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DISCUSSION PAPER

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Which Government Subsidies Are Relevant for Eco-Innovation? Empirical Evidence from Firm-Level Panel Data

Which Government Subsidies are Relevant for Eco-innovation? Empirical Evidence from Firm-level Panel Data

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Abstract

Eco-innovations are highly important for mitigating climate change and transitioning towards a circular economy. There is extensive literature on the determinants of eco-innovation. The analysis of the role of government subsidies, however, is still under-developed. Subsidies are controversially discussed because they may distort competition and lead to less efficient solutions. At the same time, eco-innovations may produce positive externalities both at the innovation stage (knowledge spillovers) and the diffusion stage (reducing environmental damage). Subsidies may hence be important to avoid private under-investment in such innovations. The paper investigates which types of subsidies (e.g. general vs. research oriented, regional vs. national vs. supranational) are used by firms that engage in different fields of eco-innovation. The analysis is based on panel-econometric estimations using data from the German part of the Community Innovation Survey (CIS), covering the years 2020 to 2024. The results show that regional subsidies and general industry support are important for the diffusion of eco-innovations, such as the substitution of fossil fuels by renewables, because they help to overcome financial constraints. Specific R&D subsidies are important for innovations leading to less CO_2 emissions in production processes.

JEL Classification: C23, C25, Q55, Q58

Keywords: Green subsidies, eco-innovation, random effects panel probit models

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1. Introduction

Eco-innovations leading to lower environmental impacts are a pre-condition for climate change mitigation (Horbach and Rammer 2025). Following Rennings (2000), eco-innovations are characterized by a double externality, as they produce positive spillovers both in the innovation phase (knowledge spillovers) and the diffusion stage (lowering environmental externalities), making eco-innovations different from other innovation activities. Positive spillovers in the diffusion phase might particularly be accompanied by lower incentives to invest in such innovations as only a part of the innovation's benefits can be acquired by the innovator. As a result, investment in eco-innovation activities might be lower than for other investments. This might be especially true for firms already facing financial constraints (Ghisetti et al. 2017, Jensen et al. 2019, Cecere et al. 2020). The double externality character of eco-innovations may thus justify the use of government subsidies to inducing and supporting environmental-friendly innovation activities.

While many studies of the determinants of eco-innovation include the role of subsidies (see Meissner et al. 2026 for a recent literature survey, Ren et al. 2021 for China, Tchorzewska 2024 for Spain, and Marino et al. 2022 for the Netherlands), there is no comprehensive study that analyzes the importance of different types of subsidies for different eco-innovation fields. Such an analysis is highly relevant, however, since eco-innovation fields differ in various dimensions and are subject to different types of market failures that may be addressed by government support. For example, the substitution of fossil fuels by renewables are diffusion-oriented innovations as the main components like solar cells or wind turbines are already developed, but they must be installed by firms. In this case, general subsidies simply helping to overcome financial constraints might be useful. In other cases, such as the new development of machinery and equipment with lower energy consumption redirecting already existing technology paths (Acemoglu et al. 2012), research-oriented subsidies might be the right choice.

The present paper aims to find out which types of subsidies are most relevant for different eco-innovation activities, and which eco-innovation activities do particularly rely on which type of public financial support. First, we analyze the relative importance of subsidies for eco-innovation activities compared with other determinants such as regulation or taxes, cost-saving opportunities, reputation and public pressure or customer demand. In a second step, we investigate the link between different types of public subsidies and different eco-innovation activities. Our analysis is explorative in nature and not intended to evaluate the causal impact of government subsidies on eco-innovation.

The empirical analysis is based on panel data combining three waves of the German part of the Community Innovation Survey (CIS), covering the reference years 2020, 2022 and 2024. The data contains detailed information on different types of subsidies that were used by eco-innovators, and on seven types of process-related and four types of product-related eco-innovations.

The paper is organized as follows: Section 2 discusses the theoretical background of the relationship between subsidies and eco-innovation and includes an overview of the respective empirical literature. Section 3 provides information on the data, descriptive statistics and our panel estimation strategy. Section 4 shows the results of econometric models on the importance of subsidies for eco-innovation. Section 5 summarizes and concludes.

2. Subsidies and Eco-Innovation: Literature Overview and Hypotheses

Literature overview

In the following, recent theoretical and empirical analyses on the role of government subsidies for eco-innovation are summarized. For a comprehensive literature overview, see Meissner et al. (2026). Systematic analyses of the role of subsidies for different eco-innovation fields are rather rare. In an early study, Johnstone et al. (2010) show that investment incentives are particularly relevant for solar and waste-related eco-innovations. Casey et al. (2025) analyze clean energy production subsidies in a quantitative climate-economy model. Following their results, subsidies are only successful in decreasing carbon emissions if they lead to a lower marginal product of dirty energy. This depends on the elasticity of substitution between clean and dirty energy and on the price elasticity of demand for energy. The authors claim that a tax on dirty energy is a more efficient instrument compared to subsidies. Based on a calibrated theoretical model, Meissner (2025) shows that R&D subsidies support knowledge accumulation and lead to a higher competitiveness of the clean sector.

Johansson and Kriström (2019) analyze the effects of phasing out the Swedish green certificate scheme supporting renewable energy at the beginning of 2018, connected with an ex-post assessment for 2003-2017. The authors find that in the absence of the certificate scheme, the buildup of renewable power plants would have been slower compared to the observed scenario. The economic effects seem to be negative because the certificate system "shifted investments from later and cheaper to earlier and more expensive technologies" (Johansson and Kriström 2019: 152). Fink and Talbi (2024) use Swedish data for the 1970 to 2021 period and find that public funding is particularly important for the development of renewable energy technologies and radical innovations. The authors conclude that their analysis shows, against widespread opinion, that governments are able picking winners in the innovation process.

Koski and Wang (2024) investigate the effects of R&D and compensation subsidies on competitiveness and innovation, using firm-level data from Finnish energy-intensive industries for 2010 to 2022. Compensation subsidies that reduce the additional electricity costs caused by the European Emission Trading Scheme do not show employment or productivity effects whereas R&D subsidies promote innovation activities measured by citation stocks of climate change mitigation technology patents.

For Dutch manufacturing firms between 1999 and 2011, Marino et al. (2022) find out that environmentally oriented subsidies help to finance process integrated and end-of-pipe technologies. A high amount of subsidy payments particularly favors the implementation of the latter technologies. Furthermore, environmental subsidies seem to be more important for internal R&D compared to external R&D expenses. Tchorzewska (2024) analyzes the impacts of the Spanish Environmental Investment (EI) tax credit on the adoption of green technologies using data of a sample of Spanish firms over six years. She finds out that the tax credit was accompanied by a decrease in investment in end-of-pipe technologies whereas the investment in cleaner production technologies increased but only for small firms below 50 employees.

Jensen et al. (2019) look at financial constraints of environmentally innovative firms. Using data from the German CIS, the authors find out that these firms seem to have higher financial needs compared to other firms so that subsidies are an important tool to reduce financial restrictions of eco-innovations. Ghisetti et al. (2017) also analyze the role of financial barriers in affecting the adoption of environmental innovations (EI) for manufacturing small and medium-sized enterprises in Europe. The authors show direct negative effects of financial barriers on environmental innovation investments. Using data on more than 2000 European SMEs from the 2016 Eurobarometer, Ghisetti and Montresor (2020) explore the relevance of different financial sources for the Circular Economy (CE). Self-financing seems to be a significant enabler of the adoption of CE practices whereas debt financing plays a less important role. For small- and medium-sized enterprises from different European countries, Cecere et al. (2020) show that public funds and fiscal incentives help to overcome financial constraints thus improving firms´ ability to realize eco-innovations. D'Orazio and Valente (2018) develop a theoretical model combining evolutionary economics concepts and methods with environmental economics concerns. The authors show "… that financial constraints act as a deterring barrier and affect firms' innovation strategies as well as the evolution of technological paradigms.” (D´Orazio and Valente 2018: 1)

Bartels and Werthschulte (2025) use an experimental design to analyze the demand effects of subsidies. The participants shall decide on purchasing a low-flow showerhead. A subsidy or a price decrease is offered as purchase incentive. “We find a demand increase of about 3 percentage points when the price decreases and a significantly larger demand increase of about 9 percentage points when the subsidy is introduced.” (Bartels and Werthschulte 2025: 1)

Ren et al. (2021) use Chinese panel data of manufacturing firms for the period 2011-2015. They show that subsidies promote environmental management innovations but there is no significant positive correlation with environmental technology innovations. For Chinese service firms and the period 2014 to 2020, Xu et al. (2024) find that subsidies promote green innovations particularly in less developed regions. Zhang (2022), also using data of Chinese firms, shows positive effects of subsidies for green innovation. Cleaner production firms seem to receive significantly greater benefits from subsidies compared to heavily polluting firms. Using 2010-2023 data for Chinese listed firms, Zhang et al. (2025) show that government subsidies and green innovation are positively correlated. A high environmental, social, and governance performance supports environmentally oriented R&D activities.

All in all, the existing literature shows positive correlations between subsidies and eco-innovation activities of firms. Investment incentives seem to be particularly relevant for the development of renewable energy technologies and other cleaner production technologies. Eco-innovators seem to be more affected by financial constraints compared to other innovators so that subsidies are an important tool to reduce these financial restrictions of eco-innovations and mitigate negative effects of financial barriers on investments in these technologies. Although there are studies on different effects of subsidies on end-of-pipe technologies compared to cleaner production technologies (Tchorzewska 2024, Zhang 2022), there is a research gap in analyzing the role of different subsidies for a more detailed breakdown of eco-innovation fields.

Theoretical background: government subsidies for eco-innovation

Government subsidies for eco-innovation activities can be justified by the double externality problem. As Rennings (2000: 325) states, “an important peculiarity of eco-innovations is that they produce positive spillovers in both the innovation and diffusion phase. Positive spillovers in the diffusion phase appear due to a smaller amount of external costs compared to competing goods and services on the market.” Incentives for firms to invest in eco-innovation activities might thus be lower compared to other investments. Government subsidies can provide incentives to firms to invest in eco-innovations despite the presence of both kinds of externalities.

There are further arguments in favor of eco-innovation subsidies. Environmental technologies are often embedded in complex production systems. For many eco-innovations, e.g. innovations to increase energy or material efficiency, these systems need to be modified, which can be technologically complex and expensive, making eco-innovations particularly risky and costly. With respect to capital market, uncertainty about technological and economic prospects of eco-innovation and information asymmetries between investors and financiers of eco-innovation projects limit financing for eco-innovations (Buchholz et al. 2024) and may result in higher financial constraints for eco-innovators as compared to other innovators (Ghisetti et al. 2017, D´ Orazio and Valente 2018, Cecere et al. 2020).

Innovations in production technology may also require the establishment of new networks, e.g. when replacing fossil fuel with renewable energy sources. This redirection of production processes (Acemoglu et al. 2012) might be supported by fitting subsidies particularly in early stages of these cost-intensive changes to production processes. Furthermore, research subsidies might help to avoid negative economic effects of high carbon taxes, mitigating adverse distributional effects and improving political feasibility (Buchholz et al. 2024, Acemoglu et al. 2012).

Government subsidies are, however, only one way to stimulate the implementation of eco-innovation. The literature often focuses on two other government instruments that governments frequently use to increase the rate of eco-innovations in an economy: regulation and taxation (Demirel and Kesidou 2012). In general, taxation and other market-based instruments such as emission trading are viewed superior over regulation (characterized as command-and-control instrument) due to cost efficiency and higher flexibility (Requate and Unold 2003, Requate 2005). However, some studies showed that regulation can play an important role for certain types of eco-innovation. Frondel et al. (2007) found that regulation stimulates end-of-pipeline solutions while having a minimal role for integrated cleaner production technologies. Regulations were also found to create ‘win–win’ situations when firms can achieve high profits and growth from R&D activities (and following innovations) that were initiated or triggered by environmental regulation (Hart 2004, Popp 2005, Rothfels 2002), or when regulation creates new 'green' markets and eco-innovators become market leaders (Rothfels 2002). Both situations have been described as the 'Porter Hypothesis' (Porter and Van Der Linde 1995). Rexhäuser and Rammer (2014) showed that these situations mainly relate to efficiency-increasing eco-innovations (such as an increase in energy and material efficiency), but less for eco-innovations that primarily reduce environmental externalities without producing efficiency gains for the eco-innovator.

Compared to taxation and regulation, subsidies are useful government instruments in case the double externality is particularly strong, i.e. when the eco-innovation activities of firms produce high knowledge spillovers (e.g., because they tap into new fields of technology) and significantly reduce environmental externalities for others, strongly limiting the private returns of the eco-innovator. In addition, subsidies will be relevant whenever neither regulation requires firms to invest in abatement technologies, nor taxation provides incentives for eco-innovation. Our first hypothesis hence reads:

H1: Subsidies are more important for eco-innovations that are faced by high financial constraints and low private returns, or which are not addressed by regulation or taxation.

Theoretical background: types of subsidies for different types of eco-innovation

Most of the existing empirical analyses on the role of government subsidies for eco-innovation do not consider the type of subsidy nor the type of eco-innovation activity. This is a relevant knowledge gap, since different subsidies may spur different types of eco-innovations. To maximize the contribution of public support to achieving environmental goals, a better understanding of the links between subsidies and eco-innovation is required. In fact, governments offer a variety of subsidy programs, covering different policy objectives and often demanding specific requirements from firms when using the programs. Three dimensions of subsidy programs are particularly relevant in this context: (a) Whether the program supports R&D (i.e., generating new knowledge and new technology) or more diffusion-oriented forms of investment (e.g., adopting existing technology); (b) Which type of financing instrument is offered (grants, loans, venture capital); (c) Which government level is running the program (regional, national, supranational).

The design of subsidies for different eco-innovation fields is hence a key issue for maximizing the impact of government support. Existing studies show that financial constraints restrain eco-innovation, but do not provide insights into the type of subsidy or the type of eco-innovation (Ghisetti et al. 2017, Ghisetti and Montresor 2020, D´Orazio and Valente 2018). The extent to which financial constraints are relevant for eco-innovation, and hence government subsidies needed to overcome financial constraints, will vary by the type of eco-innovation, however. For investigating the link between different types of government subsidies and different types of eco-innovation, we start by discussing relevant dimensions of eco-innovations that determine the type and amount of financing, distinguishing risk exposure, tangibility, investment size, and private returns (Hall and Lerner 2010, Hottenrott and Peters 2012, Spielkamp and Rammer 2009, Giebel and Kraft 2019). We relate these four dimensions to different types of eco-innovation and analyze how different types of government subsidies relate to these four dimensions, focusing on two financing instruments most frequently used for supporting eco-innovation: R&D grants and general investment subsidies distributed through government loans.

In general, financial constraints will be higher, the higher risk exposure and investment size of an eco-innovation activity, the more intangible an investment is, and the lower the private returns (due to positive externalities) from the innovation will be (Hall and Lerner 2010). At the same time, higher financial constraints will call for government interventions through offering subsidies to provide sufficient incentives to firms for investing in eco-innovations needed to address environmental challenges such as climate change.

Risk exposure refers to the probability that an innovation effort will fail. Such risk can relate to the technological feasibility of an innovation idea, the acceptance of the innovation in the market, and likely simultaneous innovation efforts of competitors that may limit the commercial prospects of the innovation. It is also closely linked to the concept of uncertainty (Knight 1921) that is common to many innovations, describing the lack of information to establish in advance whether an innovative idea can be put into practice and will succeed economically. In addition, assessing the risk of an innovation project requires in-depth knowledge about the information, which external investors may lack. These information asymmetries further complicate external financing (Hall 2009, Brown and Petersen 2009, Bond et al. 2010). The concept of *tangibility* refers to the extent to which an eco-innovation involves investment in fixed assets such as machinery, equipment and buildings. A high share of tangible investment eases external financing as tangible investment produces assets that can be used as collaterals for loans. Eco-innovations are often associated with high tangible investment for re-designing production processes aiming at lower emission levels and lower consumption of energy and other resources. The *amount of investment* required for eco-innovation determines the financing demand for the innovator and is closely linked to the scale, scope and complexity of the eco-innovation project. The private returns from innovation largely determine the extent to which an innovation can be self-financed from the profits it generates. For eco-innovation, private returns tend to be lower than for other innovations, owing to the double externality nature. With respect to *private returns*, Rexhäuser and Rammer (2014) distinguished efficiency-enhancing from other eco-process innovation, the latter mainly producing fewer negative externalities and offering little private returns to the innovator.

In the empirical part of our study, we distinguish seven different types of eco-innovation related to processes performed by a firm ('eco-process innovation'), and four types of eco-innovation related to the environmental performance of products (incl. services) offered by a firm and used by the firm's customers ('eco-product innovation'). The types of eco-innovation are taken from the CIS questionnaire and have been developed by Kemp and Pearson (2007). The individual types are separated along the type of environmental externality they aim to reduce. Based on typical characteristics of the different types of eco-innovation, it is possible to classify them by risk exposure, tangibility, investment size and private returns (see Table 1), although the classification has to remain somewhat superficial owing to the variety of technologies and investments that may be used to reduce a certain environmental externality in a specific firm setting. In general, eco-process innovations are typically characterized by lower risk exposure compared to eco-product innovations, since for most processes, there is proofed state-of-the-art technology available, e.g. for increasing energy efficiency, reducing air, water, soil or noise emissions, or for substituting fossil energy sources by renewables. At the same time, these eco-innovations often require a significant amount of investment as production technologies need to be adapted or replaced. Most of the investment required is tangible in nature (machinery and equipment, buildings).

There are, however, some types of eco-process innovation with higher risk exposure, as they often require R&D efforts, e.g. in case of substituting hazardous substances by less dangerous ones through re-designing products and production processes. Other types of eco-process innovation such as improved recycling of waste, water and material often involve organizational innovations along with smaller investment amounts and more intangible expenditures.

Eco-innovations that reduce energy use, material use and CO_2 emissions have been classified as efficiency improving by Rexhäuser and Rammer (2014), since the directly lower operation costs of the innovator (for CO_2 emissions only in case an emission trading system is in place). The reduction of other emissions and the substitution of dangerous substances are mainly reducing negative externalities. Substituting fossil energy sources by renewable ones and improved recycling of waste, water and material may be either way, depending on the relative prices of fossil and renewable energy, and the relation between recycling cost and market prices for recycled items.

For eco-product innovation, risk exposure is typically higher as many of these innovations require own R&D efforts. At the same time, investment size tends to be lower than for eco-process innovation and involve more intangible investment (e.g., expenditure for R&D personnel). Private returns of eco-product innovation are likely to be higher than for eco-process innovation, since a better environmental performance of products can help users to save cost (e.g. in case of higher energy efficiency or improved recyclability), which can be transferred into higher product prices. Some features of eco-product innovation such as longer product lifetime may limit private returns for innovators, however, in case longer lifetime reduces overall demand (in number of items sold) for their products while users are not willing to pay a proportionately higher price for the more durable products (Nishijima 2026).

Table 1: Classification of types of eco-innovation by risk exposure, tangibility, investment size and private returns

Type of eco-innovation	Risk exposure	Tangibility	Investment size	Private returns
Eco-process innovation				
Reduction of energy use per unit of output	-	+	+	+
Reduction of material use per unit of output	0	+	+	+
Reduction of CO_2 emissions	-	0	+	+
Reduction of other emissions (air, water, soil, noise)	-	0	+	-
Substitution of fossil energy sources by renewables	-	+	+	0
Substitution of dangerous substances	+	-	0	-
Recycling of waste, water, material	-	0	0	0
Eco-product innovation				
Reduction of energy use and/or CO_2 footprint	0	-	-	+
Reduction of other emissions (air, water, soil, noise)	0	-	-	0
Improvement of recyclability after use	+	-	0	+
Increase in product lifetime	+	-	0	0

Source: Own presentation.

In the next step, we analyze how financial support by governments can address risk exposure, tangibility, investment size and limited private returns in order to lower financial constraints of eco-innovators. We focus on two types of subsidies that are most frequently used when it comes to eco-innovation: R&D grants and loans for general investment.[1] R&D grants are the preferred financing instrument for high-risk activities (Franzoni et al. 2022). They are typically limited in volume and are hence less suited for large investment. R&D grants typically address financial

[1] Two other major financing instruments used by governments include venture capital and tax credits. We do not consider venture capital in this study because it is of very limited relevance in the context of government subsidies for eco-innovation in Germany, which is the empirical case for our analysis. Tax credits for R&D have been introduced recently in Germany and are designed in a way that they operate very similar to R&D grants (Rammer 2025), as they provide 25-35% subsidy on the costs of eligible R&D projects and are directly paid to firms (including payout in case of loss).

constraints resulting from high knowledge spillovers, resulting in limited private returns. General loans, in contrast, are rarely suited for high-risk investment, since a high likelihood of failure would result in total loan default. Loans typically require a certain amount of collaterals and hence prefer tangible investment. While loans offer financing for large investment volumes, private returns from the investment are essential to serve interest payment.

Table 2: Types of government subsidies to address risk exposure, tangibility and amount of investment

Type of subsidy	Risk exposure	Tangibility	Investment size	Private returns
R&D Grants	+	-	-	-
General loans	-	+	+	+

Source: Own representation.

Combining the typical situation for different types of eco-innovations with respect to risk exposure, tangibility, investment size, and private returns with the suitability of different government subsidies to provide appropriate financing, leads to the following hypotheses:

H2: Firms with eco-innovation activities that require higher investment volumes for tangible assets while relying on proofed technology and offering a sufficient level of private returns will rely on general subsidies based on loans.

H3: R&D grants will be more often used for eco-product innovation, as they require firm-specific development which involves higher risk, and for those eco-process innovations that require the development of new technological solutions.

In addition to the type of financing instrument, we also consider the role of government levels for subsidizing different types of eco-innovation. In the German context, three government levels are relevant: regional governments (i.e. the governments of the 16 German Federal States), the Federal Government (national level), and the European Commission (international level). Regional governments are primarily interested in advancing the local economy. While they have limited financial resources, they aim to leverage most for their region, e.g. by focusing on regional cooperation and clusters. With respect to eco-innovation, regional governments tend to prioritize those types of eco-innovations that are particularly needed in their region to address local environmental challenges.

The national government typically aims to support eco-innovation activities that are relevant for the entire economy, following national strategic goals such as the transition of the energy supply system towards renewable sources or meeting national climate policy objectives in terms of CO_2 emissions. To meet these goals, the Federal government runs several R&D programs aiming to develop new environmental technologies that promise to reach the national goals quickly and comprehensively. These programs are typically highly competitive, and agencies running the programs focus on a "picking the winners" approach in order to allocate public money to those firms that can create the required technologies fastest and most cost-efficient. Since the content of eco-technological developments for addressing specific environmental externalities is usually pre-defined by the agencies, the number of beneficiaries is rather limited. In addition, there are Federal loan programs that provide financing to firms for adopting these technologies. These programs typically focus on specific technologies that have been identified as critical at the national level, which may not always match regional priorities.

Distinguishing different government levels is also relevant with respect to how subsidies are delivered to eco-innovators. Costly and time-consuming application processes are likely to reduce the relevance of programs. This is particularly true for supranational programs such as the European Horizon program, which involves rather complex procedures and favors large, often international project consortia, resulting in high coordination costs at the side of firms and lengthy processes to develop and implement a project. There are schemes in place to ease access for smaller firms ('SME Instrument'), but also these schemes are demanding and require specific capabilities from SMEs (Mina et al. 2021). While European programs such as the Horizon program include schemes that address environmental challenges (e.g., solutions for a circular economy), the projects have to follow pre-defined topics and technological solutions that are not specific to the situation in a particular country. Funding through European Structural Funds is more flexible in terms of project size but also needs to meet pre-defined European environmental goals, which often do not match with the eco-innovation strategies of local firms.

Based on the characteristics of the programs offered by different government levels, we derive the following hypothesis:

H4: Local subsidies are more important for financing eco-innovations than national subsidies as they are more tailor-made to the specific eco-innovation activities of firms, while supranational subsidies are less important due to high cost of accessing the programs.

3. Eco-innovation and government subsidies: data and descriptive statistics

To analyze our research question, we need detailed data on both eco-innovation activities of firms and government subsidies that have been used by the same firms. The Community Innovation Survey (CIS) of the European Commission provides a very useful database in this respect as it surveys both types of information. For this paper, we rely on the German part of the CIS, which is called the Mannheim Innovation Panel (MIP) as it provides panel data along with additional firm-level information (Peters and Rammer 2023). We use the survey waves for reference years 2020, 2022 and 2024 since they contained questions on innovations with environmental benefits that allow separating between different fields of eco-product and eco-process innovations (Horbach et al. 2012). At the same time, each of the three survey waves included a question on government subsidies used by the firm.

The MIP is a sample survey based on a stratified random sample. The sample size of the MIP 2024 wave included 44,106 firms. The net response rate was 32.9% (Rammer and Schubert 2026). For earlier survey waves, sample size and response rate were at a similar level. Methodological details of the survey can be found in Peters and Rammer (2023).

Table 3 shows the distribution of the different process- and product eco-innovation fields from 2020 to 2024 that are captured in the CIS questionnaire. The question asks firms for each type of eco-innovation whether the innovation had a significant or only a minor impact on reducing environmental externalities. Table 3 reports the results for firms with significant environmental impacts only. Concerning eco-process innovations, the reduction of energy use (10.5% in 2024) and the substitution of fossil energy sources by renewables (10.3%) are most frequently used, while the reduction of energy use and CO_2 footprint is the most frequent type of eco-product innovations.

Table 3: Importance of different eco-innovation fields, 2020-2024

Eco-innovation field	Eco-innovators by eco-innovation field (share in all firms, %)		
	2020	2022	2024
Eco-process innovations			
Reduction of energy use	9.8	7.1	10.5
Reduction of material use	5.3	4.3	6.3
Reduction of CO_2 emissions	7.4	5.9	8.7
Reduction of other emissions (air, water, noise, soil)	7.7	5.5	4.4
Substitution of fossil energy sources by renewables	6.5	6.4	10.3
Substitution of dangerous substances	3.4	2.4	3.5
Recycling of waste, water, material	7.2	6.1	7.2
Eco-product innovations			
Reduction of energy use and/or CO_2 footprint	11.0	10.0	12.5
Reduction of other emissions (air, water, soil, noise)	6.9	5.4	8.1
Improvement of recyclability after use	6.1	5.3	6.8
Increase in product lifetime	7.1	6.2	7.7
Eco-innovative firms (= at least one eco-process or eco-product innovation)	26.4	22.8	26.8

Eco-innovator: firm that introduced an eco-innovation that made a significant contribution to protecting the environment.
Source: German CIS 2020-2024, own calculations.

When combining the seven types of eco-process innovation and the four types of eco-product innovation, 26.8% (2024) of all firms had at least one eco-innovation with a significant environmental impact. This share was about the same in 2020, but somewhat lower in 2022 (22.8%), potentially reflecting the more difficult economic situation for many firms at the end of the COVID-19 pandemic.

The CIS waves of 2020 and 2024 allow an analysis of the drivers of eco-innovation activities, including the relevance of government subsidies (Table 4). Based on a question that asks firms to rate the importance of nine different drivers of eco-innovations, existing regulations (27.7% in 2024) and high energy or raw material costs (27.3%) were most often reported as highly important drivers for the eco-innovations that have been introduced by a firm in the preceding three-year period. Expected environmental regulations/taxes, the improvement of the firm's reputation as well as voluntary agreements and industry standards are further important drivers of eco-innovations. Environmental subsidies by governments were highly important for 8.1% (2024) of all eco-innovators. From 2020 to 2024, there was no substantial change in the importance of the different drivers of eco-innovations.

Table 4: Drivers of eco-innovations in Germany 2020 and 2024

Determinants (in the order as presented in the questionnaire)	High importance of the driver (share in all eco-innovators, %)	
	2020	2024
Existing environmental regulations	27.2	27.7
Existing environmental taxes	11.1	12.2
Expected environmental regulations or taxes	15.8	18.2
Environmental subsidies	8.5	8.1
Demand for eco-friendly products	9.9	8.0
Improving the reputation of the firm	14.6	14.3
Voluntary agreements, industry standards	13.5	13.6
High cost of energy or raw material	26.0	27.3
Public procurement requirements	5.7	6.0

Source: German CIS 2020 and 2024, own calculations.

Table 5 shows the main types of government subsidies available to firms in Germany. The subsidy types are classified by the two dimensions discussed in section 2, R&D grants vs. general investment subsidies on the one hand, and the three government levels offering subsidies on the other. Both regional, national and supranational governments offer R&D grants and general investment subsidies, though at different scales. While regional governments rather focus on general subsidies and only run a limited number of small R&D programs, the supranational level (EU) is mainly offering R&D subsidies through the Horizon program, while general subsidies are limited to investment schemes co-financed from EU regional development funds. The national level offers both types of subsidies at a significant level. The requirements firms must meet to be eligible differ by type of subsidy. Subsidies from regional governments require a location in the respective Federal State. For R&D subsidies, in-house R&D capacity is usually a prerequisite, though the level of technological capabilities that a firm must have vary, with national and EU programs being more demanding. For R&D subsidies from EU programs, international co-operation is another requirement.

Table 5: Characteristics of different subsidy programs available to firms in Germany

Type of subsidy	Policy objective	Requirements for firms
Regional general subsidies: loans and small financial support (e.g. subsidies for consulting services) provided by State Governments	Strengthening investment and growth of the local economy	Located in the State, investment capabilities, sound financial situation
Regional R&D subsidies: grants for R&D projects provided by State Governments	Promoting innovation (including adoption of others' technologies)	Located in the State, basic R&D and innovation capabilities
Federal general subsidies: loans and small financial support (e.g. subsidies for consulting services) provided by the Federal state-owned bank KfW and Federal programs	Improving competitiveness of firms, mitigating financial constraints, strengthening investment	Investment capabilities, sound financial situation
Federal R&D subsidies: grants and R&D tax credits for R&D projects provided through technology programs, SME-focused R&D programs and R&D tax credits	Developing new/emerging/enabling technologies, fostering research cooperation, developing new-to-market innovations	Capabilities in key technologies, experience in R&D cooperation (particularly with universities), in-house R&D capacities
EU general subsidies: loans provided through EU structural funds and other European institutions (e.g., EIB)	Strengthening investment and growth, supporting innovation and technology diffusion	Located within the area of the EU structural fund program
EU R&D subsidies: grants provided through the Horizon program	Strengthening the scientific and technological basis in the EU for addressing societal challenges and increasing industrial competitiveness	Experience in EU application processes, capabilities for international cooperation, in-house R&D capacities

Source: Own representation.

In principle, all types of subsidies may be used for financing eco-innovation activities, though their relevance is likely to differ depending on the firm's environmental goals and the environmental technology as well as on the firm's capacities and capabilities. Table 6 reports the relevance of different government subsidies for eco-innovative firms with significant environmental impact from 2020 to 2024. The information is taken from a question that asks firms whether they have received government subsidies from regional or national government agencies within Germany or from the EU Commission, and whether these subsidies have been used for R&D or for other purposes (allowing both types of uses). Subsidies for other purposes are labelled 'general subsidies' in the remainder of the paper. The most frequently used type of subsidies are national government R&D subsidies (20.2% of all eco-innovative firms in 2024), whereas EU subsidies were used by a small fraction of all eco-innovative firms. Considering all six types of government subsidies, 41.5% of all eco-innovative firms received at least one government subsidy in 2024. This share shows an upward trend, which is mainly driven by a new R&D tax incentive of the national government that is increasingly used by firms from 2022 onwards (Rammer 2025).

Table 6: Relevance of government subsidies for eco-innovative firms 2020-2024

Subsidies	Eco-innovative firms using government subsidies (share in all eco-innovative firms, %)		
	2020	2022	2024
Regional governments: General subsidies	11.4	13.0	12.7
Regional governments: R&D subsidies	6.3	5.8	6.3
National government: General subsidies	11.8	17.2	17.8
National government: R&D subsidies	19.5	18.0	20.2
EU: General subsidies	4.2	3.9	4.1
EU: R&D subsidies	4.6	3.7	3.5
Any government subsidy	37.6	39.6	41.5

Source: German CIS 2020-2024, own calculations

4. Subsidies and eco-innovation: Findings from econometric analyses

For testing our hypotheses, we apply a two-step analyses: In the first step, we explore the relative importance of subsidies as compared to other determinants such as regulation or energy cost as drivers of eco-innovation (see the factors listed in Table 4). This analysis reveals the role of subsidies for eco-innovation vis-à-vis other drivers of eco-innovation activities, related to hypothesis H1. In a second step, we analyze the importance of different types of subsidies (as presented in Table 5) for all eco-innovators and for different types of eco-innovations. This analysis investigates which types of subsidies are relevant for which fields of eco-innovations, related to hypotheses H2 to H4.

Estimation approach

For both analyses, we use an unbalanced panel to estimate random effects panel probit models. The first-step model includes the survey waves 2020 and 2024, while the second-step model uses data for all three survey waves. Fixed effects models are not useful in this context because only two or three time points are available. Furthermore, we are interested in structural differences between firms rather than in dynamic aspects of firm behavior. The dependent variables on firms' eco-innovations are measured in a binary way, i.e., whether a firm implemented an eco-innovation in a certain field (y=1) or not (y=0). Following the theoretical considerations, different factors may affect these firm decisions, summarized by a vector $\mathbf{x}$. The random effects probit model (StataCorp 2026: 453) for the probability to introduce an eco-innovation reads as follows:

$\Pr(y_{it} = 1|x_{it}) = \Phi(x_{it}\beta + v_i)$ (for i=1, …, n panels, t=1, …, n_i)

with v_i are i.i.d. and Φ is the standard normal cumulative distribution function. The model is estimated via maximum likelihood and considers the variance components model: $y_{it} = x_{it} + v_i + \varepsilon_{it}$, where ε_{it} are i.i.d. normally distributed and independent of v_i. Average marginal effects for all covariates are calculated, allowing comparisons of the different energy-related activities.

Dependent variables

We consider different dependent variables y. *Ecoinno* receives the value 1 if the firm introduced at least one eco-innovation with important environmental impact. Accordingly, *Energy, Material, CO2, Airwaternoise, Renewable, Dangersubst* and *Recycling* are dummy variables for the seven types of eco-process innovations, and *Prodenergy, Prodemission, Prodrecyc* and *Lifetime* are dummy variables for the four types of eco-product innovations as shown in Table 3. For a more detailed description and descriptive statistics see Table A1.

Independent variables

In our first-step model, we consider nine different drivers of eco-innovations, as shown in Table 4. The dummy variables *Subsidies, Regulation, Tax, Futurereg, Demand, Reputpressure, Self, Energycost* and *Publicprocure* receive the value 1 if a firm reported the driver to be highly important for the eco-innovations introduced in the preceding three-year period (i.e. 2018 to 2020 for the 2020 survey wave, and 2022 to 2024 for the 2024 survey wave). In our second-step model, we employ the six variables *Subreggen, Subregrad, Subnatgen, Subnatrad, Subeugen* and *Subeurad* which describe subsidies from regional, national and EU agencies for either general (*-gen*) or R&D-related (*-rad*) purposes, as shown in Table 5. *Subgen* aggregates the general subsidies *Subreggen, Subnatgen, Subeugen* and *Subrad* summarizes *Subregrad, Subnatrad and Subeurad.*

Control variables

The models include a series of control variables. A key driver of eco innovation activities is the increasing pressure from climate change, which can affect business activities in various ways (Horbach and Rammer 2025). We create an index that runs from 0 to 15 for the degree to which a firm's business activities are affected by climate change (*Climaaffect*), using the same approach as Horbach and Rammer (2025). *Academic* denotes the share of employees with a university degree and indicates the general innovation capacity of a firm. The *Age* of the firm is included because young firms might show a different eco-innovation behavior compared to older established ones. The size of the firm is also relevant: A large *size* (lagged by one year) of a firm might be connected with higher resources to finance innovation activities. At the same time, small firms might be more open to new ideas and radical innovation. As an indicator for possible financial constraints that may act as a barrier to eco-innovation (see Section 2), we use a one-year lagged scale indicator of creditworthiness (*Creditworthy*). Since networks of firms might be important for the realization of eco-innovation, we also control for *Cooperation* activities. A higher competition intensity (*Compintensity*) might promote innovation activities. We use an index that summarizes eight aspects of competition, following Rexhäuser and Rammer (2014). As potential inputs to the development and implementation of eco-innovations, the use of artificial intelligence methods (*AI*) and *R&D* activities are considered. *R&D* gets the value 1 if the firm performed in-house R&D activities or contracted out R&D. *Sec*tor and *year* dummies as well as a control variable for firms located in *East* Germany are also included.

The role of subsidies for different eco-innovation fields compared to other drivers

Table 7 (for eco-product innovations) and Table 8 (for eco-process innovations) show the results of the first step on the drivers of eco-innovations for the different types of eco-innovations. Note that these models are estimated only for firms with at least one eco-innovation activity. The models compare eco-innovators (i.e., firms with eco-innovation activity that had significant environmental benefits in the respective field of eco-innovation) to firms with eco-innovation activity in the respective field that produced only insignificant environmental benefits. This analysis hence reports on the relative role of subsidies as compared to other potential drivers to produce eco-innovations with a significant impact on reducing environmental externalities, following hypothesis H1.

For the model on eco-product innovators (Table 7), *Subsidies* show a highly significant positive link to product innovations that reduce energy use or CO_2 footprint. The marginal effect is 7.5%. For the other three types of eco-product innovations, no significant coefficient for *Subsidies* emerges. At the same time, *Regulation* is a significant driver for all four types of eco-product innovation, with the highest marginal effects for product innovations leading to a lower energy use or CO_2 footprint (5.3%) or lower emission levels (5.0%). The prominent role or regulation for driving eco-product innovation may explain the absence of a significant correlation with subsidies, providing some support for H1. However, for eco-product innovation targeting energy efficiency and CO_2 footprint, both subsidies and regulation are relevant drivers, suggesting a complementary rather than substitutive role of the two government instruments. Interestingly, neither taxation (*Tax*) nor expected future regulations (*Futurereg*) are significant drivers for a specific eco-product innovation.

Table 7: Drivers of eco-product innovations: results of panel estimations

Correlates	Prodenergy	Prodemission	Prodrecyc	Lifetime
Subsidies	0.075**	0.019	-0.018	-0.018
	(0.020)	(0.015)	(0.012)	(0.014)
Regulation	0.053**	0.050**	0.022*	0.035**
	(0.013)	(0.011)	(0.010)	(0.011)
Tax	-0.014	0.023	0.014	-0.005
	(0.016)	(0.014)	(0.013)	(0.014)
Futurereg	0.011	0.016	0.006	0.005
	(0.015)	(0.012)	(0.011)	(0.012)
Demand	0.096**	0.085**	0.061**	0.032*
	(0.020)	(0.017)	(0.016)	(0.016)
Reputpressure	0.072**	0.045**	0.046**	0.051**
	(0.016)	(0.013)	(0.013)	(0.014)
Self	0.064**	0.035**	0.063**	0.060**
	(0.016)	(0.014)	(0.014)	(0.015)
Energycost	0.078**	0.024*	0.044**	0.042**
	(0.013)	(0.010)	(0.010)	(0.011)
Publicprocure	-0.037*	-0.001	0.025	0.060**
	(0.019)	(0.016)	(0.017)	(0.020)
Climaaffect	0.018**	0.017**	0.009**	0.008**
	(0.002)	(0.002)	(0.002)	(0.002)
Academic	0.046*	0.052**	0.005	-0.012
	(0.022)	(0.018)	(0.018)	(0.019)
Age	-0.027**	-0.011+	-0.012*	-0.011+
	(0.008)	(0.006)	(0.006)	(0.007)
Creditworthy	0.014	-0.006	-0.006	0.003
	(0.010)	(0.008)	(0.007)	(0.008)
Cooperation	0.022*	0.018*	0.017+	0.026**
	(0.011)	(0.009)	(0.009)	(0.009)
Compintensity	-0.003*	-0.002*	0.002+	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
AI	0.003	-0.007	0.005	0.014
	(0.011)	(0.009)	(0.009)	(0.010)
R&D	0.056**	0.036**	0.023*	0.050**
	(0.012)	(0.010)	(0.009)	(0.010)
Size	-0.004	-0.008**	-0.010**	-0.025**
	(0.004)	(0.003)	(0.003)	(0.003)
Year2020	-0.023*	-0.019*	-0.008	-0.015+
	(0.009)	(0.008)	(0.007)	(0.008)
East	-0.017+	-0.034**	-0.014+	0.014
	(0.010)	(0.008)	(0.008)	(0.009)
Observations	6,811	6,811	6,811	6,811
Wald Chi	327**	253**	230**	223**
Rho	0.26**	0.27**	0.32**	0.38**

Random Effects Probit models. Average marginal effects are reported. Robust standard errors in parentheses, ** p<0.01, * p<0.05, + p<0.1. Industry dummies are included but not reported. A significant value of rho signifies that the panel level variance component matters in that a simple pooled model cannot be applied.
Source: German CIS 2020 and 2024, own estimations.

The results also show a high relevance of *Demand*, the improvement of reputation and public pressure (*Reputpressure*) for eco-product-innovations. The improvement of reputation is even significant for all eco-product innovations. High energy and material costs (*Energycost*) can also be a motivation for eco-product innovations whereas public procurement (*Publicprocure*) is only positively significant for eco-innovations leading to a longer lifetime.

With respect to control variables, a high affectedness by climate change (*Climaaffect*) is significantly relevant for all eco-product innovations. Not surprisingly, the highest marginal effect (1.8%) is estimated for product innovations leading to less energy consumption and CO_2 emissions. A good financial standing (*Creditworthy*) seems to be not a precondition for a specific eco-product innovation. Smaller firms (*Size*) are more likely to introduce products leading to less emissions and those with a higher recyclability and lifetime.

The results for eco-process-innovations (Table 8) show a positive link between *Subsidies* and three types of eco-process innovations: process technology to increase energy efficiency (marginal effect: 8.9%), lowering CO_2 emissions (6.2%), and substituting fossil by renewable energy sources (8.2%). For the first two of these types, also *Regulation* is a significant driver, while the latter is neither correlated with regulation nor taxation or expected future regulation. This suggests that H1 holds for the transition from fossil to renewable energy sources, for which regulation and taxation seem to be not strong enough to encourage firms to focus their eco-innovation activities on this field. This is in line with the situation in Germany during the study period, which was characterized by reduced energy tax incentives and regulatory push towards renewables (Horbach and Rammer 2026).

Regulation is also a driver for eco-process innovations leading to higher material efficiency, lower air, water or noise emissions, the substitution of dangerous substances by less harmful ones, and for improving recycling. Improving the reputation of a firm and responding to public pressure (*Reputpressure*) serve as a driver for all eco-process innovations, with the highest marginal effect found for *Renewable* (9.6%). High *energy cost*s are significantly relevant for all eco-process innovations. Not surprisingly, the highest marginal effects can be observed for energy savings (11.9%), but also for the introduction of renewables (6.3%).

For our control variables, we find a significant positive correlation of high affectedness by climate change (*Climaaffect*) with all seven types of eco-process innovations. The introduction of renewables substituting fossil fuels is supported by a good financial standing (*Creditworthy*), also strengthening the argument that general subsidies are highly relevant for this type of eco-process innovation, supporting H1. A high competition intensity (*Compintensity*) accompanied by a lower financial scope may act as a barrier to the introduction of renewables.

Table 8: Drivers of eco-process innovations: results of panel estimations

Correlates	Energy	Material	CO2	Airwater-noise	Renewable	Danger-subst	Recycling
Subsidies	0.089**	0.021	0.062**	0.022	0.082**	-0.010	-0.009
	(0.019)	(0.014)	(0.017)	(0.014)	(0.018)	(0.010)	(0.013)
Regulation	0.042**	0.038**	0.036**	0.031**	-0.010	0.045**	0.032**
	(0.012)	(0.010)	(0.010)	(0.010)	(0.011)	(0.009)	(0.011)
Tax	0.030+	0.018	0.015	0.029*	-0.026+	-0.007	0.013
	(0.016)	(0.013)	(0.014)	(0.013)	(0.014)	(0.009)	(0.014)
Futurereg	-0.014	-0.012	0.016	0.017	0.006	0.007	0.007
	(0.013)	(0.010)	(0.012)	(0.011)	(0.013)	(0.009)	(0.012)
Demand	0.005	0.011	0.019	0.024+	0.015	0.013	-0.001
	(0.016)	(0.013)	(0.015)	(0.014)	(0.016)	(0.011)	(0.014)
Reputpressure	0.081**	0.045**	0.078**	0.061**	0.096**	0.038**	0.048**
	(0.016)	(0.012)	(0.015)	(0.013)	(0.016)	(0.010)	(0.014)
Self	0.060**	0.056**	0.056**	0.056**	0.051**	0.018+	0.063**
	(0.016)	(0.013)	(0.014)	(0.013)	(0.015)	(0.009)	(0.014)
Energycost	0.119**	0.050**	0.055**	0.024**	0.063**	0.009	0.058**
	(0.013)	(0.010)	(0.011)	(0.009)	(0.011)	(0.007)	(0.010)
Publicprocure	-0.027	-0.001	-0.008	0.005	-0.011	0.064**	0.024
	(0.017)	(0.014)	(0.015)	(0.015)	(0.017)	(0.016)	(0.017)
Climaaffect	0.012**	0.010**	0.014**	0.011**	0.014**	0.003*	0.007**
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.002)
Academic	-0.037+	-0.028	-0.015	-0.021	-0.019	-0.000	-0.060**
	(0.022)	(0.018)	(0.020)	(0.018)	(0.021)	(0.013)	(0.020)
Age	0.000	-0.002	-0.012+	-0.009	-0.011	-0.004	-0.010
	(0.007)	(0.006)	(0.006)	(0.006)	(0.007)	(0.005)	(0.006)
Creditworthy	0.000	-0.012+	-0.001	-0.007	0.031**	-0.005	-0.000
	(0.010)	(0.007)	(0.008)	(0.007)	(0.010)	(0.005)	(0.008)
Cooperation	0.010	0.003	0.008	0.009	0.001	-0.002	0.006
	(0.010)	(0.008)	(0.009)	(0.008)	(0.010)	(0.007)	(0.009)
Compintensity	-0.001	0.001	-0.004**	-0.003**	-0.004**	0.002*	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
AI	0.006	0.011	0.006	-0.003	0.010	0.006	0.008
	(0.011)	(0.009)	(0.010)	(0.009)	(0.010)	(0.007)	(0.010)
R&D	0.032**	0.034**	0.043**	0.034**	0.034**	0.021**	0.018+
	(0.011)	(0.009)	(0.010)	(0.009)	(0.010)	(0.007)	(0.009)
Size	0.006+	-0.001	0.003	-0.005+	0.001	-0.001	-0.002
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	(0.003)
Year2020	-0.007	-0.014+	-0.014+	0.060**	-0.062**	-0.003	-0.004
	(0.009)	(0.007)	(0.008)	(0.007)	(0.008)	(0.006)	(0.008)
East	0.002	0.008	-0.024**	-0.004	-0.023*	-0.010	-0.010
	(0.010)	(0.008)	(0.009)	(0.008)	(0.009)	(0.006)	(0.008)
Observations	6,811	6,811	6,811	6,811	6,811	6,811	6,811
Wald Chi^2	328**	240**	261**	218**	254**	129**	206**
Rho	0.21**	0.13+	0.31**	0.16*	0.24**	0.47**	0.39**

Random Effects Probit models. Average marginal effects are reported. Robust standard errors in parentheses, ** p<0.01, * p<0.05, + p<0.1. Industry dummies are included but not reported. A significant value of rho signifies that the panel level variance component matters in that a simple pooled model cannot be applied.

Source: German CIS 2020 and 2024, own estimations.

Types of subsidies and types of eco-innovations

In the second step, we analyze the role of different subsidy types for all eco-innovations as well as for different types of eco-product and eco-process innovation using panel data from the CIS waves 2020, 2022 and 2024 (Table 9 and Table 10). The results for all eco-innovative firms (first column in Table 9) compared to all other firms show that regional subsidies (*Subreggen, Subregrad*) and general subsidies from national agencies (*Subnatgen*) are significantly relevant for all eco-innovations compared to all other firms. R&D subsidies from national agencies (*Subnatrad*) and general EU subsidies (*Subeugen*) do not play a significant role, supporting H4. Contrary to H4, R&D subsidies from the EU are positively correlated to eco-innovation. When looking at any general and any R&D subsidy (regardless of the government level that supplies the subsidy), both general and R&D subsidies are significantly positively related to eco-innovations, supporting H2 and H3. The marginal effect for general subsidies (5.0 %) is higher than the one for R&D subsidies (3.2%), suggesting a stronger preference of eco-innovators for general subsidies (see Table A2 in the Appendix).

With respect to control variables, a high credit rating by Germany's leading credit rating agency Creditreform (*Creditworthy*) is positively (but only weakly significant) correlated to eco-innovations underlining the important role of the financial situation and constraints for eco-innovation. This argument is also supported by the negative sign of the year dummy for 2022, which mirrors the adverse macroeconomic environment in Germany caused by the COVID-19 pandemic and the Russian war against Ukraine. A high affectedness by climate change (*Climaaffect*) is highly relevant for eco-innovations. *Cooperation* activities, *R&D* activities and the use of *AI* also support eco-innovations activities. The *age* of a firm does not play a significant role for eco-innovation.

The results for different types of eco-product innovations (Table 9) and eco-process innovations (Table 10) are based on estimations that only consider the sub-sample of eco-innovators, i.e. they compare the relevance of a certain type of subsidy for a specific eco-innovation field with the relevance of the subsidy type for other eco-innovation fields. For eco-product innovations (Table 9), general subsidies from regional authorities (*Subreggen*) are significantly correlated to energy-efficiency (marginal effect of 5.1%) and emission-related (2.3%) product innovations but not for the other eco-product innovations, supporting H2. R&D oriented regional subsidies (*Subregrad*) are only weakly significant for energy and lifetime-related eco-product innovations. For national and EU subsidies, there are no highly significant differences between types of eco-product innovation. When looking at the aggregated variables for general and R&D subsidies (*Subgen, Subrad*, see Table A2 in the Appendix), only eco-innovators with energy-efficiency product innovations are more likely to rely on both types of subsidies.

Table 9: Subsidies, all eco-innovators and eco-product innovation: Results of panel estimations

Correlates	All eco-innovators	Prodenergy	Prodemission	Prodrecyc	Lifetime
Subreggen	0.033**	0.051**	0.023*	-0.009	-0.001
	(0.012)	(0.014)	(0.011)	(0.010)	(0.010)
Subregrad	0.042*	0.036+	0.017	-0.007	0.030+
	(0.018)	(0.019)	(0.015)	(0.014)	(0.016)
Subnatgen	0.049**	0.016	0.006	0.012	-0.001
	(0.011)	(0.011)	(0.009)	(0.009)	(0.009)
Subnatrad	0.015	0.021+	0.007	0.005	0.002
	(0.011)	(0.013)	(0.010)	(0.010)	(0.010)
Subeugen	0.017	0.017	-0.005	0.029	0.014
	(0.020)	(0.022)	(0.017)	(0.018)	(0.019)
Subeurad	0.049*	0.034	0.003	0.012	0.033
	(0.024)	(0.025)	(0.019)	(0.020)	(0.022)
Climaaffect	0.034**	0.027**	0.023**	0.017**	0.015**
	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)
Academic	-0.065**	0.042*	0.037*	-0.008	-0.011
	(0.016)	(0.019)	(0.016)	(0.015)	(0.016)
Age	-0.008	-0.019**	-0.013**	-0.014**	-0.013*
	(0.006)	(0.006)	(0.005)	(0.005)	(0.005)
Creditworthy	0.013+	0.004	-0.005	-0.002	0.003
	(0.007)	(0.008)	(0.006)	(0.006)	(0.007)
Cooperation	0.048**	0.018+	0.011	0.011	0.015+
	(0.009)	(0.010)	(0.008)	(0.008)	(0.008)
Compintensity	0.001+	-0.002	-0.002*	0.001	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
AI	0.066**	0.025*	0.007	0.015+	0.023*
	(0.010)	(0.011)	(0.008)	(0.008)	(0.009)
R&D	0.108**	0.053**	0.046**	0.034**	0.055**
	(0.009)	(0.010)	(0.008)	(0.008)	(0.008)
Size	0.008**	0.003	-0.000	-0.003	-0.018**
	(0.003)	(0.003)	(0.002)	(0.002)	(0.003)
Year2020	0.014+	-0.008	-0.006	-0.002	-0.009
	(0.008)	(0.009)	(0.007)	(0.007)	(0.008)
Year2022	-0.029**	-0.033**	-0.044**	-0.021**	-0.023**
	(0.007)	(0.009)	(0.007)	(0.007)	(0.007)
East	-0.029**	-0.028**	-0.033**	-0.012+	0.006
	(0.007)	(0.009)	(0.007)	(0.007)	(0.007)
Observations	16,897	10,204	10,204	10,204	10,204
Wald Chi^2	1,400**	447**	371**	282**	298**
Rho	0.38**	0.38**	0.38**	0.43**	0.45**

Random Effects Probit models. Average marginal effects are reported. Robust standard errors in parentheses, ** p<0.01, * p<0.05, + p<0.1. Industry dummies are included but not reported. A significant value of rho signifies that the panel level variance component matters in that a simple pooled model cannot be applied.
Source: German CIS 2020-2024, own estimations.

Among the control variables, *AI* is particularly important for energy-related and lifetime-oriented product innovations compared to other eco-innovations. This result confirms a study of Ghoreishi and Happonen (2020) showing that AI helps to process complex data so that energy savings concerning the whole complex product design may be better addressed.

With respect to eco-process innovations (Table 10), general regional subsidies (*Subreggen*) are particularly important for energy consumption (5.4%) related innovations and for the substitution of fossil fuels by renewables (3.4%) – more diffusion-oriented eco-innovation fields supporting H2. R&D related regional subsidies (*Subregrad*) are not significant for eco-process-innovations. General subsidies of German ministries (*Subnatgen*) are highly positively correlated to energy- (2.3%), CO_2 (2.5%) and renewable-related (3.0%) eco-process innovations whereas R&D-oriented national subsidies (*Subnatrad*) seem to be only relevant for process innovations related to CO_2 (2.9%) supporting H3. For the substitution of fossil fuels by renewables these subsidies are less important because these eco-innovation activities mainly show diffusion processes of already existing technologies rather than completely new processes and products so that general, but not R&D related subsidies are more relevant (H2). EU subsidies do not play a significant role in specific eco-process innovations.

When looking at any general and any R&D subsidy (*Subgen, Subrad*, see Table A3 in the Appendix), general subsidies are positively correlated with eco-process innovation that increase energy efficiency, that reduce CO_2 emissions and that substitute fossil by renewable energy sources. R&D subsidies are preferred by eco-innovators that focus on reducing CO_2 emissions or other emissions (including water pollution and noise emissions).

Concerning the control variables, a high competition intensity (*Compintensity*) is connected to fewer eco-innovations that reduce CO_2 emissions, that reduce other air, water or noise emissions or that substitute fossil by renewable energy sources.

Table 10: Subsidies and eco-process innovation: results of panel estimations

Correlates	Energy	Material	CO2	Airwater-noise	Renewa-ble	Danger-subst	Recycling
Subreggen	0.054**	0.006	0.016	0.008	0.034**	-0.001	-0.017+
	(0.013)	(0.010)	(0.011)	(0.010)	(0.012)	(0.007)	(0.009)
Subregrad	0.034+	0.002	0.017	-0.001	0.007	0.017	-0.003
	(0.018)	(0.013)	(0.016)	(0.014)	(0.016)	(0.011)	(0.015)
Subnatgen	0.023*	0.009	0.025*	0.009	0.030**	-0.017**	-0.002
	(0.011)	(0.009)	(0.010)	(0.009)	(0.011)	(0.006)	(0.009)
Subnatrad	0.008	0.002	0.029**	0.018+	0.019+	0.001	0.002
	(0.012)	(0.009)	(0.011)	(0.010)	(0.011)	(0.007)	(0.010)
Subeugen	0.020	-0.002	0.017	0.022	0.024	0.010	0.007
	(0.021)	(0.015)	(0.019)	(0.018)	(0.020)	(0.013)	(0.019)
Subeurad	0.017	0.017	-0.005	0.011	-0.011	0.006	0.021
	(0.024)	(0.019)	(0.019)	(0.019)	(0.020)	(0.014)	(0.021)
Climaaffect	0.020**	0.015**	0.022**	0.018**	0.018**	0.008**	0.014**
	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Academic	-0.040*	-0.028+	-0.025	-0.014	-0.029+	-0.007	-0.079**
	(0.018)	(0.015)	(0.017)	(0.015)	(0.017)	(0.011)	(0.017)
Age	-0.001	-0.003	-0.010+	-0.007	-0.008	-0.005	-0.011*
	(0.006)	(0.005)	(0.005)	(0.005)	(0.005)	(0.004)	(0.005)
Creditworthy	-0.003	-0.015**	-0.004	-0.009	0.022**	-0.000	-0.005
	(0.008)	(0.005)	(0.007)	(0.006)	(0.008)	(0.005)	(0.006)
Cooperation	0.005	0.006	0.003	0.002	0.003	-0.001	0.009
	(0.009)	(0.007)	(0.008)	(0.007)	(0.008)	(0.006)	(0.008)
Compintensity	-0.000	0.001	-0.002*	-0.002*	-0.002**	0.002*	0.002*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
AI	0.024*	0.018*	0.024**	0.014+	0.022*	0.010	0.023*
	(0.010)	(0.008)	(0.009)	(0.008)	(0.009)	(0.006)	(0.009)
R&D	0.032**	0.029**	0.042**	0.032**	0.036**	0.017**	0.025**
	(0.009)	(0.007)	(0.008)	(0.008)	(0.009)	(0.006)	(0.008)
Size	0.008**	0.005*	0.009**	0.001	0.003	0.002	0.003
	(0.003)	(0.002)	(0.003)	(0.002)	(0.003)	(0.002)	(0.002)
Year2020	-0.001	-0.010	-0.005	0.072**	-0.047**	0.001	-0.000
	(0.009)	(0.007)	(0.008)	(0.009)	(0.007)	(0.005)	(0.008)
Year2022	-0.056**	-0.033**	-0.041**	0.020*	-0.055**	-0.018**	-0.021**
	(0.008)	(0.006)	(0.007)	(0.008)	(0.007)	(0.005)	(0.007)
East	-0.008	0.004	-0.025**	-0.006	-0.035**	-0.006	-0.006
	(0.008)	(0.007)	(0.007)	(0.007)	(0.007)	(0.005)	(0.007)
Observations	10,204	10,204	10,204	10,204	10,204	10,204	10,204
Wald Chi^2	372**	250**	378**	329**	373**	168**	286**
Rho	0.32**	0.33**	0.37**	0.31**	0.35**	0.47**	0.40**

Random Effects Probit models. Average marginal effects are reported. Robust standard errors in parentheses, ** p<0.01, * p<0.05, + p<0.1. Industry dummies are included but not reported. A significant value of rho signifies that the panel level variance component matters in that a simple pooled model cannot be applied.

Source: German CIS 2020-2024, own estimations.

5. Summary and conclusions

This paper offers an explorative analysis of the role of government subsidies for different types of eco-innovations, using firm-level panel data from Germany. Subsidies for eco-innovations can be justified by the double externality problem (Rennings 2000). Positive externalities of eco-innovation can occur both in the stage of technology development (knowledge spillovers) and the diffusion phase (reducing environmental damage), limiting private returns from eco-innovation and contributing to financial constraints. Government subsidies can compensate for these market failures and provide incentives to invest in eco-innovation activities. This is particularly relevant in a situation when other government instruments such as regulation or taxation are absent. A key policy question that is addressed in this paper is the adequate design of subsidies for different eco-innovation fields.

The existing literature reports positive correlations between subsidies and eco-innovation activities of firms (Ghisetti et al. 2017, Jensen et al. 2019, Cecere et al. 2020, Zhang 2025). Eco-innovators seem to be more affected by financial constraints compared to other innovators so that subsidies seem to be an important tool to reduce these financial restrictions of eco-innovations. However, only few studies analyzed the role of subsidies for different eco-innovation fields, mainly focusing on different effects of subsidies on end-of-pipe technologies compared to cleaner production technologies (Tchorzewska 2024, Zhang 2022). The present study aims at closing this research gap by analyzing the role of different subsidies for a more detailed breakdown of eco-innovation fields, employing data from the German part of the Community Innovation Survey (CIS). We investigate which types of government subsidies are preferred by firms implementing innovations in different environmental fields. By separating seven fields of process-related eco-innovations and four fields of product-related eco-innovations and distinguishing six types of government subsidies (general or R&D related subsidies from regional, national and supranational authorities), the study provides a much more detailed insight into the link between subsidies and eco-innovation than existing studies.

The results of econometric panel estimations show that eco-innovative firms are more likely to rely on regional subsidies and on general subsidies from the national government compared to firms that do not engage in eco-innovation, whereas EU subsidies only play a significant role in case of R&D grants (delivered through the Horizon program). A high creditworthiness of a firm is positively correlated to eco-innovation, underpinning that financial constraints are likely to hamper eco-innovations.

A more detailed analysis reveals that general subsidies from regional authorities are significantly correlated to eco-product innovations that aim at increasing the energy efficiency of products, reducing their CO_2 footprint and lowering other types of emissions during the use of a product. General regional subsidies are also important for firms that increase energy efficiency of production processes and substitute fossil fuels by renewable energy sources. These results suggest that the regional policy level is particularly relevant for diffusion-oriented eco-innovations that target climate-related policy goals. General subsidies from the national government show similar links to eco-innovation types as general regional subsidies, suggesting that both government levels in Germany pursue similar environmental objectives with their financial support to general investment in firms. For R&D subsidies by national authorities, we find a strong link to eco-process innovations that reduce CO_2 emissions. For EU subsidies, we do not find a preference for a certain environmental field, indicating that the EU approach is not targeted at specific environmental goals.

Our results complement the existing literature on subsidies and eco-innovation by stressing the role of general financial support and regional authorities for promoting the diffusion of eco-innovations helping to reduce the country´s CO_2 burden. Specialized public R&D subsidies for risky but promising eco-innovation activities seem to be useful in cases when firms have difficulties financing their investment via the capital market.

While our study provides insights into the use of different government subsidies on different types of eco-innovation, it does not touch the important issue of effectiveness of subsidies, i.e. whether providing government funding leads to more or more impactful eco-innovation. Existing studies on the effects of eco-innovation subsidies usually focus on a specific subsidy (Molica and Santos 2026) or do not differentiate by type of subsidy (Bartels and Werthschulte 2025), and do not separate by type of environmental externality. Our results call for a more differentiated approach when analyzing the effects of subsidies on eco-innovation.

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Table A1: Definition and descriptive statistics of variables

Variables	Description	Mean	Std. Dev.
Eco-innovations (2020-2024) (1: With significant environmental benefits, 0: Otherwise)			
Ecoinno	Eco-innovator (any type of eco-process or eco-product innovation)	0.248	0.432
Energy	Reduced energy use by unit of output	0.089	0.285
Material	Reduced material and water use by unit of output	0.052	0.221
CO_2	Reduced CO_2 emissions	0.070	0.256
Airwaternoise	Reduced other air emissions, water, soil or noise pollution	0.056	0.229
Renewable	Substitution of fossil energy sources by renewables	0.076	0.264
Dangersubst	Substitution of dangerous substances	0.031	0.172
Recycling	Recycling of waste, water or materials	0.066	0.247
Prodenergy	Reduced energy use or CO_2 'footprint'	0.108	0.311
Prodemission	Reduced emissions (air, water, soil, noise)	0.066	0.249
Prodrecyc	Facilitated recycling of products after use	0.059	0.236
Lifetime	Extended product life through longer-lasting, more durable products	0.068	0.252
Subsidies (2020-2024) (1: Yes, 0: No)			
Subreggen	General subsidies from the regional governments (Federal States)	0.089	0.285
Subregrad	R&D subsidies from the regional governments (Federal States)	0.037	0.188
Subnatgen	General subsidies from the German Federal government	0.108	0.310
Subnatrad	R&D subsidies from the German Federal government	0.124	0.329
Subeugen	General subsidies from the European Commission	0.027	0.163
Subeurad	R&D subsidies from the European Commission	0.021	0.143
Subgen	Any general subsidy	0.183	0.386
Subrad	Any R&D subsidy	0.138	0.345
Determinants of eco-innovation (2020 and 2024) (1: High importance, 0: Otherwise)			
Regulation	Present regulations	0.275	0.446
Tax	Environmental taxes	0.116	0.321
Futurereg	Future, anticipated regulations or taxes	0.170	0.376
Subsidies	Public financing of eco-innovations	0.082	0.275
Demand	Demand for environmental innovations	0.089	0.285
Reputpressure	Improvement of reputation, public pressure	0.154	0.361
Self	Self commitments	0.135	0.342
Energycost	High energy or material costs	0.267	0.442
Publicprocure	Requirements of public procurement	0.059	0.235
Control variables			
Academic	Share of employees with a university degree	0.265	0.294
Age	Age of the firm in years (logarithm)	3.304	0.726
Climaaffect	Climate change affectedness score (index from 0 to 15)	5.189	3.001
Creditworthy	Creditworthiness (scale from 0 to 5), one year lagged	3.665	0.536
Cooperation	Cooperation with other firms/institutions 2020-2024 (1: Yes, 0: No)	0.253	0.434
Compintensity	Competition intensity (Score from 0 to 24)	10.528	4.560
AI	Use of artificial intelligence (1: Yes, 0: No)	0.189	0.391
Rad	In-house or external R&D activities (1: Yes, 0: No)	0.364	0.481
Size	Number of employees (logarithm), one year lagged	3.292	1.566
East	Location (1: East Germany, 0: West Germany)	0.440	0.496
Sector dummies (1: Yes, 0: No)			
Sec1	Manufacture of food products and beverages, tobacco	0.038	0.191
Sec2	Manufacture of textiles, clothing, leather products	0.024	0.153
Sec3	Manufacture of wood and paper products, printing	0.024	0.153
Sec4	Manufacture of chemicals and pharmaceutical products	0.024	0.154
Sec5	Manufacture of rubber and plastic products	0.025	0.156
Sec6	Manufacture of glass, ceramics and concrete products	0.020	0.140
Sec7	Manufacture of basic metals and fabricated metals	0.068	0.251
Sec8	Manufacture of electrical machinery, electronics, instruments	0.047	0.211
Sec9	Manufacture of machinery	0.059	0.236
Sec10	Manufacture of motor vehicles and other transport equipment	0.017	0.130
Sec11	Manufacture of medical products, furniture and other products	0.059	0.236
Sec12	Energy and water supply, mining	0.026	0.159
Sec13	Recycling, waste and wastewater removal	0.046	0.209
Sec14	Wholesale trade	0.044	0.206

Sec15	Transport and logistics services	0.074	0.262
Sec16	Media services	0.041	0.197
Sec17	Computer programming, data processing, telecommunication	0.031	0.173
Sec18	Financial services	0.052	0.222
Sec19	Technical and R&D services	0.084	0.277
Sec20	Business consulting and advertising	0.066	0.249
Sec21	Other sectors	0.131	0.337

Source: German CIS 2020-2024, own estimations.

Table A2: Subsidies (aggregated variables), all eco-innovators and eco-product innovation: results of panel estimations

Correlates	All eco-innovators	Prodenergy	Prodemission	Prodrecyc	Lifetime
Subgen	0.050**	0.037**	0.012	0.005	-0.003
	(0.009)	(0.010)	(0.008)	(0.007)	(0.008)
Subrad	0.032**	0.032**	0.015	0.001	0.014
	(0.011)	(0.012)	(0.010)	(0.009)	(0.009)
Observations	16,897	10,204	10,204	10,204	10,204
Wald Chi^2	1,398**	443**	367**	278**	292**
Rho	0.38**	0.38**	0.38**	0.43**	0.45**

Random Effects Probit models. Average marginal effects are reported. Robust standard errors in parentheses, ** p<0.01, * p<0.05, + p<0.1. Industry dummies are included but not reported. For the results of the control variables see Table 9. A significant value of rho signifies that the panel level variance component matters in that a simple pooled model cannot be applied.
Source: German CIS 2020-2024, own estimations.

Table A3: Subsidies (aggregated variables) and eco-process innovation: results of panel estimations

Correlates	Energy	Material	CO2	Airwater-noise	Renewable	Danger-subst	Recycling
Subgen	0.048**	0.008	0.028**	0.012+	0.041**	-0.016**	-0.011
	(0.009)	(0.007)	(0.008)	(0.007)	(0.009)	(0.005)	(0.007)
Subrad	0.018	0.005	0.034**	0.019*	0.020+	0.005	0.002
	(0.011)	(0.008)	(0.010)	(0.009)	(0.010)	(0.007)	(0.009)
Observations	10,204	10,204	10,204	10,204	10,204	10,204	10,204
Wald Chi^2	370**	249**	377**	328**	369**	168**	284**
Rho	0.32**	0.33**	0.37**	0.31**	0.35**	0.47**	0.40**

Random Effects Probit models. Average marginal effects are reported. Robust standard errors in parentheses, ** p<0.01, * p<0.05, + p<0.1. Industry dummies are included but not reported. For the results of the control variables see Table 10. A significant value of rho signifies that the panel level variance component matters in that a simple pooled model cannot be applied.
Source: German CIS 2020-2024, own estimations.

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