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Regional determinants of low carbon transition in Russian companies: the impact of human capital and digitalization on corporate carbon management practices

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ABSTRACT
Objective. The purpose of this article is to identify the regional determinants of the low carbon transition in Russian companies. These determinants are related to human capital and digital technologies development in local economic ecosystems.
Methods. The study relies on linear regression methods and examines the impact of education, wages, the use of the broadband Internet, cloud technologies and ERP (Enterprise Resource Planning) systems in Russian regions on companies' motivation to manage their carbon dioxide emissions.
Results. The results show that human capital has an ambiguous effect on the behavior of companies that support the low carbon transition. On the contrary, the digitalization of regions is significantly and positively associated with the implementation of environmental and energy management practices in Russian companies, especially among service companies.
Conclusion. Low carbon transition is becoming an essential component of the national development strategy, as climate resilience issues directly affect the economic performance of production systems. The study considers two types of factors that influence the implementation of management practices for the low-carbon transition: these are human capital and the digitalization of regions.

KEYWORDS
low carbon transition, carbon dioxide, human capital, digitalization, carbon management, management practices, national intellectual capital

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Региональные детерминанты низкоуглеродного перехода в российских компаниях: влияние человеческого капитала и цифровизации на внедрение практик управления выбросами углекислого газа

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АННОТАЦИЯ
Цель исследования. Целью данной статьи является выявление региональных детерминант низкоуглеродного перехода в российских компаниях. Эти детерминанты связаны с развитием человеческого капитала и цифровых технологий в локальных экономических экосистемах.
Данные и методы. Исследование опирается на методы линейной регрессии и изучает влияние образования, заработной платы, использования широкополосного Интернета, облачных технологий и систем ERP (Enterprise Resource Planning) в регионах России на мотивацию компаний управлять своими выбросами углекислого газа.
Результаты. Результаты показывают, что человеческий капитал оказывает неоднозначное влияние на поведение компаний, поддерживающих низкоуглеродный переход. Наоборот, цифровизация регионов существенно и положительно связана с внедрением практик экологического и энергетического менеджмента в российских компаниях, особенно среди сервисных компаний.
Выводы. Переход к низкоуглеродному режиму становится важным компонентом национальной стратегии развития, поскольку вопросы устойчивости к изменению климата напрямую влияют на экономические показатели производственных систем. В исследовании рассматриваются два типа факторов, влияющих на реализацию управленческих практик низкоуглеродного перехода: это человеческий капитал и цифровизация регионов.

КЛЮЧЕВЫЕ СЛОВА
низкоуглеродный переход, углекислый газ, человеческий капитал, цифровизация, углеродный менеджмент, управленческие практики, национальный интеллектуальный капитал

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俄罗斯公司低碳转型的区域决定因素：人力资本和数字化对二氧化碳管理实践的影响

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摘要
研究目标：本文的目的是确定俄罗斯公司低碳转型的区域决定因素。这些决定因素与当地经济生态系统中人力资本和数字技术的发展有关。
数据与方法：该研究基于线性回归方法，考察了俄罗斯地区的教育、工资、宽带互联网的使用、云技术和 ERP（企业资源规划）系统对企业管理碳排放的积极性影响。
研究结果：结果表明，人力资本对低碳转型公司的行为具有矛盾影响。相反，地区的数字化对俄罗斯公司引入环境和能源管理实践有着积极作用，尤其是在服务公司中。
结论：低碳转型正在成为国家发展战略的重要组成部分，因为气候变化问题直接影响生产系统的经济绩效。该研究考虑了影响低碳转型管理实践实施的两类因素：人力资本和区域数字化。

关键词
低碳转型，二氧化碳，人力资本，数字化，碳管理，管理实践，国家智力资本

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Introduction

The balance of carbon dioxide in the environment is fundamental to maintaining climate stability and resilience as it ensures thermal equilibrium in aquatic environment and atmosphere (Ward et al., 2017). Predictability of climatic conditions, in turn, is one of the key factors that ensure economic efficiency of the use of natural resources, such as agricultural land, minerals, water and forests. Advances of the industrial era have contributed to a shift in natural carbon balance, leading to dramatic climate changes that will make a number of areas uninhabitable and significantly reduce the efficiency of economic activities associated with the exploitation of natural resources. It is assumed that more than 40% of all anthropogenic carbon dioxide emissions are attributed to material industrial production (Hekkert et al., 2000). With the heightened public awareness of climate issues and disruptions in global supply chains resulting from the volatility in weather conditions, the debate on the need for a low carbon transition has taken on unprecedented global dimensions in recent years and has become the subject of serious political discourse. Developed and developing countries today are seeking to join forces and introduce investment programs stimulating and supporting new technologies and management tools that would facilitate a strategic low carbon transition.

The concept of low carbon development is becoming an important addition to the strategy already adopted by many countries to maintain a sustainable transformation of economic, social and ecological systems. This approach involves improving energy efficiency, using alternative energy sources, introducing new technologies for a more efficient use of material resources, promoting the principles of responsible consumption through educational programs, and developing investment programs for industry transformation (Kapitonov, 2021). In the current stream of literature, it is noted that the factors that support the concept of a low carbon transition are intellectual capital and new digital technologies (Colla et al., 2020; Pu & Lam, 2021; Sareen & Haarstad, 2021). The accumulation of environmentally significant human capital occurs through educational strategies focused on promoting green competencies: awareness of the global environmental issues, the impact of carbon balance on climate sustainability, economic development and business environment (Freitas et al., 2021; Shoaib et al., 2021). Digital technologies help businesses to transform supply chains, improve control of the production environment, to use alternative energy sources more effectively, to enhance resource efficiency and communication with stakeholders on sustainable development issues.

Russia has the fourth largest carbon footprint in the world, after China, the United States, and India (Burakov & Bass, 2019). The low carbon strategy adopted at the national level in Russia in October 2021 requires an active position of the state in matters of carbon dioxide regulation, which is of anthropogenic origin[1]. The positive role of the strategy is that, first, the government recognizes the reality of the carbon regulation problem and its fundamental importance for the development of the national economy. The current version of the strategy provides up-to-date estimates of greenhouse gas emissions; an increase of 40–50% is noted compared to 1990. Second, it declares the importance of the reallocation of capital flows for priority financing of sustainable socio-economic development, considering environmental risks. Third, the government proposes a targeted, intensive scenario for managing climate risks in the economy. The basis of this scenario is investment programs that support infrastructure renewal, technological regulation, financial and tax policies that stimulate carbon pricing and the introduction of product and process innovations. Since Russia is a party to the 2015 Paris Agreement, the government is committed to adjusting not only the industrial policy, but also to renew the social institutions that develop green human capital and promote digital technologies to ensure a low carbon transition.

Despite the fact that the role of the Russian government in carbon regulation is potentially high, the primary policy goal is to involve market actors and civil society in the process of infrastructure renovation, transformation of production systems and the creation of an appropriate culture and values of the transition period (Khan, 2013). Plans to decarbonize the economy may face a number of obstacles at the national level because of certain geographic, socio-economic, and cultural national characteristics (Yakovleva et al., 2017). In particular, Fedorov (2014) points out that the deficit of the carbon adsorbing capacity of Russian natural biomes is estimated at more than $ 1.3 billion, therefore the national economy is experiencing significant losses from the burning of fossil fuels and deforestation. It is likely that in the future Russia will introduce standard fiscal instruments for a low carbon transition, such as carbon tax and emission quotas at market prices (Orlov & Grethe, 2014). National industries that are major contributors to the carbon footprint, such as oil, gas and coal, depend significantly on government subsidies (Orlov & Aaheim, 2017; Stepanov & Makarov, 2021). This position of the Russian industry distorts the environmental performance of enterprises, as well as jeopardizes the proclaimed climate goals. The transformation of Russian industry is largely dependent on innovation and technological renewal of infrastructure, that is why it is extremely important to develop intellectual resources and introduce digital technologies in order to ensure a low carbon transition. In the contemporary research literature on the topic, the regional determinants of the low carbon transition in the Russian context are underexplored, which is the research gap that this study seeks to address.

The purpose of this article is to study the determinants of the low-carbon transition in the Russian context, in particular, we are going to investigate the impact of human capital and digital transformation of Russian regions on the implementation of carbon dioxide management practices. The objectives of the study include, first, studying the role of human capital in adapting management practices that support the low-carbon transition, and second, determining the contribution of digitalization of regions to the development of business processes that reduce greenhouse gas emissions. The term 'low carbon transition' means a strategy for the technological and intellectual transformation of the manufacturing and service sectors of the world economy, which would ensure a significant reduction in substance emissions (for example, greenhouse gases) that affect climate resilience: first of all, it concerns the introduction of carbon dioxide management technologies. The research focuses on the manufacturing and service companies that identify, monitor and control carbon dioxide emissions, and purposefully manage energy resources. The originality of the proposed approach is that an economic contribution to the low carbon transition implementation is made not only by practices related to direct management of carbon dioxide, but also by the approaches that support specific types of business activities, such as the development of energy management systems, optimization of supply chains, introduction of new production technologies, and strengthening the relationships with the stakeholders who ensure responsible allocation and consumption of resources. In this regard, the development of energy management systems in companies is considered as an additional indicator of the implementation of economically significant practices for ensuring the low carbon transition.

[1] Government of the Russian Federation. (2021). Strategy for the socio-economic development of the Russian Federation with a low level of greenhouse gas emissions until 2050. http://static.government.ru/media/files/ADKkCzp3fWO32e2yA0BhtIpyzWfHaiUa.pdf (Last accessed 12/12/2021)

Theoretical background

The important components of the low carbon transition strategy are considered to be as follows: (1) the development of products and services with high added value, (2) adherence to principles of knowledge economy; and (3) creation of a highly efficient service sector focused on innovation and science-intensive technologies (Orlov & Aaheim, 2017). One of the key resources providing such post-industrial values is intellectual capital, since it focuses on the development of human resources and structural assets (formalized results of stakeholders' intellectual activities). Human capital embodies the individual practical competencies and expertise required to make effective decisions that are consistent with national and regional low carbon transition strategies (Wang & Xu, 2021). However, it is often difficult to disentangle relevant skills in the flow of the general stock of human capital, so all knowledge is assumed to contribute to the awareness and responsible behavior, therefore advances in education should contribute to the promotion of environmental values (Freitas et al., 2021; Shoaib et al., 2021). In developed and developing countries, better educated population also provide an adequate level of demand for products from responsible manufacturers that reduce environmental impact. Responsible manufacturers develop low carbon projects to create new products, services or improved processes and attract green investment in manufacturing development. All of this stimulates the introduction of environmental and energy management practices that increase resource efficiency and help to identify environmental deficiencies in the existing production systems.

In the modern research on human capital, there are two competing hypotheses that provide different explanations of how knowledge and skills are applied in the labor market. According to the first hypothesis (see, for example, Schulz (1968), Becker (2010; 1986) and Mincer et al. (1984, 1997, 2012)), human capital is maintained as a stock of knowledge and skills used by the employed population in the labor market. According to the second hypothesis, human capital, reflected in formal education and work experience, is only a signal for the labor market, since employers do not have a reliable data on the productivity of workers before they enter the labor market (Blaug, 1976; Stiglitz, 1975). In this study, we adhere to the first hypothesis, assuming that a relevant stock of environmental knowledge and skills can, in most cases, have a positive impact on the implementation of low-carbon transition practices in the economy. From this point of view, the stock of knowledge obtained through formal education has a positive impact on social institutions, translating the values of sustainable development into the strategic plans and business processes of companies. Modern work in the field of intellectual capital at the national level also shows that knowledge and practical skills application transcends the effects at the individual level and positively affects the potential of society as a whole (Lin & Edvinsson, 2011; Roos & O'Connor, 2015; Vo & Tran, 2021).

Previous research shows that the accumulation of human capital stock embedded in formal education can lead to higher carbon dioxide emissions in some developed countries. However, after a certain threshold, these effects are reversed (Sheraz et al., 2021). Other studies report an unequivocally negative impact of accumulated human capital on environmentally sustainable economic development (Bashir et al., 2019). The evidence reviewed suggests that human capital has at times controversial effects on the overall low carbon transition. Human capital can also create complex effects on economies by mediating the adoption and further development of carbon dioxide management technologies. Wang and Xu (2021) show that human capital accumulation contributes to lower energy consumption and can positively impact the energy efficiency of projects and operations, which plays a significant role in restoring carbon balance. Individual income growth also contributes to an increase in responsible consumption, the likelihood of alternative energy sources implementation. In general, the low carbon transition is intended to support human development values, as green investments develop health and education systems, skills, employment opportunities and improve the social functions of the family (Shen et al., 2021). Therefore, we put forward the following hypothesis:

H1. *The human capital of the regions has a significant positive effect on the development and adaptation of carbon dioxide management practices that ensure a low carbon transition.*

The dominant hypothesis in contemporary literature on business digitalization is the positive impact of new information and computer technologies on the performance of companies (Brynjolfsson & Yang, 1996; Choi & Choe, 2016; Osei-Bryson & Ko, 2004; Shahi & Sinha, 2021) and their ability to create and sustain innovation for the development of local and global communities (Ghobakhloo et al., 2021; Zhang et al., 2017). Successful adoption of digital technologies leads to an increase in the level of production culture through the creation of "smart" factories, support of innovations, development of employees' human capital and maintaining the desired level of stakeholder awareness on sustainability issues (Osterrieder et al., 2020). The positive effects of digitalization, however, require a significant effort from the management team to introduce appropriate management practices that can support talent management and coordinate complex socio-technical manufacturing systems (Fenton et al., 2020).

Technological development is also an important determinant of the low carbon transition in a regional setting. In response to the new market demands and changing individual preferences and habits, it is necessary to diversify the supply and update production systems in which a gradual increase in added value shifts the attention of stakeholders towards sustainable development and the culture of responsible consumption (Kotzab et al., 2011). Among the trends in technological development of the 21st century, digitalization occupies a dominant position as a guarantor of increased efficiency and control of the business environment (Ramos-Meza et al., 2021). The attractiveness of modern applied digital technologies lies in the ability to solve unstructured problems and conduct intelligent analysis of significant data sets in real time. In addition, digitalization also stimulates the consumption of resources, therefore, it can be considered as a threat to the carbon balance, stimulating excess consumption through the active promotion of new communication and information technologies. There is an obvious example of cryptocurrency mining, which is associated with an increase in energy consumption in the financial sector, but at the same time it creates economic value for a very narrow circle of stakeholders.

Digitization is recognized as a driver of transformative environmental development, enabling unprecedented levels of coordination and efficiency of multiple stakeholders across the supply chain (Sareen & Haarstad, 2021). In manufacturing and services, digitalization is also often associated with technological leadership and the ability to make decisions in a flexible and timely manner that benefit most stakeholders (Ramos-Meza et al., 2021). Digitalization provides predictive analytics that are necessary to reduce the uncertainty of the external environment and support the productivity, investment attractiveness and financial sustainability of individual projects and companies. Modern digital technologies, such as those related to Industry 4.0, can be used for tracking of the carbon footprint, efficient decentralized planning and resource allocation, for example, they can eliminate up to 99% of all carbon emissions from paper documents (Pu & Lam, 2021). On the other hand, the spread of the Internet and the rational development of the corresponding information and computer infrastructure can collectively have a positive impact on people's lifestyles and their values, providing social support for the low carbon transition process in companies (Wang & Xu, 2021).

Therefore, we put forward the following hypothesis:

H2. *The level of digitalization of regions has a significant positive effect on the development and adaptation of the carbon dioxide management practices that ensure a low carbon transition.*

Methods and data

The linear regression method is used to study the determinants of the low carbon transition in Russian regions. The *dependent variable* indicates the performance of Russian companies in terms of carbon dioxide management. For each surveyed company, this indicator is calculated separately based on two approaches. First, it examines exclusively the practices of identifying, monitoring and targeting carbon dioxide emissions along the entire production chain (CO2_Control). The first type of dependent variable is measured on a scale of 0 to 3, where 3 is the maximum score that indicates that this or that company is actively implementing all of the management practices for low carbon transition and 0, that the company is implementing none of such practices. Second, we evaluate the degree of development of environmental management, in particular the low carbon efforts of internal stakeholders. To this end, we consider energy management indicators that demonstrate the existence of systematic approaches to energy consumption planning and controlling in companies (CO2_General). The second type of dependent variable is measured on a scale of 0 to 6, where 6 is the value which reflects how the company is implementing all of the environmental and energy management practices that support the low carbon transition. The formulae for calculating the indicators, original names of variables from the World Bank Enterprise Surveys (ES) database and their descriptive statistics are shown in the Results section in Table 1. To analyze the significance of a particular variable, the regression coefficients and the change in the coefficient of determination in the models are estimated.

The *control variables* are selected as the individual characteristics of companies: their revenue, logarithm of rubles per year (SALES), innovative activity (the latter means that the company has introduced new or significantly improved products or services during the last year (INNOV), and the regional component indicating the share of captured and processed emissions in the region of presence (WASTE_EFF).

The indicators of human capital and digitalization are used as *explanatory independent variables*. The assessment of human capital is represented by two variables: the first reflects the flow of human capital entering the labor market, the second shows the level of skills relevant to the labor market. The flow of human capital input is estimated by using the indicators from the Rosstat base; this is the logarithm of the number of graduates of vocational education institutions (LN_HC_Q, for calculating the variable, the number of skilled workers, mid-level specialists and graduates of bachelor's, master's and specialist's programs are considered). This indicator is chosen as an independent variable for a number of reasons. First, it reflects the entire inflow of human capital into the regional economy during the period. Second, some graduates can contribute to the development of the region at the level of self-employment, without interacting directly with employers in the labor market. Third, the individual stock of human capital of tertiary graduates has a number of externalities associated with the transmission of environmental values and other aspects of work culture that can positively influence local low-carbon transition practices. Thus, part of the human capital is assessed by looking at the skilled labor *inflow* into the labor market. The use of the skills that are relevant to the labor market, in turn, is reflected in the logarithm of the average annual nominal wages in the region (LN_HC_W). Digitalization of regions is measured by one variable, the digitalization index. The digitalization index is calculated by looking at the number of companies in the region that use the broadband Internet, cloud technologies, electronic sales, ERP (Enterprise Resource Planning) systems and RFID (Radio Frequency Identification) technologies. The index is the arithmetic average of all digitalization indicators, measured as a percentage of companies that have implemented such technologies (DIGIT_INDEX).

The study relies on the data of the World Bank's Enterprise Surveys (ES), collected in 2019 from 1,323 Russian companies. The ES questionnaire contains a module on a green economy, reflecting the environmental variables used in the study[2]. Based on the regional variables, the indicators of waste recycling efficiency, human capital and digitalization are calculated for each respondent. To calculate these variables, we use Rosstat data published jointly with the Higher School of Economics (Abdrakhmanova et al., 2020). A total of 1,204 observations on manufacturing and service companies from all eight regions of Russia are included in the sample. The following method is used to integrate the databases of the World Bank and Rosstat. For each company in the original ES database, there is a variable that indicates the company's region of presence (a3a); that is, the territory of Russia where the company operates, hiring employees and using local social institutions and infrastructure to coordinate its activities. Using this variable for each company, the values of regional development indicators are calculated for the purposes of the study. Thus, for each company we determine a set of indicators of the external environment where managers implement and develop practices that support the low-carbon transition.

Results and discussion

Most of the companies surveyed by the World Bank use carbon dioxide and energy management practices, however, companies often implement no more than 1–2 practices, mainly related to planning and targeting energy in production processes. Practices supporting the low-carbon transition related to the identification, monitoring and targeting of carbon dioxide emissions throughout the supply chain play a significantly smaller role in the day-to-day activities of Russian companies (Table 1). Among the surveyed companies, about 14% on average implemented significantly improved products or services in 2019, with even fewer companies conducting carbon emissions identification. The average score for carbon technologies was 0,15 out of 3, while the average score for the depth of tracking of CO_2 and the level of

[2] World Bank Database (2021). Enterprise surveys: COVID-19: Impact on firms. https://login.enterprisesurveys.org/content/sites/financeandprivatesector/en/library.html (Last accessed 12/12/2021)

energy development was only 1.3 out of 6 possible. Despite this, the Russian regions, according to official statistics, are characterized by a high level of utilization of pollutants (on average, more than 73% of waste is captured and recycled in Russian regions). Human capital indicators also remain stably high: on average, each of the considered regions accounted for more than 200 thousand graduates in 2009, the Central Federal District became the leader, with more than 450 thousand skilled workers and university graduates entering the labor market (Table 2).

The Ural and Volga Federal Districts became the leaders in the low-carbon transition. Nevertheless, they have practically minimal indicators of the efficiency of atmospheric emissions processing (no more than 73% of emissions are captured and neutralized in 2019). These regions are also characterized by a high level of digitalization, which contributes to the development of production systems and increases the likelihood of carbon emissions control (Table 2). The Central Federal District has the highest level of income and digitalization, as well as the highest quantitative indicator of human capital, because it concentrates the most significant amount of financial, organizational and administrative resources among all the regions of Russia. Despite this, industrialized regions have a comparatively higher level of development in terms of low carbon transition technologies.

The results of the regression analysis are shown in Tables 3 and 4. The indicators of CO_2 control (Table 3) are consistently used. In addition, indicators of the energy management development in companies are considered (Table 4). The first models contain only control variables, all factors demonstrate high significance. As expected, larger companies as well as innovative companies are more likely to implement carbon dioxide and energy performance management practices (Figure 1). Service sector companies are also clearly more involved in footprint monitoring.

Table 1

Descriptive statistics for selected variables

Variable name (ES original name) and label	Mean	Std. Dev.
CO2_Control (BMGc7+ BMGc11 + BMGc18) CO_2 identification, monitoring and targeting along the supply chain (maximum value = 3)	0.15	0.46
CO2_General (BMGc7+ BMGc11 + BMGc18 + BMGc1 + BMGc16 + BMGc23d) CO_2 identification, monitoring and targeting along the supply chain, energy consumption planning and control (maximum value = 6)	1.30	1.38
SALES (d2) Sales volume in the last financial year, natural logarithm of rubles	18.20	2.14
INNOV (h1) New products / services introduced in the last 3 years (dummy)	0.14	0.35
WASTE_EFF Amount of captured and neutralized emissions into the environment, percentage of the total volume of emitted harmful substances (Rosstat data)	73.84	6.34
LN_HC_Q Logarithm of the number of vocational education graduates in the region (Rosstat data)	12.28	0.57
LN_HC_W Logarithm of annual nominal wages in the region (Rosstat data)	13.24	0.23
DIGIT_INDEX General index of digitalization in the region (Rosstat data)	29.64	1.42

Source: Authors' own calculations based on the World bank ES and Rosstat data. Retrieved from: https://login.enterprisesurveys.org/content/sites/financeandprivatesector/en/library.html (Accessed 12.12.2021).

Table 2

Distribution of the key indicators of low carbon transition by region in 2019

Federal districts	CO2_Control, points (max 3 points)	CO2_General, points (max 6 points)	WASTE_EFF, % of total waste emission	LN_HC_Q, logarithm of number of graduates	LN_HC_W, logarithm of wages in rubles	DIGIT_INDEX, %
Central Federal District	0.13	1.63	73.50	13.03	13.50	31.20
Southern Federal District and North-Caucasian Federal District	0.02	0.97	70.70	12.09	12.93	27.22
North-West Federal District	0.07	0.93	87.30	11.90	13.38	30.42
Far Eastern Federal District	0.04	1.02	80.40	11.31	13.43	26.92
Siberian Federal District	0.11	0.59	71.60	12.13	13.11	27.92
Ural Federal District	0.34	2.02	72.50	11.76	13.33	30.32
Volga Federal District	0.40	1.83	65.30	12.73	12.94	30.14

Source: Authors' own calculations based on the World bank ES and Rosstat Database. Retrieved from: https://login.enterprisesurveys.org/content/sites/financeandprivatesector/en/library.html (Accessed 12.12.2021).

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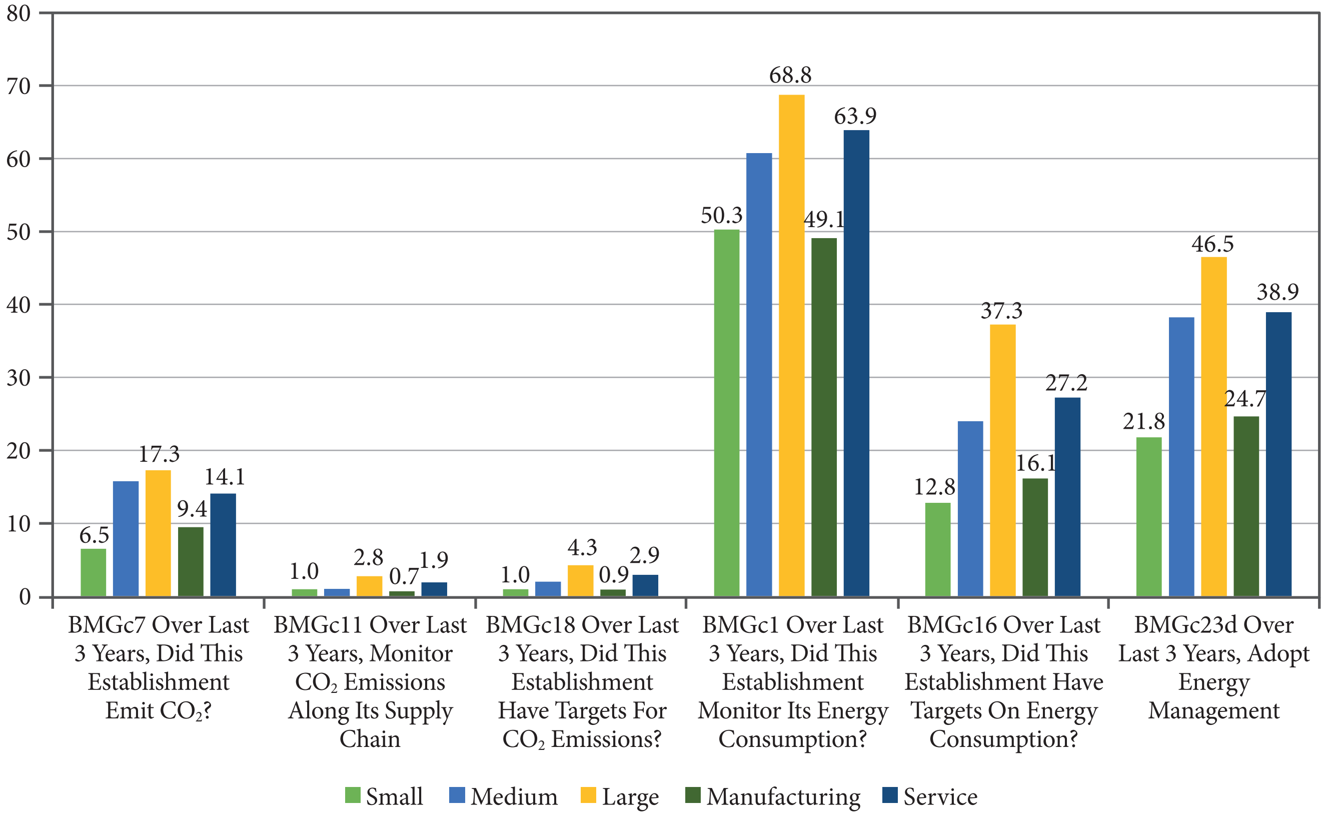

Figure 1. *Prevalence of CO_2 and energy management practices in the surveyed companies (percentage of the number of surveyed companies). The original names and labels of the variables are shown*

Source: Compiled by the authors from the World Bank ES database. Retrieved from: https://login.enterprisesurveys.org/content/sites/financeandprivatesector/en/library.html (Accessed 12.12.2021).

Table 3

Evaluation of the regression coefficients. Dependent variable is CO2_Control (Practices of CO_2 identification, monitoring and targeting along the supply chain)

Independent variables	Control variables only		Human capital (HC)		HC + Digitalization	
	B	t	B	t	B	t
Constant	0.612	3.391***	0.432	0.503	1.167	2.701**
SALES	0.030	4.923***	0.031	5.032***	0.027	4.314***
INNOV	0.171	4.622***	0.171	4.592***	0.157	4.227***
WASTE_EFF	−0.014	−6.806***	−0.017	−4.793***	−0.019	−7.468***
LN_HC_Q	–	–	−0.034	−1.114	−0.152	−3.702***
LN_HC_W	–	–	0.059	0.708	–	–
DIGIT_INDEX	–	–	–	–	0.060	4.085***
R^2	0.169		0.170		0.282	
Adjusted R^2	0.167		0.167		0.278	
R^2 change	–		0.000		+0.111	
F-statistic	29.636***		18.026***		17.921***	
Durbin-Watson	1.744		1.744		1.751	
Number of observations	1204		1204		1204	

Note to Table 3. *** – significant at the 1% level, ** – significant at the 5% level, * – significant at the 10% level.

Source: Authors' own calculations.

The industrially developed regions in the Urals and around the Volga demonstrate low efficiency of processing emissions into the atmosphere, which is why the models demonstrate the negative impact of the level of captured and processed emissions on carbon management practices. Despite the fact that companies in these regions are more active in the field of environmental protection, their performance leaves much to be desired compared to other companies.

The estimation of the regression coefficients shows that an increase in the new labor inflow is negatively associated with the development of carbon dioxide management practices in companies. It is likely that in the regions that hold the leading positions in the reproduction of human capital, a significant part of the added value is formed in the manufacturing sector. The negative impact of the new labor inflow on the low carbon transition is obviously consistent with the fact that Russian manufacturers appear to pay less attention to dissemination and implementation of carbon dioxide management practices compared to service companies. The inclusion of the two additional explanatory variables in the equation explains slightly more than 10% of the variance, so the contribution of these variables remains very moderate. The indicators of human capital are statistically insignificant in the second model.

We use an extended approach to assess the performance of carbon dioxide management and evaluate the development of energy management in companies. We conclude that human capital inflows have a negative impact on the intention of companies to implement environmental monitoring and planning practices. On the contrary, an increase in individuals' incomes due to better use of their accumulated human capital is positively associated with the introduction of management practices that maintain the carbon balance. Companies in richer regions are attracting investment to develop carbon dioxide monitoring practices throughout the supply chain. This can be explained by the general level of investment activity of companies that create an attractive labor market in the region and thus provide opportunities for the human capital. In addition, industrially developed regions, for example, the Ural Federal District, have rather high incomes. Consequently, **the first hypothesis is refuted**: the human capital of the regions has an ambiguous influence on the behavior of companies in supporting the low-carbon transition. Despite the fact that the rising incomes of the population have a positive effect on the propensity of companies to carry out carbon monitoring and control, the new human capital inflow does not support this trend.

The development of digital technologies in the region has a positive effect on the intention of companies to implement environmental management practices relevant to the low carbon transition (Table 4). The digitalization index is

Table 4

Evaluation of the regression coefficients. Dependent variable is CO2_General (Practices of CO_2 identification, monitoring and targeting along the supply chain, energy consumption planning and control)

Independent variables	Control variables only		Human capital (HC)		HC + Digitalization	
	B	t	B	t	B	t
Constant	1.196	2.284**	–12.804	–5.219***	–10.753	–4.389***
SALES	0.171	9.802***	0.173	9.856***	0.156	8.909***
INNOV	0.657	6.112***	0.615	5.787***	0.557	5.284***
WASTE_EFF	–0.042	–7.128***	–0.081	–8.182***	–0.094	–9.346***
LN_HC_Q	–	–	–0.164	–1.881*	–0.643	–5.307***
LN_HC_W	–	–	1.426	5.962***	1.287	5.421***
DIGIT_INDEX	–	–	–	–	0.234	5.608***
R^2	0.231		0.307		0.379	
Adjusted R^2	0.229		0.304		0.375	
R^2 change	–		+0.075		+0.146	
F-statistic	60.394***		44.696***		43.435***	
Durbin-Watson	1.774		1.826		1.851	
Number of observations	1204		1204		1204	

Note to Table 4. *** – significant at the 1% level, ** – significant at the 5% level, * – significant at the 10% level.

Source: Authors' own calculations.

statistically significant and positively associated with the increased activity of companies in the field of carbon dioxide management and implementation of energy management practices. **Thus, the second hypothesis is confirmed. The digital environment in the regions is indeed c**reating a supportive infrastructure for the enterprises seeking to control their carbon footprint, even though investments in information and computing technologies are likely to be associated with increased energy consumption.

Conclusions

Russian companies are at an early stage of technological development regarding the low carbon transition, since only a few, no more than 2–3% of them, actually engage in planning, monitoring and control of their carbon dioxide emissions into the environment.

The first hypothesis of this study about the positive impact of human capital on the environmental and energy management practices that affect the reduction of greenhouse gas emissions is rejected. Despite the high importance of industrial values in Russia and significant role of manufacturing companies in generating national income, service companies are showing greater interest in controlling the low carbon transition. Human capital has a controversial impact on the propensity of companies to monitor energy consumption and CO_2 emissions, while digitalization of regions contributes to the development of new approaches to environmental management and increases the awareness of business leaders and employees of climate change.

The second hypothesis of this study was confirmed. We found that digital technologies have a positive impact on the ability of Russian companies to implement management practices that support the low carbon transition. The high digitalization index is associated with an inflow of additional investments that not only support production and service infrastructure of companies, but also contribute to the development of internal business processes that ensure environmental responsibility. Digitalization thus provides an important platform for the development of management practices that promote the low carbon transition values in companies. Information and computer technologies provide manufacturing companies with strategic opportunities, increasing transparency and the degree of internal processes control for sustainable development.

Therefore, the investment in human capital alone is not a guarantee of progress in the low carbon transition and sustainable development in general, since it should lead to qualitative changes in the value system as well as in the intellectual capital used in production chains. The national education system, obviously, does not provide enough resources to form the corresponding flows of green human capital; in addition, financial and material resources can have a more significant impact on the motivation of companies to implement low carbon transition technologies.

This study has several limitations. First, the authors use of a rather narrow approach to examining the determinants of low carbon transition in companies, as it is assumed that regional factors have a significant impact on the companies' motivation to demonstrate climate-responsible behavior. Second, an important limitation of the study is also the use of wages as an indicator of the effectiveness of human capital in regional labor markets. Despite the fact that differences in wages show a return on investment in training and work experience, the specific contribution of human capital to individual wages does not exceed 30-40% in the context of the digitalization of the Russian economy (Chernenko et al., 2021) human capital development depends on differences in earnings. Previous studies examined the relationship between wage differentiation and employee competencies without considering the regional digitalisation. The present research tests a hypothesis of the dependence of wage differentiation on individual digital competencies, likelihood of job computerisation and digital development of a region. Linear regression method based on Mincer equations was utilised. The empirical basis comprises data from the Russia Longitudinal Monitoring Survey — Higher School of Economics (RLMS-HSE. In addition, in some regions of Russia, the share of natural resource rent in the structure of wages is obviously significant.

In further research, it is necessary to investigate the factors associated with the influence of gross regional income and investment in fixed assets and their impact on the behavior of companies in the context of the low carbon transition. In addition, an important task is to evaluate the stock of specific green human capital (that is, the capital that is relevant only to specific types of employers or sectors) available to companies to develop and maintain their practices aimed at the low carbon transition.

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