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Investigating the Association between Education and Climate Change: A Country-Level Study

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Abstract

Education is widely expected to be inversely related to climate change: better-educated societies should, through awareness, values, and technical capacity, degrade the environment less. Yet education is also tightly bound to income, which independently raises consumption and per-capita emissions, so the relationship need not appear directly in carbon. Using a country-year panel of 97 countries observed over 2013-2020 (402 observations) from the World Development Indicators, we relate six education measures—attainment at the master's and bachelor's levels, tertiary enrollment, advanced-education labor, government education spending, and scientific output—to five climate-change and environmental indicators (per-capita CO_2, PM2.5 air pollution, forest depletion, the coal share of electricity, and the renewable-energy share), controlling for income, population, and unemployment. In pooled country-year regressions, the expected inverse relationship appears on specific margins: government education spending, master's attainment, and advanced-education labor are associated with a greater renewable share, and tertiary enrollment and advanced-education labor with lower particulate pollution; only the spending-renewables association remains significant after adjustment for multiple testing. The relationship is concentrated between countries rather than within them, as a within-between hybrid model shows, which we attribute to the slow-moving, stock-like nature of educational attainment over a short panel. A mediation analysis indicates that about half of the association between education spending and per-capita CO_2 runs through the renewable-energy share: higher spending accompanies a higher renewable share, which accompanies lower per-capita CO_2, yielding a statistically significant indirect association, while the direct association is of similar size but not statistically significant. Because the three variables are measured in the same year, this is an indirect association consistent with the proposed channel rather than evi-

dence of a causal sequence. We interpret the pattern through human-capital and ecological-modernization perspectives and the environmental Kuznets curve tradition.

Keywords

Education, Human Capital, Climate Change, CO_2 Emissions, Renewable Energy, Mediation, Indirect Effect, Panel Data, Environmental Kuznets Curve, Ecological Modernization

1. Introduction

That education should be good for the environment is one of the more intuitive propositions in sustainability research. Educated populations are expected to understand environmental risks, to value long-term outcomes, to support environmental regulation, and to possess the technical and institutional capacity to adopt cleaner technologies [1]. By this logic, education should be inversely related to climate change: because the climate-change indicators are all measures of degradation, more education should mean lower emissions, less pollution, and cleaner energy. The general logic is that the higher and better the education, the less the climate degradation. The proposition is attractive because it connects a policy lever that societies already invest in heavily—schooling—to an outcome, environmental quality, whose importance is difficult to overstate, and because it is supported by a substantial body of micro-level evidence that more-educated individuals report greener attitudes and undertake more pro-environmental behaviours [2] [3].

The relationship is, however, less straightforward than intuition suggests, and two complications motivate this study. The first is that education is tightly entangled with income. Richer countries are both more educated and, through greater consumption and production, higher emitters of carbon per capita [4]-[6]. A simple comparison of more- and less-educated countries may therefore show more education accompanying more per-capita carbon—the opposite of the expected sign—even if education genuinely improves environmental outcomes through other channels. Any credible test of the education-climate relationship must separate the educational association from the developmental one with which it is confounded, either by holding income constant or by isolating the variation in education that is not simply a proxy for affluence.

The second complication is that education may not act on carbon directly at all. Its environmental influence may be indirect—operating through the composition of energy, the quality of the environment, and the capacity to decarbonize—so that any association with carbon is mediated by these intermediate outcomes rather than immediate ones [7] [8]. On this view, an educated society lowers its carbon not because education reduces emissions mechanically, but because educa-

tion shifts the energy system and the regulatory environment that together determine how much carbon a given level of economic activity produces. If that is the mechanism, then the direct education-carbon coefficient may be weak or absent even where education is doing real environmental work, and the relationship will only become visible when the intermediate channel is modelled explicitly.

This study examines both issues with a delineated, country-level design. We relate six distinct education measures to five climate-change and environmental indicators, separating cross-country from within-country variation and controlling for income, and we then test the indirect pathway explicitly, using renewable energy as a mediator between education and carbon. The delineated design is deliberate: rather than collapsing education into a single index, we keep attainment, enrollment, spending, and research output as separate measures because they are theorized to bear on different environmental margins, and because averaging them would blur exactly the heterogeneity that identifies which facet of education matters for which outcome.

The contribution is threefold. First, we provide a delineated mapping of which education measures are associated with which environmental outcomes, rather than a single aggregate coefficient. Second, we show that the expected inverse relationship is real but concentrated—cross-nationally rather than within countries, and on the energy-composition and air-quality margins rather than on carbon. Third, we present a mediation result showing that about half of education spending's association with carbon runs through the renewable-energy share, which helps account for a weak direct carbon coefficient.

The remainder of the paper is organized as follows. Section 2 reviews the literature on education, human capital, and the environment, together with the environmental Kuznets curve, STIRPAT, and ecological-modernization traditions that frame the analysis. Section 3 develops the conceptual framework and states five hypotheses. Section 4 describes the data, variables, and estimation strategy, including the mediation design and the rationale for the estimators we do and do not use. Section 5 presents the descriptive statistics, correlations, regression results, within-country estimates, and the mediation analysis. Section 6 reports endogeneity and robustness checks. Sections 7 and 8 discuss the findings and their theoretical and policy implications. Section 9 sets out the scope and limitations, and Section 10 concludes.

2. Literature Review

2.1. Education, Human Capital, and the Environment

The proposition that education improves environmental outcomes draws on human-capital theory [1] and on a large body of work linking schooling to pro-environmental attitudes, behaviours, and policy support [2] [3]. Human-capital theory holds that schooling raises the productive, cognitive, and civic capabilities of a population, and each of these capabilities has a plausible environmental corollary. Cognitively, education improves the capacity to process complex, probabil-

istic, and temporally distant information—precisely the character of climate risk—so that better-educated populations are argued to perceive environmental hazards more accurately and to discount the future less steeply. Civically, education is associated with greater political participation and with support for the collective institutions, from regulation to public investment, through which environmental goods are provided. Technically, an educated labour force adopts and operates cleaner and more efficient technologies more readily, lowering the emissions intensity of a given level of output.

Taken together, these mechanisms imply a demand-side and a supply-side channel. On the demand side, educated citizens want cleaner environments and vote, consume, and organize accordingly; on the supply side, educated workers and firms are better able to deliver cleaner production. Both point in the same direction: more education should be associated with less environmental degradation. The micro-level evidence is broadly consistent with this expectation, though it is nuanced: quasi-experimental work exploiting compulsory-schooling reforms finds that additional education causally raises several pro-environmental behaviours [2], and schooling has been shown to yield "green returns" in the form of more environment-friendly conduct [3], even as the effect is stronger for knowledge-based actions than for stated concern or willingness to pay [2].

The macro-level evidence, however, is mixed and sensitive to the outcome considered and to whether income is held constant, reflecting precisely the entanglement of education with development that this study foregrounds. In long-run panel data for OECD economies, advanced (tertiary) human capital is associated with substantially lower per-capita CO_2 [4]; yet other cross-national studies find the association weak, absent, or contingent on income and on the measure of human capital used. Because education and income co-evolve, isolating an educational association from a developmental one is the central empirical challenge of the cross-national literature. A society becomes more educated as it grows richer, and it emits more carbon per capita as it grows richer; the two movements are confounded at the level of the country. We address this in three ways: by controlling for income directly, by distinguishing cross-country from within-country variation, and by treating the slow-moving, stock-like character of educational attainment explicitly when interpreting within-country estimates. The result is a design in which the education signal is estimated net of affluence rather than in place of it.

2.2. Indirect Pathways: Energy Composition, Environmental Quality, and Capacity

A recurring theme in this literature is that education's environmental influence is indirect. Rather than lowering emissions by itself, education is thought to shift the conditions that determine emissions: it raises support for and adoption of renewable energy, accelerates the move away from coal, improves environmental quality through regulation and cleaner production, and builds the research and human-

capital base needed to decarbonize. On this view, the appropriate way to test the education-climate relationship is not only to estimate direct associations but also to identify the channels through which education operates. A direct regression of carbon on education asks whether educated countries emit less; a mediation model asks why, and answers by locating the intermediate outcomes that carry the relationship.

The renewable-energy share is a natural candidate mediator. Education plausibly promotes renewable adoption—through public support for energy transition, through the skilled labour and engineering capacity that renewable deployment requires, and through the research base that lowers the cost of clean technology—and renewable adoption plausibly lowers carbon by displacing fossil fuels in final energy use. Cross-national evidence for OECD countries indicates that the extent to which renewable-energy consumption translates into environmental quality itself depends on education, consistent with education operating on the environment through the energy mix [7]. Part of education's association with carbon should therefore run through the energy mix. If the mediator carries most of the relationship, the direct education-carbon path will be small once the mediator is included, and the indirect path—the product of the education → renewables and renewables → carbon effects—will be the locus of the action.

This motivates a formal mediation framework, in which the total association of education with carbon is decomposed into a direct component and an indirect component operating through renewable energy [9] [10]. The classic causal-steps logic [9] and the resampling-based inference for indirect effects [10] together provide a way to estimate the education → renewables path, the renewables → carbon path, and the residual direct path, and to test whether the product of the first two is distinguishable from zero. A finding of a significant indirect effect with little direct effect would support the view that education greens carbon outcomes by greening the energy system rather than by acting on carbon directly—the indirect-only case in the taxonomy of mediation, and the sharpest possible statement of the hypothesis that education's environmental value is real but mediated.

2.3. The Environmental Kuznets Curve and STIRPAT

The role of income makes the environmental Kuznets curve (EKC) directly relevant. The EKC posits an inverted-U relationship between income and degradation: pollution rises in the early stages of development and falls once income is high enough that societies demand and can afford environmental quality [5]. If education rises with income, then part of any education-environment association may simply be the downward-sloping arm of the EKC operating through affluence rather than through schooling as such. Controlling for income, and for its square, is therefore essential to prevent the EKC from masquerading as an education effect. Recent work embeds education directly within the EKC and finds that the expansion of higher education has increasingly offset the per-capita emissions associated with income growth, suggesting that education carries an environmental

effect distinct from affluence [11].

The empirical status of the EKC is, however, fragile. The inverted-U is frequently undetectable, is sensitive to the pollutant, the functional form, and the sample, and often fails to reappear when the specification is varied [12] [13]. This fragility cuts two ways for the present study. It means we cannot lean on the EKC as a settled account of the income-environment relationship, but it also means that income is treated as a control rather than a hypothesis. Log income enters linearly in the pooled models and with a squared term in the fixed-effects models, and the pooled models are re-estimated with the squared term as a sensitivity check (Section 6), so that any curvature is absorbed without committing the analysis to a particular shape.

The STIRPAT framework offers a complementary decomposition. Building on the IPAT identity, STIRPAT expresses environmental impact as a stochastic function of population, affluence, and technology [6] [14], and it situates both education and the energy mix within the technology term. In this accounting, education is not a fourth factor standing outside the identity but a determinant of the technology multiplier—the efficiency and cleanliness with which a given population and level of affluence are converted into environmental impact. This is exactly the intermediating role that the mediation design formalizes: education shapes technology, technology shapes impact. The STIRPAT tradition thus justifies controlling for population and affluence, anticipates that affluence will carry a positive association with per-capita carbon that competes with any mitigating role of education, and locates education's influence precisely where the mediation analysis looks for it.

2.4. Ecological Modernization and the Gap

Ecological modernization theory holds that advanced societies can decouple environmental harm from economic growth through knowledge, technology, and institutions [8]. On this account, modernization is not inherently at war with the environment; beyond a certain level of development, the same capacities that drive growth—scientific knowledge, technological sophistication, and institutional capacity—can be turned to environmental ends, so that richer, more knowledge-intensive societies begin to clean up rather than degrade further. Recent empirical tests of the theory's core claim—that technological innovation decouples environmental impact from growth—use cross-national environmental-technology patent data and find qualified support, underscoring that the mechanism runs through the greening of technology rather than through growth itself [15]. Education is a central enabler in this story, both as a source of the knowledge that makes cleaner production possible and as a driver of the institutional and civic capacity that turns that knowledge into policy. Ecological modernization therefore predicts precisely the pattern this paper investigates: an inverse education-degradation relationship that runs through the greening of technology and the energy system rather than through a mechanical reduction of emissions.

Two gaps remain in the empirical literature, and this study is organized around them. First, education is usually represented by a single measure, so the comparative environmental association of attainment, enrollment, spending, and research output is rarely assessed together. Different facets of education plausibly bear on different environmental margins—spending on the financing of clean-energy capacity, advanced human capital on the skills of decarbonization, research output on the technological frontier—and collapsing them into one index averages these distinct channels into a single, less informative number. Second, the widely asserted indirect character of the education-climate link is seldom tested as an explicit mediation; it is asserted in theory and left unmodeled in estimation. This study addresses both gaps by estimating each education measure against each climate indicator and by formally testing the education → renewables → carbon pathway.

3. Conceptual Framework and Hypotheses

Figure 1 organizes the analysis. Education influences climate-change outcomes primarily through intermediate channels—a higher renewable share, a lower coal share, and improved air quality—rather than acting on carbon directly; income sits beneath the relationship as a confounder: the level of development shapes both a country's educational endowment and its per-capita carbon, and income is treated as a pre-exposure common cause to be held constant. The framework thus predicts an inverse relationship that is concentrated on the composition of energy and the quality of the environment, and that reaches carbon indirectly. Reading the diagram from left to right, education is expected to raise the intermediate environmental outcomes; those outcomes are expected to lower degradation; and income enters as a confounding path that must be controlled if the education signal is to be recovered. The estimand throughout is the association of each education measure with each environmental outcome conditional on income, population, and unemployment. Because income may also be partly a consequence of past educational investment, this conditional association is not the total effect of education: any part of education's environmental association that operates through income is absorbed by the income control rather than attributed to education.

From this framework, we derive five hypotheses, each stated as an empirical expectation and each mapped to a specific test in Section 5.

H1. Cross-national inverse relationship. Cross-nationally, education will be inversely associated with climate degradation, with more education accompanying a higher renewable share, less coal, and lower particulate pollution. This is the baseline expectation of human-capital and ecological-modernization reasoning applied at the level of the country.

H2. Concentration on composition and quality, not carbon. The relationship will be concentrated in the energy-composition and air-quality margins rather than in per-capita carbon, because income competes with education on the carbon

margin. Where affluence does most of the work—on carbon—the education signal will be hard to see; where affluence does less—on the energy mix and air quality—it will be visible.

H3. Indirect (mediated) path to carbon. Education's association with carbon will be largely indirect, mediated by the renewable-energy share, with a significant indirect effect and little direct effect. This is the formal statement of the claim that education greens carbon by greening the energy system.

H4. Between-country, not within-country. The inverse relationship will appear primarily between countries rather than within them, because educational attainment is a slow-moving stock and the panel is short, leaving little within-country variation to identify. A weak within-country coefficient is thus predicted in advance, and interpreted as a property of the data rather than as evidence against the relationship.

H5. Spending and advanced human capital as the strongest channels. Education spending and advanced human capital will be among the strongest channels, given their direct connection to the financing and skills of decarbonization. Of the six education measures, these two are theorized to bear most tightly on the energy transition and so should show the clearest associations with the renewable share.

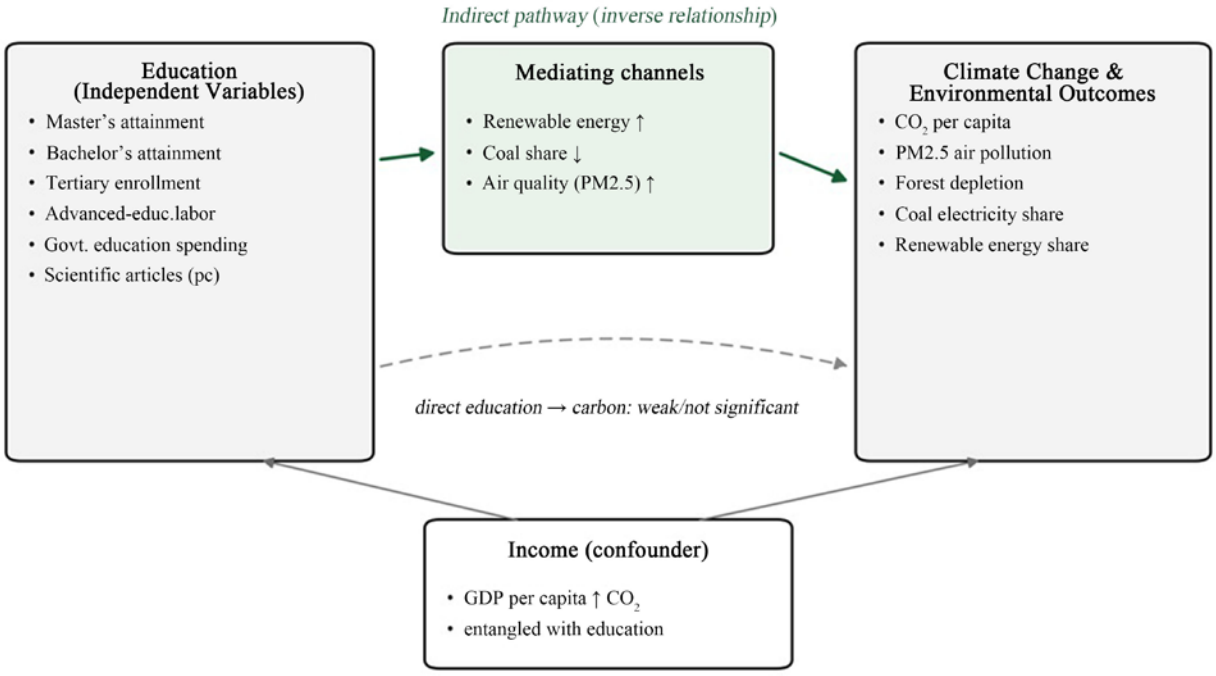

Figure 1. Conceptual framework: education influences climate outcomes indirectly through energy composition and environmental quality, with income as a confounder.

4. Data and Methods

4.1. Data and Sample

We use a country-year panel of 97 countries observed from 2013 to 2020, com-

prising 402 observations, drawn from the World Development Indicators, where the dependent indicators fall under the World Bank's Climate Change theme. The panel spans every region and income level, from low-income to high-income economies and from Sub-Saharan Africa to Oceania, which gives the cross-country dimension wide gradients in both education and environmental performance that the design exploits. The panel is short and unbalanced, averaging 4.1 years per country; this is an important feature for interpretation, because educational attainment changes slowly and a short panel offers limited within-country variation. We therefore treat cross-country variation as the primary source of identification for slow-moving education stocks and interpret within-country estimates with corresponding caution. This is a design choice made in advance and stated openly, not a post hoc rationalization of weak within-country results.

4.2. Variables

Each education measure enters as a distinct independent variable and each climate-change indicator as a distinct dependent variable (Table 1 and Table 2). The six education measures—master's attainment, bachelor's attainment, tertiary enrollment, the advanced-education share of the labour force, government education spending, and scientific output—capture different facets of a country's educational endowment, from the stock of highly qualified people to the flow of resources into schooling and the output of its research base. Four of the five environmental indicators—per-capita CO_2, PM2.5, forest depletion, and the coal share of electricity—are oriented so that higher values denote greater degradation; the renewable-energy share is oriented so that higher values denote improvement. Keeping this orientation convention in mind is essential to reading the coefficient tables because the expected sign of an environment-improving education effect is negative on the four degradation indicators and positive on the renewable share.

Scientific output is expressed per capita to remove country-size scaling, so that a large country does not appear research-intensive merely by virtue of its population. Income is entered as the natural log of GDP per capita, mean-centered, linearly in the pooled and mediation models and with a squared term in the fixed-effects models; a pooled sensitivity analysis adds the squared term (Section 6).

The renewable-energy indicator is the WDI series Renewable energy consumption (% of total final energy consumption) (EG.FEC.RNEW.ZS), the measure used for Sustainable Development Goal indicator 7.2. It counts all renewable sources in final energy use—hydropower, wind, solar, geothermal, and solid, liquid, and gaseous biofuels and renewable waste—including the traditional use of biomass for cooking and heating. It is therefore a measure of renewable final-energy consumption rather than of clean-electricity generation, and in lower-income economies a high value can reflect reliance on traditional biomass rather than modern renewable deployment. Results for the renewable share are interpreted accordingly.

Table 1. Independent and control variables.

Variable	Definition	Unit	Source
Education (independent variables)			
Master's attainment	Population 25+ with at least a master's degree or equivalent	% of 25+	WDI
Bachelor's attainment	Population 25+ with at least a bachelor's degree or equivalent	% of 25+	WDI
Tertiary enrollment	School enrollment, tertiary, gross	% gross	WDI
Advanced-education labor	Labor force with advanced education	% of working-age	WDI
Govt. education spending	Government expenditure on education	% of GDP	WDI
Scientific articles (per cap.)	Scientific and technical journal articles, per capita (log)	per capita	WDI
Control variables			
GDP per capita	GDP per capita (natural log, mean-centered; squared term for EKC in fixed-effects models)	constant US$	WDI
Population	Total population (natural logarithm)	persons	WDI
Unemployment	Unemployment, total (modeled ILO estimate)	% labor force	WDI

Table 2. Dependent variables (climate change and environmental indicators).

Variable	Definition	Unit	Source
CO_2 per capita	Carbon dioxide emissions per capita (excluding LULUCF)	t CO_2e/capita	WDI
PM2.5	Mean annual population exposure to PM2.5	$\mu g/m^3$	WDI
Forest depletion	Adjusted savings: net forest depletion	% of GNI	WDI
Coal electricity	Electricity production from coal sources	% of generation	WDI
Renewable energy	Renewable energy consumption, incl. traditional biomass (EG.FEC.RNEW.ZS) (orientation: higher = better)	% of final energy	WDI

4.3. Estimation Strategy

We first report descriptive statistics, a correlation matrix, and variance-inflation factors to characterize the sample and to confirm that multicollinearity among the education measures and income is within tolerable bounds. We then estimate, for each climate indicator, a multiple linear regression on the full set of six education measures and controls, with country-clustered standard errors [16], mapping which education-indicator associations are significant in the pooled country-year sample. Because pooled estimates combine between- and within-country variation, they are described as pooled associations, and the two components are separated explicitly in Section 5.4. The full set of education measures is retained in every specification, so that no result depends on a favorable choice of which facet of education to include; the delineated design is carried through the estimation rather than imposed only at the descriptive stage. Each estimator yields 30 education-indicator coefficients (six measures × five outcomes), which form a multiple-testing family. Significance markers in the tables are unadjusted; we additionally compute Benjamini-Hochberg false-discovery-rate q-values across each family of

30 [17] and treat cells that are nominally significant but do not survive the adjustment as exploratory.

To probe whether these associations operate within countries as well as between them, we re-estimate the full model with two-way fixed effects and with Driscoll-Kraay standard errors [16]; we emphasise at the outset that, because educational attainment is near-constant within countries over this short panel, the within-country estimates are underpowered for the slow-moving stocks and should be read as a limitation rather than as a contradiction of the cross-country results. Fixed effects difference out everything that is constant within a country, including most of the variation in attainment, so the estimator is being asked to identify an education effect from the small year-to-year movements that remain—a demand the data cannot meet over four-odd years. To separate the between- and within-country components directly, we also estimate a within-between hybrid model [18] [19], in which each education measure and control enters both as its country mean and as the deviation from that mean, with year effects and country-clustered standard errors; the coefficient on the country mean is the between-country association and the coefficient on the deviation is the within-country association.

Because the inverse relationship is expected to be indirect, we test mediation explicitly. Using renewable energy as the mediator, we estimate the education → renewables path (a), the renewables → carbon path conditional on education (b), and the direct education → carbon path (c′), and we obtain the indirect effect (a × b) with a country-clustered bootstrap confidence interval [10]. We report mediation both for a composite education index and for government education spending, the channel most directly tied to the financing of renewable adoption. The mediation analysis rests on the standard sequential-ignorability assumptions, and education spending, the renewable share, and CO_2 are measured in the same year, so the models cannot establish temporal ordering among them; we treat the resulting indirect association as evidence consistent with the hypothesized channel rather than as a fully identified causal mechanism, and we return to this point in the limitations.

The mediation models are three linear regressions estimated by ordinary least squares on the full analytic sample of 402 country-year observations from 97 countries:

$$M_{it} = a_0 + a \cdot X_{it} + \gamma_1' C_{it} + \varepsilon_{1,it} \quad (1)$$

$$Y_{it} = b_0 + c' \cdot X_{it} + b \cdot M_{it} + \gamma_2' C_{it} + \varepsilon_{2,it} \quad (2)$$

$$Y_{it} = c_0 + c \cdot X_{it} + \gamma_3' C_{it} + \varepsilon_{3,it} \quad (3)$$

where X is government education spending (% of GDP), M is the renewable-energy share (% of final energy consumption), Y is per-capita CO_2, and C contains log GDP per capita, log population, and unemployment; the other five education measures do not enter the mediation models. Standard errors are clustered by country. The indirect association is a × b and the direct association is c′; because Equations (1)-(3) share the same covariates and sample, the total association decomposes exactly as $c = c' + a \times b$. The 95% confidence interval for a × b is the

percentile interval from 2000 cluster-bootstrap draws, each of which resamples the 97 countries with replacement, keeping all years of a sampled country together, and re-estimates Equation (1) and Equation (2). The same models are estimated with the composite education index in place of X.

We also report Hausman tests comparing fixed- and random-effects specifications [20] and reverse-causality checks. We do not estimate system GMM: with an average of 4.1 years per country and nearly time-invariant education stocks, a dynamic panel estimator is not credibly identified, and we prefer to say so rather than report fragile dynamics. Reporting a dynamic-panel specification on a panel this short would convey a precision the data do not support; the honest description of the identification available here is cross-sectional and mediation-based, and we let the analysis rest on that footing.

5. Results and Analysis

5.1. Descriptive Statistics

Table 3 summarizes the sample, which spans a wide range of educational development and environmental performance. The spread is the engine of the cross-country design: per-capita carbon ranges from near zero to 44.82 tonnes, the renewable share from 0 to 97 percent, and PM2.5 exposure from 4.90 to 88.79 μg/m^3, so the between-country gradients that the regressions exploit are wide rather than compressed. The education measures show comparably broad variation, with master's attainment ranging from 0 to 30.65 percent of the population aged 25 and over, and government education spending from under 1 to 8.60 percent of GDP. This dispersion is what makes it possible to detect margin-specific education effects that would be invisible in a narrower, more homogeneous sample.

Table 3. Descriptive statistics (402 country-year observations).

Variable	N	Mean	Std. Dev.	Min/Max
CO_2 per capita (t)	402	5.51	4.28	0.04/44.82
PM2.5 (μg/m^3)	402	20.04	14.64	4.90/88.79
Forest depletion (% GNI)	402	0.31	1.55	0.00/18.19
Coal electricity (% gen.)	402	19.35	24.31	0.00/99.85
Renewable energy (% final)	402	28.48	20.67	0.00/97.00
Master's attainment (% 25+)	402	8.46	6.88	0.00/30.65
Bachelor's attainment (% 25+)	402	19.62	10.43	0.00/40.41
Tertiary enrollment (% gross)	402	56.22	26.26	3.67/143.96
Advanced-educ. labor (%)	402	77.65	7.01	44.38/94.03
Govt. education spending (% GDP)	402	4.73	1.45	0.96/8.60
Scientific articles (per capita, log)	402	5.73	1.88	0.15/7.92
GDP per capita (US$)	402	22,544	22,820	261/107,592
Population	402	42,424,328	114,606,503	327,386/1,402,617,695
Scientific articles (count)	402	22,888	58,062	2/457,587

5.2. Correlation Matrix

Table 4 reports Pearson correlations among the outcomes, education measures, and controls. Two features stand out. First, the education measures correlate with one another and with income, as expected of variables that co-evolve with development; bachelor's attainment, tertiary enrollment, and scientific output are all strongly correlated with log GDP per capita (0.75, 0.74, and 0.90, respectively). This is the collinearity the design must manage, and it is the reason income is controlled directly rather than left to contaminate the education coefficients. Second, the raw correlations already foreshadow the regression pattern: the renewable share is negatively correlated with per-capita carbon (−0.43) and with the coal share (−0.36), while advanced-education labour and education spending are among the education measures least entangled with income (correlations with log GDP of 0.26 and 0.46), which is part of why their environmental associations survive the income control.

After expressing scientific output per capita, no variance-inflation factor exceeds nine (maximum 8.6), and the residual income-education correlation is handled by direct control. The VIF diagnostic matters because the delineated design keeps all six education measures in the model simultaneously; a maximum VIF below the conventional threshold confirms that the coefficients can be separately estimated despite the correlations among the regressors, so that the margin-specific pattern in Table 5 is not an artifact of collinearity.

Table 4. Pearson correlation matrix.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. CO_2/cap	1													
2. PM2.5	−0.31	1												
3. ForDepl	−0.22	0.22	1											
4. Coal	0.19	0.05	−0.13	1										
5. Renew	−0.43	0.22	0.41	−0.36	1									
6. Master's	0.34	−0.41	−0.20	−0.13	−0.20	1								
7. Bachelor's	0.55	−0.53	−0.28	−0.09	−0.37	0.71	1							
8. Tertiary enroll.	0.47	−0.61	−0.32	0.04	−0.34	0.50	0.71	1						
9. Adv. labor	0.04	−0.39	−0.03	0.04	0.18	0.04	0.08	0.08	1					
10. Educ. spending	0.20	−0.39	−0.12	−0.09	0.10	0.15	0.37	0.35	0.24	1				
11. Sci. articles pc	0.64	−0.61	−0.39	0.04	−0.43	0.63	0.75	0.78	0.08	0.38	1			
12. loggdp_c	0.67	−0.71	−0.38	−0.03	−0.38	0.55	0.75	0.74	0.26	0.46	0.90	1		
13. logpop	−0.02	0.27	0.04	0.24	−0.15	−0.25	−0.21	−0.12	−0.25	−0.28	−0.09	−0.16	1	
14. Unemp	−0.05	−0.06	−0.07	0.18	−0.17	0.03	−0.09	0.05	−0.04	−0.02	0.06	−0.06	−0.09	1

Variables: 1 = CO_2 per capita (t); 2 = PM2.5 (μg/m^3); 3 = Forest depletion (% GNI); 4 = Coal electricity (% gen.); 5 = Renewable energy (% final); 6 = Master's attainment (% 25+); 7 = Bachelor's attainment (% 25+); 8 = Tertiary enrollment (% gross); 9 = Advanced-educ. labor (%); 10 = Govt. education spending (% GDP); 11 = Scientific articles (per capita, log); 12 = log GDP per capita; 13 = log Population; 14 = Unemployment (%).

5.3. Multiple Linear Regression: Each Education Measure on Each Indicator

Table 5 reports the coefficient of every education measure and control on every climate indicator, each from a separate country-clustered regression. Reading the table with the orientation convention in mind, the pooled pattern matches the inverse-relationship expectation and concentrates where theory predicts. Government education spending is strongly associated with a higher renewable share (4.679, $p < 0.001$); advanced-education labor and tertiary enrollment with lower PM2.5 (−0.381 and −0.147, both $p < 0.05$); and master's attainment and advanced labor with a higher renewable share (0.802 and 0.581, both $p < 0.05$). These are exactly the energy-composition and air-quality margins anticipated by H2, and the two strongest channels—spending and advanced human capital—are those predicted by H5. After Benjamini-Hochberg adjustment across the 30 education cells, only the spending coefficient on the renewable share remains significant ($q = 0.022$); the other nominally significant cells have q-values of about 0.13 and are treated as exploratory. Income, meanwhile, carries the anticipated positive association with per-capita carbon (2.070, $p < 0.01$), competing with education on that margin, while explaining the strong fit for CO_2 ($R^2 = 0.51$) and PM2.5 ($R^2 = 0.60$); the model fits the income-governed outcomes well precisely because income does much of the work there.

The delineated design earns its keep in the differences across measures. The education measures do not move together: master's attainment raises the renewable share, while bachelor's attainment is negatively signed on it (−0.735, $p < 0.05$), and scientific output—strongly correlated with income—shows no independent environmental association once income is controlled. Collapsing these into a single education index would average away the very heterogeneity that identifies which facet of education bears on which outcome. The negative bachelor's coefficient on the renewable share, set against the positive master's coefficient, is a case in point: an aggregate measure would net these to something close to zero and report, misleadingly, that attainment has no bearing on the energy mix, when in fact the two levels of attainment pull in opposite directions on that margin.

Table 6 and Table 7 report the full regressions for per-capita CO_2 and for the renewable-energy share—the carbon outcome and the principal channel—showing coefficients, standard errors, and significance for every predictor. The contrast between them is the empirical heart of the paper: on carbon, no education measure attains significance and income dominates (2.070, $p < 0.01$), while the model still fits well ($R^2 = 0.511$) because income carries the outcome; on the renewable share, four of the six education measures are significant—master's (0.802, $p < 0.05$), bachelor's (−0.735, $p < 0.05$), advanced labour (0.581, $p < 0.05$), and spending (4.679, $p < 0.001$)—and income is not (−6.271, n.s.). Education's signal lives on the energy-composition margin, not the carbon margin, exactly as H2 anticipates, and the weak direct carbon coefficient is the clue that motivates the mediation analysis rather than an embarrassment to be explained away.

Table 5. Multiple linear regression coefficients: each education measure on each climate indicator (pooled country-year associations).

Predictor	CO_2/cap	PM2.5	ForDepl	Coal	Renew
Master's attainment (% 25+)	−0.125	−0.141	0.017	−0.682	0.802*
Bachelor's attainment (% 25+)	0.101	0.086	0.002	−0.013	−0.735*
Tertiary enrollment (% gross)	−0.027	−0.147*	−0.002	0.083	0.050
Advanced-educ. labor (%)	−0.061	−0.381*	0.011	0.596	0.581*
Govt. education spending (% GDP)	−0.399	−0.281	0.080	−1.286	4.679***
Scientific articles (per capita, log)	0.468	1.989	−0.142	5.399	−1.691
log GDP per capita	2.070**	−7.831***	−0.351	−6.249	−6.271
log Population	0.035	0.800	0.017	3.471	−1.420
Unemployment (%)	−0.000	−0.267	−0.020	0.728	−0.883**
R^2	**0.511**	**0.605**	**0.169**	**0.150**	**0.402**
N	**402**	**402**	**402**	**402**	**402**

Each column represents a separate regression; country-clustered standard errors are used; significance levels are unadjusted for multiple testing, and only Govt. education spending → Renew survives Benjamini-Hochberg adjustment (q = 0.022). Orientation: CO_2/PM2.5/ForDepl/Coal higher = worse; Renew higher = better. ***p < 0.001, **p < 0.01, *p < 0.05.

Table 6. Full regression for per-capita CO_2 emissions (pooled).

Predictor	Coef.	Std. err.	t	Sig.
Constant	9.438	7.069	1.34	0.182
Master's attainment (% 25+)	−0.125	0.077	−1.63	0.103
Bachelor's attainment (% 25+)	0.101	0.053	1.91	0.055
Tertiary enrollment (% gross)	−0.027	0.025	−1.07	0.284
Advanced-educ. labor (%)	−0.061	0.035	−1.71	0.086
Govt. education spending (% GDP)	−0.399	0.295	−1.35	0.177
Scientific articles (per capita, log)	0.468	0.363	1.29	0.198
log GDP per capita	2.070	0.725	2.85	0.004**
log Population	0.035	0.262	0.13	0.895
Unemployment (%)	−0.000	0.068	−0.00	0.999
R^2 = 0.511; adj. R^2 = 0.500; F = 16.6; N = 402				

Table 7. Full regression for the renewable-energy share (pooled).

Predictor	Coef.	Std. err.	t	Sig.
Constant	5.709	39.401	0.14	0.885
Master's attainment (% 25+)	0.802	0.346	2.32	0.020*
Bachelor's attainment (% 25+)	−0.735	0.330	−2.22	0.026*
Tertiary enrollment (% gross)	0.050	0.094	0.53	0.594
Advanced-educ. labor (%)	0.581	0.253	2.30	0.022*

Continued

Govt. education spending (% GDP)	4.679	1.386	3.38	<0.001***
Scientific articles (per capita, log)	−1.691	2.298	−0.74	0.462
log GDP per capita	−6.271	3.853	−1.63	0.104
log Population	−1.420	1.485	−0.96	0.339
Unemployment (%)	−0.883	0.314	−2.81	0.005**
R^2 = 0.402; adj. R^2 = 0.388; F = 11.2; N = 402				

5.4. Within-Country Estimates and Their Limits

Table 8 re-estimates the full model under two-way fixed effects. Consistent with H4, the pooled associations largely do not appear within countries over this short panel. We interpret this as a consequence of limited within-country variation in slow-moving education stocks rather than as evidence against the inverse relationship: educational attainment changes by fractions of a percentage point per year, so a 4.1-year window leaves little signal for fixed-effects identification, and the few within-country coefficients that reach significance should be treated cautiously. The one within-country coefficient that is robustly significant—scientific output on per-capita carbon (0.426, $p < 0.01$) and on the coal share (3.969, $p < 0.01$)—is most naturally interpreted as a development-and-industrialization dynamic rather than as an education effect on the environment, since research output tracks the growth of an industrial, energy-intensive economy. The cross-country evidence remains the appropriate basis for inference about education stocks.

Table 8. Fixed-effects coefficients: each education measure on each indicator (within country).

Predictor	CO_2/cap	PM2.5	ForDepl	Coal	Renew
Master's attainment (% 25+)	−0.056	0.493*	0.004	−0.332	0.205
Bachelor's attainment (% 25+)	−0.038	−0.121	−0.014	−0.025	0.193
Tertiary enrollment (% gross)	0.001	0.022	0.003	0.054	−0.080
Advanced-educ. labor (%)	0.016	−0.142	0.004	0.071	−0.067
Govt. education spending (% GDP)	0.013	0.198	0.004	−0.441	−0.204
Scientific articles (per capita, log)	0.426**	0.435	0.021	3.969**	−1.556
Within R^2	**0.319**	**0.050**	**0.007**	**0.103**	**0.135**

Country and year effects; country-clustered standard errors; controls are log GDP per capita and its square, log population, and unemployment. ***p < 0.001, **p < 0.01, *p < 0.05.

Table 9 separates the two sources of variation directly with the within-between hybrid model. The between-country coefficients reproduce the pooled pattern: education spending (5.274, $p < 0.001$), master's attainment (0.847, $p < 0.05$), and advanced-education labor (0.670, $p < 0.05$) are associated with a higher renewable share and bachelor's attainment with a lower one (−0.773, $p < 0.05$), while tertiary

enrollment (−0.157, $p < 0.05$) and advanced-education labor (−0.423, $p < 0.05$) are associated with lower PM2.5; bachelor's attainment on per-capita CO_2 (0.112, $p < 0.05$) and scientific output on PM2.5 (2.408, $p < 0.05$) are the between-country associations in the worsening direction. The within-country coefficients are almost uniformly insignificant, the exceptions being master's attainment on per-capita CO_2 (−0.077, $p < 0.05$) and advanced-education labor on forest depletion (0.016, $p < 0.05$). A between estimator fitted to the 97 country means gives the same picture for the renewable share (spending 4.883, $p < 0.001$; master's 1.174, $p < 0.01$; advanced labor 0.627, $p < 0.05$; bachelor's −0.752, $p < 0.05$) and for advanced-education labor on PM2.5 (−0.484, $p < 0.05$). The education associations are therefore concentrated in the between-country component, as H4 anticipates.

Table 9. Within-between hybrid model: between-country and within-country coefficients of each education measure on each indicator.

Predictor	CO_2/cap	PM2.5	ForDepl	Coal	Renew
Panel A. Between-country (*country means*)					
Master's attainment (% 25+)	−0.129	−0.164	0.019	−0.693	0.847*
Bachelor's attainment (% 25+)	0.112*	0.098	0.001	0.034	−0.773*
Tertiary enrollment (% gross)	−0.028	−0.157*	−0.003	0.084	0.060
Advanced-educ. labor (%)	−0.073	−0.423*	0.011	0.717	0.670*
Govt. education spending (% GDP)	−0.445	−0.411	0.088	−1.241	5.274***
Scientific articles (per capita, log)	0.484	2.408*	−0.136	5.483	−2.242
Panel B. Within-country (*deviations*)					
Master's attainment (% 25+)	−0.077*	0.482	0.037	−0.780	0.433
Bachelor's attainment (% 25+)	−0.046	0.100	0.007	−1.164	−0.029
Tertiary enrollment (% gross)	0.000	0.025	0.006	−0.027	−0.117
Advanced-educ. labor (%)	0.017	−0.122	0.016*	0.003	0.020
Govt. education spending (% GDP)	0.056	0.324	0.026	−1.286	−0.340
Scientific articles (per capita, log)	0.458	0.912	0.037	0.288	−2.859

Each column is a single regression in which every education measure and control (log GDP per capita, log population, unemployment) enters as its country mean (Panel A) and as the deviation from that mean (Panel B); year effects; country-clustered standard errors; N = 402 country-years, 97 countries. Orientation: CO_2/PM2.5/ForDepl/Coal higher = worse; Renew higher = better. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.

5.5. The Inverse Relationship

The pooled results support the inverse-relationship hypothesis. Counting nominally significant education-indicator cells across the five indicators, the pooled model yields 5 associations that improve the environment (less degradation or more renewables) against only 1 that worsens it; the within-country model, underpowered for slow-moving stocks, yields 0 and 3. With 30 tests per estimator, these tallies are exploratory summaries of direction: after Benjamini-Hochberg

adjustment, the pooled model retains one improving cell (spending on the renewable share) and the within-country model none. The improving associations are not scattered: they concentrate in the renewable-energy share and in air quality, exactly the energy-composition and quality margins through which education is theorized to act, and they are led by education spending and advanced human capital. Figure 2 displays the full sign pattern, with environment-improving associations in one shade and worsening associations in another.

The pattern is consistent with the view that education is inversely related to climate degradation, but that it acts on the composition of the energy system and the quality of the environment rather than uniformly on every indicator. The 5-to-1 tally in the pooled model and the 0-to-3 tally within countries are two views of the same fact: the inverse relationship is a between-country phenomenon over this panel, and the within-country estimator, deprived of variation, produces a handful of coefficients whose signs are as likely to reflect development dynamics as environmental ones. Where education is weakest is precisely on per-capita carbon, the margin most strongly governed by income—motivating the mediation analysis that follows. That the direct carbon association is weak is therefore not an anomaly to be explained away but the central clue: it points toward an indirect pathway in which education reaches carbon through the energy mix rather than on its own.

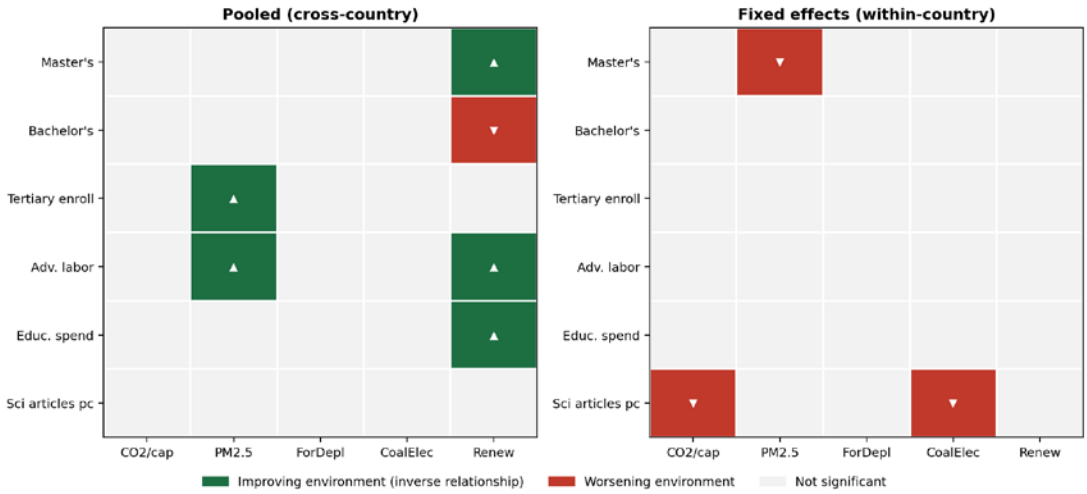

Figure 2. Sign map of education-indicator associations: environment-improving (inverse relationship) and worsening cells, under pooled and fixed-effects estimations.

5.6. Mediation: Education → Renewable Energy → Carbon

The central question is whether education's association with carbon is direct or indirect. Figure 3 reports the mediation for government education spending, with the renewable-energy share as the mediator and per-capita CO_2 as the outcome, controlling for income, population, and unemployment. Education spending is associated with a higher renewable share (path a = 4.30, $p < 0.01$), and a higher renewable share is associated with lower per-capita carbon (path b = −0.040, p <

0.05). The resulting indirect effect is negative and statistically significant ($a \times b = -0.173$; 95% bootstrap CI [−0.373, −0.019], excluding zero), while the direct association of education spending with carbon is not statistically significant ($c' = -0.167$, $p = 0.51$). Because $c = c' + a \times b$, the total association is −0.339 ($p = 0.22$), of which the indirect component accounts for about half and the direct component for the other half. The indirect association is distinguishable from zero and the direct association is not, but the two are similar in magnitude, so the direct association is imprecisely estimated rather than shown to be absent. The result therefore supports the indirect component of H3 but not its expectation of little direct effect, and it does so on the spending channel that H5 identified as the one most tightly linked to the financing of clean-energy capacity.

The structure of the result is worth stating precisely. Both constituent paths carry the signs the framework expects—higher spending accompanies a higher renewable share, and a higher renewable share accompanies lower carbon—so their product, the indirect association, is negative and its bootstrap interval excludes zero. The direct path, by contrast, is statistically indistinguishable from zero but not small: at −0.167 it is close to the indirect component (−0.173), and the total association (−0.339) divides roughly equally between them. The renewable-share channel therefore accounts for part of the association of spending with carbon, leaving a residual association of comparable size that the data estimate imprecisely. Because spending, the renewable share, and CO_2 are measured in the same year, the decomposition describes how the associations are arranged rather than a sequence in which spending raises the renewable share and thereby lowers carbon.

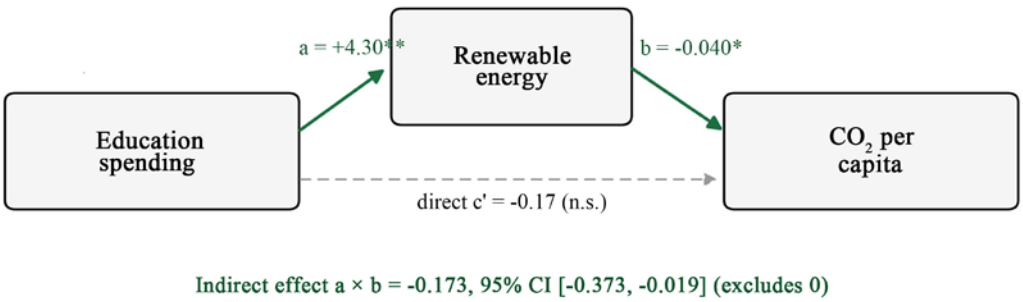

Figure 3. Mediation of the education-carbon relationship through renewable energy (government education spending channel). Indirect association is significant; direct association is not significant; total association $c = c' + a \times b = -0.339$.

The composite education index shows the same directional pattern—education is associated with a higher renewable share, which is associated with lower carbon—but its indirect effect is not statistically distinguishable from zero, because the index blends fast-moving, policy-sensitive spending with slow-moving attainment stocks that are bound to income. The reason is instructive rather than disappointing: averaging across facets dilutes the sharp spending signal with noisier, more confounded components. This is the delineated design speaking again—the

mediation is visible on the specific channel where theory locates it and blurs when that channel is averaged with others. Together with the cross-country pattern, the mediation is consistent with the paper's thesis that part of education's association with climate outcomes runs through the composition of the energy system.

6. Endogeneity and Robustness

We probe robustness while retaining the full set of education measures, so that no result depends on a favourable choice of specification. Hausman tests comparing fixed- and random-effects estimates of the full model (Table 10) reject random effects for per-capita CO_2, PM2.5, and forest depletion, and do not reject it for the coal and renewable shares; this favours fixed effects for the emissions and pollution outcomes, even though, as noted, fixed effects are underpowered for the slow-moving education stocks. The two facts are not in tension. The Hausman test concerns the controls and the correlation between the country effects and the regressors—much of which is driven by income—as much as the education terms, while the limited within-country variation in attainment is what blunts the education coefficients specifically. A rejection of random effects for the income-governed outcomes, therefore, tells us about the controls, not that the fixed-effects estimator recovers the education signal.

We also examine reverse causation, regressing each education measure on the lagged climate indicators within countries (Table 11). The evidence is limited and mostly insignificant, as expected when both education and the environment move slowly; where significant, it is consistent with development dynamics rather than with environmental conditions driving education. The scattered significant cells—lagged carbon on master's and bachelor's attainment, and forest depletion on advanced labour and spending—do not form a coherent pattern of the environment shaping education, and are more plausibly read as coincidental correlates of development than as a reverse-causal channel that would threaten the main interpretation.

Because the pooled models enter log income linearly, we also re-estimate them with the squared term added. The renewable-share associations of spending (2.998, $p < 0.05$), master's attainment (0.583, $p < 0.05$), advanced-education labor (0.772, $p < 0.001$), and bachelor's attainment (−0.988, $p < 0.001$) keep their signs and significance, and advanced-education labor remains associated with lower PM2.5 (−0.330, $p < 0.05$); tertiary enrollment's PM2.5 association is no longer significant (−0.096), while its renewable-share association becomes significant (0.242, $p < 0.001$). The squared term is significant for PM2.5, forest depletion, coal, and the renewable share, but its inclusion leaves the education associations on the energy-composition and air-quality margins in place.

Finally, as noted in the methods, we do not estimate system GMM: with an average of 4.1 years per country and nearly time-invariant education stocks, dynamic-panel identification is not credible, and reporting it would convey false precision. The robustness evidence therefore supports a cautious, cross-sectional,

mediation-based reading rather than a within-country dynamic one. We regard this as the honest boundary of what the panel can support, and we draw our conclusions within it.

Table 10. Hausman tests (fixed vs. random effects), full education model by outcome.

Outcome	χ^2	p-value	Decision
CO_2 per capita (t)	47.9	<0.001	Fixed effects
PM2.5 (μg/m³)	24.1	0.007	Fixed effects
Forest depletion (% GNI)	40.4	<0.001	Fixed effects
Coal electricity (% gen.)	18.1	0.053	Random effects adequate
Renewable energy (% final)	−123.8	1.000	Random effects adequate

Table 11. Reverse causality: lagged climate indicator → current education measure (two-way fixed effects).

Predictor	CO_2/cap	PM2.5	ForDepl	Coal	Renew
Master's attainment (% 25+)	−0.777*	−0.014	−0.033	−0.025	0.075
Bachelor's attainment (% 25+)	−1.233*	−0.030	0.256	−0.057	0.168*
Tertiary enrollment (% gross)	−1.056	−0.022	−0.314	0.003	−0.028
Advanced-educ. labor (%)	0.860	−0.167	−5.528***	0.014	−0.096
Govt. education spending (% GDP)	−0.117	−0.002	−0.203***	−0.009	−0.000
Scientific articles (per capita, log)	0.049	−0.002	0.009	0.003	−0.003

Coefficient on the lagged indicator. ***p < 0.001, **p < 0.01, *p < 0.05.

7. Discussion

The findings support a qualified version of the intuition that education is good for the climate. Cross-nationally, more education is associated with less environmental degradation, but the relationship is neither uniform nor direct. It concentrates on the composition of energy and the quality of the environment—more renewables and cleaner air—and it is led by education spending and advanced human capital, the channels most closely tied to the financing and skills of decarbonization. The qualification is not a retreat from the intuition but a sharpening of it: education's environmental value is real, but it is specific in where it appears and in how it operates.

It is useful to state the verdict on each hypothesis explicitly. H1, the cross-national inverse relationship, is consistent with the evidence: the pooled model returns five nominally significant environment-improving associations against one worsening, concentrated on the renewable share and air quality, although only the spending-renewables association survives adjustment for multiple testing. H2, concentration on composition and quality rather than carbon, is consistent with the evidence: the significant cells fall on the renewable and PM2.5 margins, while on carbon income dominates and no education measure is significant. H3, the

indirect mediated path, is partly supported: the education-spending → renewables → carbon indirect association is significant with a bootstrap interval excluding zero, but the direct association, though not significant, is of similar magnitude, so the expectation of little direct effect is not borne out. H4, the between-country rather than within-country character of the relationship, is supported: in the hybrid model the education associations are carried by the between-country component, and the within-country coefficients are almost all insignificant. H5, the primacy of spending and advanced human capital, is consistent with the evidence: these are the measures that carry the renewable-share result and the mediation.

The relationship's near-absence within countries is, on the evidence, a property of the data rather than of the world: educational attainment is a slow-moving stock, and a short panel cannot identify its within-country effect. This is an important caution for the literature, which sometimes reads weak within-country education coefficients as evidence that education does not matter. Here, the more defensible reading is that the cross-country dimension is where the variation lies, and that a four-year window is simply the wrong instrument for detecting the effect of a stock that changes over decades. The methodological lesson generalizes: for slow-moving human-capital variables, the choice between within- and between-country identification is not a neutral technical matter but a decision about whether the estimator can see the variation the hypothesis is about.

The mediation result is the paper's core. Part of education spending's association with carbon is indirect: higher spending accompanies a higher renewable share, which accompanies lower per-capita carbon, producing a significant indirect association that accounts for about half of the total, alongside a direct association of similar size that is not statistically significant. This reframes the education-climate question: education's association with carbon is visible chiefly through the composition of the energy system rather than as a precisely estimated direct link. The reframing also addresses an apparent tension in the descriptive picture—that education correlates with more carbon at the country level, through income—by showing that, net of income, the associational pathway from education spending through renewables runs toward lower carbon. The raw correlation and the conditional mediated association are not in conflict; they are answers to different questions.

8. Implications

The results carry distinct implications for theory and for policy. For theory, the central contribution is to relocate education within models of environmental outcomes from a direct driver to an upstream, mediated one. Much cross-national work enters education as one more regressor on emissions and reports a coefficient whose sign and significance are then debated. The present analysis suggests that this specification asks the wrong question of the data: on carbon, income dominates and education is quiet, so a direct education-carbon coefficient will typically be weak regardless of whether education is doing environmental work.

The productive question is not whether education lowers emissions directly but through which channels it operates, and the answer here—the composition of the energy system—places education squarely within the technology term of the STIRPAT decomposition [6] [14] and within the knowledge-and-institutions mechanism of ecological modernization [8]. Education belongs in these models as a shaper of the technology multiplier, not as an independent subtractor of carbon.

The delineated design also has a methodological implication for the literature. Because the six education measures bear on different environmental margins—and, in the case of master's and bachelor's attainment on the renewable share, in opposite directions—an aggregate education index averages away the mechanism. Studies that represent education by a single measure risk reporting a null where offsetting channels cancel, or a significant coefficient whose interpretation is opaque because it pools distinct pathways. Keeping the facets of education separate is not a mere robustness nicety; it is what makes the mechanism visible.

For policy, the implication is correspondingly specific. If education greens the environment by greening the energy system, then the environmental return to education is realized where educational investment translates into a higher renewable share of final energy use—through the financing captured by education spending and the skills captured by advanced human capital. Investments in education that build the engineering, research, and institutional capacity for the energy transition are where the environmental payoff concentrates; general increases in attainment, absent that translation into energy-system change, are a weaker lever on carbon over the horizons observed here. This is a more targeted claim than the familiar assertion that education is good for the environment, and a more actionable one: it points policymakers toward the specific human-capital investments—in the financing and the skills of decarbonization—that the evidence links to cleaner energy and, through it, to lower carbon.

None of this implies that the broader civic and cognitive benefits of education are irrelevant to the environment; the design simply cannot see them over a short panel dominated by between-country variation. What it can see, and what it recommends acting on, is the energy-composition channel through which education's environmental value most clearly and most measurably runs.

9. Scope and Limitations

Several limitations bound these conclusions. The panel is short and unbalanced, averaging 4.1 years per country, which—combined with the slow-moving nature of education stocks—precludes credible within-country and dynamic-panel identification; we rely on cross-country variation and say so. The analysis is association-based: education, income, and the energy mix are jointly determined, and although we control for income and test mediation, unobserved time-varying confounders may remain. The mediation analysis assumes the standard sequential-ignorability conditions, which cannot be fully verified, so the indirect effect should

be read as evidence consistent with the hypothesized channel rather than as a fully identified causal mechanism. Because education spending, the renewable share, and CO_2 are measured contemporaneously, the mediation cannot establish that spending precedes the change in the energy mix or that the energy mix precedes the change in carbon. Apart from the spending-renewables association, the cell-level results do not survive adjustment for multiple testing and are exploratory.

Several measures are imperfect proxies: attainment stocks change slowly, scientific output captures only one facet of research capacity, and forest depletion is a monetized adjusted-savings measure. The renewable-energy share measures renewable final-energy consumption, including traditional biomass; it does not isolate clean-electricity deployment or the displacement of fossil fuels in power generation, and the mediation result pertains to renewable final-energy use. The renewable-energy share serves here as a single mediator, whereas the true pathway likely involves multiple channels—efficiency, regulation, and behaviour—that the data do not separate. A single-mediator model attributes to the renewable share what may in part flow through correlated channels, so the estimated indirect effect should be understood as the effect of the energy-composition pathway broadly construed rather than of renewable adoption alone. These limitations point to the value of longer panels, finer education measures, and richer mediation models capable of distinguishing the channels through which education greens the environment.

10. Conclusions and Future Research

Across 97 countries, education is inversely related to climate change—on specific margins and partly through the energy mix. Cross-nationally, education spending and advanced human capital are associated with a greater renewable share and cleaner air, although only the spending-renewables association survives adjustment for multiple testing; a within-between decomposition places these associations between countries rather than within them, as a short panel offers little within-country variation in slow-moving education stocks; and about half of education spending's association with carbon runs through the renewable-energy share as a significant indirect association, alongside a direct association of similar size that is not statistically significant. The three findings are one story told at three levels: a delineated cross-country mapping, a between-versus-within decomposition, and a mediation that locates the mechanism.

Future research should extend the panel so that within-country and dynamic analysis become feasible; disaggregate education by field and quality rather than attainment alone; and broaden the mediation model beyond renewable energy to include efficiency, regulation, and behavioural channels, so that the full set of pathways through which education bears on the climate can be identified. A longer panel would allow the slow-moving stock of attainment to reveal whatever within-country effect it has; field-level education data would show whether the environmental return concentrates in the scientific and technical disciplines that

the mechanism implicates; and a multi-mediator design would apportion the indirect effect among the channels that a single renewable-share mediator here bundles together. The central lesson—that education's environmental association is visible chiefly on the energy-composition margin and is partly mediated by it—suggests that both scholarship and policy should focus on the channels that translate human capital into a cleaner energy system.

Reproducibility. All statistics are derived from rb_build_panel.py, rb_full_analysis.py, rb_mediation.py, rb_revision.py, and rb_display_build.py applied to the frozen WDI panel; figures are from rb_fig1.py and rb_figs.py; results JSONs and a SHA-256 manifest accompany the manuscript.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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