DOI: 10.52950/ES.2023.12.2.003

PUBLIC FUNDING IN R&D AND R&D OUTCOME SUSTAINABLE DEVELOPMENT: ANALYSIS OF MEMBER STATES EU

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Abstract:

This paper examines the relationship between public funding in research and development (R&D) and the sustainable development outcomes within the European Union (EU) member states from 2000 to 2022. It investigates the allocation and effectiveness of public funding towards R&D in sustainable technologies and its alignment with the EU's strategic growth and sustainability goals. Through a mixed-method approach, including descriptive analysis, econometric modelling, and a review of pa-tents and scientific publications, the study addresses three core research questions: the extent of public R&D funding, the R&D outcomes in sustainable development, and the efficacy of recent EU public research funding in fostering innovation in sustainable technologies. The analysis reveals that while there is a positive correlation between targeted public expenditures and R&D outcomes, disparities exist among member states in terms of investment levels and innovation outputs. The paper also dis-cusses the implications of these findings in the context of the EU's broader sustainability objectives, including the European Green Deal, and suggests pathways for future research to enhance the impact of public R&D funding on sustainable development.

Keywords:

research and development (R&D); public funding; sustainable development; patents; panel data; Euro-pean Union; econometric analysis

JEL Classification: O30, O32, O38

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Citation:

LUCIE KUREKOVA, KLARA CERMAKOVA, EDUARD HROMADA, BOZENA KADERABKOVA (2023). Public funding in R&D and R&D outcome sustainable development: Analysis of Member States EU. International Journal of Economic Sciences, Vol. XII(2), pp. 40-62., 10.52950/ES.2023.12.2.003

1 Introduction

Sustainable development refers to the process of meeting the needs of the present without compromising the ability of future generations to meet their own needs. Within the European Union (EU), sustainable development has been a significant concern and is closely tied to the region's overall strategy for growth and development. This paper explores three related research questions that center around the public funding allocated towards research in sustainable development within EU countries between 2000 and 2022. From 2000 to 2022, the EU and its member states have committed substantial funds to research aimed at achieving sustainable development. The level of funding has not been constant, reflecting changes in economic conditions, political priorities, and societal needs. Initially, in the early 2000s, the emphasis was on the implementation of the Lisbon Strategy, which set a goal for the EU to become the world's most competitive and dynamic knowledge-driven economy by 2010. This led to the establishment of the Seventh Framework Programme (FP7), which allocated €50.5 billion from 2007 to 2013, with a significant portion directed towards sustainable development research.

Under Horizon 2020, the EU's research and innovation program from 2014 to 2020, around €80 billion was allocated. The focus on sustainability was strengthened, integrating climate change, energy efficiency, and renewable energies into various research domains.

Finally, the EU introduced Horizon Europe, spanning from 2021 to 2027, with a budget of approximately €95.5 billion. Here, sustainable development remains a key priority, highlighting the EU's commitment to the United Nations' Sustainable Development Goals (SDGs). Different EU countries have displayed various levels of commitment and investment. Wealthier nations like Germany, France, and the United Kingdom (prior to Brexit) have generally allocated higher levels of public funding. In contrast, countries with smaller or struggling economies have devoted fewer resources.

For our research three following research question were set up: (Q1) What was the level of public funding allocated from 2000 to 2022 in EU countries. (Q2) What was the level of R&D outcome in sustainable development from 2000 to 2022 in EU countries. (Q3) Has the recent European public research funding effectively promoted knowledge and innovation in sustainable technologies.

The paper has following structure. Section 2 comprises the literature review, while Section 3 outlines the materials and methods used in this study. Section 4 presents the results aimed at addressing the research questions. Moving on to Section 5, it delves into the discussion of the obtained results. Lastly, Section 6 concludes the paper and highlights the study's limitations.

2 Literature review

In the literature review, the role of green finance in sustainable development within the EU is explored through various lenses, highlighting the importance of both public and private investment in achieving environmental goals.

The spatial Durbin model applied by Kwiliński, Lyulyov, and Pimonenko (2023) underscores the heterogeneous impact of green finance on sustainable development across different EU regions. Their findings advocate for a tailored approach to EU green finance policy, emphasizing the need for alternative funding mechanisms, such as green bonds, to support region-specific sustainable projects.

The SafeWAVE project, as discussed by Bald et al. (2023), addresses non-technological barriers to the development of ocean energy, a critical component of the EU's renewable energy strategy. The project's focus on environmental research and consenting strategies underscores the complexity of implementing marine renewable energy sources while balancing environmental concerns and stakeholder interests.

In their study, Liu et al. (2023) propose a novel policy framework that examines the synergy between green innovation and public-private partnerships in achieving sustainable development goals. This research highlights the critical role of collaborative efforts in fostering sustainable outcomes, suggesting that such partnerships could be instrumental in advancing the EU's sustainability agenda.

Moskalenko and colleagues (2022) delve into the relationship between the quality of institutions and a country's attractiveness for sustainable investments within the EU. Their analysis reveals that political stability, freedom, and quality governance are significant factors that enhance a country's ability to attract sustainable investments, pointing to the need for robust institutional frameworks to support green growth.

Simionescu, Radulescu, and Cifuentes-Faura (2022) provide a nuanced analysis of the renewable energy consumption-growth nexus in European countries, emphasizing the need for sector-specific policies. Their research, which spans from 1990 to 2020, suggests that while renewable energy use in transport positively influences economic growth, its consumption in the industry is driven by economic development rather than being a determinant of it.

In their study on the integration of renewable energy technologies into urban landscapes, Gawryluk, Krawczyk, and Rodero (2022) highlight the challenges and considerations for the placement of photovoltaic panels and solar collectors in cities. Their work, which includes case studies from Poland and Spain, underscores the importance of balancing energy efficiency with architectural and landscape aesthetics to preserve cityscape values.

The article by Ohorodnyk (2021) delves into the greening of production and the expansion of export opportunities for Ukraine in the context of the EU association. The study outlines the environmental modernization measures necessary for Ukrainian enterprises to adapt to the European Green Deal and to mitigate the risks associated with new non-tariff trade barriers.

Biekša, Zonienė, and Valiulė (2021) explore the potential of sustainable investment in the electricity production sector to reduce the environmental footprint in EU countries. Their research indicates that while investments in renewable energy technologies like wind and solar PV are essential, they alone are not sufficient to significantly reduce the environmental footprint, pointing to the need for broader investment in electricity network development.

The effectiveness of EU regional policy funds in advancing Poland's bioenergy sector is critically examined by J. Rakowska and J. Gołębiewski (2017). Their research, focusing on the 2007-2013 financial perspective, reveals that these funds played a pivotal role in the development of the bioenergy sub-sector, particularly in the warminsko-mazurskie voivodship. The EU's financial support facilitated the construction and modernization of biomass power plants and heating systems, showcasing the union's dedication to renewable energy and sustainable development.

Apostolopoulos (2017) delves into the factors influencing renewable energy entrepreneurship in rural areas within the EU, highlighting the unique challenges and opportunities that rurality presents. His research underscores the importance of rural entrepreneurship in the renaissance of areas left behind during the industrial revolution, emphasizing the role of technological advancements in bridging the gap between rural and urban areas. The study suggests that rural areas, with the right investment and focus on renewable energy, can significantly contribute to the EU's sustainable development goals.

The bioeconomy's growth, as Sharova, Dzedzyulya, and Lavrova (2016) discuss, is a complex interplay of industries and cross-industry research, often supported by public funding. Their analysis of the EU-Russia cooperation in bioeconomy research reveals a trend towards increasing private sector involvement in R&D funding, although historically, the sector has been characterized by state funding. The study provides insights into how international scientific programs like Horizon 2020 and ERANET are shaping regional economies and contributing to the sustainable development of emerging economies.

In the context of assessing the impact of public funding on R&D and sustainable development outcomes within the EU, the work of Kadeřábková, Jašová, and Čermáková (2017) offers a critical insight into the labour market's role in shaping economic conditions that influence R&D investment decisions. Their study employs the method of the stochastic trend to estimate the time-varying NAIRU in the Czech Republic and Slovakia, providing a nuanced analysis of the labor market's economic cycle at both the macro and meso levels. The relationship between the estimated NAIRU and actual unemployment rates serves as an indicator of economic fluctuations, which are pivotal in understanding the allocation and effectiveness of public R&D funding.

In the broader discourse on public funding in R&D and its impact on sustainable development within the EU, the research by Žák (2021) provides a valuable technical dimension by focusing on the construction sector, specifically on the performance of asphalt in terms of susceptibility to permanent deformations. Žák's study introduces a method for deriving accumulated creep compliance from creep and recovery cycles, offering a novel parameter for assessing the durability of construction materials.

The exploration of public funding in R&D and its impact on sustainable development within EU member states gains an additional layer of complexity when considering the advancements in Building Information Modelling (BIM) as discussed by Macek (2023). Macek's research delves into the utilization of BIM beyond its traditional role in the design phase, highlighting its potential to streamline the tendering process for facility management services. By advocating for the inclusion of detailed information within BIM during the construction process, the study suggests that BIM can significantly optimize costs over the lifecycle of a construction project.

Palazzo's (2023) investigation into the utilization of 3D printing technology in the construction sector offers a compelling perspective on the potential for public R&D funding to catalyse innovation in sustainable development across EU member states. The study underscores the technology's promise in automating building processes, enabling more creative architectural designs, and significantly reducing construction costs—a response to the escalating real estate prices and material scarcity. Moreover, the environmental benefits of 3D printing, such as the reduction of CO2 emissions and construction waste, align with the sustainable development goals and the global push for greener construction practices post-COP 26.

Considering the developments over the recent years, particularly since the onset of the conflict in Ukraine, it becomes imperative to engage in discussions regarding the labour force that could potentially be mobilized for the execution of research and development (R&D) initiatives in the context of sustainable development. Zubíková (2019, 2020), through her analytical assessment of integration levels within EU nations, ascertained that during the period from 2009 to 2018, the proportion of individuals possessing tertiary education within the foreign-born population was, on average, even higher compared to that within the native (host) population. Nonetheless, the degree of integration and the calibre of the foreign labour force in scientific research sectors require ongoing empirical scrutiny due to continuing migration pressures into EU Member States.

Bouška et al. (2022) delve into the intricacies of procurement processes within the Czech Republic, emphasizing the integration of Building Information Modelling (BIM) to enhance the selection of suppliers for construction projects. Their research is pivotal in establishing a standardized evaluation methodology that assists both public and private entities in assessing suppliers' capabilities in BIM implementation. This methodology not only streamlines the procurement process but also ensures the adherence to BIM requirements across various project phases, reflecting a commitment to quality and efficiency. The implications of their findings are significant for the broader EU context, as they suggest that the adoption of such evaluative frameworks could lead to more effective allocation of public R&D funding. By ensuring that only the most competent and technologically adept suppliers are chosen, the research by Bouška et al. supports the notion that targeted public investment in R&D, particularly in innovative construction methodologies like BIM, can substantially contribute to the sustainable development goals of the EU.

The effectiveness of the deployment of European funds in the economies of the V4 countries and their regions at the NUTS 2 level for the period 2000 - 2017 is dealt with in work (Řežábek, P., Marek, L., Doucek, P., & Nedomova, L., 2022), in which the authors examine the issues of beta convergence of regions. In this article, the authors first compare the V4 states as a whole and then with neighboring countries such as Germany and Austria. For convergence analysis is approximated the GDP growth trend in individual countries, using a trend line for different time periods - the period of growth (2000 - 2007), the period of crisis (2008 - 2012) and the period of economic recovery after the crisis (2013 - 2017). Based on all used indicators, authors have shown that the regions with capital cities have a completely privileged position and that the other regions lag far behind economically. These results point to persistent disparities between regions and suggest the need for more effective cohesion policy measures to increase the economic performance of lagging regions. In this regard, results have confirmed that the cohesion policy in the regions of the V4 countries should promote innovations and investments into less developed and predominantly agricultural regions, complete the necessary backbone infrastructure and develop a high-quality regional education, which further recommends focusing on a carefully selected specialization with a high-added-value and innovative potential in selected regions.

3 Materials and Methods

The initial two research questions investigate the scope and distribution of public R&D funding through descriptive analysis. As for the third research question, which examines the overall effectiveness of R&D funding as a catalyst for green innovation, the analysis relies on a panel dataset and econometric analyses.

The primary emphasis of this study is on the analysis of data originating from the years 2000 to 2022, encompassing 27 countries within the European Union. These countries are: Austria (AT), Belgium (BE), Bulgaria (BG), Croatia (HR), Cyprus (CY), Czech Republic (CZ), Denmark (DK), Estonia (EE), Finland (FI), France (FR), Germany (DE), Greece (GR), Hungary (HU), Ireland (IE), Italy (IT), Latvia (LV), Lithuania (LT), Luxembourg (LU), Malta (MT), Netherlands (NL), Poland (PL), Portugal (PT), Romania (RO), Slovakia (SK), Slovenia (SI), Spain (ES), Sweden (SE).

Unfortunately, in the case of individual research questions, data were not always available to the required extent, see more in the following chapters and the description of the variables in the econometric model.

3.1 Public funding R&D

Data on total public R&D funding collects Eurostat, data are published by Sector of performance and by Source of funds. It is thus possible to track the distribution of public support by national and foreign sources, specifically European Commission support. For international comparisons of public expenditures on Research and Development (R&D), ratio indicators are also used besides the absolute amount (e.g., in purchasing power parity). The most common of these is the share of public expenditures on R&D in Gross Domestic Product (GDP). To investigate the level of public support, data expressed as a share of GDP were analysed.

Given the focus of this research on sustainable development, it was desirable to analyse data on public support for technologies related to this topic. Unfortunately, similar data were unavailable in the Eurostat database. However, national R&D budgets are accessible through the International Energy Agency's (IEA) data browser. The 'Detailed country R&D budgets' report contains the required country- and sector-specific data (IEA, 2023a), expressed in millions of national currencies. Therefore, only funding within 'Group 3: Renewable Energy Sources' was considered (IEA, 2023b) and calculated as a share of GDP. Data on the amount of GDP in national currency was used from Eurostat.

3.2 R&D outcome in sustainable development

Three distinct variables have been identified to analyse the research and development (R&D) outputs within sustainable development. These variables encompass: the count of patents pertaining to Environment-related technologies (Y1), the count of patents associated with Climate Change adaptation technologies (Y2), and the variable that also effectively represents R&D outcomes in sustainable development, namely scientific publications (Y3).

Data on the variables (Y1) and (Y2) which represents number of patens were extracted from the OECD's Environment Database for Technology Development, especially from Innovation in environment-related technologies. The data were sorted by year in which the patent was filed and by the inventor's country of origin. The patent statistics offered by the OECD were formulated through algorithmic methodologies, meticulously designed to avoid double counting.

Data on variable (Y3) which represents number of articles published in academic journals in published in first or second quartile (Q1 or Q2) were extracted from Web of Science especially using tool Incites. The data is also sorted by country of origin and includes articles published in the research area 'GREEN & SUSTAINABLE SCIENCE & TECHNOLOGY'.

3.3 Econometric Approach and Additional Covariates

Equation (1) was exploited to examine whether public R&D funding promoted R&D outcome in sustainable development. It extends prior research (see Costantini et al., 2015; Pitelis, 2018; Gasser et al., 2022) and seeks to establish the overall impact of public R&D funding. Causality plays a very important role in econometrics and economics (see Hejduková and Kureková, 2016), and econometric modeling and panel data analyses may help assess the effects of selected variables in our model.

Equation (1): $Y_{it+1}^{j} = \beta_0 + \beta_1 nat\_RD\_exp_{it} + \beta_2 EC\_RD\_exp_{it} + \beta_3 nat\_RD\_exp\_energy_{it} + \beta_4 patent\_all_{it} + \beta_5 articles\_all_{it} + \beta_6 energy\_cons_{it} + \beta_7 electricity\_prices_{it} + \beta_8 renewable\_energy\_cons_{it} + \beta_9 EPS_{it} + \beta_{10} taxes_{it} + \beta_{11} feed_{it} + \alpha_i + \varepsilon_{it}$

The dependent variable Y_{it+1}^{j} that captures R&D outcome in sustainable development are represented by three (j=1–3) the country-specific (i) variables forwarded by one year (t+1). It means that all explanatory variables are lagged towards dependent variables. Using time-dependent explanatory variables considers the fact that there is some innovation process takes time. The existing literature supports the use of time-lag regressors and suggests that a statistically significant effect of R&D on patenting occurs in the first lag (see Hall et al., 1983; Wang & Hagedoorn, 2014; Gasser et al., 2022).

Indices i = 1, …, N represent indexes for countries and t = 2000, …, T represent time indexes. The key regressors of main interest consist of 'at_RD_exp', 'EC_RD_exp' and 'nat_RD_exp_energy' that directly target the R&D outcome in sustainable development, measured in percentages of GDP. The estimation includes the additional covariates 'patents all technologies', 'all articles published towards sustainability', 'energy consumption', 'electricity prices' and, as well as data on the environmental stringency of other public policies than R&D expenditures through the covariates 'EPS', 'taxes' and 'feed'. Time-invariant country fixed effects are captured by α_i and ε_{it} represents error term. Table 1 provides a summary of the variables along with their fundamental descriptions.

Table 1. Overview of variables for econometric analysis

Variable		Note		Model	Assumed effect	Data source
Y1	(log)	Patents: Climate change mitigation	Number of patents, with country fractional value			OECD
Y2	(log)	Patents: Environment-related technologies	Number of patents, with country fractional value			OECD
Y3	(log)	Articles published in academic journals in Q1 and Q2	Number of documents related GREEN & SUSTAINABLE SCIENCE & TECHNOLOGY			WoS
nat_RD_exp		National public expenditure on R&D (gov and higher educ)	% GDP	M1	+	EUROSTAT
EC_RD_exp		public expenditure on R&D from European Comission	% GDP	M1	+	EUROSTAT
nat_RD_exp_energy		Total public RD&D expenditure data on Renewable energy	% GDP	M2	+	IEA
patent_all	(log)	Patents: All technologies	Number of patents, with country fractional value	M2	+	OECD
articles_all	(log)	Articles published in academic journals	Number of documents related GREEN & SUSTAINABLE SCIENCE & TECHNOLOGY	M2	+	WoS
energy_cons	(log)	Energy consumption	Tonnes of oil equivalent (TOE) per capita	M3	+	EUROSTAT
electricity_prices		Electricity prices	PPS (Excluding VAT and other recoverable taxes and levies)	M3	+	EUROSTAT
renewable_energy_cons		Renewable energy share in total final energy consumption	share	M3	+	SDR 2023
EPS		Environmental Policy Stringency	score	M4	+	OECD
taxes		Environmentally related tax revenue	revenue % GDP	M4	+	OECD
feed		Renewable energy feed-in tariffs (OECD)	Mean feed-in tariff, US dollar	M4	+	OECD

Source: based on data from EUROSTAT (2023), OECD (2023), WoS (2023), Sustainable development report (2023), IEA (2023a)

For each of the dependent variables Y1–Y3, a set of four models (M1–M4) was estimated. The foundational model (M1) incorporates the key regressors 'at_RD_exp' and 'EC_RD_exp'. Subsequent to this, additional explanatory factors are introduced to models M2–M4 (see Table 1). Despite certain variables having a potential pool of 621 observations, constraints arising from data unavailability and lag-structure have led to reduced observation counts in certain estimates. Hence, the foundational models (M1) exhibit a diminished observation count of approximately 330–380, while the subsequent models (M2–M4) experience further declines in observation numbers and unfortunately some countries are dropped out from estimation.

4 Results

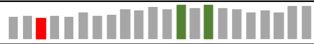
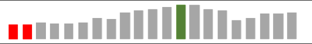
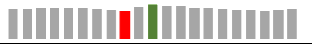
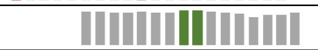
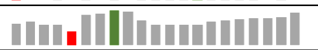
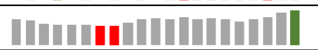
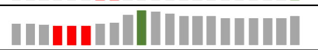
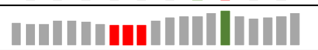
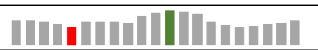
4.1 Public Funding

The following text presents data and analyses on public support for R&D in EU countries. These data have been examined and processed to identify main trends and differences among states, thereby addressing the research question (Q1): "What was the level of public funding allocated from 2000 to 2022 in EU countries?" Tables 2-4 provide relevant information on public support for R&D expressed as a share of GDP, including average values for the specified period, minimum and maximum values, as well as mini-graphs to capture key developmental trends visually.

Table 2 records data on "National public funding R&D (% GDP) between 2000 and 2021. The data indicate that the highest average share of public expenditures on R&D relative to GDP was observed in Austria (0.9), Finland (0.85), and France (0.81). According to the European Commission report (2023), these countries are categorized as "Strong innovators," with Finland even being classified as an "Innovation leader." Conversely, the lowest share of public expenditures on R&D was recorded in Malta (0.19), Latvia (0.19), and Romania (0.22). It is important to emphasize that Latvia and Romania generally have low overall expenditures on R&D and are classified as "Emerging innovators" according to the European Commission report (2023), while Malta is assessed as a "Moderate innovator.

For some countries, such as Denmark, Luxembourg, the Netherlands, and Sweden, only 70% of observations were available from 2000 to 2021, corresponding to fewer than 15 observations. This limitation may affect the precision of the analysis. Regarding the evolution of the analysed indicator, it does not appear that there was a parallel development of this indicator across all countries. Approximately half of the states reached their maximum share of national public expenditures on R&D between 2009 and 2015, coinciding with the global economic crisis when GDP growth slowed down or halted.

Table 2 National public funding R&D (% GDP)

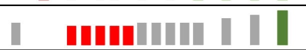
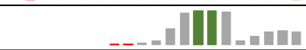
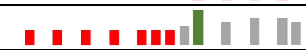
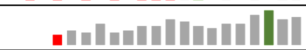
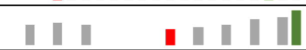
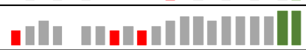
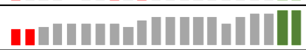
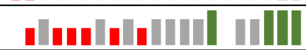
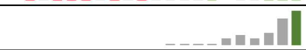
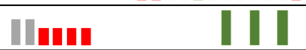
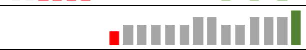
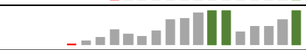
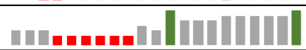
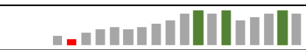
country	AVG	SD	MIN	MAX	Rank	Graph	N (2000–2021)
AT	0.90	0.1	0.69	1.10	1		22
BE	0.53	0.1	0.46	0.64	13		17
BG	0.24	0.1	0.17	0.34	24		21
CY	0.26	0.1	0.15	0.34	23		21
CZ	0.60	0.1	0.47	0.70	8		22
DE	0.80	0.1	0.68	0.93	4		21
DK	0.79	0.1	0.65	0.92	6		12
EE	0.57	0.1	0.37	0.82	10		21
EL	0.43	0.1	0.26	0.68	17		17
ES	0.54	0.1	0.38	0.69	12		21
FI	0.85	0.0	0.78	0.96	2		21
FR	0.81	0.0	0.75	0.89	3		20
HR	0.43	0.1	0.32	0.56	18		19
HU	0.46	0.1	0.31	0.58	15		21
IR	0.38	0.1	0.26	0.50	21		20
IT	0.51	0.0	0.45	0.55	14		16
LT	0.40	0.1	0.33	0.52	20		21
LU	0.44	0.2	0.12	0.62	16		14
LV	0.21	0.0	0.12	0.29	26		21
MT	0.19	0.0	0.14	0.28	27		17
NL	0.67	0.0	0.63	0.72	7		15
PL	0.42	0.1	0.33	0.58	19		21
PT	0.58	0.1	0.43	0.77	9		21
RO	0.22	0.1	0.15	0.40	25		21
SE	0.80	0.3	0.03	0.95	5		10
SK	0.31	0.0	0.24	0.41	22		21
SL	0.55	0.1	0.41	0.77	11		21

Source: based on data from Eurostat (2023)

Table 3 records data on "Public funding R&D from the European Commission (% GDP)" between 2000 and 2021. From these results, it is evident that, on average, the highest proportion of this public support was achieved in Latvia (0.2), Lithuania (0.18), and the Czech Republic (0.14). All three of these countries became European Union members in 2004 and, in comparison to other states that joined the EU the same year (such as Cyprus, Estonia, Hungary, Malta, Poland, Slovakia, and Slovenia), they obtained public support from the EU relatively successfully. In contrast, Luxembourg, the Netherlands, and Croatia exhibited the lowest average Public funding R&D from the European Commission as a percentage of GDP. It is noteworthy that Luxembourg and the Netherlands, as expected, have relatively low values for this indicator, as they belong to countries with relatively high GDP and, being EU15 member states, had more limited opportunities for accessing R&D support from EU funds such as cohesion funds.

Considering that 13 countries only joined the EU in 2004 or later, there is limited available data for these nations throughout the entire observed period. Furthermore, even among the EU15 countries, a relatively substantial amount of missing values is observable. This fact complicates the analysis of the indicator's development. Nonetheless, the majority of countries reached their maximum share of public support for Research and Development (R&D) in the last two years, specifically in 2020 and 2021. This phenomenon can be attributed to the increased R&D support aimed at mitigating the impacts of the COVID-19 pandemic and the concurrent decline in GDP during this period.

Table 3 Public funding R&D from European commission (% GDP)

country	AVG	SD	MIN	MAX	Rank	Graph	N (2000–2021)
AT	0.05	0.01	0.03	0.06	15		10
BE	0.06	0.01	0.05	0.09	10		14
BG	0.03	0.01	0.02	0.06	21		12
CY	0.07	0.04	0.01	0.16	9		20
CZ	0.14	0.11	0.02	0.30	3		14
DE	0.05	0.00	0.05	0.05	13		4
DK	0.05	0.02	0.04	0.09	11		13
EE	0.10	0.03	0.05	0.16	5		18
EL	0.11	0.03	0.08	0.17	4		9
ES	0.05	0.01	0.03	0.07	14		20
FI	0.08	0.02	0.05	0.11	6		21
FR	0.03	0.01	0.02	0.04	22		19
HR	0.03	0.04	0.00	0.13	26		16
HU	0.04	0.01	0.03	0.06	18		12
IR	0.03	0.01	0.02	0.04	23		9
IT	0.03	0.01	0.02	0.05	20		14
LT	0.18	0.10	0.02	0.32	2		17
LU	0.02	0.00	0.01	0.02	27		5
LV	0.20	0.06	0.07	0.28	1		9
MT	0.04	0.03	0.01	0.12	17		17
NL	0.03	0.00	0.02	0.03	25		10
PL	0.05	0.04	0.01	0.15	12		19
PT	0.04	0.02	0.02	0.07	19		21
RO	0.03	0.02	0.01	0.06	24		19
SE	0.05	0.01	0.03	0.06	16		9
SK	0.07	0.10	0.01	0.41	8		15
SL	0.08	0.03	0.02	0.11	7		18

Source: based on data from Eurostat (2023)

Table 4 presents data concerning "National public funding R&D for renewable energy (% GDP)" between 2000 and 2022. Data were available for only 20 countries, and complete time series were not accessible. From the available data, it is evident that, on average, the highest proportion of this public support was achieved in Denmark (0.0166), Finland (0.0152), and the Netherlands (0.0102). All these countries belong to the so-called EU15. Conversely, on average, the lowest shares were observed in Portugal (0.0017), Spain (0.0019), and the Czech Republic (0.0031). Given that most time series are incomplete, it is difficult to compare and comment on the indicator's development across countries. Nevertheless, similar to "National public funding R&D (% GDP)," in many states, "National public funding R&D for renewable energy (% GDP)" reached its peak between 2009 and 2015.

Table 4 National public funding R&D for renewable energy (% GDP)

country	AVG	SD	MIN	MAX	Rank	Graph	N 2000–2022
AT	0.0067	0.0025	0.0031	0.0114	6		22
BE	0.0041	0.0012	0.0015	0.0067	14		13
BG							0
CY							0
CZ	0.0031	0.0016	0.0004	0.0062	18		20
DE	0.0059	0.0020	0.0025	0.0091	8		23
DK	0.0166	0.0082	0.0051	0.0336	1		23
EE	0.0052	0.0070	0.0006	0.0273	9		12
EL	0.0019	0.0008	0.0011	0.0031	19		7
ES	0.0046	0.0027	0.0021	0.0134	13		22
FI	0.0152	0.0065	0.0057	0.0295	2		22
FR	0.0071	0.0035	0.0009	0.0118	5		22
HR							0
HU	0.0033	0.0025	0.0000	0.0114	17		22
IR	0.0052	0.0033	0.0004	0.0116	10		20
IT	0.0046	0.0016	0.0018	0.0079	12		20
LT	0.0050	0.0005	0.0045	0.0058	11		4
LU	0.0038	0.0032	0.0015	0.0083	15		3
LV							0
MT							0
NL	0.0102	0.0036	0.0056	0.0217	3		21
PL	0.0036	0.0017	0.0002	0.0070	16		15
PT	0.0017	0.0022	0.0001	0.0068	20		19
RO							0
SE	0.0099	0.0032	0.0043	0.0190	4		23
SK	0.0064	0.0072	0.0000	0.0195	7		17
SL							0

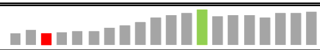
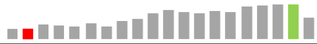
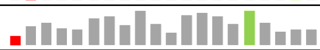
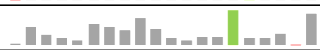
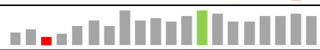
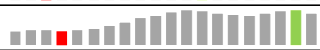
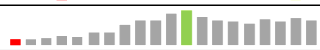
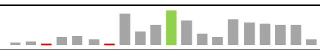
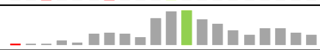
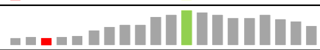
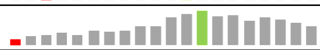
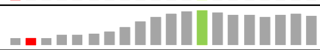
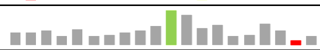
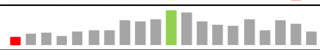
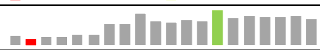
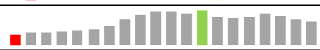
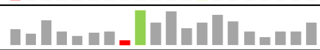
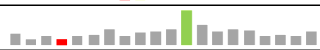
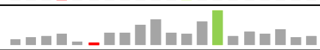
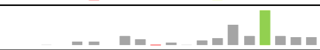
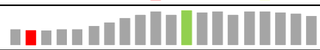
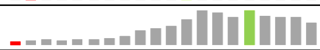
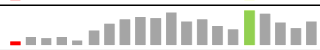
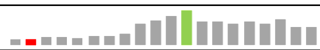
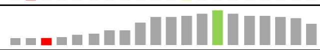
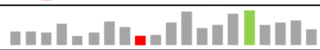
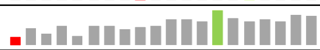
Source: based on data from IEA (2023)

4.2 R&D outcome

The following text presents data and analyses related to R&D outcomes in sustainable development. These data have been examined and processed to identify main trends and differences among countries, thereby addressing the research question (Q2): "What was the level of R&D outcome in sustainable development from 2000 to 2022 in EU countries?" Tables 5-7 provide relevant information on patents and publication results, including calculated average values for the specified period, minimum and maximum values, and mini-graphs to capture key developmental trends visually.

Table 5 records data on the number of "Patents: Climate change mitigation" between 2000 and 2019. The data indicate that, on average, the highest number of patents was registered in Germany (5,133.8), France (1,488.3), and Italy (497.4). Conversely, the lowest average number of patents was recorded in Cyprus (2.5), Malta (2.9), and Estonia (7.4). From the comparison, it is evident that there is a difference on the order of several thousand patents between the most and least active countries. Data availability was accessible for all countries except Malta for the entire period. For most countries, patent activity reached its peak after 2010.

Table 5 Patents: Climate change mitigation

country	AVG	SD	MIN	MAX	Share	Graph	N 2000–2019
AT	305.2	99.5	154.0	446.7	3.0%		20
BE	179.8	64.5	84.6	276.2	1.8%		20
BG	18.4	6.0	7.7	28.3	0.2%		20
CY	2.5	1.7	0.3	6.5	0.0%		20
CZ	69.8	20.9	24.8	99.5	0.7%		20
DE	5 133.8	1 567.4	2 902.7	6 971.8	51.3%		20
DK	334.2	143.8	100.3	576.5	3.3%		20
EE	7.4	4.8	1.0	16.9	0.1%		20
EL	39.2	26.5	5.2	94.2	0.4%		20
ES	352.1	146.9	120.0	572.7	3.5%		20
FI	224.7	88.6	74.1	381.1	2.2%		20
FR	1 488.3	649.2	493.1	2 287.7	14.9%		20
HR	13.4	6.0	5.1	30.0	0.1%		20
HU	54.0	19.4	23.2	94.4	0.5%		20
IR	46.4	18.7	14.3	75.7	0.5%		20
IT	497.4	161.7	214.9	711.1	5.0%		20
LT	7.7	3.3	2.3	14.5	0.1%		20
LU	12.6	5.5	6.0	32.1	0.1%		20
LV	9.9	5.5	2.0	25.5	0.1%		20
MT	2.9	2.8	0.3	12.0	0.0%		16
NL	406.7	109.3	226.1	530.1	4.1%		20
PL	204.5	121.8	45.2	386.1	2.0%		20
PT	33.4	15.0	7.2	57.9	0.3%		20
RO	73.5	34.2	25.5	141.8	0.7%		20
SE	454.7	199.5	151.8	743.1	4.5%		20
SK	21.2	8.0	9.9	37.3	0.2%		20
SL	15.9	4.9	6.3	25.5	0.2%		20

Source: based on data from OECD (2023)

Table 6 records data on the number of "Patents: Environment-related technologies" between 2000 and 2019. The data indicate that, on average, the highest number of patents was once again registered in Germany (6,769.1), France (1,854.5), and Italy (682.2). Conversely, the lowest average number of patents was also recorded in Cyprus (3.7), Malta (3.0), and Estonia (10.7). From the comparison, it is evident that there is a difference in the order of several thousand patents between the most and least active countries. Data availability was again accessible for all countries except Malta for the entire period. For most countries, patent activity also reached its peak after 2010.

Table 6 Patents: Environment-related technologies

country	AVG	SD	MIN	MAX	Share	Graph	N 2000–2019
AT	393.1	103.3	219.4	546.4	3.0%		20
BE	234.4	70.0	132.0	344.6	1.8%		20
BG	25.5	5.8	14.2	34.9	0.2%		20
CY	3.7	2.8	0.3	11.8	0.0%		20
CZ	102.2	22.8	53.2	134.0	0.8%		20
DE	6 769.1	1 481.5	4 574.0	8 597.8	51.6%		20
DK	382.7	146.4	144.7	629.6	2.9%		20
EE	10.7	6.3	2.2	23.8	0.1%		20
EL	50.1	31.5	9.2	116.4	0.4%		20
ES	450.4	160.4	187.3	692.5	3.4%		20
FI	307.8	101.2	140.1	483.6	2.3%		20
FR	1 854.5	737.2	662.4	2 746.7	14.1%		20
HR	18.5	7.6	8.6	42.0	0.1%		20
HU	75.9	20.3	49.3	123.9	0.6%		20
IR	58.9	19.1	27.3	88.3	0.4%		20
IT	682.2	191.5	338.0	965.6	5.2%		20
LT	12.7	4.5	7.7	22.0	0.1%		20
LU	19.0	5.8	11.8	38.6	0.1%		20
LV	15.3	8.4	4.0	33.5	0.1%		20
MT	3.0	2.7	0.3	12.0	0.0%		19
NL	524.7	118.2	316.1	661.0	4.0%		20
PL	344.5	162.6	149.7	616.0	2.6%		20
PT	41.6	18.7	11.2	73.9	0.3%		20
RO	101.9	43.9	41.7	183.4	0.8%		20
SE	568.6	209.3	236.0	854.5	4.3%		20
SK	30.7	9.2	12.3	49.2	0.2%		20
SL	24.8	8.8	10.0	42.5	0.2%		20

Source: based on data from OECD (2023)

Table 7 records data on the number of "Articles published in academic journals in Q1 and Q2 (Number of documents related to GREEN & SUSTAINABLE SCIENCE & TECHNOLOGY)" between 2000 and 2022. The data indicate that, on average, the highest number of articles was registered in Slovakia (288.1), Finland (267.3), and Ireland (240.5). Conversely, the lowest average number of articles was recorded in Latvia (2.3), Bulgaria (2.9), and Italy (3.2). From the comparison, it is evident that there is a difference of several hundred articles between the most and least active countries. Regarding data availability, data were accessible for all countries for the entire time period. For most countries, activity has been on the rise over the last ten years.

Table 7 Articles published in academic journals in Q1 and Q2 (Number of documents related GREEN & SUSTAINABLE SCI-ENCE & TECHNOLOGY)

country	AVG	SD	MIN	MAX	Share	Graph
AT	56.1	61.5	0.0	200.0	2.9%	
BE	71.2	76.9	0.0	226.0	3.6%	
BG	2.9	2.8	0.0	9.0	0.1%	
CY	12.5	16.2	0.0	52.0	0.6%	
CZ	10.3	11.1	0.0	38.0	0.5%	
DE	33.0	46.7	0.0	134.0	1.7%	
DK	89.1	100.9	0.0	309.0	4.6%	
EE	5.1	7.7	0.0	25.0	0.3%	
EL	72.7	81.9	0.0	227.0	3.7%	
ES	176.3	165.9	6.0	477.0	9.0%	
FI	267.3	274.0	2.0	780.0	13.7%	
FR	56.7	48.4	0.0	153.0	2.9%	
HR	18.4	17.9	0.0	62.0	0.9%	
HU	36.2	40.1	0.0	131.0	1.9%	
IR	240.5	272.9	3.0	874.0	12.3%	
IT	3.2	4.5	0.0	17.0	0.2%	
LT	16.0	18.2	0.0	75.0	0.8%	
LU	4.8	6.3	0.0	20.0	0.2%	
LV	2.3	3.2	0.0	12.0	0.1%	
MT	162.9	160.9	2.0	455.0	8.3%	
NL	61.3	78.3	0.0	251.0	3.1%	
PL	90.0	98.0	0.0	261.0	4.6%	
PT	23.9	34.9	0.0	156.0	1.2%	
RO	6.3	10.5	0.0	49.0	0.3%	
SE	13.7	14.5	0.0	48.0	0.7%	
SK	288.1	297.8	2.0	994.0	14.8%	
SL	131.4	139.9	0.0	422.0	6.7%	

Source: based on data from WoS (2023)

4.3 The Effectiveness of Public R&D Funding

In the following text, the results of econometric estimations for models M1-M4 are presented. The econometric analysis was conducted to address the research question (Q3): "Has the recent European public research funding effectively promoted knowledge and innovation in sustainable technologies?" Tables 8-9 provide estimated coefficients for individual variables along with their statistical significance. For model M4, the limited availability of data led to a significant reduction in the number of observations (N), making it necessary to regard the results of this estimation as more indicative.

Regarding the key variables representing national public expenditures on R&D (nat_RD_exp) and public R&D expenditures from the EU (EC_RD_exp), it is evident that the estimated coefficients are statistically significant only in Model 1. The statistical insignificance may be attributed to the decrease in the number of observations in Models M2-M4. The results of Model 1, suggest that increasing expenditures support knowledge and innovation in sustainable technologies.

Looking specifically at national expenditures on R&D for renewable energy (nat_RD_exp_energy), which were part of Models M2-M4, the estimated coefficients suggest that increased national expenditures on R&D for renewable energy could significantly enhance R&D outcomes in sustainable technologies. Furthermore, it is also possible to observe that the overall patent activity (patent_all_log) and publication activity (articles_all_log) influence the production of R&D outcomes in sustainable technologies.

Table 8 Results of econometric estimations for models M1 and M2

	M1			M2(1)		
	Y1	Y2	Y3	Y1	Y2	Y3
nat_RD_exp	1.655***	1.803***	3.053***	0.181	0.268	-0.287
EC_RD_exp	1.267**	1.474**	8.607***	-0.571	-0.742	-0.699
nat_RD_exp_energy				22.200***	25.193***	19.072***
patent_all_log				0.942***	0.932***	0.104***
articles_all_log				0.049***	0.083***	0.880***
_cons	3.602***	3.207***	0.950**	-2.176***	-2.576***	-0.615**
N	335	334	383	188	188	206
chi2	53.01	50.53	65.23	1 117.89	1 007.98	1 698.65
p-value	0.000	0.000	0.000	0.000	0.000	0.000

note: .01 - ***; .05 - **; .1 - *; (1) These countries were excluded due to missing data: BG, CY, HR, LU, LV, MT, RO, SL

Source: based on data from EUROSTAT (2023), OECD (2023) and WoS (2023)

From results from M3 and M4, it is also possible to observe whether electricity consumption (energy_cons_log) and, specifically, the consumption of energy from renewable sources (renewable_energy_cons) or electricity prices (electricity_prices) influenced R&D outcome in sustainable technologies. The results indicate that higher energy consumption did not have a positive effect on increasing R&D activity in sustainable technologies. However, in the case of increasing energy consumption from renewable sources, there was a corresponding increase in R&D activity. In the case of changes in electricity prices, no positive effect on R&D outcome was observed, and the results were also statistically insignificant.

Table 9 Results of econometric estimations for models M3 and M4

		M3(1)			M4(2)	
	Y1	**Y2**	**Y3**	**Y1**	**Y2**	**Y3**
nat_RD_exp	0.055	-0.340	0.090	0.572	0.412	-0.898
EC_RD_exp	-0.688*	0.007	-0.862**	-0.563	-0.294	0.224
nat_RD_exp_energy	19.745***	35.942***	22.652***	5.910	2.279	16.788
patent_all_log	1.001***	0.249***	0.998***	0.962***	0.978***	0.458***
articles_all_log	0.001	0.756***	0.022	-0.035	-0.043	0.590***
energy_cons_log	-0.540***	-1.018***	-0.600***	-0.257	-0.185	-1.689***
electricity_prices	-0.039	0.583	-0.003	-0.251	-0.338	-0.954
renewable_energy_cons	0.857**	1.314**	1.017**	-0.382	-0.085	4.530***
EPS				0.317***	0.268***	0.303
taxes				-0.058	-0.050	-0.237
feed				0.108	0.094	0.251*
_cons	-1.976***	-0.829**	-2.331***	-2.916***	-2.584***	-1.426
N	168	186	168	96	96	104
chi2	1 222.02	1 366.77	894.87	758.57	939.07	627.06
p-value	0.000	0.000	0.000	0.000	0.000	0.000

note: .01 - ***; .05 - **; .1 - *; (1) These countries were excluded due to missing data: BG, CY, HR, LU, LV, MT, RO, SL | (2) These countries were excluded due to missing data: BE, BG, CY, EE, HR, LT, LU, LV, MT, PL, RO, SL

Source: based on data from EUROSTAT (2023), OECD (2023), WoS (2023), Sustainable development report (2023), IEA (2023a)

The final model, M4, included variables representing Environmental Policy Stringency (EPS), Environmentally related tax revenue (taxes), and Renewable energy feed-in tariffs (feed). As previously mentioned, there were limited observations available for estimation. With increasing Environmental Policy Stringency and rising Renewable energy feed-in tariffs, there was an increase in R&D outcomes. However, a statistically significant relationship was observed only for the EPS variable, specifically concerning patents. In the case of tax revenue, no positive and statistically significant impact on the dependent variables was found.

5 Discussion

Public expenditures on R&D in sustainable development are crucial in achieving a sustainable future and addressing global challenges such as climate change, biodiversity loss, and environmental degradation. Adequate investments in this area can have long-term positive impacts on society, the economy, and the environment. The results of the analysis suggest that public expenditures had a positive effect on R&D outcomes in sustainable technologies. Specifically, targeted public expenditures for renewable energy had a strong motivating effect, indicating that public research funding effectively promoted knowledge and innovation in sustainable technologies. These findings align with studies by Gasser et al. (2022) and Peters et al. (2012).

Developing new products and technologies in sustainable technologies can be relatively inexpensive. Patent protection is crucial in enabling patent holders to recoup their investments and secure a long-term competitive advantage in the market. Without this protection, competitors could quickly replicate their innovations and gain a market share without the development costs. The analysis results have shown that countries that exhibit relatively high patent activity also have a higher level of engagement in patent protection related to sustainable technologies. It is important to note that there is strong global competition in the field of patent protection, and obtaining a patent is not always an easy task. This can lead to situations where countries actively support research and development in sustainable technologies but may not always see a commensurate increase in patent protection for sustainable technologies to the same extent as in countries that have been successful in patent protection in general in the past.

A similar situation is also observed in the field of publication activity, where countries that traditionally publish in high-quality journals are more likely to have a higher number of publications in prominent journals in sustainable development.

Energy consumption, particularly from renewable sources, can play a crucial role in motivating the creation of R&D outcomes in sustainable development and technologies. The results indicate that economies that increase their share of energy consumption from renewable sources are a significant driver for innovation in sustainable development. In other words, economies that transition to renewable sources simultaneously generate R&D outcomes in sustainable technologies. Based on this finding, countries already equipped with renewable sources will participate more in their refinement and development than countries just transitioning to renewable sources. Furthermore, it was also expected that countries with high prices would be more active in R&D outcomes, although the analysis results did not confirm this expectation.

For our research three following research question were set up: (Q1) What was the level of public funding allocated from 2000 to 2022 in EU countries. (Q2) What was the level of R&D outcome in sustainable development from 2000 to 2022 in EU countries. (Q3) Has the recent

European public research funding effectively promoted knowledge and innovation in sustainable technologies.

Towards (Q1): Three indicators of public expenditures were examined: National public funding of research and development (R&D), Public funding of R&D from the European Commission, and National public funding of R&D for renewable energy. To facilitate the comparison of these indicators, they were expressed as a percentage of Gross Domestic Product (GDP). The average values of the National public funding of R&D indicator ranged from 0.19% to 0.9% and applied to 14 countries where this share exceeded 0.5% of GDP. Public expenditures on R&D from European Union sources are considered supplementary sources of research and development funding, ranging from 0.02% to 0.2% of GDP. Only four countries had a higher share than 0.1% of GDP. It is also important to monitor public expenditures that were directly allocated to research and development in renewable energy sources. In the case of this indicator, it is not easy to obtain data for all European Union member states, which limits the possibilities for comparison. Average values ranged from 0.002% to 0.0166% of GDP, indicating that these expenditures constitute a relatively small share of GDP.

Towards (Q2): Three indicators were analysed: Patents: Climate change mitigation, Patents: Environment-related technologies, and Articles published in academic journals in Q1 and Q2 (Number of documents related to GREEN & SUSTAINABLE SCIENCE & TECHNOLOGY). Relatively active states in patent protection also have a relatively higher share of patents related to Climate change mitigation and Environment-related technologies. The average number of patents ranged from 3 to 6700, indicating significant differences in production at the level of thousands among states. In the case of the average number of publications, values ranged from 2 to 288, with significant differences among states but at the level of hundreds.

Towards (Q3): The econometric analysis reveals that increasing public expenditure generally enhances R&D outcomes in sustainable technologies, with public R&D expenditure on renewable sources demonstrating the potential to promote knowledge and innovation in sustainable technologies effectively.

6 Conclusion

The European Commission has been a key player in coordinating and funding sustainable development research across the EU. The aforementioned programs like FP7, Horizon 2020, and Horizon Europe signify a coherent and integrated approach.

Comparison with National Budgets While the European Commission's funding has been substantial, it often complements rather than replaces national investments. Member states are responsible for aligning their research funding with European priorities, but they maintain control over significant portions of their research budgets.

For instance, Germany's national budget allocated for R&D in sustainability has fluctuated between 2.5% to 3% of its GDP throughout the period. Similarly, other countries have set individual targets and contributions.

In conclusion, the European Commission's funding has played a significant and complementary role to national budgets, fostering collaboration and setting common goals, but without overshadowing individual state investments. The EU's research funding has led to advancements in various areas of sustainability, including renewable energy, climate change mitigation, water management, and waste reduction.

The European Green Deal is a pivotal policy framework that intends to make the EU climate-neutral by 2050. The funding towards this initiative has led to innovative projects in clean energy, transportation, and agriculture. Despite these successes, some criticisms and challenges remain.

Bureaucratic obstacles, unequal distribution of funds between member states, and the gap between research and marketable technologies have been identified as areas for improvement.

The EU's investment in sustainable development research from 2000 to 2022 reveals a consistent and growing commitment to this vital area. National and European-level funding have worked hand-in-hand to foster innovation and knowledge, although not without challenges. The future of sustainable development within the EU depends on continued investment, collaboration, and a focus on translating research into practical and widespread applications. The lessons learned in this period serve as a guide for future endeavours in achieving a sustainable and resilient European Union.

Similar to previous studies, limitations stem from data availability and quality, with many indicators either absent or with only incomplete time series. In the case of the model, a time lag between R&D outcomes and explanatory variables was assumed, in line with the innovation cycle hypothesis. All limitations have been thoroughly discussed and provide avenues for further research in this field in the future.

7 Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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