Do We Need Human Capital Heterogeneity for Energy Efficiency and Innovativeness? Insights from European catching-up territories

Abstract

This study brings a new perspective on the energy efficiency issue within the “catching-up territory” of Southern, Baltic, and Eastern European countries, where such analyses are missing. We create an original theory mix, combining theories of human capital, natural resource-based view, gender socialization, and upper echelons, to address three important research gaps: (i) the missing link regarding the effects of firm-specific human capital on energy efficiency; (ii) the interrelationship between energy efficiency and firms’ innovativeness; and (iii) nonlinear relationships between firm-specific human capital, energy efficiency, and innovativeness. Moreover, we test whether energy efficiency has a mediating role within firms’ innovation processes. Our results confirm the key role experiences and skills play in energy efficiency and surprisingly refute the importance of gender diversity in this case. We also confirm the importance of environmental behaviour for innovativeness and reveal the mediating role of energy efficiency for process innovations. Finally, we propose several important implications for managers and policy makers.

Key words: Energy efficiency, Human capital, Innovativeness, Southern Europe, Central and Eastern Europe

Highlights

- Novel theory mix linking four important theoretical concepts
- The key role of experiences and skills in energy efficiency
- Rejection of the importance of gender diversity for energy efficiency
- Firms’ environmental behaviour triggers innovativeness
- The mediating role of energy efficiency for process innovations
- Nonlinear relationships revealed

1 Introduction

Environmental protection and the transition to a circular economy are some of the main challenges facing the world in recent times because climate changes causing negative externalities (Dauda et al., 2021). Efficient energy use is one of the most cost-effective ways to address these negative externalities, making it an important policy strategy to mitigate climate change, promote economic progress, tackle energy security, and decrease energy intensity as well as consumption, which are critical for addressing environmental problems (Sun et al., 2019; Wen et al., 2022). The first efforts to integrate energy efficiency (EE) into the EU energy policy agenda emerged in the 1970s. However, these efforts were insufficient. Even today "*actual investments in energy efficiency remain at suboptimal levels and not in par with their potential*" (Economidou et al., 2020, p. 2). Several factors contribute to the insufficient investment in EE as well as the emergence of the "energy efficiency gap", which refers to the difference between actual and optimal energy use (Jaffe & Stavins, 1994). These factors stem from, for example, market and non-market failures (Jaffe & Stavins, 1994).

The sudden surge in energy use is alarming (Zakari et al., 2022), highlighting the increased importance and need for EE (Dong et al., 2022) and evoking an increasing body of research. For example, recent research has focused on the main barriers to EE (Schleich, 2009; Chai & Baudelaire, 2015), the evaluation of firms' performance in EE (Viesi et al., 2017), the effects of environmental policy stringency on EE (Galeotti et al., 2020), household energy use behaviour (Mills & Schleich, 2012), the impact of economic, social, and environmental development initiatives on the development of renewable energy systems (Lerman et al., 2021), and EE impacts on income inequality and energy poverty (Dong et al., 2022), as well as EE measures (Fleiter et al., 2012; Trianni et al., 2014; Lidelöw et al., 2019; Ceballos-Fuentealba et al., 2019). Another string of studies analysed the effects of regulatory frameworks and policies on EE in industrial sectors (Malinauskaite et al., 2019), including an analysis of what are the driving forces behind EE improvement (Ouyang et al., 2019). Finally, yet importantly, we can find studies on determinants of EE. These are, for example, payback time and investment costs (Abadie et al., 2012), GDP per capita (Jebali et al., 2017), CO_2 emissions per capita and the share of industry in the economy (Sineviciene et al., 2017), institutional quality (Sun et al., 2019), green innovation (Zakari et al., 2022), environmental technology (Paramati et al., 2022), or investment in renewable energy resources (Chen et al., 2022).

Despite the burgeoning literature on EE, empirical evidence on the link between firms' EE and human capital (HC) is limited. Here, we see the role of HC as an important aspect to examine in conjunction with EE. The role of HC in combating climate change is crucial, as recent literature has demonstrated (Edziah et al., 2021). The fragments of empirical research are especially evident at the country level, as Edziah et al. (2021) showed. Their recent study analysed the effects of HC on EE in a panel of developing countries, confirming that HC can increase EE. From the firm's perspective, Mubarik and Naghavi (2022) found that a higher level of HC pushes firms to go green by reducing non-renewable energy consumption. Their novel work further demonstrated that HC could play an influential role in channelling the demand for energy toward the demand for green energy. However, as far as we know, no clear understanding exists regarding the effects of the personal characteristics of firms' HC (including employees and management), such as employee experiences, skills, and gender diversity, on firms' environmental behaviour (Horbach & Jacob, 2018; Bano et al., 2018), including EE (Edziah et al., 2021).

The same is true about the missing empirical literature linking EE and firms' innovativeness, despite these being connected parts of the same managerial puzzle (Gerstlberger et al., 2014). According to Gerstlberger et al. (2016), firms, which invest in technical process innovations, are more likely to adopt EE technologies. The authors stated that firms' product innovation relates to their adoption of EE technologies, albeit in a non-trivial way. Meanwhile, EE can also contribute to innovation creation. Wen et al. (2022) showed that renewable energy and EE promote innovation performance. Results of previous empirical research suggest a nexus between EE and firm's innovativeness. Prokop et al. (2022) also mentioned the importance of examining a so-called reverse relationship between firms' environmental behaviour, including energy management and energy consumption monitoring, and non-environmental innovations. The authors showed that firms' monitoring of energy consumption affects firms' product innovation creation differently using a sample of Central and Eastern European countries.

Considering these arguments, we identify three major gaps across the extant literature. To define and interconnect them, it is necessary to realize that the same factors may drive firms' innovation and EE. These are superior intangible assets of the firm, including HC (Gerstlberger et al., 2016). The first research gap is a missing link regarding the effects of firm-specific HC on EE, also considering the effects of firms' innovativeness on EE. Second, given the little empirical evidence on the effects of EE on firms' innovativeness (Wen et al., 2022), the so-called reverse relationship between EE and firms' innovativeness should be examined (Prokop et al., 2022), with an emphasis on the effects of firm-specific HC. Third, most prior studies analysed linear relationships between a firm-specific HC and environmental outputs as well as the firm's innovativeness, while neglecting possible nonlinear links, which are more realistic. Indeed, researchers have called for further analyses of nonlinear links among these variables (Nuber & Velte, 2021). Few studies have considered the mediating role of EE (Zhao et al., 2022; Murshed et al., 2022), so we also test the mediating role of EE in the creation of firms' innovation.

To address the identified research gaps and contribute to the current literature, *we aim to offer a more holistic view of this issue by combining different theoretical concepts and subsequently empirically examining the effects of selected forms of firm-specific HC (experiences, skills, and gender diversity) on EE and innovativeness*. More specifically, this study creates a theory mix linking four important theoretical concepts. To highlight the indisputable but not-thoroughly-analysed role of firm-specific HC in influencing firms' environmental behaviour and outputs, we draw on the HC theory and the natural resource-based view to find the missing link between firm-specific HC and EE. Next, to highlight the increasingly important role of gender diversity as part of the personal characteristics of firms' HC, we link gender socialization theory and upper echelons theory, thereby identifying the need for gender diversification in firms while simultaneously contributing a new perspective by examining the gender diversity of other groups of employees (compared to upper echelons theory by focusing on board gender diversity). Finally, we find a nexus among HC, EE, and firms' innovativeness (understood in this study as firms' creation of product and/or process innovations).

Another contribution is evident in the research sample that we use. Prior research has primarily focused on Western and Northern European countries. For example, Zhang et al. (2016) estimated firm-level EE in Swedish industry, and Rammer et al. (2017) studied Germany, Switzerland, and Austria to reveal the effects of energy policy on firms' export performance. Moreover, cross-country studies have indicated the leading roles of Western countries. Sun et al. (2021) confirmed that Germany, France, the UK, the Netherlands, and Switzerland are the most energy-efficient countries. In contrast, our study aims to provide a more comprehensive picture about the link among firm-specific HC, EE, and firms' innovativeness using a sample of 11 "catching-up" countries from South, Baltic, and Eastern Europe, which have not received as much attention as their western and northern neighbours. This situation has led to a lack of useful data for policy makers aiming to design new sustainable industrial policies (Viesi et al., 2017), which could be harmonized, such as throughout the "catching-up territory". Therefore, this study covers Italy, Portugal, Slovenia, Czech Republic, Estonia, Latvia, Lithuania, Slovakia, Cyprus, Poland, and Bulgaria.

We pose the central research question (RQ_{CENT}) of this study as follows:

RQ_{CENT}: How does HC heterogeneity affect firms' EE and innovativeness within catching-up European countries?

The rest of the paper is structured as follows. Section 2 introduces the basic theoretical concepts. Section 3 presents the data and methods used. Section 4 presents the results, and Section 5 includes a discussion of the results. Contributions and conclusions are in Section 6, along with practical implications.

2 Theoretical framework, literature review, and research questions

2.1 HC theory and natural resource-based view

Once research confirmed HC as the "residual factor" contributing to clarifying the economic growth of states and representing the so-called "new production factor" (Lucas Jr., 1988), it became a multidimensional theoretical concept in the economic literature of the 21st century. It led to HC theory overlapping several other theoretical concepts as well as to several extensions, including such terms as organizational, intellectual, social, innovation, and other capital (Nafukho et al., 2004). The fundamental principle underpinning this theoretical concept was evident in the belief that peoples' learning capacities are of comparable value to other production resources (Nafukho et al., 2004). We can categorize HC into three parts (Bano et al., 2018): (1) general HC (also called HC stock) that represents the combination of general education and experience; (2) firm-specific HC, accumulated through firm-related education, knowledge, skills, and experiences; and (3) task-specific HC (task-related training, experience, skills, and knowledge).

Considering the nexus among firms' HC and their environmental behaviour, we found theoretical support in the natural resource-based view (Hart, 1995), which argues that firms' competitive advantage develops because of the resources (physical capital, HC, and organizational capital) available to the firm (Barney, 1991). These are diverse and inimitable, whereas HC resources occur in forms such as knowledge, training, experience, relationships, individual managers, and employees. Meanwhile, increased competitiveness is also a result of firms' sustainable development, pollution prevention, and product stewardship resources (Yusoff et al., 2019). However, despite extensive literature on the determinants of eco-innovation and firms' environmental behaviour (Hojnik & Ruzzier, 2016), to date research has not considered the influence of personal characteristics of a firm's HC (Horbach & Jacob, 2018), and less research has considered the link between firms' EE and HC (Edziah et al., 2021), especially at the firm level. Therefore, to bring a new perspective and knowledge to the current state of the art, we consider HC as firm-specific HC in this study and focus on the effects of employees' and/or top managers' experiences and skills on EE.

2.2 Gender socialization and upper echelons theories

In line with the gender socialization theory, we bring another perspective to the current research by considering gender diversity as an important personal characteristic of a firm's HC (employees and/or top managers), which could significantly affect its EE. This theoretical concept highlights differences between men and women when dealing with decisions on competition and ethical practices (Yarram & Adapa, 2021). This perspective sees women as being more likely to promote environmental activities, possess communal values, and harm communities less than men (Nadeem et al., 2020). Prior research confirmed these assumptions and linked the gender socialization theory with the research on the gender diversity of firms' boards by using upper echelons theory (see, for example, Nadeem et al., 2020). These recent studies show that female representation on a firm's board is expected to increase the firm's environmental behaviour and sustainability performance (Naciti, 2019).

Despite this increased interest, recent results are mixed. For example, Orazalin and Baydauletov (2020) showed a dual role, both positive and negative, of board gender diversity on a sample of European firms. The authors initially confirmed that board gender diversity promotes sustainable development as it is positively associated with firms' environmental and social performance. In contrast, they demonstrated that board gender diversity negatively moderates the positive relationship between corporate social responsibility strategy and environmental performance. The studies of Zaid et al. (2020) and Qureshi et al. (2020) also produced mixed results.

In light of the current call for additional studies exploring the effects of workforce diversity (Yarram & Adapa, 2021), we developed our arguments focusing not only on top managers, but also on the gender diversity of other groups of workers to consider whether they are production or non-production male or female workers.

2.3 HC, EE, and firm innovativeness – the nexus

Considering our arguments thus far and the results of recent research (Wen et al., 2022; Prokop et al., 2022), we assume a nexus exists between EE and firms' innovativeness because adopting EE technologies at the firm level represents an integrative part of a "larger innovation picture" (Gerstlberger et al., 2016), whereas EE is highly advantageous for firms. EE can lead to decreased production costs and the acceleration of permanent investment decisions favourable for technological progress (Wen et al., 2022). In addition, firms' innovativeness and EE could be understood as "different areas of firms' innovation", which require the use of the same or similar resources that could include, among others, firm-specific human resources, such as managerial skills and competencies (Gerstlberger et al., 2016).

Pye and McKane (2000) and Gerstlberger et al. (2014) argued that firms must understand all costs and benefits associated with EE, which could be a by-product of firms' innovation and can also lead to innovations that become by-products of EE. Thus, we consider it highly relevant to study these relationships to reveal the effects of firm-specific HC within these processes. Despite the limited number of studies on the link between HC and EE at the firm level, the empirical studies showed that well-educated, well-trained, and skilled executives and employees are much more energy efficient (Edziah et al., 2021). Similarly, HC plays an important role in innovation success because it can promote firms' innovativeness by creating, absorbing, sharing, and applying new knowledge (Wen et al., 2022).

This theory mix highlights the need for further research in this area. We create following research sub-questions ($RQ_{SUB1\text{-}3}$) to reveal the ambiguities of the research to date:

RQ_{SUB1}: Does firm-specific HC in forms of experiences, skills, and gender diversity significantly affect firms' EE? Do these forms of HC influence firms' EE differently?

RQ_{SUB2}: Does firm-specific HC in forms of experiences, skills, and gender diversity significantly affect firms' innovativeness? Do these forms of HC influence firms' innovativeness differently?

RQ_{SUB3}: Are there significant mutual effects between firms' EE and innovativeness?

2.4 Linear and nonlinear relationships among variables and mediating role of EE

As some of our input variables are continuous (see Section 3 for more details), we can respond to most of the previous research's limitations due to assumptions of linear relationships among the variables representing firm-specific HC and firms' environmental behaviour (Nuber & Velte, 2021). Although a proportional relationship among these factors might be unrealistic, prior studies neglected possible nonlinear relationships. Nuber and Velte (2021) also recommended analysing nonlinear relationships. For example, Birindelli (2019) demonstrated a nonlinear relationship between board gender diversity and banks' environmental performance. Nuber and Velte (2021) confirmed the indication of a U-shaped relationship between board gender diversity and firms' carbon performance. Sarto and Saggese (2022) also confirmed a U-shaped relationship between board industry expertise and innovation input.

However, to our knowledge, ours is one of the first studies to test nonlinear relationships among firm-specific HC, EE, and firms' innovativeness.

Similarly, apart from assessing only the independent impacts, very few studies have examined EE's mediating role (Zhao et al., 2022; Murshed et al., 2022). Recent studies have shown that EE could act as a mediator in neutralizing the energy sustainability-inhibiting effects of economic growth (Murshed et al., 2022) and that EE mediates the relationship between industrial structure adjustment and CO_2 emissions (Zhao et al., 2022). Therefore, as EE and firms' innovativeness are connected parts of the same managerial puzzle (Gerstlberger et al., 2014), we contribute to the current knowledge by analysing EE's mediating role in firms' creation of innovations.

In addition to our research questions, we test whether nonlinear relationships exist among firm-specific HC, EE, and innovativeness and whether EE can act as a mediator in the creation of product and process innovations.

3 Empirical Strategy

3.1 Data source, research models, and dependent variables

This article employs data from the World Bank Enterprise Survey (WBES) 2019 and its Green Economy Module (World Bank, 2022). WBES provides data on enterprises in the manufacturing and service sectors by using a global methodology, including standardized survey instruments and a uniform sampling methodology. Private contractors conduct WBES on behalf of the World Bank, covering various topics focused on firm characteristics, gender participation, and business environment (e.g., performance measures, access to finance, competition). Survey respondents include business owners and top managers, although company accountants and human resource managers may also answer specific questions. WBES uses stratified random sampling methodology. For more details, please see https://enterprisesurveys.org/en/methodology.

Our dataset includes respondents from 2,806 firms in 11 South, Baltic, and Eastern European countries: Italy, Portugal, Slovenia, Czech Republic, Estonia, Latvia, Lithuania, Slovakia, Cyprus, Poland, and Bulgaria. The division of states into these three groups will subsequently be used to verify the consistency of the results of our research models working with a combined dataset including all the states under study.

Table 1 Analysed states and their percentages

Country	Relative freq. in %	Group
Bulgaria	10.41	East
Czech Republic	8.62	42.59
Poland	17.18	
Slovakia	6.38	
Estonia	3.99	Baltic
Latvia	4.21	12.12
Lithuania	3.92	
Cyprus	2.39	South
Italy	14.29	45.29
Portugal	24.48	
Slovenia	4.13	

Our empirical strategy involved creating three models, working with three different output variables (all these variables are binary; 1 indicates “yes”):

- **Model 1** for *energy efficiency (EE)*, proxied by the question: *Over the last three years, did this establishment adopt any measures to enhance energy efficiency?*
- **Model 2** for *product innovation*, proxied by the question: *During the last three years, has this establishment introduced new or improved products or services?*
- **Model 3** for *process innovation*, proxied by the question: *During the last three years, has this establishment introduced any new or improved processes?* These include methods of manufacturing products or offering services; logistics, delivery, or distribution methods for inputs, products, or services; and supporting activities for processes.

Next, to explore the relationships between the dependent variables and to verify the correctness of their use in separate regression models, we also created the following bivariate regression models working with two dependent variables together:

- **Model 4** for *energy efficiency* and *product innovation* as dependent variables.
- **Model 5** for *energy efficiency* and *process innovation* as dependent variables.
- **Model 6** for *product innovation* and *process innovation* as dependent variables.

We used variables pertaining to energy efficiency, product innovation, and process innovation as both input and output variables in the different models. Table 1 lists the relative frequencies of the variables.

Table 2 Relative frequencies of dichotomous dependent (independent) variables

	Relative frequencies in %	
Variable name	1 (yes)	0 (no)
Energy efficiency	46.40	53.60
Product innovation	30.40	69.60
Process innovation	18.03	81.97

3.2 Independent and control variables

To express firm-specific HC (independent variables), based on the WBES data availability, we selected several variables and categorized them as *employees' experiences*, *skills*, and *gender diversity*. More specifically:

- We measured *employees' experiences* using a binary variable expressing the question: *How many years of experience working in this sector does the top manager have?* (1: above average; 0: otherwise).
- We divided *employees' skills* into three variables (*professionals*, *technicians*, *unskilled*) based on the question: *At the end of fiscal year, how many permanent, full-time production workers in this establishment were (i) in highly skilled jobs (i.e., professionals whose tasks require extensive theoretical and technical knowledge); (ii) in semi-skilled jobs (i.e., technicians whose tasks require some level of mechanical or technical knowledge); and (iii) in unskilled jobs (i.e., those whose tasks involve no specialized knowledge)?* We created three variables, representing the percentage of a given group of employees among the total number of employees making up these three groups (*professionals*, *technicians*, *unskilled*).
- We used three proxy variables for *employees' gender diversity*. First, we used a variable denoting whether *the top manager is female* (1: yes, 0: no). Second, we created two variables for the categories *production workers* and *non-production workers* based on the question: *At the end of fiscal year, in this establishment how many permanent, full-time workers in each of the following categories were female?* Each of these variables expresses the percentage of women in each group of workers (*production workers* and *non-production workers*).

Based on prior literature, our models also applied a set of control variables including the standard controls of *firm size* and *firm age*. We measured firm size by the number of full-time employees, including all employees and managers. We hypothesized that, with an increasing size, firms can allocate more resources to EE adoption and innovation activities (Gerstlberger et al., 2016). We identified three groups: small, medium, and large firms. Concerning firm age, Prokop et al. (2022) showed that young firms have a greater chance of creating product innovations than older firms. In contrast, due to the lack of (financial) resources, experience, and other factors, younger (and smaller) firms could be ineffective when carrying out corporate social responsibility activities (D'Amato & Falivena, 2020). For firm age, similarly to Coad et al. (2016), we used four categories: less than 10 years, 10 to 19 years, 20 to 29 years, and more than 29 years. The reference categories for *firm size* and *firm age* were selected based on the most frequent occurrence of variables in these categories (see Tab. 5).

Following Gerstlberger et al.'s (2016) argument that similar *obstacles* hamper firms' innovativeness and EE, we also controlled our results for selected barriers: (i) *access to finances* (1: major obstacles; 0: no, minor, or moderate obstacles); (ii) firm was subjected to an *energy tax or levy* (1: yes); and (iii) firm was subjected to an *energy performance standard* in its operations (1: yes).

In line with Hojnik et al. (2022), who stated that R&D investment could improve firms' environmental performance and innovation, thereby helping firms achieve more energy-efficient technological development, we also controlled our results for the effects of firms' R&D. We employed two variables: (i) firms' acquisition of *external knowledge* (1: yes; *Over the last three years, did this establishment spend money on the acquisition of external knowledge?*), including the purchase or licensing of patents and non-patented inventions, know-how, and other types of knowledge from other businesses or organizations; and (ii) firms' *R&D expenditures* (1: yes; *Over the last three years, did this establishment spend money on research and development activities within the establishment?*).

We also controlled our results for firms' *ecological (eco) value drivers* (Gunawan et al., 2020), which could include firms' ecological responsibility and environmental conservation and could pursue firms' initiatives that lessen its environmental impact. We employed four variables: *monitoring* (1: yes; *Over the last three years, did this establishment monitor its energy consumption?*); *targets* (1: yes; *Over the last three years, did this establishment have targets for energy consumption?*); *objectives* (1: yes; *In this fiscal year, did this firm have strategic objectives that mention environmental or climate change issues?*); and *manager* (1: yes; *In this fiscal year, did this establishment have a manager responsible for environmental and climate change issues?*).

Tables 3, 4 and 5 present the descriptive statistics of the input variables.

Table 3 Descriptive statistics of continuous input variables

Variable name	Mean	Standard deviation	Median
Professionals in %	27.78	27.28	17.86
Technicians in %	28.96	26.33	20
Unskilled in %	20.3	25.29	9.02
Female production workers	28.49	30.32	16.67
Female non-production workers	11.3	10.55	9.32

Table 4 Relative frequencies of categorical binary input variables (factors)

	Relative frequencies in %	
Variable name	1	0
Top Manager experience	55.17	44.83
Top Manager female	17.43	82.57
Obstacles - access to finance	54.81	45.19
Obstacles - energy tax or levy	22.81	77.19
Obstacles - energy performance	15.22	84.78
Eco Value drivers - monitoring	55.84	44.16

Eco Value drivers - targets	33.57	66.43
Eco Value drivers - objectives	24.38	75.62
Eco Value drivers - manager	16.18	83.82
External knowledge	11.08	88.92
R&D expenditures	23.02	76.98

Table 5 Relative frequencies of categorical non-binary input variables (factors)

Firm size		**Firm age**	
Level	**Relative freq. in %**	**Level**	**Relative freq. in %**
Small - ref.	64.01	< 10	7.24
Medium	28.08	from10 to 19	23.45
Large	7.91	From 20 to 29	32.25
		over 29 - ref.	37.06

3.3 Model descriptions

As the explained (dependent, output) variables are dichotomous (binary; 1: yes, 0: no) for all estimated models, we used a binary logistic regression. The general form of the binary logistic model is:

$$\ln \frac{\pi}{1-\pi} = \beta_0 + \sum_{j=1}^{p} \beta_j x_j = \eta(\mathbf{x}). \qquad (1)$$

The expression on the left side of Eq. (1) is often called logit, and $\pi = \text{Prob}[Y = 1|\mathbf{x}]$ denotes the probability that for given values of explanatory variables $X_1, \dots, X_p,$ the explained variable Y is equal to 1. The ride hand side of Eq. (1) is often called linear predictor or risk score and it marks by $\eta(\mathbf{x})$. According to Eq. (1) the probability π has the expression:

$$\pi = \frac{\exp\left(\beta_0 + \sum_{j=1}^{p} \beta_j x_j\right)}{1 + \exp\left(\beta_0 + \sum_{j=1}^{p} \beta_j x_j\right)}. \qquad (2)$$

An odds ratio OR is used to interpret the influence of the k-th explanatory variable X_k on a dependent variable Y and is given by:

$$OR = \frac{\left(\frac{\text{Prob}\left[Y = 1|X_k = 1, X_1, \dots, X_{k-1}, X_{k+1}, \dots, X_p\right]}{\text{Prob}\left[Y = 0|X_k = 1, X_1, \dots, X_{k-1}, X_{k+1}, \dots, X_p\right]}\right)}{\left(\frac{\text{Prob}\left[Y = 1|X_k = 0, X_1, \dots, X_{k-1}, X_{k+1}, \dots, X_p\right]}{\text{Prob}\left[Y = 0|X_k = 0, X_1, \dots, X_{k-1}, X_{k+1}, \dots, X_p\right]}\right)} = \exp(\beta_k). \qquad (3)$$

In Eq. (3), we assume that the explanatory variable X_k is dichotomous while the other $p-1$ explanatory variables may or may not be dichotomous. Therefore, the value of $\exp(\hat{\beta}_k)$ is the estimated odds ratio $\widehat{OR}$ between two levels of X_k (related to Y) when the values of the other $p-1$ explanatory variables are fixed. When the variable X_k is categorical (but not dichotomous; for example, *firm size*), the reference category has to be specified. Then the value of $\exp(\hat{\beta}_k)$ is the estimated odds ratio $\widehat{OR}$ between the particular level of X_k and specified reference category. Finally, if the input variable X_k is continuous, the value of $\exp(\hat{\beta}_k)$ is the estimated odds ratio $\widehat{OR}$ between two values of X_k, which differ by one. Details concerning the binary logistic regression model and its applications can be found in, for example, Hosmer and Lemeshow (2000).

For comparison with binary logistic regression models, also the bivariate logistic (specifically, the bivariate odds ratio) model was used. Such a model allows to couple two logistic regressions together with an equation for the odds ratio. The form of the bivariate odds ratio model is:

$$\ln \frac{\pi_i}{1-\pi_i} = \eta_i(\mathbf{x}), \qquad i = 1,2, \tag{4}$$

$$\ln \psi(\mathbf{x}) = \eta_3(\mathbf{x}). \tag{5}$$

The odds ratio $\psi(\mathbf{x})$ is given by

$$\psi(\mathbf{x}) = \frac{\mathrm{Prob}[Y_1 = 1, Y_2 = 1|\mathbf{x}]\ \mathrm{Prob}[Y_1 = 0, Y_2 = 0|\mathbf{x}]}{\mathrm{Prob}[Y_1 = 1, Y_2 = 0|\mathbf{x}]\ \mathrm{Prob}[Y_1 = 0, Y_2 = 1|\mathbf{x}]}, \tag{6}$$

i.e., ψ is the odds ratio of event $Y_1 = 1$for an observation with covariates $(Y_2 = 1, \mathbf{x})$ relative to an observation with covariates $(Y_2 = 0, \mathbf{x})$. For great details of bivariate logistic regression see, for example, Yee (2015).

Because the discussed models contain some continuous input variables and because prior research on this topic assumed linear relationships of input variables to the (transformed) output variable while neglecting possible nonlinear relationships (Nuber & Velte, 2021), we considered whether it is appropriate to include those variables as the linear terms, as assumed in Eq. (1). We used Royston and Altman's (1994) approach based on fractional polynomials to test and model possible nonlinearities. We further analysed whether a mediating role for EE exists in binary logistic models (Models 2 and 3).

4 Empirical Results

The results of our models are presented in the following section. To get a more comprehensive picture of the effects of the variables we investigated, we did not use variable selection (elimination) methods in our models. Therefore, estimated models contain all explanatory variables, including, for example, all control variables, even if their influence was not confirmed at the level of significance.

4.1 Model 1: EE as dependent variable

We tested the effects of firm-specific HC on firms' EE. The results in Table 6 show that the presence of more experienced managers in the firm leads to a higher chance of EE. We also found statistically significant effects of our continuous variables denoting employees' skills. Concerning professionals and technicians, we showed that their effects on the logit transformation of EE are positive and linear. Thus, a higher percentage of professionals and technicians increases the chance for EE in the firm. For example, if a firm has 20% more professionals (technicians) than another firm, its chance of EE is 1.3 (1.12) times higher.

In contrast, the presence of unskilled workers on firms' EE has a nonlinear effect and is modelled through such a function (see Table 6), which shows that a firm has a higher chance of EE if it substantially reduces the percentage of unskilled workers. If the firm has a very low or zero value of unskilled workers, the chance of it achieving EE is 1.8 times higher than in a firm with a higher percentage of unskilled workers (non-zero). Interestingly, the chances of EE are similar in firms where unskilled workers are about 80% or 20%. These results clearly indicate that only the absence of unskilled workers significantly increases the chances of EE.

Given our third element of firm-specific HC, gender diversity, we revealed significant effects of female top managers in Model 1. Surprisingly, female top managers have less of an effect on the adoption of measures to enhance EE than male top managers.

Regarding the effects of firms' innovativeness, we found that both product and process innovation increase firms' chances of adopting measures to enhance EE product innovation produced higher effects.

Table 6 Model 1: Binary logistic regression (dependent – *EE*)

Variable	Variable level or transformation	Coeff.	OR	p-value	Sign. Code
(Intercept)		-2.482	0.084	2E-16	***
Top Manager experience	1	0.2886	1.335	0.00554	**
Top Manager female	1	-0.3282	0.72	0.011005	*
Professionals in %		0.01331	1.013	1.1E-07	***
Technicians in %		0.005748	1.006	0.024478	*
Unskilled in % - x	((x + 0.1)/10)^-2	-5.1E-05		3.94E-05	***
Production workers female		0.003324	1.003	0.04089	*
Non-production workers female		0.001648	1.002	0.730042	
Product innovation	1	0.4366	1.547	7.19E-05	***
Process innovation	1	0.2578	1.294	0.053512	.
Obstacles - access to finance	1	0.4299	1.537	7.48E-06	***
Obstacles - energy tax or levy	1	0.2401	1.271	0.040021	*
Obstacles - energy performance	1	0.9737	2.648	3.39E-10	***
Eco Value drivers - monitoring	1	1.02	2.773	2E-16	***
Eco Value drivers - targets	1	1.27	3.561	2E-16	***
Eco Value drivers - objectives	1	0.4973	1.644	0.000241	***
Eco Value drivers - manager	1	0.3247	1.384	0.044185	*
Firm size	Large	0.2798	1.323	0.177622	
ref. - Small	Medium	0.1168	1.124	0.302519	
Firm age	< 10	-0.3099	0.734	0.138846	
ref. - over 29	from 10 to 19	-0.22	0.803	0.102964	
	from 20 to 29	-0.02278	0.977	0.842049	
External knowledge	1	0.006746	1.007	0.968261	
R&D expenditures	1	0.2318	1.261	0.073331	.

The results in Table 6 also demonstrate that firms' obstacles (financial, in the form of energy tax or levy, and energy performance) increase the chances of adopting measures to enhance EE. Firms' ecological value drivers (monitoring, targets, objectives, manager) increase the chances of adopting measures to enhance EE.

Considering the role of firm size, the results suggest that large firms have a higher chance of implementing EE than SMEs, and that younger firms, compared to older firms (over 29 years), have a lower chance of implementing EE. However, the results for both size and age are not confirmed at the usual level of significance 0.05.

4.2 Model 2: Product innovation as dependent variable

Table 7 shows that the presence of more experienced managers in firms leads to a greater chance of introducing product innovations, however, not at the usual level of significance. Regarding the effects of continuous variables denoting employees' skills as well as gender diversity, we showed that the effects on logit transformation of product innovation are both linear and nonlinear.

We found linear relationships between firms' product innovation and percentages of professionals, unskilled workers, and female production workers. These relationships are negative for increased percentages of professionals and unskilled workers but positive for an increased percentage of female production workers. More specifically:

- an increase of professionals by 20% leads to a reduction in the chances of creating a product innovation by approximately 23%; and
- an increase of unskilled workers by 20% leads to a decrease in the chances of creating a product innovation by approximately 26%; and
- an increase of female production workers by 20% leads to increase in the chances of creating a product innovation by approximately 8%.

In addition, we found nonlinear relationships between the logit transformation of firms' product innovation and the percentage of technicians. An increase in the percentage of technicians leads to a decrease in the chances of creating product innovation. However, the percentage decrease in the chances of introducing product innovations is higher with a lower percentage of technicians. For example, an increase of technicians from 10% to 20% leads to an approximately 29% decrease in the chances of creating product innovation. In contrast, an increase of technicians from 50% to 60% leads to an approximately 9% decrease in the chances of creating product innovation.

Furthermore, the presence of female top managers increases the chances of introducing product innovations. EE also increases firms' chances of creating product innovations.

Table 7 Model 2: Binary logistic regression (dependent – *Product Innovation*)

Variable	**Variable level or transformation**	**Coeff.**	**OR**	**p-value**	**Sign. Code**
(Intercept)		-0.69208	0.501	0.065381	
Top Manager experience	1	0.146842	1.158	0.156452	
Top Manager female	1	0.4489	1.567	0.000327	***
Professionals in %		-0.01281	0.987	0.000677	***
Technicians in % - x	((x + 0.1)/10)^-0.5	-0.34606	0.707	2.37E-06	***
	log((x + 0.1)/10)	-0.6359	0.529	2.67E-06	***
Unskilled in %		-0.01537	0.985	7.58E-05	***
Production workers female		0.003705	1.004	0.027028	*
Non-production workers female		0.002306	1.002	0.656904	
Energy efficiency	1	0.453382	1.574	3.99E-05	***
Process innovation	1	1.096274	2.993	2E-16	***

Obstacles - access to finance	1	-0.11177	0.894	0.238114	
Obstacles - energy tax or levy	1	0.331569	1.393	0.002842	**
Obstacles - energy performance	1	-0.13868	0.871	0.318398	
Eco Value drivers - monitoring	1	0.363768	1.439	0.001964	**
Eco Value drivers - targets	1	0.023003	1.023	0.846444	
Eco Value drivers - objectives	1	-0.1246	0.883	0.346484	
Eco Value drivers - manager	1	0.01066	1.011	0.941714	
Firm size	Large	0.124798	1.133	0.493192	
ref. - Small	Medium	0.015393	1.016	0.892538	
Firm age	< 10	0.064705	1.067	0.752782	
ref. - over 29	from 10 to 19	-0.12502	0.882	0.35342	
	from 20 to 29	-0.05545	0.946	0.625396	
External knowledge	1	0.448287	1.566	0.002249	**
R&D expenditures	1	1.126583	3.085	2E-16	***

Considering the effects of control variables, obstacles in the form of an energy tax or levy and ecological value drivers in the form of monitoring energy consumption increase the chances of introducing product innovations. We obtained the same significant effects for process innovations, external knowledge acquisition, and R&D expenditures.

In Model 2, considering the effects of company size and age, we did not demonstrate significant differences. We also did not reveal any mediating effects of EE.

4.3 Model 3: Process innovation as dependent variable

The results for Model 3 show that employee experiences in the form of managerial experiences and female top managers are not significant. In addition, we did not find nonlinear relationships between the logit transformation of firms' process innovation and our continuous variables in Model 3.

Table 8 Model 3: Binary logistic regression (dependent – *Process Innovation*)

Variable	**Variable level or transformation**	**Coeff.**	**OR**	**p-value**	**Sign. Code**
(Intercept)		-2.67E+00	0.069	1.29E-08	***
Top Manager experience	1	-6.19E-02	0.94	0.608649	
Top Manager female	1	-8.57E-02	0.918	0.581437	
Professionals in %		-1.43E-02	0.986	0.004445	**
Technicians in %		-1.36E-02	0.987	0.019966	*
Unskilled in % - x		-2.47E-03	0.998	0.620701	
Production workers female		-1.23E-03	0.999	0.576935	
Non-production workers female		-7.83E-05	1	0.992803	
Energy efficiency	1	1.24E+00	3.463	6.23E-05	***
Product innovation	1	1.12E+00	3.05	2E-16	***
Obstacles - access to finance	1	-2.91E-01	0.748	0.009978	**
Obstacles - energy tax or levy	1	2.23E-01	1.249	0.076934	.
Obstacles - energy performance	1	1.83E-01	1.201	0.219084	
Eco Value drivers - monitoring	1	1.17E+00	3.225	1.24E-08	***

Eco Value drivers - targets	1	2.62E-01	1.299	0.047751	*
Eco Value drivers - objectives	1	6.92E-02	1.072	0.638617	
Eco Value drivers - manager	1	7.86E-02	1.082	0.619285	
Firm size	Large	-4.83E-01	0.617	0.019491	*
ref. - Small	Medium	-2.21E-01	0.802	0.091733	.
Firm age	< 10	1.66E-01	1.181	0.527989	
ref. - over 29	from 10 to 19	3.41E-01	1.406	0.032221	*
	from 20 to 29	4.05E-01	1.499	0.002737	**
External knowledge	1	5.63E-01	1.756	0.000213	***
R&D expenditures	1	1.13E+00	3.099	5.67E-08	***
Energy efficiency: Eco Value drivers - monitoring	1: 1	-9.37E-01	0.392	0.000813	***
Energy efficiency: R&D expenditures	1: 1	-6.75E-01	0.509	0.006707	**
Energy efficiency: Non-production female workers	1: 1	-2.22E-02	0.978	0.038496	*
Energy efficiency: Technicians in %	1: 1	8.10E-03	1.008	0.087716	.

Table 8 shows that an increased number of professionals and technicians decreases the chances of introducing process innovations. We also determined that firms introducing EE have a 3.5-time higher chance of achieving process innovations. Moreover, EE can act as a mediator within practices of process innovation creation. More specifically, concerning our binary variables, we discovered that firms which monitor energy consumption (*eco value drivers – monitoring*) have approx. 3.2-times greater chance of process innovation. However, if these firms monitor energy consumption in interactions with EE, they have a 4.4-time higher chance of process innovation. Similarly, firms' *R&D expenditures* increase the chances of process innovation by 3.1 times, while interaction between firms' R&D expenditures and EE increases the chances of process innovation by 5.5 times.

When we considered our continuous variables (*non-production female workers* and *technicians*), we found that their different values modified the chances of firms introducing process innovation to different degrees. The interactions with EE in the firm showed that having (i) 5% non-production female workers increases the chances of process innovation by 3.1 times; (ii) 10% non-production female workers increases the chances of process innovation by 2.77 times; and (iii) more than 20% non-production female workers results in statistically insignificant chances of process innovation. In sum, the interaction between EE and non-production female workers is significant, but only up to a certain percentage. A greater percentage of non-production female workers (in interaction with EE) reduces firms' process innovation.

In contrast, the interactions with EE in the firm showed that having (i) 10% technicians increases the chances of process innovation by 3.75 times while (ii) 20% technicians increases the chances of process innovation by 4.1 times. An increased number of technicians leads to increased chances of introducing process innovation (more with a higher percentage of technicians).

Considering our control variables, we show that financial obstacles decrease the chance to introduce process innovations, while obstacles in the form of energy tax or levy slightly increase the chance to introduce process innovations. Ecological value drivers - monitoring energy consumption and targets for energy consumption – also increase the chance to introduce process innovations. The same is true for product innovations, external knowledge acquisition, and R&D expenditures. Regarding firm age, a higher chance to introduce process innovations is given in firms with the age 10-19 and 20-29 years, compared to firm age over 29 years. Surprisingly, against our expectations that firms can allocate more resources to innovation activities with an increasing size, we show that small firms are more likely to introduce process innovation within catching-up territories.

4.4 Bivariate regression and country group models

In the next step, we verified our results using bivariate logistic regression, the aim of which is to determine whether our dependent variables (EE, Product, and Process Innovation) could be used in separate regression models. In these models, we considered two dependent variables simultaneously (see Eq. (4)). Because we considered the same linear predictors $\eta(\mathbf{x})$ for both explanatory variables in our bivariate logistic regression models, please note that nonlinear relationships and mediating roles of the variables were not examined. Tables 9-11 show the estimates of the coefficients contained in the linear predictor for the corresponding explained variable (see Eq. (4)). An estimate of the logarithm of the odds ratio $\psi(\mathbf{x})$ links the relevant explanatory variables (see Eq. (5)). Bivariate logistic regression and binary logistic regression models can be compared through estimated coefficients.

Table 9 Model 4: Bivariate logistic regression (dependents – *EE* and *Product Innovation*)

Variable	**Variable level**	**coef. (EE)**	**coef. (Prod. Inn.)**
(Intercept)		-2.789313802	-1.08831164
Top Manager experience	1	0.316247852	0.176910263
Top Manager female	1	-0.300724267	0.423790811
Professionals in %		0.012568336	-0.012188324
Technicians in %		0.005333593	-0.014488503
Unskilled in % - x		0.006054614	-0.013873309
Production workers female		0.003184965	0.004566823
Non-production workers female		0.003270476	0.001688456
Process innovation	1	0.357064696	1.12240984
Obstacles - access to finance	1	0.433457853	-0.0776387
Obstacles - energy tax or levy	1	0.263272261	0.341414362
Obstacles - energy performance	1	0.977507023	-0.065586875
Eco Value drivers - monitoring	1	1.05732399	0.459656911
Eco Value drivers - targets	1	1.269518365	0.154313871
Eco Value drivers - objectives	1	0.467234026	-0.091725338
Eco Value drivers - manager	1	0.3433606	0.014048294
Firm size	Large	0.437384936	0.224824403
ref. - Small	Medium	0.211789875	0.103656825
Firm age	< 10	-0.321008032	0.032834994
ref. - over 29	from 10 to 19	-0.217494016	-0.125824538
	from 20 to 29	-0.022972426	-0.057289034
External knowledge	1	0.054268268	0.433168149

R&D expenditures	1	0.350528701	1.151283655
		$\psi(\mathbf{x})$	0.449471

In Table 9, we compared coefficients corresponding to the explanatory variables with the coefficients in Table 6 (Model 1 for EE) and in Table 7 (Model 2 for Product Innovation). These can be considered comparable in most cases. Next, we compared the value of an estimate of the logarithm of the odds ratio $\psi(\mathbf{x}) = 0.449$ with (i) the value assigned for the effect of Product Innovation on EE in Table 6 (0.437); and (ii) with the value assigned for the effect of EE on Product Innovation in Table 7 (0.453). The value of $\psi(\mathbf{x})$ is quite close to both coefficients, and we can say that it corresponds to their approximate average.

Table 10 Model 5: Bivariate logistic regression (dependents – *EE* and *Process Innovation*)

Variable	**Variable**	**coef. (EE)**	**coef. (proc. Inn.)**
(Intercept)		-2.89010725	-2.227115499
Top Manager experience	1	0.30319681	-0.032950491
Top Manager female	1	-0.341114291	-0.118810091
Professionals in %		0.01319543	-0.014629111
Technicians in %		0.006208422	-0.009140053
Unskilled in % - x		0.007085207	-0.003257654
Production workers female		0.00282993	-0.000964949
Non-production workers female		0.002744009	-0.012009119
Product innovation	1	0.487270539	1.138962603
Obstacles - access to finance	1	0.433524808	-0.244227577
Obstacles - energy tax or levy	1	0.244400532	0.228674959
Obstacles - energy performance	1	0.994663614	0.214005768
Eco Value drivers - monitoring	1	1.049729667	0.848688276
Eco Value drivers - targets	1	1.275813238	0.317827136
Eco Value drivers - objectives	1	0.480886971	0.062402905
Eco Value drivers - manager	1	0.34502951	0.05735719
Firm size	Large	0.403865074	-0.507626495
ref. - Small	Medium	0.199013833	-0.212594748
Firm age	< 10	-0.321971816	0.130957691
ref. - over 29	from 10 to 19	-0.199466156	0.356625782
	from 20 to 29	-0.00677687	0.41442152
External knowledge	1	0.039566832	0.544418973
R&D expenditures	1	0.271514857	0.691086376
		$\psi(\mathbf{x})$	0.2692448

In an analogous way, we tested the relationships between Model 1 (Table 6) and Model 3 (Table 8) in Table 10 (Model 5). We can see that the value of $\psi(\mathbf{x}) = 0.269$ (Table 10) is close to the value of the effect of Process Innovations on EE (= 0.258) in Table 6 (Model 1). By contrast, since EE is part of several interactions as a mediator in Model 3 (Table 8), its comparison with $\psi(\mathbf{x})$ is limited.

When comparing the values in Model 2 (Table 7) and Model 3 (Table 8) with $\psi(\mathbf{x}) = 1.106$, we can confirm that the influence values of (i) Process Innovations (1.096) on Product

Innovations, and (ii) Product Innovations (1.120) on Process Innovations are again quite similar.

Table 11 Model 6: Bivariate logistic regression (dependents – *Product Innovation* and *Process Innovation*)

Variable	**Variable**	**coef. (Prod. Inn.)**	**coef. (Proc. Inn.)**
(Intercept)		-0.875640341	-1.791132384
Top Manager experience	1	0.141968869	-0.014200855
Top Manager female	1	0.434687271	0.000492799
Professionals in %		-0.015534217	-0.018207143
Technicians in %		-0.016394298	-0.012780114
Unskilled in % - x		-0.014912413	-0.006938772
Production workers female		0.004174345	-0.000125687
Non-production workers female		-0.000208414	-0.01160723
Energy efficiency	1	0.506713076	0.38627073
Obstacles - access to finance	1	-0.160190064	-0.291369462
Obstacles - energy tax or levy	1	0.365837906	0.296121897
Obstacles - energy performance	1	-0.094001805	0.144070646
Eco Value drivers - monitoring	1	0.459587496	0.862019101
Eco Value drivers - targets	1	0.07565842	0.250602936
Eco Value drivers - objectives	1	-0.119108431	0.006005456
Eco Value drivers - manager	1	0.006862252	0.043407884
Firm size	Large	0.100440282	-0.470399983
ref. - Small	Medium	0.048424809	-0.202483757
Firm age	< 10	0.08001086	0.152952289
ref. - over 29	from 10 to 19	-0.055221802	0.33496632
	from 20 to 29	0.00825228	0.397218504
External knowledge	1	0.553101401	0.648787872
R&D expenditures	1	1.259599315	0.963642402
		$\psi(\mathbf{x})$	1.106055

Given the proven similarities in the estimates of the bivariate and binary logistic regression models, the use of separate binary logistic regression models for Models 1-3 can be considered acceptable and correct. In addition, this procedure gives us more flexibility to investigate, for example, nonlinear effects of explanatory variables or their possible interactions (mediating roles).

In the last step, we controlled our results for different country groups (see Appendix A and Tables A1-A9). First, we controlled for the EE output within Eastern (Table A1), Baltic (Table A2), and Southern (Table A3) European countries. Next, we controlled for the Product Innovation output within Eastern (Table A4), Baltic (Table A5), and Southern (Table A6) European countries. Last, we controlled for the Process Innovation output within Eastern (Table A7), Baltic (Table A8), and Southern (Table A9) European countries.

When comparing control models for country groups (A1-A9) with our aggregated models (Models 1-3), we cannot find a single explanatory variable (with statistically significant coefficients), which shows opposite effect for different country groups. Moreover, these significant coefficients take on similar values in many cases. For example, the effects of EE on Process Innovation in the Table 8 are similar to effects in Tables A7, A8, and A9. However, we must note a limitation, which is the small number of significant effects demonstrated for the group of Baltic countries, which is mainly due to the smaller size of that group.

Summarizing above tests presented in the sub-Section 4.4, confirming the robustness of the results of Models 1-3, applied regression models can be considered correctly chosen and acceptable.

5 Discussion

5.1 Energy efficiency as a dependent variable

Starting with the first sub-RQ, we tested whether experiences, skills, and gender diversity (firm-specific HC) have significant effects on firms' EE. Moreover, we checked whether these effects differ. Our results show that both experiences and skills affect firms' EE. Thus, the human factor, specifically the experience and knowledge of top managers as well as the knowledge of technicians and professionals, can influence EE in European catching-up countries. With this finding, we confirm the previous research's assumption highlighting the role of skills and knowledge as a new production factor that can significantly influence the performance and outputs of firms. From the perspective of firms' environmental behaviour, our findings are consistent with those of Paillé and Halilem (2019), who concluded that firms' green absorption capacity and ability to effectively use (external) knowledge determine firms' environmental innovativeness and eco-innovation capacity. According to this finding, firms should put humans at the centre of their strategies.

Despite the importance of highly skilled employees with specialized knowledge, we also demonstrated that firms' EE may increase if they reduce the number of unskilled workers. These findings clearly indicate the importance of knowledge, skills, and experiences for EE. Furthermore, and surprisingly, concerning gender diversity, our findings contradict most recent literature. We demonstrate that top managers' gender diversity does not lead to an increase in the chances of EE in firms in catching-up European countries. More specifically, our results contradict previous assumptions that gender diversity increases firms' environmental behaviour and corporate social responsibility (Nadeem et al., 2020; Orazalin & Baydauletov, 2020; Number & Velte, 2021). Historically, the energy sector and related companies have been primarily male dominated, bearing the remains of low or no gender equality efforts within decision-making processes. Carlsson-Kanyama et al. (2010) supported this finding using a sample of large energy companies in Germany, Spain, and Sweden. It can therefore be assumed that the topic of EE will also be more male dominated in the future. Consequently, growing gender diversity will not play a significant role for EE compared to the generally perceived environmental behaviour of firms, for which research previously confirmed the importance of gender diversity.

In addition, we showed that firms facing our selected obstacles also focus on EE. These obstacles include financial obstacles as well as environmental regulations in the form of energy tax or levy and energy performance standards. Not only internal knowledge and skills, but also the acquisition of external knowledge is important for firms' EE. Finally, consistent with

Gunawan et al. (2020), we demonstrated that firms' ecological value drivers (monitoring, targets, objectives, manager) increase their EE.

5.2 Product and process innovations as dependent variables

The second sub-RQ asked: *Does firm-specific HC in forms of experiences, skills, and gender diversity significantly affect firms' innovativeness? Do these forms of HC influence firms' innovativeness differently?*

Firm-specific HC has significant effects on the firm's innovativeness. We found that managerial experiences significantly affect product innovation, but not process innovation. In contrast, employee skills (especially an increase in employees, such as professionals and technicians) have the opposite (negative) effects for both product and process innovation. This finding contradicts Leiponen's (2005) conclusion that technical skills are complementary with product or process innovation and that HC can act as a trigger of profitable innovation. Yet Schneider et al. (2010, p. 199) confirmed that skills and education are significant drivers of firms' innovativeness, although they also found that "*the high share of qualified employees as such is not a sufficient condition to enhance the propensity of product innovation at the firm level*". The authors also pointed out that it is necessary to focus primarily on the qualitative rather than quantitative aspects of HC.

Considering HC gender diversity, our findings are in line with prior research (Attah-Boakye et al., 2020; Ain et al., 2021). We confirmed the importance of managerial gender diversity for product innovations, but not for process innovation. We also showed that gender diversity among employees at lower levels (female production workers) can have significant effects on firm product innovation. Female production workers can significantly influence the creation of process innovation, mediated by EE. Overall, in accordance with Zhao et al.'s (2022) and Murshed et al.'s (2022) studies, we revealed that EE could act as a mediator during the creation of process innovations.

Regarding our control variables, obstacles in the form of environmental regulations (energy tax or levy) have positive effects on firms' product innovation, in line with the Porter hypothesis (Porter & Van der Linde, 1995). Moreover, both types of environmental regulations tested have positive effects on process innovations. However, financial obstacles have negative effects on firms' process innovation. Consistent with Prokop et al. (2022), we confirmed positive effects of firms' environmental behaviour on both product innovation and process innovation. In addition, we highlighted significant effects of external knowledge acquisition and R&D expenditures on product innovation. Surprisingly, our results regarding the effect of firm size on process innovation go against the original expectation and contradict the claims of Golovko and Valentini (2014) or Gerstlberger et al. (2016). Moreover, we did not prove differences between effects of firm age and size on product innovation. Fritsch and Meschede (2001) state that the effect of firm size on product and process innovation can be influenced by several external factors and industry characteristics such as product complexity, market structure, and type of technology applied, and therefore process- and product R&D expenditure could rise less than in proportion to size. Moreover, Hervas-Oliver et al. (2014) show that a process innovation strategy relies heavily on the external knowledge sources acquisition. It represents the driving innovation engine in the catching-up countries, which are more dependent on external knowledge and technology flows (Radošević, 2017). It can therefore be assumed that these factors have also been reflected in the sample of firms we analysed.

Finally, concerning our third research sub-question, we tested whether significant mutual effects occur between firms' EE and innovativeness. Consistent with Gerstlberger et al.'s (2016) findings, we confirmed that firms' innovativeness has significant and positive effects on EE. Product innovations' effects are higher than those of process innovation. Regarding EE's effects on firm's innovativeness, we found highly significant effects on both product and process innovations.

6 Conclusions

6.1 Summary and contributions

This study responded to recent calls (Horbach & Jacob, 2018; Edziah et al., 2021) for studies to help clarify and better understand the effects of the personal characteristics of firms' HC on firms' environmental behaviour and EE. We addressed three important research gaps – (i) the missing link regarding the effects of firm-specific HC on EE; (ii) the interrelationship between EE and firms' innovativeness; and (iii) nonlinear relationships between firm-specific HC, EE, and innovativeness – as well as the mediating role of EE within processes of firms' innovation creation. Our results confirmed that HC heterogeneity, proxied by employee experiences, skills, and gender diversity, is linked to, and significantly influences EE and innovativeness across European catching-up territories. The importance of examining HC heterogeneity is also confirmed by the fact that each of its elements (experiences, skills, gender diversity) influence EE and innovativeness in a different way. This constitutes a challenge for further follow-up studies. At the same time, we show that EE and innovativeness also significantly influence each other. As a result, we offer important contributions to the academic and practical discussion.

Our theoretical contributions advance the current literature by creating an original theory mix. In doing so, we have linked novel and more social science- and human-resource-based theoretical frameworks to – thus far – rather "technically" discussed EE aspects at the firm level. We also identified a missing link between firm-specific HC and EE. Finally, we highlighted the importance of investigating firm-specific HC at different firm levels in terms of employees' skills and experiences as well as gender diversity.

Our empirical contribution is twofold. First, we revealed nonlinear empirical (quantitative) results of a secondary data analysis and the mediating role of EE. More concretely, we produced novel findings that contribute to the ongoing debate on the linearity of the examined relationships. Contrary to previous studies neglecting possible nonlinear relationships, we showed that the presence of unskilled workers has nonlinear effects on firms' EE. We further revealed nonlinear relationships between product innovation and technicians. Moreover, in response to the limited attention devoted to EE's mediating role, we found that EE could act as a mediator within practices of process innovation creation, in HC interactions (non-production female workers and technicians), and with eco value drivers (monitoring energy consumption). We also verified whether our main empirical results for our "catching-up countries" are in line with the results of studies conducted on samples from Western and Northern European countries.

Second, our selected countries belong to groups of average eco-innovation performers or countries catching-up with eco-innovation (as measured by the European Commission); therefore, we empirically contributed analyses performed within the catching-up territory. According to Viesi et al. (2017, p. 369), these countries consider EE measures and efficient/sustainable manufacturing policies to only a small extent, meaning "*margins for improvement in energy efficiency are still large*". Moreover, given the historical consequences and transition of Central and Eastern European countries from socialist command economies to market demand economies, these countries "*inherited an energy-intensive industrial sector, coupled with high dependence on raw materials and primary energy sources*" (Jorgenson et al., 2014, p. 420). Therefore, this area offers the opportunity to observe lower EE, associated with several factors that have their roots in the Soviet era, such as older equipment, outdated technologies, and the inadequate metering and control of energy consumption (Jorgenson et al., 2014). Consequently, our empirical findings are highly relevant for public policy makers as well.

In sum, we demonstrated that firm-specific HC can act both positively and negatively within the examined European territory. By answering our central research question, we pointed out that the heterogeneity of HC can play a significant role for EE, as well as for the innovativeness of firms, and therefore is highly needed. However, to increase the chances of benefitting from firm-specific HC heterogeneity to the greatest extent possible, we next provide several managerial and political implications.

6.2 Implications and limitations

Our empirical and theoretical findings and arguments give us the opportunity to provide managers and public policy makers with a more complex picture of the catching-up European countries and to propose several practical implications.

From the perspective of managerial implications, we strongly suggest that firms consider new/updated strategies for selecting management/advisory board members, depending on the specific tasks needed. Although EE and innovativeness are connected parts of the same managerial puzzle, the effects of HC differ in some cases. To increase EE, highly experienced and skilled workers with relevant knowledge are necessary. For these purposes, we also suggest increasing firms' knowledge pool and (green) absorption capacity as well as building trust and social capital among employees to simplify and speed up firms' knowledge transfer. Consistent with Dzhengiz and Niesten's (2020) work, it is also necessary to increase managers' ability to recognize and acquire external knowledge, which could help them develop environmental competences. The authors further confirmed that firms capable of assimilating, transforming, and exploiting knowledge can develop their environmental capabilities. They should also increase unskilled workers' knowledge and skills, such as through training activities. Generally, we recommend that firms focus on the qualitative aspects of HC more than the quantitative ones (Schneider et al., 2010).

Next, it would be beneficial for firms within the catching-up European territory to increase their general environmental awareness, including that of unskilled workers, such as by explaining to them not only the environmental but also other advantages of firms' ecological orientation (e.g., saved costs, competitive advantage, and increased firm reputation). In accordance with our results, firms' environmental behaviour is significant for both EE and innovativeness.

Concerning firms' innovativeness, in line with prior international findings, we recommend increasing gender diversity in firms.

Both political and managerial decision makers should face the above-mentioned historical legacy influencing their EE as well as the lack of capacity to conduct their own country- and firm-specific cost-efficient energy efficiency improvement measures, such as energy audits. Different parameters affect why they are unable to self-assess their country/firm resource efficiency performance (Viesi et al., 2017). However, "*energy audits are one of the most widespread and used instruments to overcome barriers to energy efficiency and promote energy efficiency in industry*" (Fresner et al., 2017, p. 1658). Therefore, specific strategies and updates of business models are needed, as well as a good understanding of firms' constraints and needs. To increase firms' willingness to make these changes, as well as the chances of these changes being successful, chambers' and/or industry associations' support is crucial (Fresner et al., 2017).

Public policy makers should support efforts to increase personal environmental concerns in society, which could subsequently trigger individual actions, which could be powerful tools in the fight against environmental pollution (Hopwood et al., 2021). We also recommend that policy makers support firms' training and educational activities, such as through financial support of (foreign) exchanges. Triggering active collaboration between private organizations and public authorities also seems to be another way to support EE, as it successfully increases the efficiency of EE policies in countries like the Netherlands and Finland through, for example, voluntary agreements (Bertoldi & Mosconi, 2020).

Our study is not without limitations, such as the secondary statistical data analyses we conducted with a limited set of pre-defined variables and a specific set of "catching-up" countries. This main limitation leads to potential paths for future research, such as the inclusion of additional countries in secondary data analyses and (mixed-method) studies with primary survey and/or interview data for a smaller set of selected countries. Next, our study could be also limited by the fact that our explained variables are binary, expressed by questions that examine whether EE, product innovations and process innovations have been introduced in the last three years (without a closer time specification). However, there is a risk of crowding out effects between these three investments that would potentially reduce the impact of one type of investment on the other. For future research, it is therefore necessary to use qualitative data and personal questionnaire surveys, which would find out whether EE, product innovations and process innovations do not overlap with each other. At the same time, more detailed information regarding the period of implementation and other important specific characteristics of these investments must be explored (e.g., size, length, cost, or speed).

The emergence of possible reverse causality problem could be other limitation of this study. We know so far, and we also supported these finding by our results, that EE, product innovations and process innovations are parts of the same managerial puzzle (Gerstlberger et al., 2014) and that EE could trigger innovations (Wen et al., 2022), as well as that firms investing in innovations are more likely to adopt EE technologies (Gerstlberger et al., 2016). Prokop et al. (2022) also confirm that reverse relationship between EE and firms' innovativeness is an important issue. We worked with this problem using bivariate logistic models, however, future research should investigate this issue using for example reverse causality models (see Guloglu & Tekin, 2012 or Tan et al., 2019). We further recommend that future research should focus on other firm-specific HC characteristics not included in this paper (due to dataset limitations). As we identified the importance of employees' knowledge and the necessity to increase firms' green absorptive capacity, we suggest analysing the effects of firm-specific HC and technological knowledge on green absorptive capacity for environmental innovation and EE (Paillé & Halilem, 2019).

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Appendix A

Table A1 Binary logistic regression for Eastern country group (dependent – *EE*)

Variable	Variable level or transformation	Coeff.	OR	p-value	Sign. Code
(Intercept)		-2.335	0.097	1.01E-12	***
Top Manager experience	1	0.1267	1.135	0.43206	
Top Manager female	1	-0.2717	0.762	0.14338	
Professionals in %		0.006956	1.007	0.08447	.
Technicians in %		0.004957	1.005	0.18749	
Unskilled in % - x	((x + 0.1)/10)^-2	-0.00006585	1	0.00131	**
Production workers female		0.004673	1.005	0.05266	.
Non-production workers female		0.002044	1.002	0.78231	
Product innovation	1	0.3973	1.488	0.01937	*
Process innovation	1	0.3311	1.392	0.09888	.
Obstacles - access to finance	1	0.3469	1.415	0.01914	*
Obstacles - energy tax or levy	1	-0.05759	0.944	0.83693	
Obstacles - energy performance	1	1.3	3.669	6.41E-10	***
Eco Value drivers - monitoring	1	1.037	2.821	5.61E-10	***
Eco Value drivers - targets	1	1.153	3.168	6.36E-12	***
Eco Value drivers - objectives	1	0.3806	1.463	0.04915	*
Eco Value drivers - manager	1	0.5618	1.754	0.01098	*
Firm size	Large	-0.083	0.92	0.77761	
ref. - Small	Medium	-0.1001	0.905	0.58252	
Firm age	< 10	-0.3544	0.702	0.21633	
ref. - over 29	from 10 to 19	-0.03168	0.969	0.90999	
	from 20 to 29	-0.03591	0.965	0.90434	
External knowledge	1	-0.02023	0.98	0.94235	
R&D expenditures	1	0.07671	1.08	0.69987	

Table A2 Binary logistic regression for Baltic country group (dependent – *EE*)

Variable	Variable level or transformation	Coeff.	OR	p-value	Sign. Code
(Intercept)		-2.688	0.068	0.000371	***

Top Manager experience	1	-0.01585	0.984	0.9569	
Top Manager female	1	-0.05245	0.949	0.8847	
Professionals in %		0.006605	1.007	0.409	
Technicians in %		0.008001	1.008	0.2889	
Unskilled in % - x	((x + 0.1)/10)^-2	0.00002803	1	0.4708	
Production workers female		0.004145	1.004	0.46	
Non-production workers female		-0.003746	0.996	0.7781	
Product innovation	1	0.2819	1.326	0.3488	
Process innovation	1	0.4777	1.612	0.1305	
Obstacles - access to finance	1	0.1451	1.156	0.6329	
Obstacles - energy tax or levy	1	0.4407	1.554	0.1355	
Obstacles - energy performance	1	0.7407	2.097	0.1205	
Eco Value drivers - monitoring	1	0.9212	2.512	0.0162	*
Eco Value drivers - targets	1	1.475	4.371	1.12E-06	***
Eco Value drivers - objectives	1	0.6465	1.909	0.1504	
Eco Value drivers - manager	1	0.1376	1.148	0.7597	
Firm size	Large	2.024	7.569	0.025763	*
ref. - Small	Medium	0.6546	1.924	0.04339	*
Firm age	< 10	-0.4816	0.618	0.461208	
ref. - over 29	from 10 to 19	-0.3989	0.671	0.357173	
	from 20 to 29	-0.1989	0.82	0.609838	
External knowledge	1	0.5485	1.731	0.1492	
R&D expenditures	1	0.2033	1.225	0.584	

Table A3 Binary logistic regression for Southern country group (dependent – *EE*)

Variable	**Variable level or transformation**	**Coeff.**	**OR**	**p-value**	**Sign. Code**
(Intercept)		-2.709	0.067	< 2e-16	***
Top Manager experience	1	0.5298	1.699	0.001742	**
Top Manager female	1	-0.4026	0.669	0.081539	.
Professionals in %		0.01647	1.017	1.49E-05	***
Technicians in %		0.005589	1.006	0.180054	
Unskilled in % - x	((x + 0.1)/10)^-2	-6.418E-05	1	0.000775	***
Production workers female		0.003511	1.004	0.187269	
Non-production workers female		0.0001835	1	0.980808	
Product innovation	1	0.5343	1.706	0.00285	**
Process innovation	1	0.2085	1.232	0.388568	
Obstacles - access to finance	1	0.5388	1.714	0.000541	***
Obstacles - energy tax or levy	1	-0.03912	0.962	0.822718	
Obstacles - energy performance	1	0.9282	2.53	0.002352	**
Eco Value drivers - monitoring	1	1.189	3.284	1.58E-12	***
Eco Value drivers - targets	1	1.31	3.706	2.8E-11	***
Eco Value drivers - objectives	1	0.7025	2.019	0.002142	**
Eco Value drivers - manager	1	0.4643	1.591	0.141989	
Firm size	Large	0.3686	1.446	0.29095	

ref. - Small	Medium	-0.01126	0.989	0.94976	
Firm age	< 10	-0.7156	0.489	0.059705	.
ref. - over 29	from 10 to 19	0.05564	1.057	0.786538	
	from 20 to 29	0.2077	1.231	0.25666	
External knowledge	1	-0.4286	0.651	0.143755	
R&D expenditures	1	0.4452	1.561	0.030585	*

Table A4 Binary logistic regression for Eastern country group (dependent – *Product Innovation*)

Variable	**Variable level or transformation**	**Coeff.**	**OR**	**p-value**	**Sign. Code**
(Intercept)		-1.2118	0.298	0.05765	.
Top Manager experience	1	0.361521	1.436	0.02591	*
Top Manager female	1	0.392444	1.481	0.03171	*
Professionals in %		-0.01052	0.99	0.10406	
Technicians in % - x	((x + 0.1)/10)^-0.5	-0.18172	0.834	0.12903	
	log((x + 0.1)/10)	-0.40371	0.668	0.06886	.
Unskilled in %		-0.01306	0.987	0.04042	*
Production workers female		0.002321	1.002	0.35239	
Non-production workers female		0.00651	1.007	0.42716	
Energy efficiency	1	0.418209	1.519	0.0143	*
Process innovation	1	1.097648	2.997	6.79E-10	***
Obstacles - access to finance	1	-0.08547	0.918	0.56371	
Obstacles - energy tax or levy	1	-0.10631	0.899	0.68495	
Obstacles - energy performance	1	-0.00627	0.994	0.97616	
Eco Value drivers - monitoring	1	0.203433	1.226	0.25967	
Eco Value drivers - targets	1	0.114199	1.121	0.53278	
Eco Value drivers - objectives	1	-0.06279	0.939	0.75489	
Eco Value drivers - manager	1	-0.19289	0.825	0.38857	
Firm size	Large	0.197838	1.219	0.48016	
ref. - Small	Medium	0.135884	1.146	0.4653	
Firm age	< 10	0.315786	1.371	0.27946	
ref. - over 29	from 10 to 19	-0.10318	0.902	0.63774	
	from 20 to 29	-0.15302	0.858	0.40215	
External knowledge	1	0.706753	2.027	0.00405	**
R&D expenditures	1	1.04182	2.834	7.76E-09	***

Table A5 Binary logistic regression for Baltic country group (dependent – *Product Innovation*)

Variable	**Variable level or transformation**	**Coeff.**	**OR**	**p-value**	**Sign. Code**
(Intercept)		-1.22327	0.294	0.2567	
Top Manager experience	1	-0.16807	0.845	0.4995	
Top Manager female	1	0.536781	1.71	0.0819	.
Professionals in %		-0.00159	0.998	0.8808	
Technicians in % - x	((x + 0.1)/10)^-0.5	-0.10521	0.9	0.5782	

	log((x + 0.1)/10)	-0.15645	0.855	0.6545	
Unskilled in %		-0.00855	0.991	0.4247	
Production workers female		0.000308	1	0.9501	
Non-production workers female		0.022501	1.023	0.1089	
Energy efficiency	1	0.316863	1.373	0.2841	
Process innovation	1	0.322306	1.38	0.224	
Obstacles - access to finance	1	0.516073	1.675	0.0504	.
Obstacles - energy tax or levy	1	-0.53432	0.586	0.0374	*
Obstacles - energy performance	1	-0.02404	0.976	0.9471	
Eco Value drivers - monitoring	1	0.372778	1.452	0.3115	
Eco Value drivers - targets	1	-0.12448	0.883	0.6736	
Eco Value drivers - objectives	1	0.824229	2.28	0.016	*
Eco Value drivers - manager	1	0.076555	1.08	0.8285	
Firm size	Large	0.227556	1.256	0.6612	
ref. - Small	Medium	0.246211	1.279	0.4049	
Firm age	< 10	-0.20532	0.814	0.7346	
ref. - over 29	from 10 to 19	0.077922	1.081	0.8307	
	from 20 to 29	0.317349	1.373	0.3433	
External knowledge	1	-0.21768	0.804	0.486	
R&D expenditures	1	0.873526	2.395	0.0045	**

Table A6 Binary logistic regression for Southern country group (dependent – *Product Innovation*)

Variable	**Variable level or transformation**	**Coeff.**	**OR**	**p-value**	**Sign. Code**
(Intercept)		-0.06915	0.933	0.90146	
Top Manager experience	1	0.00219	1.002	0.99036	
Top Manager female	1	0.31541	1.371	0.17549	
Professionals in %		-0.01561	0.985	0.00528	**
Technicians in % - x	((x + 0.1)/10)^-0.5	-0.58726	0.556	3.96E-07	***
	log((x + 0.1)/10)	-1.00778	0.365	2.44E-06	***
Unskilled in %		-0.0167	0.983	0.00571	**
Production workers female		0.007327	1.007	0.00972	**
Non-production workers female		-0.00048	1	0.95397	
Energy efficiency	1	0.524515	1.69	0.00331	**
Process innovation	1	1.453729	4.279	9.02E-12	***
Obstacles - access to finance	1	-0.21397	0.807	0.17759	
Obstacles - energy tax or levy	1	0.768919	2.157	5.73E-06	***
Obstacles - energy performance	1	-0.29773	0.743	0.24684	
Eco Value drivers - monitoring	1	0.316467	1.372	0.09472	.
Eco Value drivers - targets	1	-0.07525	0.928	0.70532	
Eco Value drivers - objectives	1	-0.43665	0.646	0.05199	.
Eco Value drivers - manager	1	0.347665	1.416	0.18998	
Firm size	Large	0.120989	1.129	0.68273	
ref. - Small	Medium	-0.11437	0.892	0.53137	
Firm age	< 10	-0.16403	0.849	0.65732	

ref. - over 29	from 10 to 19	-0.18692	0.83	0.39639	
	from 20 to 29	0.065434	1.068	0.73504	
External knowledge	1	0.73033	2.076	0.00473	**
R&D expenditures	1	1.269047	3.557	1.72E-12	***

Table A7 Binary logistic regression for Eastern country group (dependent – *Process Innovation*)

Variable	**Variable level or transformation**	**Coeff.**	**OR**	**p-value**	**Sign. Code**
(Intercept)		-1.53605	0.215	0.042463	*
Top Manager experience	1	0.227659	1.256	0.236541	
Top Manager female	1	-0.39053	0.677	0.109887	
Professionals in %		-0.02531	0.975	0.002786	**
Technicians in %		-0.02585	0.974	0.007234	**
Unskilled in % - x		-0.01686	0.983	0.034147	*
Production workers female		0.000951	1.001	0.769387	
Non-production workers female		-0.01071	0.989	0.427073	
Energy efficiency	1	1.231062	3.425	0.010339	*
Product innovation	1	1.126747	3.086	3.82E-10	***
Obstacles - access to finance	1	-0.18334	0.832	0.302174	
Obstacles - energy tax or levy	1	0.207198	1.23	0.470249	
Obstacles - energy performance	1	-0.01854	0.982	0.938641	
Eco Value drivers - monitoring	1	0.997903	2.713	0.00105	**
Eco Value drivers - targets	1	0.37391	1.453	0.071182	.
Eco Value drivers - objectives	1	-0.10523	0.9	0.650886	
Eco Value drivers - manager	1	-0.18605	0.83	0.452773	
Firm size	Large	-0.25206	0.777	0.415616	
ref. - Small	Medium	0.035227	1.036	0.865776	
Firm age	< 10	-0.39147	0.676	0.348591	
ref. - over 29	from 10 to 19	0.220886	1.247	0.39622	
	from 20 to 29	0.185093	1.203	0.395817	
External knowledge	1	0.477166	1.612	0.069717	.
R&D expenditures	1	1.128283	3.09	0.000267	***
Energy efficiency: Eco Value drivers - monitoring	1: 1	-0.97083	0.379	0.021485	*
Energy efficiency: R&D expenditures	1: 1	-0.61434	0.541	0.111523	
Energy efficiency: Non-production female workers	1: 1	-0.02521	0.975	0.160197	
Energy efficiency: Technicians in %	1: 1	0.011668	1.012	0.119878	

Table A8 Binary logistic regression for Baltic country group (dependent – *Process Innovation*)

Variable	**Variable level or transformation**	**Coeff.**	**OR**	**p-value**	**Sign. Code**
(Intercept)		-1.8797	0.153	0.1224	
Top Manager experience	1	0.017345	1.017	0.9455	

Top Manager female	1	-0.3988	0.671	0.2103	
Professionals in %		-0.0118	0.988	0.3436	
Technicians in %		-0.01323	0.987	0.337	
Unskilled in % - x		-0.01019	0.99	0.4139	
Production workers female		0.003211	1.003	0.5469	
Non-production workers female		0.020651	1.021	0.2995	
Energy efficiency	1	2.074399	7.96	0.0175	*
Product innovation	1	0.303158	1.354	0.2613	
Obstacles - access to finance	1	-0.0666	0.936	0.8055	
Obstacles - energy tax or levy	1	-0.12079	0.886	0.6442	
Obstacles - energy performance	1	0.03892	1.04	0.9131	
Eco Value drivers - monitoring	1	0.776281	2.173	0.1527	
Eco Value drivers - targets	1	0.18347	1.201	0.5436	
Eco Value drivers - objectives	1	0.162992	1.177	0.6259	
Eco Value drivers - manager	1	0.609548	1.84	0.0726	.
Firm size	Large	-0.2829	0.754	0.5832	
ref. - Small	Medium	0.013886	1.014	0.9616	
Firm age	< 10	0.257146	1.293	0.6931	
ref. - over 29	from 10 to 19	0.464396	1.591	0.2251	
	from 20 to 29	0.47705	1.611	0.1704	
External knowledge	1	0.206771	1.23	0.4963	
R&D expenditures	1	1.033124	2.81	0.0539	.
Energy efficiency: Eco Value drivers - monitoring	1: 1	-1.24112	0.289	0.1238	
Energy efficiency: R&D expenditures	1: 1	-0.40579	0.666	0.508	
Energy efficiency: Non-production female workers	1: 1	-0.02409	0.976	0.2873	
Energy efficiency: Technicians in %	1: 1	-0.00695	0.993	0.5199	

Table A9 Binary logistic regression for Southern country group (dependent – *Process Innovation*)

Variable	**Variable level or transformation**	**Coeff.**	**OR**	**p-value**	**Sign. Code**
(Intercept)		-3.85232	0.021	1.43E-06	***
Top Manager experience	1	-0.40954	0.664	0.066131	.
Top Manager female	1	0.359406	1.432	0.217707	
Professionals in %		-0.00818	0.992	0.334767	
Technicians in %		0.000992	1.001	0.91736	
Unskilled in % - x		0.017006	1.017	0.046522	*
Production workers female		-0.00881	0.991	0.039652	*
Non-production workers female		0.001329	1.001	0.932331	
Energy efficiency	1	1.368436	3.929	0.008092	**
Product innovation	1	1.430009	4.179	1.64E-11	***
Obstacles - access to finance	1	-0.14812	0.862	0.482224	
Obstacles - energy tax or levy	1	0.313533	1.368	0.143115	

Obstacles - energy performance	1	0.604665	1.831	0.027225	*
Eco Value drivers - monitoring	1	1.322604	3.753	0.000361	***
Eco Value drivers - targets	1	0.211741	1.236	0.370436	
Eco Value drivers - objectives	1	0.57361	1.775	0.025298	*
Eco Value drivers - manager	1	-0.28336	0.753	0.358938	
Firm size	Large	-0.70946	0.492	0.061234	.
ref. - Small	Medium	-0.65178	0.521	0.006952	**
Firm age	< 10	0.584434	1.794	0.18461	
ref. - over 29	from 10 to 19	0.126411	1.135	0.650835	
	from 20 to 29	0.248312	1.282	0.321455	
External knowledge	1	0.581385	1.789	0.032601	*
R&D expenditures	1	1.04404	2.841	0.006024	**
Energy efficiency: Eco Value drivers - monitoring	1: 1	-1.13245	0.322	0.019252	*
Energy efficiency: R&D expenditures	1: 1	-0.56166	0.57	0.208217	
Energy efficiency: Non-production female workers	1: 1	-0.02968	0.971	0.128282	
Energy efficiency: Technicians in %	1: 1	0.009383	1.009	0.2465	

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