/Eurostat), 2008. Statistical Classification of Products by Activity in the European Economic Community, 2008 Version. https://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_NOM_DTL&StrNom=CPA_2008&StrLanguageCode=EN&IntPcKey=&StrLayoutCode=HIERARCHIC.
Costantini, V., Crespi, F., Palma, A., 2017. Characterizing the policy mix and its impact on eco-innovation: a patent analysis of energy-efficient technologies. Res. Policy 46 (4), 799–819. https://doi.org/10.1016/j.respol.2017.02.004.
Crespi, F., Ghisetti, C., Quatraro, F., 2015. Environmental and innovation policies for the evolution of green technologies: a survey and a test. Eurasian Bus. Rev. 5 (2), 343–370. https://doi.org/10.1007/s40821-015-0027-z.
del Río González, P., 2009. The empirical analysis of the determinants for environmental technological change: a research agenda. Ecol. Econ. 68 (3), 861–878. https://doi.org/10.1016/j.ecolecon.2008.07.004.
Die Bundesregierung, 2017. Deutsche Nachhaltigkeitsstrategie—Neuauflage 2016. Die Bundesregierung. https://www.bundesregierung.de/Content/DE/_Anlagen/2017/01/2017-01-11-nachhaltigkeitsstrategie.pdf?__blob=publicationFile&v=5.
Droste, N., Hansjürgens, B., Kuikman, P., Otter, N., Antikainen, R., Leskinen, P., Pitkänen, K., Saikku, L., Loiseau, E., Thomsen, M., 2016. Steering innovations towards a green economy: understanding government intervention. J. Clean. Prod. 135, 426–434. https://doi.org/10.1016/j.jclepro.2016.06.123.
European Commission, 2011. Innovation for a Sustainable Future—The Eco-innovation Action Plan (Eco-AP).
Fabrizio, K.R., Hawn, O., 2013. Enabling diffusion: how complementary inputs moderate the response to environmental policy. Res. Policy 42 (5), 1099–1111. https://doi.org/10.1016/j.respol.2013.02.003.
Fichter, K., Clausen, J., 2013. Erfolg und Scheitern “grüner” Innovationen. Metropolis.
Fichter, K., Clausen, J., 2016. Diffusion dynamics of sustainable innovation—insights on diffusion patterns based on the analysis of 100 sustainable product and service innovations. J. Innov. Manage. 4 (2), 30–67.
Figenbaum, E., 2017. Perspectives on Norway’s supercharged electric vehicle policy. Environ. Innov. Soc. Transit. 25, 14–34. https://doi.org/10.1016/j.eist.2016.11.002.
Fombrun, C.J., 1996. Reputation: Realizing Value From the Corporate Image. Harvard Business Review Press.
Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Res. Policy 31 (8–9), 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8.
Geels, F.W., 2013. The Arduous Transition to Low-Carbon Energy A Multi-Level Analysis of Renewable Electricity Niches and Resilient Regimes. September 25. Climate - KIC Summer school, Manchester. http://ckic-phd-ffm.net/wp-content/uploads/2013/08/Geels.pdf.
Geels, F.W., 2014. Reconceptualising the co-evolution of firms-in-industries and their environments: developing an inter-disciplinary Triple Embeddedness Framework. Res. Policy 43 (2), 261–277. https://doi.org/10.1016/j.respol.2013.10.006.
Geroski, P.A., 2000. Models of technology diffusion. Res. Policy 29 (4–5), 603–625. https://doi.org/10.1016/S0048-7333(99)00092-X.
Grafström, J., Lindman, Å., 2017. Invention, innovation and diffusion in the European wind power sector. Technol. Forecast. Soc. Change 114, 179–191. https://doi.org/10.1016/j.techfore.2016.08.008.
Haubach, C., Held, B., 2015. Ist ökologischer Konsum teurer? Ein Warenkorbbasierter Vergleich. WISTA 1, 41–54.
Hintemann, R., 2002. Die Diffusion umweltfreundlicher und hochwertiger Gebrauchsgüter: Dargestellt am Beispiel des 3-Liter-Autos, Vol. 2852. Peter Lang; Borderstep Büro Berlin.
Hockerts, K., Wüstenhagen, R., 2010. Greening Goliaths versus emerging Davids—theorizing about the role of incumbents and new entrants in sustainable entrepreneurship. J. Bus. Ventur. 25 (5), 481–492. https://doi.org/10.1016/j.jbusvent.2009.07.005.
Hockerts, K., Wüstenhagen, R., 2012. When David meets Goliath: sustainable entrepreneurship and the evolution of markets. In: Nicholls, A., Murdock, A. (Eds.), Social Innovation. Palgrave Macmillan, UK, pp. 268–293. https://doi.org/10.1057/9780230367098_12.
Hojnik, J., Ruzzier, M., 2016. What drives eco-innovation? A review of an emerging literature. Environ. Innov. Soc. Transit. 19, 31–41. https://doi.org/10.1016/j.eist.2015.09.006.
Horbach, J., 2016. Empirical determinants of eco-innovation in European countries using the community innovation survey. Environ. Innov. Soc. Transit. 19, 1–14. https://doi.org/10.1016/j.eist.2015.09.005.
Horbach, J., Rammer, C., Rennings, K., 2012. Determinants of eco-innovations by type of environmental impact—the role of regulatory push/pull, technology push and market pull. Ecol. Econ. 78, 112–122. https://doi.org/10.1016/j.ecolecon.2012.04.005.
Iyer, G., Hultman, N., Eom, J., McJeon, H., Patel, P., Clarke, L., 2015. Diffusion of low-carbon technologies and the feasibility of long-term climate targets. Technol. Forecast. Soc. Change 90, 103–118. https://doi.org/10.1016/j.techfore.2013.08.025.
Jacobsson, S., Lauber, V., 2006. The politics and policy of energy system transformation—explaining the German diffusion of renewable energy technology. Energy Policy 34 (3), 256–276. https://doi.org/10.1016/j.enpol.2004.08.029.
Jaffe, A.B., Stavins, R.N., 1995. Dynamic incentives of environmental regulations: the effects of alternative policy instruments on technology diffusion. J. Environ. Econ. Manage. 29 (3), S43–S63. https://doi.org/10.1006/jeem.1995.1060.
Jaffe, A.B., Newell, R.G., Stavins, R.N., 2005. A tale of two market failures: technology and environmental policy. Ecol. Econ. 54 (2–3), 164–174. https://doi.org/10.1016/j.ecolecon.2004.12.027.
Jänicke, M., 2005. Trend-setters in environmental policy: the character and role of pioneer countries. Eur. Environ. 15 (2), 129–142. https://doi.org/10.1002/eet.375.
Jänicke, M., 2008. Ecological modernisation: new perspectives. J. Clean. Prod. 16 (5), 557–565. https://doi.org/10.1016/j.jclepro.2007.02.011.
Johnson, F.X., Silveira, S., 2014. Pioneer countries in the transition to alternative transport fuels: comparison of ethanol programmes and policies in Brazil, Malawi and Sweden. Environ. Innov. Soc. Transit. 11, 1–24. https://doi.org/10.1016/j.eist.2013.08.001.
Kanda, W., Clausen, J., Hjelm, O., Bienkowska, D., 2015. Functions of intermediaries in eco-innovation: a study of business development organizations and cluster initiatives in a Swedish and a German region. In: Global Cleaner Production and Sustainable Consumption Conference, Sitges. Barcelona, Spain. https://www.researchgate.net/publication/283352643_Functions_of_intermediaries_in_eco-innovation_a_study_of_business_development_organizations_and_cluster_initiatives_in_a_Swedish_and_a_German_region.
Kanda, W., Hjelm, O., Clausen, J., Bienkowska, D., 2018. Roles of intermediaries in supporting eco-innovation. J. Clean. Prod. 205, 1006–1016. https://doi.org/10.1016/j.jclepro.2018.09.132.
Kanda, W., Kuisma, M., Kivimaa, P., Hjelm, O., 2020. Conceptualising the systemic activities of intermediaries in sustainability transitions. Environ. Innov. Soc. Transit., S2210422420300125 https://doi.org/10.1016/j.eist.2020.01.002.
Kemp, R., Pearson, P., 2007. Final Report MEI Project About Measuring Eco- Innovation. United Nations University. UNU-MERIT.
Kern, F., Kivimaa, P., Martiskainen, M., 2017. Policy packaging or policy patching? The development of complex energy efficiency policy mixes. Energy Res. Soc. Sci. 23, 11–25. https://doi.org/10.1016/j.erss.2016.11.002.
Kiefer, C.P., Del Río González, P., Carrillo-Hermosilla, J., 2019. Drivers and barriers of eco-innovation types for sustainable transitions: a quantitative perspective. Bus. Strat. Environ. 28 (1), 155–172. https://doi.org/10.1002/bse.2246.
Kivimaa, P., Kern, F., 2016. Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions. Res. Policy 45 (1), 205–217. https://doi.org/10.1016/j.respol.2015.09.008.

Klitkou, A., Bolwig, S., Hansen, T., Wessberg, N., 2015. The role of lock-in mechanisms in transition processes: the case of energy for road transport. Environ. Innov. Soc. Transit. 16, 22–37. https://doi.org/10.1016/j.eist.2015.07.005.

Köhler, J., Geels, F.W., Kern, F., Markard, J., Onsongo, E., Wieczorek, A., Alkemade, F., Avelino, F., Bergek, A., Boons, F., Fünfschilling, L., Hess, D., Holtz, G., Hyysalo, S., Jenkins, K., Kivimaa, P., Martiskainen, M., McMeekin, A., Mühlemeier, M.S., et al., 2019. An agenda for sustainability transitions research: state of the art and future directions. Environ. Innov. Soc. Transit. 31, 1–32. https://doi.org/10.1016/j.eist.2019.01.004.

Lanjouw, J.O., Mody, A., 1996. Innovation and the international diffusion of environmentally responsive technology. Res. Policy 25 (4), 549–571. https://doi.org/10.1016/0048-7333(95)00853-5.

Läpple, D., Rensburg, T.V., 2011. Adoption of organic farming: are there differences between early and late adoption? Ecol. Econ. 70 (7), 1406–1414. https://doi.org/10.1016/j.ecolecon.2011.03.002.

Lehmann-Waffenschmidt, M., Reichel, M., 2000. Kontingenz, Pfadabhängigkeit und Lock-In als handlungsbeeinflussende Faktoren der Unternehmenspolitik. In: Beschorner, T., Pfriem, R. (Eds.), Evolutorische Ökonomik und Theorie der Unternehmung. Metropolis.

Lüthje, C., Herstatt, C., 2004. The Lead User method: an outline of empirical findings and issues for future research. R&D Manage. 34 (5), 553–568. https://doi.org/10.1111/j.1467-9310.2004.00362.x.

Mazur, C., Contestabile, M., Offer, G.J., Brandon, N.P., 2015. Assessing and comparing German and UK transition policies for electric mobility. Environ. Innov. Soc. Transit. 14, 84–100. https://doi.org/10.1016/j.eist.2014.04.005.

Menanteau, P., Lefebvre, H., 2000. Competing technologies and the diffusion of innovations: the emergence of energy-efficient lamps in the residential sector. Res. Policy 29 (3), 375–389. https://doi.org/10.1016/S0048-7333(99)00038-4.

Mignon, I., Bergek, A., 2016. System- and actor-level challenges for diffusion of renewable electricity technologies: an international comparison. J. Clean. Prod. 128, 105–115. https://doi.org/10.1016/j.jclepro.2015.09.048.

Morton, C., Wilson, C., Anable, J., 2018. The diffusion of domestic energy efficiency policies: a spatial perspective. Energy Policy 114, 77–88. https://doi.org/10.1016/j.enpol.2017.11.057.

Mukoyama, T., 2003. A Theory of Technology Diffusion. Concordia University, Department of Ecnomics. http://128.118.178.162/eps/mac/papers/0303/0303010.pdf.

Nelson, R.R., 1994. The Co-evolution of technology, industrial structure, and supporting institutions. Ind. Corp. Change 3 (1), 47–63. https://doi.org/10.1093/icc/3.1.47.

Nill, J., Kemp, R., 2009. Evolutionary approaches for sustainable innovation policies: from niche to paradigm? Res. Policy 38 (4), 668–680. https://doi.org/10.1016/j.respol.2009.01.011.

Nolden, C., Sorrell, S., Polzin, F., 2016. Catalysing the energy service market: the role of intermediaries. Energy Policy 98, 420–430. https://doi.org/10.1016/j.enpol.2016.08.041.

Penna, C.C.R., Geels, F.W., 2012. Multi-dimensional struggles in the greening of industry: a dialectic issue lifecycle model and case study. Technol. Forecast. Soc. Change 79 (6), 999–1020. https://doi.org/10.1016/j.techfore.2011.09.006.

PricewaterhouseCoopers, 2017. Konsumentenbefragung: Bio vs. Konventionell—Was kaufen die Konsumenten zu welchem Preis? https://www.pwc.de/de/handel-und-konsumguter/assets/pwc-bevoelkerungsbefragung-bio-vs-konventionell.pdf.

Quitzow, R., 2015a. Assessing policy strategies for the promotion of environmental technologies: a review of India's National Solar Mission. Res. Policy 44 (1), 233–243. https://doi.org/10.1016/j.respol.2014.09.003.

Quitzow, R., 2015b. Dynamics of a policy-driven market: the co-evolution of technological innovation systems for solar photovoltaics in China and Germany. Environ. Innov. Soc. Transit. 17, 126–148. https://doi.org/10.1016/j.eist.2014.12.002.

Quitzow, R., Walz, R., Köhler, J., Rennings, K., 2014. The concept of "lead markets" revisited: contribution to environmental innovation theory. Environ. Innov. Soc. Transit. 10, 4–19. https://doi.org/10.1016/j.eist.2013.11.002.

Rennings, K., 1998. Towards a Theory and Policy of Eco-Innovation—Neoclassical and (Co-)Evolutionary Perspectives (ZEW Discussion Paper No. 98–24). Center for European Economic Research. http://ideas.repec.org/p/zbw/zewdip/5510.html.

Rip, A., Kemp, R., 1998. Technological change. Human Choices and Climate Change. Batelle, pp. 327–399.

Rogers, E.M., 2003. Diffusion of Innovations, Vol. 5. Free Press, Borderstep Büro Berlin.

Rogers, E.M., Medina, U.E., Rivera, M.A., Wiley, C.J., 2005. Complex adaptive systems and the diffusion of innovations. Innov. J. 10 (3).

Scherrer, A., Plötz, P., Van Laerhoven, F., 2020. Power from above? Assessing actor-related barriers to the implementation of trolley truck technology in Germany. Environ. Innov. Soc. Transit. 34, 221–236. https://doi.org/10.1016/j.eist.2020.01.005.

Schiederig, T., Tietze, F., Herstatt, C., 2012. Green innovation in technology and innovation management—an exploratory literature review. R&D Manage. 42 (2), 180–192. https://doi.org/10.1111/j.1467-9310.2011.00672.x.

Seawright, J., Gerring, J., 2008. Case selection techniques in case study research: a menu of qualitative and quantitative options. Polit. Res. Q. 61 (2), 294–308. https://doi.org/10.1177/1065912907313077.

Shapiro, C., Varian, H.R., 1999. Information Rules: A Strategic Guide to the Network Economy. Harvard Business Press. http://books.google.de/books/about/Information_Rules.html?id=aE_J4Iv_PVEC&redir_esc=y.

Tappeser, V., Fromm, C., 2018. Wärmenetze in Dänemark: Fallstudie im Rahmen des Projekts Evolution2Green – Transformationspfade zu einer Green Economy. https://evolution2green.de/sites/evolution2green.de/files/documents/2017-04-e2g-fallstudie_waermenetze_daenemark_adelphi.pdf.

Timma, L., Blumberga, A., Blumberga, D., 2015. Understanding the technological substitution by hybrid modelling practice: a methodological approach. Chem. Eng. Trans. 379–384. https://doi.org/10.3303/CET1545064.

Veugelers, R., 2012. Which policy instruments to induce clean innovating? Res. Policy 41 (10), 1770–1778. https://doi.org/10.1016/j.respol.2012.06.012.

Vollebergh, H.R.J., Kemfert, C., 2005. The role of technological change for a sustainable development. Ecol. Econ. 54 (2–3), 133–147. https://doi.org/10.1016/j.ecolecon.2004.12.025.

von Koerber, K., 2000. Preise von Erzeugnissen aus konventioneller Landwirtschaft vs. Preise von Öko-Lebensmitteln. ERNO 1, 128–130.

Walz, R., Köhler, J., 2014. Using lead market factors to assess the potential for a sustainability transition. Environ. Innov. Soc. Transit. 10, 20–41. https://doi.org/10.1016/j.eist.2013.12.004.

Wüstenhagen, R., Hamschmidt, J., Sharma, S., Starik, M. (Eds.), 2008. Sustainable Innovation and Entrepreneurship. Edward Elgar.

Zeppini, P., Frenken, K., Kupers, R., 2014. Thresholds models of technological transitions. Environ. Innov. Soc. Transit. 11, 54–70. https://doi.org/10.1016/j.eist.2013.10.002.

Zhang, T., Gensler, S., Garcia, R., 2011. A study of the diffusion of alternative fuel vehicles: an agent-based modeling approach*: diffusion of alternative fuel vehicles. J. Prod. Innov. Manage. 28 (2), 152–168. https://doi.org/10.1111/j.1540-5885.2011.00789.x.