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Rethinking Cohesion: When and Where ESI Funds Drive Socio-Economic Change?

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Abstract

This study examines the non-linear relationship between European Structural and Investment (ESI) Funds and socio-economic development across EU member states from 2007 to 2020. To accomplish this, the study utilises a novel methodological approach, employing panel threshold regression to analyse the complex interactions between these variables. Using the Human Development Index (HDI) as a comprehensive measure of socio-economic progress, this research goes beyond traditional metrics, such as GDP, to capture a multidimensional view of development. The threshold variable, represented by the ratio of ESI Funds paid to GDP, highlights critical inflexion points where the impact of funding shifts, revealing both positive and negative effects. The study finds that ESI Funds positively impact socio-economic development up to a threshold of 0.7% of GDP, beyond which their effectiveness diminishes, emphasising the need for strategic allocation and management. Additionally, the analysis of control variables identifies a critical threshold range between 2% and 2.3% of GDP, indicating the growing importance of ESI Funds in fostering development within complex socio-economic contexts. This paper contributes to the foundational model of socio-economic development informed by ESI Funds, offering valuable insights for policymakers by emphasising the importance of balancing funding levels with strategic allocation to avoid diminishing returns.

Keywords: European Structural Funds; social development; economic development; EU countries; panel threshold

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1. Introduction

The current crisis, marked by the COVID-19 pandemic and the war in Ukraine, has highlighted the importance of a coordinated response from the European Union to support economic recovery and stimulate socio-economic development. The European Structural and Investment Funds (ESI Funds) are pivotal in addressing structural challenges, promoting sustainable development, and driving economic and social progress [1]. Since their establishment in 1958, these funds have developed significantly, addressing internal and external challenges, such as the expansion of the EU, globalisation, and changes in

political orientation [2]. Given their redistributive nature, debates within the European community and academia have expanded regarding the ESI funds' impact, added value, administrative costs, and the institutional characteristics necessary for efficient and effective management [2].

The relationship between ESI Funds and socio-economic development is multifaceted, influenced by numerous contextual, institutional, and economic factors. Numerous studies based on macroeconomic models, regression analyses, and qualitative case studies have highlighted the potential of ESI funds to stimulate development across the European Community [3]. However, these traditional methods have limitations in capturing the non-linear relationships between funds and development indicators. Critical absorption thresholds, for example, can generate unexpected effects, both positive and negative, depending on the funding level. Thus, threshold analysis becomes an indispensable tool for better understanding the effectiveness of funds and identifying the points at which additional funding begins to generate unwanted effects.

Empirical evidence confirms the critical role of ESI Funds in reducing socio-economic disparities across EU member states. For example, data from the European Commission and Eurostat indicate that regions with higher absorption rates of ESI Funds experienced faster improvements in GDP per capita, Human Development Index (HDI) scores, and regional cohesion indicators compared to less-funded regions. Between 2007 and 2020, the EU allocated over €500 billion in cohesion and structural funding, with tangible positive effects on infrastructure development, education, and social inclusion, particularly in Central and Eastern European countries. By highlighting these measurable impacts, we strengthen the narrative linking the historical and current significance of ESI Funds to the EU's cohesion policy objectives, demonstrating how targeted investments promote both economic and social progress and help reduce disparities among member states.

This study contributes significantly to the literature on the impact of European Structural and Investment (ESI) Funds by offering a fresh perspective on how these funds influence socio-economic development in the EU. First, our research evaluates socio-economic development using the Human Development Index (HDI), which encompasses health, education, and living standards. By utilising the HDI, our study aims to address the limitations of traditional economic indicators, such as GDP, and to offer a more holistic perspective on socio-economic progress. Second, recognising the complexity of the relationship between ESI Funds and socio-economic development, our approach goes beyond the traditional linear models commonly employed in prior studies, adopting a panel threshold regression model to examine the non-linear dynamics between ESI Funds and socio-economic outcomes. The key innovation of this approach is that it identifies critical thresholds at which the impact of ESI Funds on socio-economic development changes, offering deeper insights into the varying impacts of funding across different regions and economic contexts within the EU. Third, by incorporating contextual variables, this study provides a more comprehensive and context-sensitive analysis, contributing to a better understanding of how ESI Funds interact with socio-economic factors. Concretely, our study goes beyond merely examining the direct relationship between funding and development and accounts for the broader socio-economic factors that influence the outcomes of ESI Funds, incorporating contextual variables such as the GINI Index, Economic Sentiment Indicator (ESI), Index of Economic Freedom, Economic Complexity Index (ECI), secondary school enrolment rates, and Gender Parity Index (GPI). Fourth, the SDG Index was used to categorise EU member states into sub-regions, with regression models re-tested to examine differences across these sub-panels, offering valuable implications for optimising the allocation and management of European funding mechanisms. Our view acknowledges the heterogeneity among EU countries in achieving Sustainable Development Goals (SDGs). It categorises them into five sub-regions based on their SDG progress,

including “achieved or on track,” “limited progress,” or “worsening,” while also considering their geographical positioning: Western Europe, Northern Europe, Southern Europe, Central and Eastern Europe, and the Baltic countries. Finally, another significant contribution of our study lies in applying mind mapping to explore the relationship between ESI Funds and socio-economic development, visually representing the key connections and dynamics. Additionally, we systematically reviewed the literature in the Web of Science database, focusing on publications from 2015 to 2023. Using a carefully constructed search algorithm—*TS = (“European structural funds”) AND (“effect”) AND (“social development”) AND (“economic development”)**—we identified relevant studies to synthesise the state of the art, offering a comprehensive understanding of the current academic discourse on this topic.

This paper is organised as follows: the introduction situates the study within the broader context of exploring the nexus between European Structural and Investment (ESI) Funds and socio-economic development, with a focus on addressing disparities across EU regions. The literature review comprehensively examines previous research, highlighting theoretical and empirical contributions to understanding the impact of ESI Funds and socio-economic indicators. Section 3 details the selection of variables, their relevance to the research framework, and the panel threshold regression model used to analyse the relationship between ESI Funds and human development. Section 4 interprets the findings, identifying critical thresholds and non-linear relationships, and explores the role of control variables in refining the analysis. Finally, the conclusion summarises the key findings, discusses policy implications for optimising the allocation of ESI Funds, and offers recommendations for enhancing socio-economic cohesion and sustainability across EU member states.

2. Literature Review

The European Structural and Investment (ESI) Funds aim to foster the socio-economic development of European Union (EU) Member States. These funds, designed to reduce disparities and promote cohesion, have been the subject of extensive academic and policy debates, particularly concerning their effectiveness and impact on regional development. Based on the historical context and current debates regarding the ESI Funds, this study systematically assesses the relationship between these funds and the socio-economic development of EU Member States.

To this end, the research methodological framework integrates a comprehensive review of the literature in the Web of Science Core Collection, focusing on the relationship between the ESI Funds and social and economic development. Using a carefully constructed search algorithm: TS = (“European structural funds”) AND (“effect*”) AND (“social development”) AND (“economic development”), the initial search generated 160 documents, which were subsequently narrowed down to 101 scientific articles by selecting those written exclusively in English. To ensure the research’s contemporary relevance, the time frame was limited to 2015–2023 (84 articles). Additionally, a rigorous analysis of abstracts and titles was conducted to select articles that provide analyses and conclusions relevant to the proposed topic (Table 1).

Table 1. Relevant articles on the relationship between ESI Funds and socio-economic development.

Study Reference	Methodology	Main Results
[4]	Case study, documentary analysis, and quantitative correlational analysis	EU Funds supported tourism entrepreneurship and short-term tourism development.
[5]	Quantitative comparative analysis and construction of a convergence/divergence index	EU Funds did not fully offset divergence after the 2008 crisis.
[6]	Econometric panel models	Uneven regional impacts, with stronger growth effects in more advanced regions.
[7]	Multinomial logistic regression	EU Funds supported convergence mainly through infrastructure investment, but the effects varied by region.
[3]	Qualitative policy analysis	EU Funds strongly shaped UK regional and social development.
[8]	Spatial econometric models and Principal Component Analysis	Limited and uneven impact on reducing micro-regional disparities.
[9]	Regression Discontinuity Design	Positive but uneven growth effects, strongest in rural areas close to cities.
[10]	Input–output and correlation analysis	EU funds had a positive impact on municipal development, particularly on GDP, population growth, and purchasing power.
[11]	Constructing a synthetic index and cluster analysis	EU Funds contributed to increased GDP per capita and reduced unemployment, but regional disparities persisted and became more polarized.
[12]	Continuous Regression Discontinuity Design	EU Funds had a positive effect on regional growth, but marginal returns declined after a funding saturation threshold was reached.
[13]	Difference-in-differences	Overall, EU Funds did not reduce regional disparities.
[14]	Correlation analysis	EU Funds had strong positive economic, social, and environmental effects, significantly enhancing SME competitiveness.
[15]	Propensity Score Matching	CAP funds stimulated farm investment and long-term sustainability, with limited and uneven short-term productivity gains.
[16]	Correlation, regression, wavelet coherence analysis	EU funds positively stimulated housing market activity, increasing building permits and construction.
[17]	Case study, correlation, and regression analysis	EU funds were reallocated to mitigate COVID-19 impacts, mainly supporting health care and entrepreneurship.
[18]	Survey-based quantitative analysis	76% of respondents reported a positive perception of EU funds' contribution to regional development.
[19]	Qualitative policy analysis	EU Funds had only marginal impacts on English regional development.

[20]	Comparative statistical analysis	EU Funds had positive but conditional effects on SMEs, strongest in the short term and mainly through employment and productivity.
[21]	Fixed-effects panel analysis	EU Funds improved access to employment but widened educational gaps.
[22]	Econometric panel analysis	EU funds had a positive but heterogeneous impact on regional economic performance.
[23]	Panel data regression	EU Funds had a modest positive effect on regional growth, but uneven absorption contributed to persistent regional disparities.

The European Union's cohesion policy is based on the imperative of promoting economic convergence, particularly by reducing disparities between Member States and aligning development levels across regions.

Numerous studies have highlighted the success of this initiative, especially in areas that have effectively harnessed European funds to stimulate national economies. For instance, research by Caldas et al. [10] in Portugal showed the positive outcomes of these funds, highlighting notable improvements in economic and social indicators, such as population growth, purchasing power and gross value added per capita. Similarly, the study by Nishimura et al. [18] reflected positive public perception, with 76% of respondents confirming that European funds have made a favourable contribution to regional development.

In Romania, the contribution of ESI Funds was also significant, as highlighted by Pîrvu et al. [11], who reported a positive impact on GDP per capita and a reduction in the unemployment rate during 2007–2013. Also, Bostan et al. [14,20] illustrated the contribution of the funds to the development of SMEs in the North-East region and the Danube Delta, supporting increased competitiveness and accelerating economic development in these regions.

Similarly, in Poland, Bedrunka et al. [17] emphasised the role of the ESI Funds in strengthening medical infrastructure and managing health crises. At a more aggregated level, Davidescu et al. [22] demonstrated that European funds have significantly contributed to regional GDP growth and to improvements in social progress indicators in Central and Eastern Europe. However, the effectiveness of ESI funds in these countries has been shaped by several underlying factors, including inefficiencies in governance and systemic weaknesses [24], the migration of skilled professionals from less developed regions to Western economies [25], inadequate investment in research and development [26], and the redistributive nature of fiscal policies [27].

However, the impact of ESI funds has not been evenly distributed across regions, as it is strongly influenced by absorption capacity and local specificities. Some studies [6,13] have shown uneven distribution of benefits generated by ESI funds, reflecting disparities between more advanced and less developed regions. Similarly, Fabrizi et al. [7] have demonstrated that funds for infrastructure and environmental improvements have positively impacted less developed regions. These contradictions can be explained, in part, by the analysis of Maris [23], who observed significant differences in the absorption and effects of funds across Central and Eastern European countries, highlighting that regional variations have profoundly influenced economic outcomes. However, Cerqua & Pellegrini [12] noted that the marginal effects of funds on economic growth tend to decrease as investments approach a saturation point, estimated at EUR 305–340 per capita.

Given the mixed empirical evidence and the institutional complexity surrounding the implementation of cohesion policy, we summarised the major advantages and disadvantages of ESI Funds in Appendix A (Table A1). This overview supports the interpretation of heterogeneous outcomes reported in the literature and provides a clearer institutional context for the non-linear effects explored in empirical analysis.

On the other hand, in the Czech Republic, the study by Novosák et al. [8] showed that structural funds failed to significantly reduce regional disparities at the micro-regional level despite targeted allocations to disadvantaged regions. Fusaro & Scandurra [21] highlighted another paradox of European funds: although the European Social Fund (ESF) improved access to education and employment for young people, it also contributed to widening disparities in access to higher education, benefiting mainly more prosperous regions.

Furthermore, the timing and scale of these funds have often been insufficient to counterbalance external economic shocks, such as the financial crisis of the late 2000s, which resulted in severe economic disruption and substantial societal costs [28]. Kohl [5] argued that European funds have not always fully mitigated the impact of external economic shocks, such as the 2008 financial crisis, which sometimes exacerbated economic divergences, undermining the core objective of economic convergence within cohesion policy.

Building on insights from the literature, a deeper understanding of the relationship between European funds and socio-economic development requires the use of analytical approaches. Studies in the field employ complex methodologies, incorporating diverse variables to capture the intricate interactions across multiple dimensions of this relationship. These variables typically fall into three main categories: (1) those quantifying the volume and distribution of European funds, (2) those measuring various dimensions of socio-economic development, and (3) control variables, which allow the analysis to be adjusted for contextual factors.

The multitude and variety of these variables generally lead to heterogeneous results—some studies show a positive relationship between ESI Funds and socio-economic development. In contrast, others indicate a marginal or the opposite effect. This difference in results confirms the complexity of the relationship between EU funds and socio-economic development, compelling a multidimensional analytical approach. Figure 1 graphically maps the complex relationship between ESI Funds and socio-economic development, drawing on the results and variables from the literature review.

Most of the studies included in this systematic review use GDP and its variations as the leading indicator of socio-economic development [3,5,6,9,11–13,22,23]. Although GDP is a central and accessible indicator in assessing economic performance, it has significant limitations in capturing the full spectrum of socio-economic development. Thus, numerous authors [29,30] emphasise the need to use complementary or alternative indicators, such as the Human Development Index (HDI), relative poverty indicators, unemployment rate, education level, life expectancy, as well as measurements of social capital and psychological well-being.

In this sense, some studies included in the analysis also incorporated social indicators, such as education level [21], the Social Progress Index [22], the risk of poverty, employment rates, youth unemployment and social protection expenditure [5]. However, the weight of these social indicators is relatively low compared to economic ones, with GDP and its variations dominating the research. This imbalance highlights the importance of GDP in measuring economic development but also underlines the need to overcome the limitations of this indicator in assessing the complexity of socio-economic development.

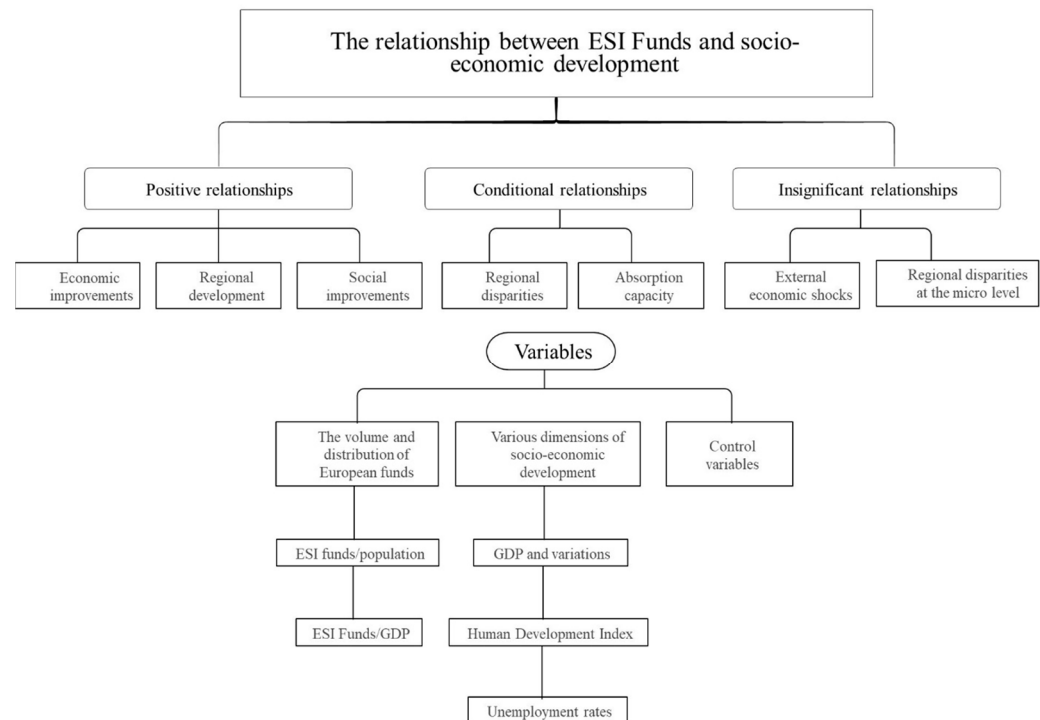


Figure 1. Mind mapping the ESI Funds—socio-economic development relationship.

In this context, a comprehensive assessment of socio-economic development requires a multidimensional approach that includes not only economic indicators but also social inequalities and the general well-being of the population. The predominant response to this requirement has been the development of sets of aggregate indicators that reflect performance in various areas at the national level [29]. The Human Development Index (HDI) is a prominent example in this regard, serving as a reference for assessing socio-economic development. The HDI overcomes the limitations of GDP by integrating fundamental dimensions of human well-being, such as health, education and living standards [29,31–33].

Measuring the European Structural Funds is key to assessing their impact on regions' socio-economic development, and the various quantification methods reflect multiple methodological and analytical perspectives. Some research [21] uses the logarithm of funds received per capita for each region, providing an adjusted measure of the distribution of funds. Given the considerable differences in fund size and absorption capacity, this method facilitates comparisons across regions with varying populations and economic structures.

Another approach is to measure the intensity of EU Structural Funds, expressed as funds per capita and normalised by population, enabling a more precise assessment of how funds are distributed and used locally [12].

However, the most frequently used variable in the analysis of the impact of structural funds is their quantification as a proportion of GDP [13,34,35]. This approach is considered superior in international comparative assessments because it quantifies the absolute amount of funds received and highlights their economic relevance. Such a measure allows for identifying discrepancies in the use of funds and their absorption, facilitating the analysis of how structural funds contribute to regional convergence and the reduction in economic disparities.

The systematic review of the specialised literature highlights the central role of regression models in assessing the impact of European funds on socio-economic development. These models facilitate the identification of causal relationships between financial interventions and essential indicators. Although these models provide a rigorous

assessment of average effects, they have limitations in capturing dynamic complexities, such as non-linear relationships or critical thresholds of fund absorption, which can cause significant and unexpected changes in regional development.

Under these circumstances, threshold analysis becomes an indispensable tool, providing a more nuanced perspective on the inflexion points at which the effects of financial interventions increase disproportionately with the investments made.

This research seeks to investigate the relationship between ESI Funds and socio-economic development. It innovatively contributes to a deeper understanding of the cumulative and non-linear effects of the funds, thus optimising resource allocation strategies. The novelty of this study lies in its approach to examining the dynamic, non-linear nexus between ESI Funds and socio-economic development. Without the threshold analysis, there is a risk of underestimating the real impact of European funds, especially in regions with limited absorption capacity, where socio-economic development may remain stagnant until a critical level of intervention is reached. Therefore, implementing this methodology is crucial for formulating better-calibrated public policies that maximise the impact of funds, given regional specificities. Following Stiglitz et al. [29] and Costanza et al. [30], the human development index (HDI) was selected as the dependent variable, serving as a proxy for socio-economic development. The HDI encapsulates three fundamental dimensions of human development: longevity and health, access to knowledge, and a decent standard of living. The threshold variable is the ratio of EU funds (paid) to GDP, based on the annual payments made from the European Union Commission budget to the Member States (following [13,34,35]). This derived variable enables a more robust comparison across countries, providing a balanced perspective on the relative importance of funds received in relation to each state's economic size [35].

We have acknowledged the heterogeneity and disparities among EU countries in their progress toward achieving Sustainable Development Goals (SDGs). The status of the EU countries' SDG targets is measured using trend indicators that assess their progress toward specific SDG targets and present the percentage of indicators showing positive, stagnant, or negative trends within each sub-region [36]. In this research, the EU countries are divided into five sub-regions based on the status of their SDG targets' progress ('achieved or on track', 'limited progress' or 'worsening') and in correlation to their geographical position: Western Europe (7 countries); Northern Europe (3 countries); Southern Europe (6 countries); Central and Eastern Europe—CEE (8 countries); and Baltic countries (3 countries). For Northern Europe, most SDG targets are categorised as "Achieved or on track", while very few indicators show "Worsening", indicating substantial progress in sustainable development. For Western Europe, a significant proportion of targets are "Achieved or on track" (green), while a moderate percentage show "Limited progress" (yellow), with a smaller share worsening (red). Concerning Southern Europe, a lower percentage of targets are "Achieved or on track" (green) compared to Northern and Western Europe and a significant share shows "Limited progress" (yellow), with a slightly larger proportion of "Worsening" (red) indicators. While many targets are "Achieved or on track" (green), Central and Eastern Europe countries show a higher proportion of "Limited progress" (yellow) and "Worsening" (red) compared to other sub-regions. For the Baltic States, many indicators are "Achieved or on track" (green), though a noticeable proportion show "Limited progress" (yellow) and a few targets are classified as "Worsening" (red). Therefore, Northern and Western Europe display higher percentages of SDG targets that are "Achieved or on track," while some Central and Eastern European nations lag significantly behind. Some sub-regions, such as Southern Europe and the Baltic States, show a greater share of "Limited progress," indicating slower advancement toward SDG targets than others. The share of "Worsening" trends (red indicators) varies, with Central and Southern Europe struggling more significantly in certain areas of sustainable

development. The differences between sub-regions, such as Northern Europe's strong performance versus the challenges faced by Central and Southern Europe, reflect disparities in economic, social, and environmental capacities for sustainable development.

This heterogeneity underscores the diverse starting points, resources, governance, and policy approaches of European countries in addressing the SDGs. It highlights the need for tailored strategies and support mechanisms to bridge the regional gaps.

Practically, our methodology is new to existing literature by accounting for non-linear attribution. This results in more accurate outcomes by capturing the non-linear relationship between ESI Funds and socio-economic development. Withal, this paper fills this research gap by exploring the relationship between ESI Funds and socio-economic development from the perspective of progress toward achieving Sustainable Development Goals (SDGs).

To account for factors that might influence the dependent variable and ensure the robustness and validity of the results, we groundbreakingly included control variables in the model to capture specific socio-economic dimensions: GINI Index, a measure of income inequality within a country; Economic Sentiment Indicator (ESI), which reflects business and consumer confidence; Index of Economic Freedom, that indicates the degree of market openness, regulatory efficiency, and rule of law; Economic Complexity Index (ECI), that measures the diversity and sophistication of a country's export basket and Educational Attainment (School Enrollment—Secondary Level), representing the level of human capital development.

3. Data and Methodology

3.1. Theoretical Assumptions

The intricate relationship between the European Structural and Investment (ESI) Funds and socio-economic development across the European Union (EU) member states has attracted significant attention in recent years. The allocation and absorption of these funds are influenced by various economic, social, and institutional factors, resulting in diverse impacts across EU regions. This interaction can be understood as a complex system characterised by feedback loops, absorbent capacity constraints, and institutional mediators, which may amplify or damage the effects of ESI Funds across different development contexts.

In exploring this complex nexus, we ground our analysis on the premise that ESI Funds are pivotal in driving human development, particularly in regions with limited domestic resources. Adopting a panel threshold regression model facilitates understanding the non-linear dynamics between ESI Funds and socio-economic indicators, identifying critical inflexion points where the impact of funding shifts. This approach allows us to move beyond average effects and capture structural changes in the marginal impact of ESI Funds, which are particularly relevant given heterogeneous institutional and socio-economic conditions across EU member states.

This research emphasises the need to go beyond traditional economic metrics, such as GDP, by employing the Human Development Index (HDI) as a comprehensive measure of socio-economic progress. The HDI encompasses three fundamental dimensions: longevity and health, education, and a decent standard of living. The threshold variable, the ratio of ESI Funds paid to GDP, provides a nuanced perspective on how funding intensity correlates with development outcomes. By combining HDI with EU funds relative to GDP, our framework explicitly aligns the measurement of development outcomes with the multidimensional objectives of EU cohesion policy.

To refine our understanding, we formulated the following research questions to address the hypothesised relationships and potential threshold effects:

RQ1: How does the intensity of ESI Funds influence socio-economic development across EU member states, and is the relationship linear or non-linear?

RQ2: At what levels of ESI Funds to GDP do significant changes in their impact on human development occur?

RQ3: How do contextual factors, such as income inequality and economic sentiment, mediate the relationship between ESI Funds and socio-economic outcomes?

RQ4: Can control variables, including the GINI Index, Economic Sentiment Indicator (ESI), Index of Economic Freedom, and others, enhance the robustness of the model in capturing regional disparities?

Hypotheses

Based on the theoretical assumptions and existing literature, we propose the following hypotheses:

Hypothesis 1: *There is a positive relationship between ESI Funds and socio-economic development, as measured by the HDI.*

Hypothesis 2: *A non-linear relationship exists between ESI Funds and HDI, with a threshold level of funds beyond which the impact diminishes or reverses.*

Hypothesis 3: *Control variables, such as the GINI Index, Economic Sentiment Indicator, and others, significantly influence the relationship between ESI Funds and socio-economic development.*

In addition, we anticipate varied outcomes across EU countries based on their socio-economic and institutional characteristics. Regional disparities and governance capacities shape the effectiveness of funds in fostering development, particularly in less developed regions. Studies have shown that well-targeted ESI Funds can drive improvements in infrastructure, education, and economic complexity, thereby enhancing efficiency, productivity, and competitiveness [3,6,12]. Furthermore, the capacity to absorb and utilise these funds effectively is often linked to each country's institutional quality and innovative potential, which are critical for achieving balanced socio-economic development across the EU.

This theoretical framing supports the inclusion of institutional, social, and economic controls in the empirical model, as these factors are expected to alter both the magnitude and the location of the estimated threshold.

3.2. Data

Following Stiglitz et al. [29] and Costanza et al. [30], we considered the human development index (HDI) as the dependent variable. HDI was selected because it captures three fundamental dimensions of human development—health (longevity), education, and living standards—going beyond traditional GDP-centric measures. It is particularly relevant for assessing the impact of ESI Funds, which target not only economic growth but also social cohesion, education, and improvements in quality of life across EU regions. Thus, HDI is fully consistent with the core objectives of EU cohesion policy, which explicitly combines economic, social, and territorial dimensions of development. HDI summarises three key dimensions of human development: a long and healthy life, knowledge, and decent living. HDI is published within the Human Development Reports, created by the United Nations Development Programme, to emphasise that people and their capabilities should be a critical criterion for a country's development assessment, going beyond economic growth [37].

The threshold variable is represented by the EU funds (paid) to GDP ratio, based on annual payments from the European Union Commission budget to the Member States, not cumulative payments (following [13,34,35]). This ratio is based on the GDP of the EU-

27 member states, emphasising the reliance on EU support, which might be significant in countries with limited domestic resources, the role of EU funds in various sectors, and the investment in development and cohesion, as higher ratios of EU funds in GDP may indicate significant investments in infrastructure, innovation, social inclusion, or environmental projects, financed by the EU to support the country's development. Using a relative indicator (the ratio of EU funds paid to GDP) allows for meaningful cross-country comparability, accounting for differences in economic size and fiscal capacity among EU member states.

To anticipate the model's limitations, we employed the aforementioned index and ratio in relation to other indicators to obtain a comprehensive picture of the role of EU funding in economic and human development. Therefore, we included seven distinct control variables and up to four within the threshold regression model. These control variables are the following: the GINI Index, the Economic Sentiment Indicator (ESI), the Index of Economic Freedom, the Economic Complexity Index (ECI), educational attainment through school enrolment—secondary level, the Gender Parity Index (GPI), and the SDG Index Score. The seven control variables were carefully selected to account for contextual and institutional factors that could mediate or moderate the impact of EU funds on human development: the GINI Index captures income inequality, which can affect how EU funds translate into improved human development, as regions with higher inequality may experience slower or uneven benefits; the Economic Sentiment Indicator (ESI) reflects business and consumer confidence, influencing investment, consumption, and overall economic activity, which mediate fund effectiveness; the Index of Economic Freedom (Econ-Freed) measures institutional quality, regulatory efficiency, and market openness, shaping how effectively ESI Funds are absorbed and utilized; the Economic Complexity Index (ECI) assesses the sophistication and diversification of a country's economy, reflecting its capacity to transform EU funds into productive and innovative outputs; educational attainment at the secondary level (EducAtt) represents human capital, a key channel through which EU funds can enhance socio-economic development; the Gender Parity Index (GPI) accounts for social inclusion and equitable access to education and resources, aligning with HDI's social dimensions; and the SDG Index Score (SDG) reflects progress toward sustainable development goals, integrating environmental, social, and economic outcomes that EU funds aim to support. This theoretically grounded selection ensures that the estimated threshold effects are not confounded by omitted socio-economic or institutional factors.

The latest index was also used to categorise EU member states into sub-regions and to retest the regression models to observe differences across sub-panels [36]. Data were collected annually from various independent sources, as indicated in Table 2, with sample periods ranging from 2007 to 2020.

Table 2. Overview of indicators employed in the analysis.

Indicator/Index	Description	Source
Human Development Index (HDI)	A composite index is used to assess a country's level of human development based on three dimensions: a long and healthy life, access to knowledge, and a decent standard of living.	United Nations Development Programme [38]
EU funds paid/GDP (EUfunds)	The ratio of European funds paid annually (non-cumulative) by the European	European Commission [39,40]; Eurostat [41]

GINI Index (GINI)	Commission to member countries and their Gross Domestic Product (GDP). A statistical indicator used to measure income distribution inequality within a society, ranging from 0 (perfect equality) to 1 (maximum inequality).	World Bank [42]
Economic Sentiment Indicator (ESI)—the average value for a year based on monthly data	A composite index reflecting business and consumer confidence in an economy, based on surveys from sectors such as industry, services, trade, and construction.	Eurostat [43]
Index of Economic Freedom (EconFreed)	An indicator that assesses a country's degree of economic freedom, based on factors such as property rights, trade freedom, regulatory environment, and government intervention in the economy.	The Heritage Foundation [44]
Economic Complexity Index (ECI)	It measures the level of sophistication and diversification of an economy, reflecting a country's ability to produce complex goods based on advanced knowledge and technologies, as well as the diversity of its exported products.	Harvard Growth Lab [45]
Educational attainment through school enrolment—secondary level (EducAtt)	The ratio of the total number of enrolled students, regardless of age, to the population of the age group officially corresponding to the secondary education level.	World Bank [46]
Gender Parity Index (GPI)	An indicator that measures gender balance in access to resources such as education represented by the ratio of girls' participation rate to boys' participation rate at various levels of education.	World Bank [47]
SDG Index Score (SDG)	The index evaluates a country's progress in achieving the 17 UN Sustainable Development Goals, measuring economic, social, and environmental performance based on specific indicators.	Sustainable Development Solutions Network [48]

Building on the presentation of the indicators used in this analysis, we detail the threshold model and discuss the econometric results.

This section of the paper examines the levels of the selected indicators, mapping their values for 2007 and 2020 to highlight variations and trends across EU member states. The two benchmark years were chosen to illustrate long-term structural changes over the programming period rather than short-term cyclical fluctuations.

Figure 2 shows a significant increase in EU funds paid, with European Commission funding doubling from 2007 to 2020, especially in the Baltic countries. These are at the top in terms of EU fund allocation, followed by CEE countries, among which Hungary and Poland stand out as the highest recipients of EU funds in both 2007 and 2020. This pattern reflects the redistributive logic of EU cohesion policy, whereby less developed regions receive proportionally higher support, and should not be interpreted as a sign of declining effectiveness per se.

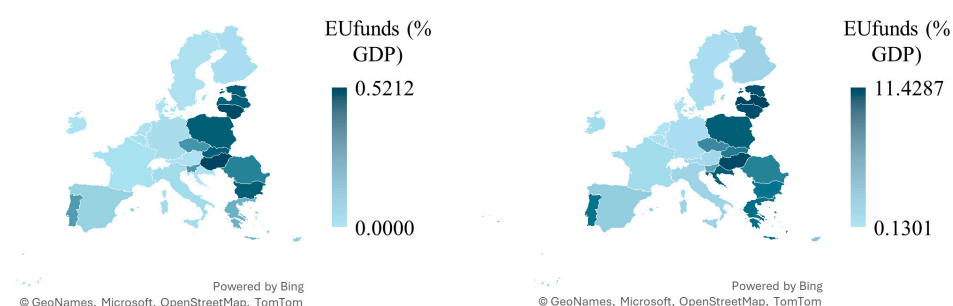


Figure 2. The level of EU funds paid in 2007 (**left**) and 2020 (**right**) across EU member states.

Figure 3 illustrates human development across the EU. HDI gradually increased over the 14 years for all member states, but the highest levels remain in Northern countries, followed by Western countries. Until 2020, the CEE and Baltic countries closed more of the HDI gap with Western and Northern countries, demonstrating that human development is faster in emerging countries. This convergence trend further supports the relevance of HDI as an appropriate outcome variable for evaluating ESI Funds.

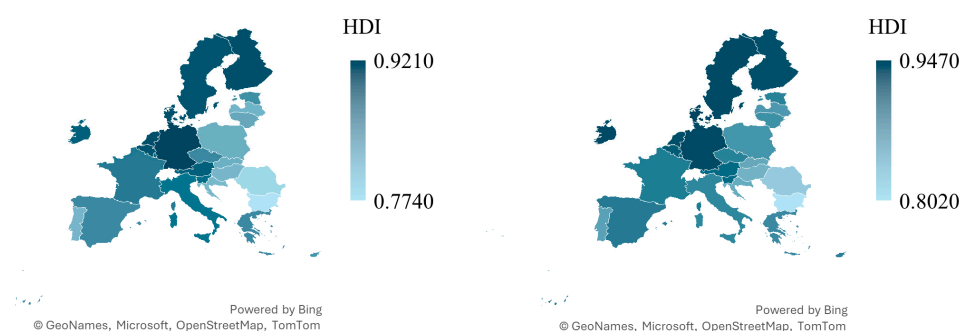


Figure 3. The level of HDI registered in 2007 (**left**) and 2020 (**right**) across EU member states.

The GINI index is illustrated in Figure 4. An interesting fact is that in 2007, the CEE countries (with Romania and Bulgaria on top), Southern countries (Portugal, Spain, and Greece), and Baltic countries (Latvia and Lithuania) had the highest GINI index. Until 2020, this index decreased for the previously specified countries and most EU member states, except for Bulgaria (which increased from 36.1 to 40.5 from 2007 to 2020).

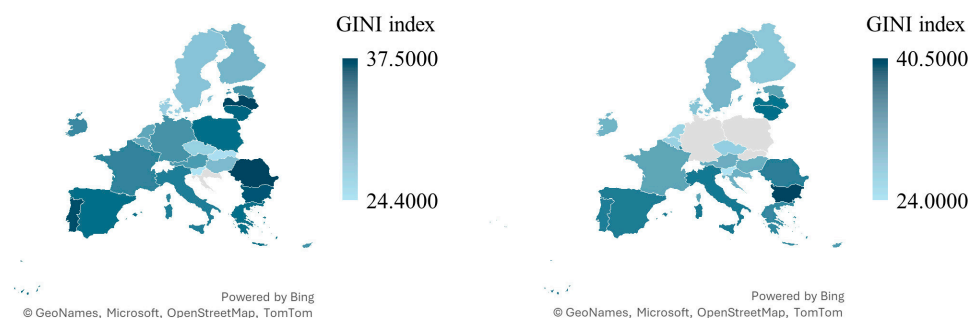


Figure 4. The level of the GINI index in 2007 (**left**) and 2020 (**right**) across EU member states.

The values for the Economic Sentiment Indicator were computed based on the average monthly data collected for 2007 and 2020. This indicator (Figure 5) shows a significant decline, indicating that confidence across sectors (manufacturers, service providers, consumers, retailers, and constructors) has gradually decreased. Initially, Poland, Bulgaria, Slovakia, Lithuania, and the Czech Republic were ahead of EU member states, but by 2020, the top five were set with Lithuania, Greece, Croatia, Germany, and Latvia. Bulgaria and Poland experienced some of the largest decreases in ESI levels from 2007 to 2020.

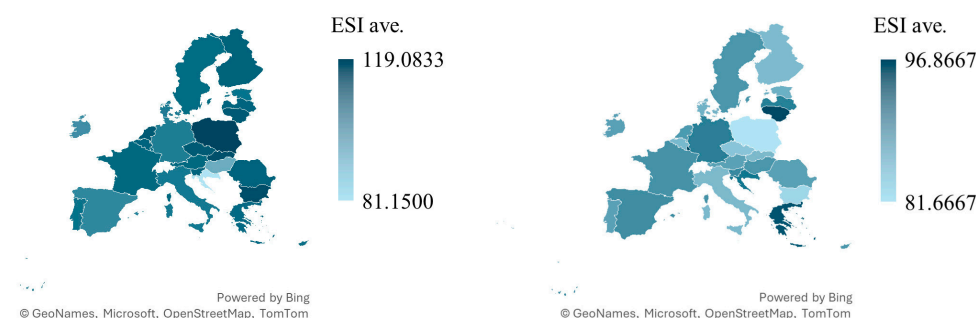


Figure 5. The level of the Economic Sentiment Indicator in 2007 (**left**) and 2020 (**right**) across EU member states.

The index of economic freedom is the highest in Ireland, categorised as the freest economy within the EU in 2007 and 2020. Other EU countries, as evidenced in Figure 6, through institutional strengths and leaders in economic freedom, were Estonia, the Netherlands, and Denmark in 2007, while in 2020, Ireland followed Denmark, Estonia, and Lithuania.

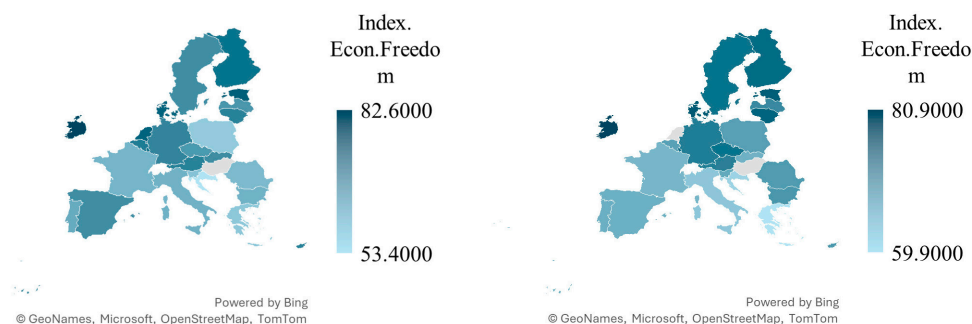


Figure 6. The level of the Economic Freedom Index in 2007 (**left**) and 2020 (**right**) across EU member states.

Figure 7 illustrates the Economic Complexity Index (ECI), and Germany is ranked first in both years. Significant levels of ECI are specific to Northern countries and a few CEE countries (the Czech Republic, Hungary and Slovenia). Although the maximum ECI level decreased from 2007 to 2020, the top level is maintained over time. Very low levels of ECI (under 0.1) were registered by Bulgaria in 2007 and Croatia and Latvia in 2020, indicating that these countries lack the capabilities of large economic systems.

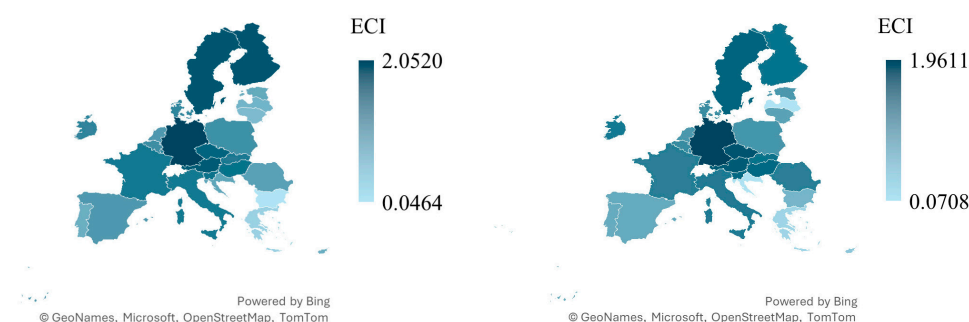


Figure 7. The level of Economic Complexity Index in 2007 (**left**) and 2020 (**right**) across EU member states.

Figure 8 maps the level of educational attainment across EU member states. The highest level in 2007 was specific to Belgium, at 159.5, compared to the second place, 119.48, held by the Netherlands (followed by Denmark, Spain, Ireland, and Finland, all with educational attainment higher than 110). In 2020, the discrepancies in the EducAtt score level significantly reduced for the top countries: Belgium remained first (with 151.57), followed by Sweden, Finland, Ireland, and Denmark (all with values above 130). At the end of the ranking related to education, we find values of 87 to 92, and the Slovak Republic, Bulgaria and Romania register them.

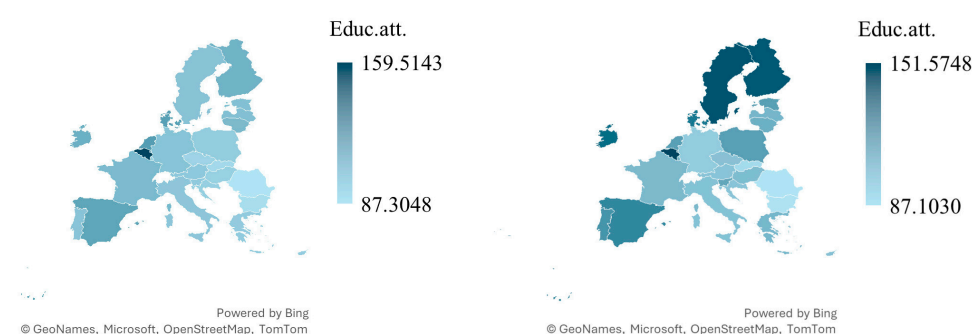


Figure 8. The level of educational attainment in 2007 (**left**) and 2020 (**right**) across EU member states.

For the gender parity index (GPI), Belgium has also been at the top of the EU ranking for both years. GPI is illustrated in Figure 9, and we observe similar minimum and maximum levels in 2007 and 2020. By 2020, Western countries are led by Belgium and Ireland; Northern countries by Sweden and Finland; CEE by Croatia; Southern countries by Spain; and Baltic countries by Estonia. Greece and Bulgaria are in last place in the gender parity ranking. It is interesting to observe that in some of the Western countries, girls are more disadvantaged than boys in learning opportunities. Germany had the lowest GPI score in the UE in 2020 (0.97), and Austria is close by (≈ 0.986).

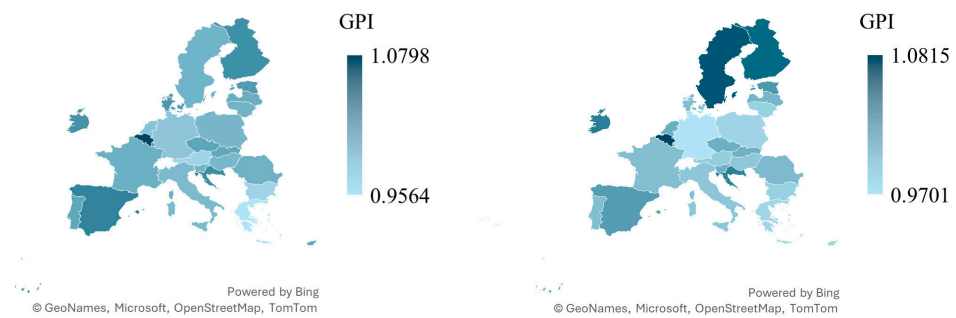


Figure 9. The level of the Gender Parity Index in 2007 (left) and 2020 (right) across EU member states.

Figure 10 maps the index of the Sustainable Development Goals. The northern countries scored the highest SDG index in 2007 and 2020, followed by Austria and Germany. Cyprus, Bulgaria, and Romania ranked bottom in both years.

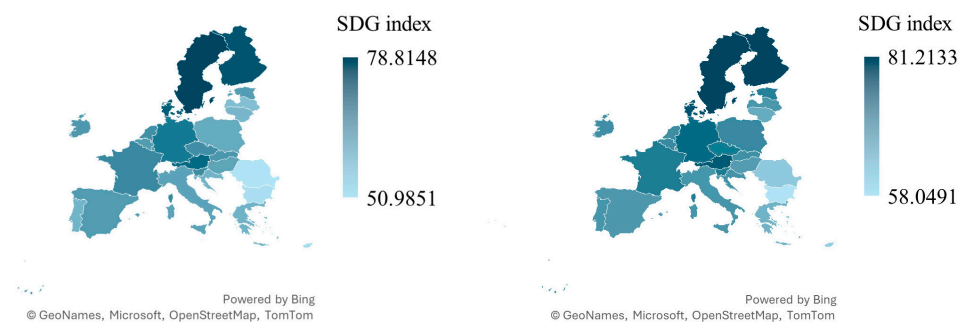


Figure 10. The level of SDG index in 2007 (left) and 2020 (right) across EU member states.

The map charts in Figures 2–10 are important for comparing values and categories across geographical regions within the EU, describing a ranking for every indicator analysed. Besides offering a geographic perspective, it helps identify significant discrepancies between the EU member states.

The panel data refers to one dependent variable and an independent variable, and in the second stage of the analysis, control variables are also included. After testing the non-linear relationship between the Human Development Index (HDI) and the ratio of EU funds paid to the country's GDP (EU funds), the model was set to a single threshold. The general equations are presented below, developed from the single model to models that also comprise one, two, or up to four control variables:

$$\begin{aligned}
 HDI_{it} &= \begin{cases} \mu_i + \beta_1 EUfunds_{it} + \varepsilon_{it}, & \text{if } EUfunds_{it} \leq \gamma \\ \mu_i + \beta_2 EUfunds_{it} + \varepsilon_{it}, & \text{if } EUfunds_{it} > \gamma \end{cases} \\
 HDI_{it} &= \begin{cases} \mu_i + \beta_1 EUfunds_{it} + \alpha_1 x_{1it} + \varepsilon_{it}, & \text{if } EUfunds_{it} \leq \gamma \\ \mu_i + \beta_2 EUfunds_{it} + \alpha_1 x_{1it} + \varepsilon_{it}, & \text{if } EUfunds_{it} > \gamma \end{cases} \\
 &\{HDI_{it}, EUfunds_{it}, x_{1it}: 1 \leq i \leq n, 1 \leq t \leq T, \} \\
 HDI_{it} &= \begin{cases} \mu_i + \beta_1 EUfunds_{it} + \alpha_1 x_{1it} + \dots + \alpha_4 x_{4it} + \varepsilon_{it}, & \text{if } EUfunds_{it} \leq \gamma \\ \mu_i + \beta_2 EUfunds_{it} + \alpha_1 x_{1it} + \dots + \alpha_4 x_{4it} + \varepsilon_{it}, & \text{if } EUfunds_{it} > \gamma \end{cases} \\
 &\{HDI_{it}, EUfunds_{it}, x_{1it}, x_{2it}, x_{3it}, x_{4it}: 1 \leq i \leq n, 1 \leq t \leq T, \}
 \end{aligned}$$

where μ_i represents the heterogeneity of countries involving the fixed effects; HDI_{it} is the dependent variable, the proxy of human development setup by the United Nations; $EUfunds_{it}$ represents the EU funds-to-GDP ratio, and it will be considered the threshold variable; β_1 and β_2 represent the threshold coefficients estimated for various threshold

values, while γ is the estimated value of the threshold, serving as a base of comparison for changes in the ratio of the annual payments made by the Commission from the EU budget to the EU Member States' GDP. The control variables (GINI, ESI, EconFreed, ECI, EducAtt, GPI, and SDG) are reflected by $x_{1it}, x_{2it}, x_{3it}, x_{4it}$ while $\alpha_{...}$ represent the estimated coefficients of the control variable(s). ε_{it} is the error term, and i refers to the country ($i = 1 \dots 27$, based on the complete list of EU member states), while t refers to the year based on the period analysed, from 2007 until 2020.

The threshold model reveals the influence of the independent variable (in this study, $EUfunds_{it}$). When it exceeds the threshold value (γ), the dependent variable, i.e., HDI_{it} , changes with β_2 units, while the $EUfunds$ variable changes by one unit.

The advanced single threshold model can be rewritten as follows:

$$HDI_{it} = \mu_1 + \beta_1 EUfunds_{it} (EUfunds_{it} \leq \gamma) + \beta_2 EUfunds_{it} (EUfunds_{it} > \gamma) + \varepsilon_{it}$$

Or with control variables:

$$HDI_{it} = \mu_1 + \beta_1 EUfunds_{it} (EUfunds_{it} \leq \gamma) + \beta_2 EUfunds_{it} (EUfunds_{it} > \gamma) + \alpha_1 x_{1it} + \dots + \alpha_4 x_{4it} + \varepsilon_{it}$$

The threshold does not represent an "optimal" level of funding, but a marginal-effect turning point, indicating where the impact of additional EU funds on HDI changes in magnitude or direction.

We limit the results presented in our study to single-threshold models because our database yielded statistically significant results only for these models, primarily for simple models or those with a single control variable. This choice ensures statistical reliability and avoids overfitting more complex threshold structures not supported by the data.

4. Results

Since our database includes more countries (27 cross-sections referring to EU countries) than years (14 years from the period overviewed, 2007–2020), the stationarity of the variables may not be a critical concern for our analysis [49,50]. In addition, we expect our variables to exhibit non-linear relationships and will emphasise the turning points through the threshold values identified.

Table 3 presents the descriptive statistics for the overall database. For the EU-27 member states, we observe that the average HDI score rate is 0.88, varying from 0.77 to 0.95. On average, EU funds paid are 1.5%, ranging from 0 to 11.4%. The income, wealth, or consumption inequality, evaluated using the GINI index, is, on average, 31.35 but varies between 23.1 and 41.3. The economic sentiment has a mean of 98 but shows significant variation across EU member states, ranging from approximately 70 to 119, emphasising differences across business sectors within the EU. The index of economic freedom, used to evaluate the global impacts of liberty and free markets, has a mean of 68.8, ranging from 53.2 to 82.6. The index for economic complexity has an average of 1.09, but it can reach 2.3. Educational attainment indicates an average of 108.8% (87–163.9%), and for gender parity, the ratio is, on average, 1, varying from 0.93 to approximately 1.1. The SDG index scores average 66.65, ranging from 50.98 to 81.21.

Table 3. Descriptive statistics.

Variables	Obs	Mean	Std. Dev.	Min	Max
HDI	378	0.8804	0.0395	0.774	0.948
EUfunds	378	0.0153	0.0214	0	0.1143
GINI	378	31.3539	3.6719	23.2	41.3
ESI	378	98.3116	9.233	69.967	119.0833
Econ.freed.	378	68.8355	5.8571	53.2	82.6
ECI	378	1.0942	0.5428	0.0065	2.3074

Educ.att.	378	108.8036	16.0173	87.103	163.9347
GPI	378	1.0023	0.0275	0.9352	1.0983
SDG	378	66.6517	6.6007	50.9851	81.2133

Based on the SDG index score extracted from the European Sustainable Development Report, we divided our sample into sub-samples to overview the relationship between EU funds disbursed and HDI and to emphasise differences in the breaking point across regions within the EU. The SDG score measures progress towards achieving all 17 Sustainable Development Goals. The countries included in every sub-sample are presented in Table 4.

Table 4. EU countries classified based on the status of their SDG targets.

Western Europe (7 Countries)	Northern Europe (3 Countries)	Southern Europe (6 Countries)	Central and Eastern Europe—CEE (8 Countries)	Baltic Countries (3 Countries)
Austria	Denmark	Cyprus	Bulgaria	Estonia
Belgium	Finland	Greece	Croatia	Latvia
France	Sweden	Italy	Czech Republic	Lithuania
Germany		Malta	Hungary	
Ireland		Portugal	Poland	
Luxembourg		Spain	Romania	
Netherlands			Slovak Republic	
			Slovenia	

Figure 11 presents graphs showing the relationship between HDI and EU funds disbursed across the EU's regions. Lower EU funding levels, up to approximately 0.055 (5.5%), are expected to directly influence HDI. However, when EU funds paid cross this level, they negatively influence HDI.

After observing the non-linear relationships evidenced by the graphs, considering that the average EU funds paid are at 1.5% of GDP, we expect that, for most EU member states, the funds allocated by the European Commission support the human development expressed through HDI.

Table 5 presents the panel threshold regression between EU funds and HDI in the 27 EU member states. Results initially indicated a non-linear relationship, an effect attributed to the single-threshold model at the 1% significance level. Up to the threshold level, the relationship between EU funds and HDI is expected to be positive, and above the threshold should be negative. The threshold was found at 0.007138 ($\approx 0.71\%$) for the simple model, with a larger coefficient associated with the lagged new business rate before the threshold (1.44 compared to -0.45 above the threshold). Accordingly, for the EU-27 countries, it is expected for EU funding to support the increase in human development, but for countries that use money from the European Union Commission budget up to 0.7% of GDP. Also, the human development index is related to its previous levels, considering the regression coefficient of 1.44 for the lagged dependent variable. However, when countries utilise EU funds beyond 0.71% of GDP, it is expected that previous HDI levels will slightly discourage the current HDI (regression coefficient of -0.45 for the lagged dependent variable).

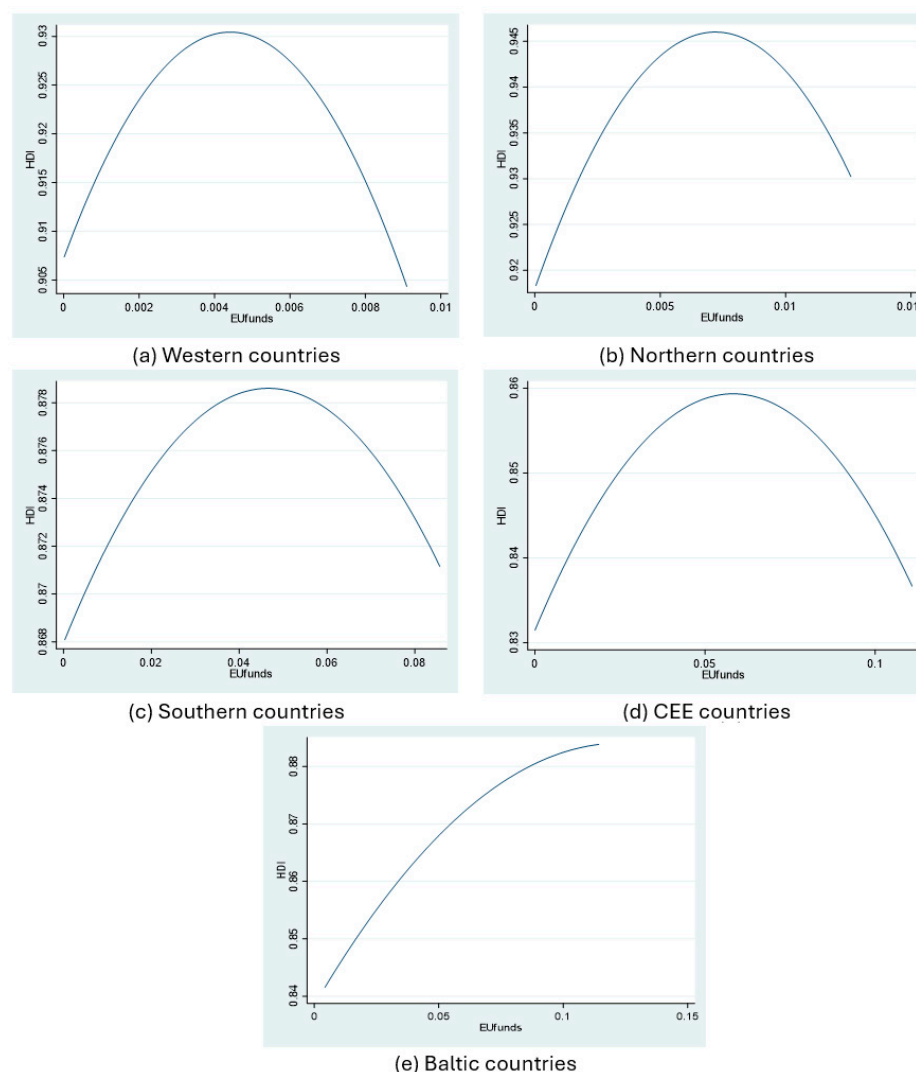


Figure 11. The relationship between EU funds and HDI for sub-samples of EU member states (over the period 2007–2020).

For the models including control variables, the threshold increases to $2\div 2.3\%$ for EU funds, above the mean value recorded in the EU-27 database over the 2007–2020 period (i.e., 0.0153, according to descriptive statistics). This indicates that under the influence of economic sentiment, the SDG index, and education, EU funds become even more important in supporting human development. EU funds exceeding the EU's mean value are expected only for CEE and Baltic countries. Generally, we expect EU funds to have a positive influence on HDI. The interplay between EU funds and HDI is shaped by various contextual factors that help explain the non-linear patterns observed. Income inequality, as captured by the GINI index, influences HDI differently above and below the threshold. Economic sentiment (ESI) consistently supports human development, while economic freedom (EconFreed) fosters progress, particularly up to the identified threshold. Human capital and gender equality, represented by educational attainment (EducAtt) and the Gender Parity Index (GPI), are key to translating EU funds into effective developmental outcomes. Finally, progress on sustainability and regional development, as reflected in the SDG index, contributes positively to HDI, especially in less developed regions. Considering these relationships allows for a nuanced interpretation of the threshold and non-linear effects of EU funds on human development across EU member states.

Table 5. Panel threshold regression results for the effects between EU funds and HDI within the EU-27 member states.

	Threshold Value	Coefficient	Z	p-Value
Threshold variable: EUfunds				
Single threshold effect test	0.00714 ***		3.16	0.000
No. of moment conditions	90			
Lag_HDI_b		1.44396 ***	24.08	0.000
Lag_HDI_d		−0.45248 ***	−5.91	0.000
cons_d		0.3686 ***	5.62	0.000
Threshold variable: EUfunds; Control variable: GINI				
Single threshold effect test	0.01197 **		2.20	0.028
No. of moment conditions	102			
Lag_HDI_b		0.949 ***	13.80	0.000
GINI_b		0.0055 ***	8.14	0.000
Lag_HDI_d		−0.2517 ***	−3.64	0.000
GINI_d		−0.0084 ***	−8.27	0.000
cons_d		0.4845 ***	6.30	0.000
Threshold variable: EUfunds; Control variable: ESI				
Single threshold effect test	0.02234 ***		7.71	0.000
No. of moment conditions	102			
Lag_HDI_b		0.6054 ***	24.82	0.000
ESI_b		0.00021 ***	8.07	0.000
Lag_HDI_d		0.4253 ***	10.87	0.000
ESI_d		0.00059 ***	5.31	0.000
cons_d		−0.41578	−9.74	0.000
Threshold variable: EUfunds; Control variable: EconFreed				
Single threshold effect test	0.00634 **		2.03	0.042
No. of moment conditions	102			
Lag_HDI_b		1.1976 ***	17.24	0.000
EconFreed_b		0.00365 ***	6.27	0.000
Lag_HDI_d		0.0492	10.87	0.541
EconFreed_d		−0.00506	−9.68	0.000
cons_d		0.2779	3.45	0.001
Threshold variable: EUfunds; Control variable: SDG				
Single threshold effect test	0.02311 ***		12.45	0.000
No. of moment conditions	102			
Lag_HDI_b		0.74 ***	9.27	0.000
SDG_b		0.0009 **	2.13	0.034
Lag_HDI_d		−1.3299	−18.67	0.000
SDG_d		0.0048 ***	15.33	0.000
cons_d		0.83134	12.00	0.000
Threshold variable: EUfunds; Control variable: ECI				
Single threshold effect test	0.0195 ***		5.85	0.000
No. of moment conditions	102			
Lag_HDI_b		0.5766 ***	16.84	0.000
ECI_b		−0.0002	−0.18	0.853
Lag_HDI_d		−0.18605 **	−2.44	0.015
ECI_d		0.0171	7.53	0.000
cons_d		0.1739	2.62	0.009
Threshold variable: EUfunds; Control variable: EducAtt				

Single threshold effect test	0.02002 ***	5.91	0.000
No. of moment conditions	102		
Lag_HDI_b	0.2288 ***	3.76	0.000
EducAtt_b	0.00077 ***	8.25	0.000
Lag_HDI_d	0.15502 ***	3.26	0.000
EducAtt_d	−0.0022 ***	−9.86	0.000
cons_d	0.13006	3.39	0.001
Threshold variable: EUfunds; Control variable: GPI			
Single threshold effect test	0.00302	1.14	0.254
No. of moment conditions	102		
Lag_HDI_b	1.3287 ***	14.89	0.000
GPI_b	0.4387 ***	5.20	0.000
Lag_HDI_d	−0.1047 ***	−0.82	0.413
GPI_d	−1.3388 ***	−12.63	0.000
cons_d	0.13006	9.48	0.000
Threshold variable: EUfunds; Control variables: GINI, ESI			
Single threshold effect test	0.0072	0.50	0.620
No. of moment conditions	114		
Lag_HDI_b	0.85181 ***	15.44	0.000
GINI_b	−0.0028 ***	−3.31	0.001
ESI_b	0.000064	0.36	0.719
Lag_HDI_d	−0.11468	−1.31	0.190
GINI_d	0.00352 ***	2.98	0.003
ESI_d	0.00046 ***	3.29	0.001
cons_d	−0.06066	−0.59	0.553
Threshold variable: EUfunds; Control variables: ESI, EconFreed			
Single threshold effect test	0.01065 *	1.70	0.089
No. of moment conditions	114		
Lag_HDI_b	0.7226 ***	7.94	0.000
ESI_b	−0.00012	−1.07	0.283
EconFreed_b	0.00155 ***	3.91	0.000
Lag_HDI_d	0.00283	0.03	0.976
ESI_d	0.00081 ***	4.96	0.000
EconFreed_d	−0.002 ***	−3.89	0.000
cons_d	0.054695	0.58	0.559
Threshold variable: EUfunds; Control variables: ESI, EconFreed, SDG			
Single threshold effect test	0.00204	0.34	0.733
No. of moment conditions	126		
Lag_HDI_b	−0.7903 ***	−2.64	0.008
ESI_b	−0.00009	−0.82	0.414
EconFreed_b	0.00106	1.21	0.227
SDG_b	0.00639 ***	4.09	0.000
Lag_HDI_d	0.7253 **	2.07	0.039
ESI_d	0.00045 ***	3.70	0.000
EconFreed_d	−0.0013	−1.40	0.162
SDG_d	−0.0049 ***	−2.51	0.012
cons_d	−0.22213	−1.10	0.270
Threshold variable: EUfunds; Control variables: ESI, ECI, EconFreed, SDG			
Single threshold effect test	0.01799	1.41	0.157
No. of moment conditions	126		
Lag_HDI_b	−0.197	−0.77	0.441

ESI_b	0.000016	0.12	0.906
ECI_b	0.00238	0.98	0.328
EconFreed_b	0.000675 *	1.80	0.072
SDG_b	0.00406 **	2.12	0.034
Lag_HDI_d	0.03167	0.25	0.801
ESI_d	0.00061 ***	4.05	0.000
ECI_d	−0.009085	−0.85	0.396
EconFreed_d	−0.0009 ***	−2.58	0.010
SDG_d	−0.001262	−1.13	0.258
cons_d	0.07286	0.68	0.499

*, **, ***—significance at the 10%, 5% and 1% levels, respectively.

The GINI index, which measures the income or wealth distribution across a population, is an important indicator of HDI, positively influencing HDI up to the threshold level of EU funds paid and negatively beyond it. The GINI coefficient measures income inequality in a population, ranging from 0, which indicates perfect equality (all individuals have the same income), to 1, indicating perfect inequality (an individual would have all income and the rest no income). Therefore, a non-linear relationship is justifiable, understanding the negative influence of GINI towards HDI up to the threshold and the positive above it. Trying to reason these influences, we note that the relationships expected when the threshold is crossed are specific to greater EU funding, primarily applicable in CEE and Baltic countries, where HDI is lower than in other EU member states and income inequality is higher.

EU funding might support human development in various sectors, contributing to social, economic, and environmental progress. EU funding supports infrastructure projects that create jobs and improve living standards, particularly in less developed regions. These projects funded by the European Commission range from building roads, bridges, and public transport to improving digital infrastructure. There is also support for the business environment. Through the European Regional Development Fund (ERDF), financial assistance is provided to small and medium-sized enterprises (SMEs), fostering innovation, helping create new businesses and industries, boosting employment, and enhancing competitiveness. Accordingly, we expect the economic complexity index (ECI), integrating the productive capabilities of large economic systems, to support human development. Still, its influence was not found to be statistically significant under the threshold model.

The economic sentiment indicator (ESI), a composite index that evaluates the confidence levels of manufacturers, service providers, consumers, retailers, and constructors, also appears to be an important indicator of human development. Among the control variables employed, it has a statistically significant positive impact on HDI, regardless of the level of EU funds paid, with a positive coefficient before and after the threshold highlighted.

The Economic Freedom Index (EconFreed) is also statistically significant under the threshold models. It promotes the fundamental right of every human to control his or her labour and property, considering the impact of liberty and free markets around the globe under various social and economic goals. This index confirms a positive relationship between economic freedom and progress, directly influencing HDI up to the threshold and negatively beyond it.

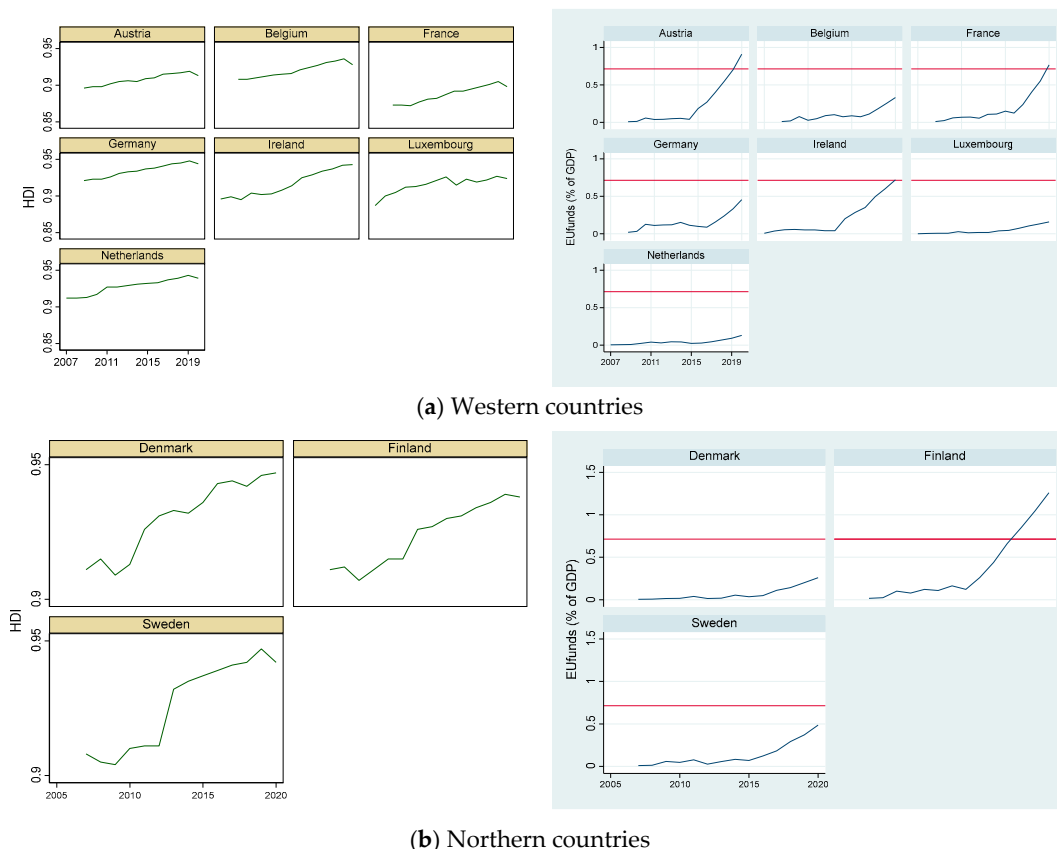
The European Union Commission invests in education, vocational training, and life-long learning through programs such as Erasmus+ and the European Social Fund (ESF). This helps improve skills, reduce unemployment, and ensure that people can adapt to a changing labour market. EU funding supports initiatives that reduce poverty and social

exclusion, especially in disadvantaged regions. Programs like the European Social Fund Plus (ESF+) target vulnerable groups, ensuring everyone has access to essential services and opportunities for advancement. EU funding also supports initiatives that promote human rights, gender equality, and social justice, combat discrimination, foster diversity, and ensure equal opportunities for all. These argue for the importance of educational attainment and the gender parity index in the relationship between EU funds and human development. For these two control variables (EducAtt and GPI), the influence under the threshold model was positive up to the threshold and negative beyond it.

Another key objective of EU funding is to reduce disparities between regions. Cohesion policy funds, such as the Cohesion Fund and the European Regional Development Fund (ERDF), target less developed regions, promoting balanced regional development and enhancing European social and economic cohesion. EU funding also supports efforts to combat climate change, promote renewable energy, and protect the environment. Current initiatives, such as the European Green Deal, are crucial for sustainable development and safeguarding the environment for future generations. Accordingly, the SDG index is relevant to our analysis, positively influencing HDI before and above the threshold observed.

Overall, we expect EU funding to be vital for human development as it drives economic growth, reduces inequality, promotes education and equality, supports environmental sustainability, and fosters regional development.

To expand our analysis on the potential non-linear relationship between HDI and EU funds across EU regional sub-samples, we continue by presenting the evolution of these indicators' patterns over the period 2007–2020, in the following graphs encompassed in Figure 12. With the evolution of EU funds, we also evidenced, in the graphs, the threshold value of 0.7138% of GDP, emphasised across the overall EU sample over the 14-year period analysed. This dynamic perspective complements the static maps by explicitly visualising how countries move relative to the estimated threshold over time.



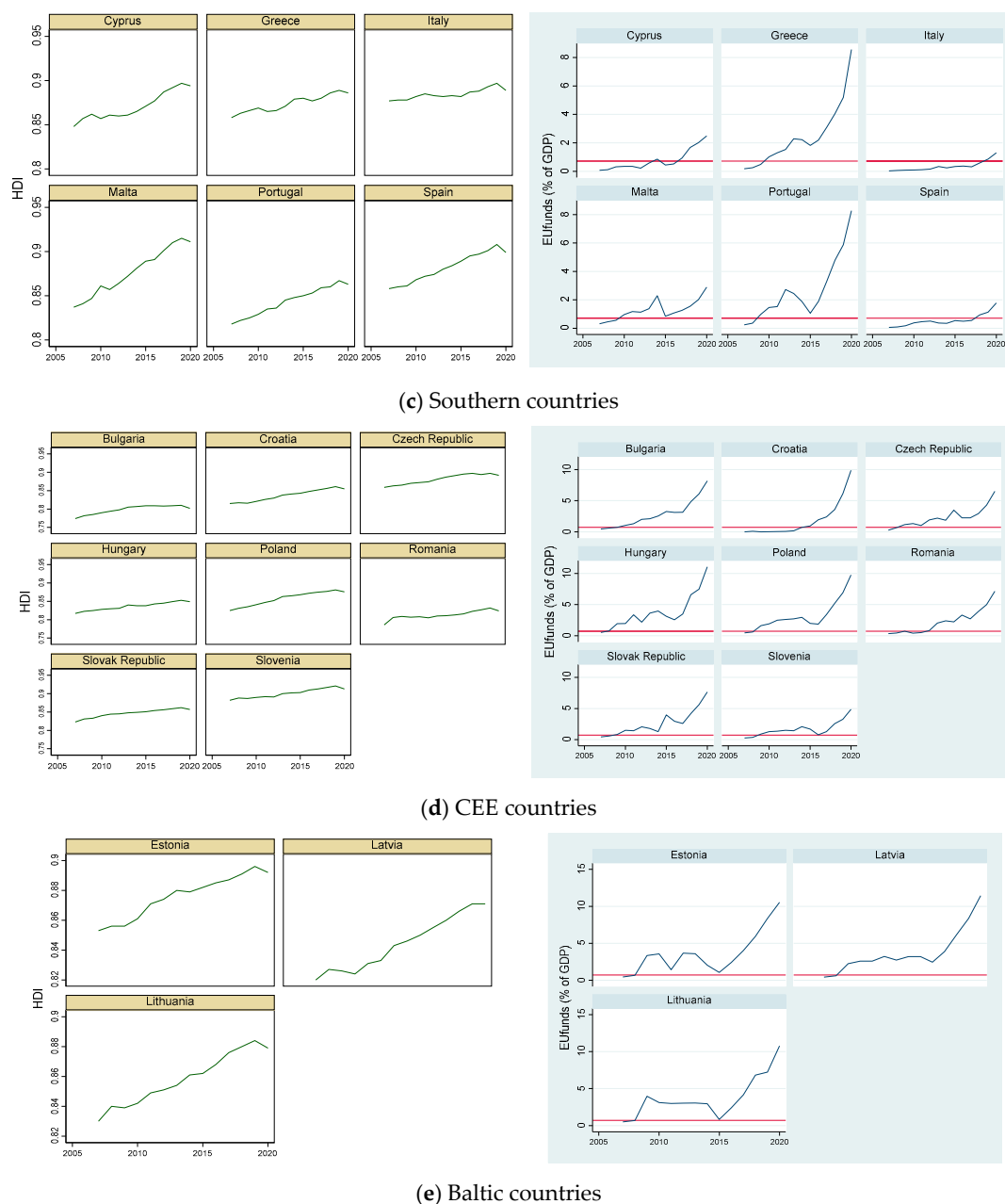


Figure 12. The evolution of HDI (left side) and EU funds as % in GDP (right side) for the sub-samples of the EU member states, over the period 2007–2020.

First, we note that welfare, health, and education are clearly improving, as evidenced by the increasing HDI across all EU countries. It is also interesting to observe from the descriptive analysis presented in the graphs that, for Western and Northern countries, the EU funds threshold (0.7138) is crossed on very few occasions and by only a few of the countries assimilated to these groups. However, for the rest of the groups (less for Southern countries but especially for Baltic and CEE countries) the level of the EU funds is, in most of the countries and throughout the period of 14 years, above the threshold of 0.71% of GDP for the EU funds. The asymmetric distribution of EU funds across regions reflects the EU's Cohesion Policy logic: countries expected to grow faster and catch up with leading EU economies receive disproportionately more support. Moreover, high GDP is associated with lower relative allocations because net contributors are paying more than they receive.

We continue our analysis by presenting in Table 6 the main results from the linear regression models applied to the five sub-samples. For these panel least-squares models, we treated HDI as the dependent variable and EU funds paid as the independent variable.

Table 6. Linear regression results for the influence of EU funds paid (EU funds) on the human development index (HDI).

	(Western Countries)	(Northern Countries)	(Southern Countries)	(CEE Countries)	(Baltic Countries)
EUfunds	2.319 ** (0.954)	2.139 *** (0.701)	0.124 (0.142)	0.254 * (0.141)	0.412 *** (0.0965)
Constant	0.912 *** (0.00223)	0.923 *** (0.00239)	0.870 *** (0.00298)	0.840 *** (0.00482)	0.844 *** (0.00450)
Observations	98	42	84	112	42
R-squared	0.058	0.189	0.009	0.029	0.313

*, **, ***—significance at the 10%, 5% and 1% levels, respectively. Standard errors in parentheses.

The regression results show that R-squared is limited for Southern, CEE, and Baltic countries. Still, in Western and Northern countries, approximately 6% and approximately 19% of the variance in the human development index might be related to changes in EU funds disbursed. According to the coefficients, the influence is positive for all sub-samples, indicating a direct influence of EU funds paid on HDI.

To test the non-linear relationship between EU funds paid and HDI, we consider the square of the funds variable and include both in the regression model. Therefore, the new regression model has two independent variables, EUfunds and the squared variable (EUfundssq), and the dependent variable remains the human development index (HDI). Results are presented in Table 7.

Table 7. Non-linear regression results for the influence of EU funds paid (EUfunds) on human development index (HDI).

	(Western Countries)	(Northern Countries)	(Southern Countries)	(CEE Countries)	(Baltic Countries)
EUfunds	10.51 *** (2.806)	7.784 *** (2.047)	0.457 (0.375)	0.957 ** (0.398)	0.741 ** (0.337)
EUfundssq	−1190 *** (385.4)	−540.7 *** (186.1)	−4.893 (5.110)	−8.207 * (4.360)	−3.005 (2.945)
Constant	0.907 *** (0.00272)	0.918 *** (0.00271)	0.868 *** (0.00383)	0.831 *** (0.00652)	0.838 *** (0.00721)
Observations	98	42	84	112	42
R-squared	0.144	0.333	0.020	0.059	0.331

*, **, ***—significance at the 10%, 5% and 1% levels, respectively. Standard errors in parentheses.

Except for the sub-sample of Southern and Baltic countries, the rest show a non-linear relationship between EU funds paid and HDI. Up to a certain level of EU funds paid by the European Commission in Western, Northern and CEE countries, they directly influence HDI. However, after this level is crossed, the influence of EU funding on HDI becomes indirect. Given the high regression coefficients for the squared EU funds variable, we expect a general direct relationship: the higher the EU funds allocated, the larger the human index will be.

We mention that for the Baltic countries, the statistically significant coefficient is associated only with EU funds. Therefore, a statistically significant coefficient of EUfunds does not confirm the non-linear effect. In Southern countries, the regression model's

relevance was not confirmed by the R-squared or by the statistical significance of the EU funds coefficients.

To address potential endogeneity and model sensitivity, we performed several robustness checks. These refer to (i) the inclusion of year fixed effects, (ii) the use of lagged EU funds to mitigate simultaneity concerns, (iii) the use of instrumental variables through a Generalised method of moments (GMM) model.

We start our robustness analysis by estimating two-way fixed-effects models to identify the impact of EU funds on HDI across regions (time FE in Table 8). The model controls for time-invariant country characteristics, as the year fixed effects absorb common shocks and programming cycles that drive synchronised funding across Europe. The lagged funding (L.EUfunds) accounts for both implementation delays and simultaneity concerns, as current HDI cannot influence the allocations and funding decisions from the previous year, mitigating reverse causality. The quadratic term (EUfundssq) confirms non-linear effects and high HDI persistence, as all models use clustered standard errors at the country level. Moreover, the GMM models with results presented in Table 8 include the linear and quadratic variables of EU funds and the first lag of HDI, but they could not be applied to regions with only three countries (i.e., the Northern and Baltic samples).

Table 8. Dynamic model results for the influence of EU funds paid (EUfunds) on human development index (HDI) and robustness checks.

	Time FE	GMM	Time FE	Time FE	GMM	Time FE	GMM	Time FE
	(Western Countries)		(Northern Countries)	(Southern Countries)		(CEE Countries)		(Baltic Countries)
EUfunds	3.207 *	1.411	−0.910	−0.313	0.973 **	0.00958	0.231	−0.193
	(1.633)	(2.096)	(2.139)	(0.373)	(0.485)	(0.110)	(0.171)	(0.189)
EUfundssq	−390.3 **	−457.5 **	94.59	0.155	−14.80 **	0.630	−2.363 **	3.969 *
	(151.7)	(211.8)	(138.0)	(3.036)	(6.211)	(0.896)	(1.170)	(2.256)
L.EUfunds	1.830		−1.173	0.303		−0.0652		0.109
	(1.974)		(3.439)	(0.310)		(0.0883)		(0.108)
2009.year	−0.000774		−0.00359	0.00345		0.00176		−6.64 × 10 ^{−5}
	(0.00224)		(0.00340)	(0.00441)		(0.00219)		(0.00413)
2010.year	0.00362		0.00150	0.00816 *		0.00601 ***		−0.000619
	(0.00231)		(0.00352)	(0.00457)		(0.00226)		(0.00500)
2011.year	0.00678 ***		0.00762 **	0.00918 *		0.00929 ***		0.00755
	(0.00227)		(0.00344)	(0.00469)		(0.00233)		(0.00447)
2012.year	0.00788 ***		0.00942 **	0.0109 **		0.0110 ***		0.0105 **
	(0.00231)		(0.00380)	(0.00485)		(0.00245)		(0.00469)
2013.year	0.0100 ***		0.0206 ***	0.0154 ***		0.0184 ***		0.0159 ***
	(0.00231)		(0.00344)	(0.00512)		(0.00259)		(0.00510)
2014.year	0.0143 ***		0.0221 ***	0.0199 ***		0.0205 ***		0.0192 ***
	(0.00240)		(0.00368)	(0.00529)		(0.00275)		(0.00474)
2015.year	0.0142 ***		0.0253 ***	0.0218 ***		0.0224 ***		0.0218 ***
	(0.00241)		(0.00368)	(0.00524)		(0.00292)		(0.00386)
2016.year	0.0170 ***		0.0294 ***	0.0271 ***		0.0267 ***		0.0282 ***
	(0.00257)		(0.00401)	(0.00494)		(0.00300)		(0.00382)
2017.year	0.0179 ***		0.0325 ***	0.0332 ***		0.0292 ***		0.0315 ***
	(0.00273)		(0.00460)	(0.00541)		(0.00300)		(0.00519)
2018.year	0.0182 ***		0.0341 ***	0.0388 ***		0.0308 ***		0.0294 ***
	(0.00303)		(0.00538)	(0.00616)		(0.00354)		(0.00763)
2019.year	0.0204 ***		0.0390 ***	0.0436 ***		0.0345 ***		0.0252 **
	(0.00330)		(0.00595)	(0.00678)		(0.00432)		(0.0109)
2020.year	0.0158 ***		0.0379 ***	0.0408 ***		0.0267 ***		0.00421

	(0.00335)		(0.00610)	(0.00712)		(0.00521)		(0.0179)
L.hdi		1.089 *** (0.247)			0.833*** (0.257)		0.786 *** (0.0870)	
Constant	0.901 *** (0.00157)	−0.0782 (0.223)	0.911 *** (0.00235)	0.854 *** (0.00316)	0.141 (0.220)	0.830 *** (0.00161)	0.180 ** (0.0703)	0.842 *** (0.00228)
dummy.year (F)	9.13 ***		13.03 ***	7.15 ***		13.96 ***		29.93 ***
Observations	91	84	39	78	72	104	96	39
R-squared	0.878		0.949	0.812		0.896		0.974

*, **, ***—significance at the 10%, 5% and 1% levels, respectively. Standard errors in parentheses.

From 2011, the year dummies are statistically significant across all regions, validating the time fixed effects, and suggesting that time trends absorb the funding cycles in terms of insignificant EU funds. More specifically, the year fixed effects flexibly control for aggregate shocks such as the recovery from the global crisis, or EU programming periods, correlated with the funding granted. Results from the time fixed effects models also evidence a quadratic term gaining significance, bringing further evidence of robust non-linearity, especially with year dummies tracing post-crisis HDI recovery (in 2009–2013) and programming peaks (related to the cohesion policy framework established for seven-year periods). Based on these results, the inverted U relationship between EU funds and HDI persists, validating absorption capacity theory in cohesion policy. Furthermore, the dynamic models (GMM) confirm the statistical significance of the squared EU funds and also the relevance of the HDI level in the prior year.

The causal relationship between EU funds and HDI could be limited by a few endogeneity sources: the EU allocation formula systematically assigns more funds to low-HDI regions, spatial spillovers from neighbouring countries' funds might inflate direct effects, while unobserved time-varying shocks related to reforms might confuse fund attribution. Although time-fixed effects and GMM can substantially mitigate these biases, residual bias remains. Results should be interpreted in the context of conditional associations revealing nonlinear patterns, but they are also limited to 14 years, a rather limited long-run dynamic if we consider the full EU programming cycle effects of 7 years.

Based on the empirical results presented above, the three research hypotheses are evaluated as follows. Hypothesis 1 is validated, as both the linear regressions (Table 6) and the panel threshold models (Table 5) indicate a generally positive and statistically significant relationship between EU funds paid and human development (HDI), particularly below the estimated threshold and across most EU regional sub-samples. Hypothesis 2 is also validated, since the panel threshold regressions reveal a statistically significant single threshold in the EU funds–HDI relationship. Below this threshold, EU funds have a positive effect on HDI, whereas above it the marginal impact weakens or becomes negative across several specifications. This non-linear pattern is further supported by the quadratic regressions reported in Table 7 and Table 8. Hypothesis 3 is partially validated, as several control variables—most notably the GINI Index, Economic Sentiment Indicator (ESI), Index of Economic Freedom, Educational Attainment, Gender Parity Index, and SDG Index—exhibit statistically significant effects on HDI within the threshold

5. Conclusions

Our study used a panel threshold regression model to analyse the relationship between European Structural and Investment (ESI) Funds and socio-economic development in EU member states between 2007 and 2020. In our empirical investigation, we employed the Human Development Index (HDI) as the dependent variable—a comprehensive metric encompassing three fundamental dimensions of human development: longevity and health, access to education, and a decent standard of living. The threshold variable was

represented by the proportion of EU funds paid annually by the European Commission to the Member States. By examining this percentage relative to each country's GDP, the study facilitated a more robust cross-country comparison, thereby elucidating the relative significance of the funds within the context of each state's economic size [35].

The inclusion of control variables such as the GINI coefficient, Economic Sentiment Indicator (ESI), Economic Freedom Index, Economic Complexity Index (ECI), Secondary School Gross Enrollment Rates, Gender Parity Index (GPI), and Sustainable Development Goals (SDG) Index enhances the analysis by accounting for socio-economic and institutional factors that influence the relationship between ESI Funds and socio-economic development outcomes. Threshold analysis indicates that ESI funds positively impact socio-economic development, as measured by the HDI, up to a threshold of 0.7% of GDP. Beyond this threshold, the relationship reverses, suggesting that effective fund management is crucial to prevent over-financing and to preserve the efficacy of developmental interventions. Consequently, allocating these funds requires a meticulous, balanced approach, particularly in developing regions that depend on them to mitigate economic disparities and enhance social welfare.

In line with Cerqua and Pellegrini's [12] findings, one potential solution would be to reallocate funds to other regions without influencing the results achieved by the supported areas. This highlights the need to streamline administrative capacity and to monitor projects rigorously to maximise the benefits from the allocation and use of funds. The responsible use of these financial resources is an inevitable condition for ensuring long-term socio-economic development.

When controlling for all relevant variables, the ESI threshold increases to 2% and 2.3% of GDP, surpassing the average expenditure of 1.53%, as evidenced by descriptive statistics for EU-27 governments from 2007 to 2020. This suggests that ESI funds become even more significant in fostering socio-economic development in the presence of these control variables.

The relationship between the GINI coefficient and HDI is non-linear: initially, reducing inequality promotes socio-economic development, but beyond a certain threshold, the effect reverses and becomes detrimental. Similarly, economic freedom facilitates social and economic progress, yet excessive deregulation can exacerbate inequality and undermine human development. Moreover, both the Gender Parity Index and educational attainment positively influence HDI, though their impact diminishes beyond a certain level.

Conversely, while the Economic Complexity Index (ECI) is a key determinant of socio-economic development, its influence was not statistically significant in our model. In contrast, the Economic Sentiment Indicator (ESI) and the SDG Index positively affect HDI, irrespective of the level of ESI funds received.

Our findings suggest that strategies for absorbing ESI funds must be finely tuned, particularly in less developed regions. A more flexible approach, incorporating periodic assessments and interim evaluations of fund effectiveness, could facilitate policy adjustments in response to evolving needs. Enhancing administrative capacities and redistributing funds to regions with higher absorption potential could also maximise their positive impact.

Furthermore, based on our results, we provide practical recommendations for all participants in ESI Funds activities: EU Fund management should enhance monitoring and adaptive allocation strategies; European institutions should promote efficient distribution and synergies between programs; EU member state authorities should align national strategies to complement EU funding; businesses and civil society should actively engage in funded projects to maximize socio-economic benefits; and all stakeholders should prioritize transparency, accountability, and equitable fund use to foster sustainable development across the EU.

This research underscores the ongoing necessity for reform of ESI funds, with a stronger focus on flexibility in fund allocation, development of administrative capabilities, and rigorous monitoring of project implementation. These measures are crucial to improving the efficiency of fund utilisation and maximising their contribution to the long-term socio-economic and sustainable development of the European Union.

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Appendix A

Table A1. Advantages and Disadvantages of European Structural and Investment (ESI) Funds.

Aspect	Advantages	Disadvantages/Challenges
Economic Convergence	Promote reducing disparities between richer and poorer regions; support less developed areas in catching up with the EU average GDP and HDI.	Convergence may be slow; regions with low administrative capacity may not fully benefit.
Social Cohesion	Enhance social inclusion by funding education, healthcare, employment, and support for vulnerable groups.	Uneven fund absorption can lead to social imbalances if some regions underutilize resources.
Infrastructure & Innovation	Support the development of transport, digital, and energy infrastructure; foster innovation and competitiveness.	The complexity of projects can cause delays or inefficiencies and the risk of misallocation of funds.
Resilience & Stability	Improve economic resilience by diversifying investments and supporting recovery during crises (e.g., post-COVID-19, economic shocks).	Dependency on EU funding may reduce incentives for domestic policy reforms; excessive reliance could pose risks if funding fluctuates.
Institutional Development	Encourage institutional strengthening, governance reforms, and capacity building at the regional and national levels.	Institutional inefficiencies or bureaucratic hurdles can limit the effectiveness of fund implementation.

Environmental & Sustainable Development projects; contribute to achieving SDGs.	Fund green transition, renewable energy, and climate adaptation projects; contribute to achieving SDGs.	The complexity of integrating sustainability requirements may slow down project approval and implementation.
	Allows tailoring of funding strategies to regional priorities; supports evidence-based policy-making.	Requires careful coordination across multiple governance levels; misalignment of priorities may occur.

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