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Decoupling Air Pollution from Economic Growth: District-Level Evidence from the Khorezm Region, Uzbekistan (2017–2024)

Raximov Faxriddin Shavkatovich*¹

1. Independent researcher, Urgench State University named after Abu Rayhon Beruniy, Urgench, Uzbekistan

* Correspondence: faxriddinraximov.uz@gmail.com

Abstract: Managing a region's natural capital well means understanding how economic growth relates to the environmental cost of air pollution, yet little sub-national evidence exists for the arid, agriculture-based economies of Central Asia. This paper studies how air pollutant emissions changed across the thirteen territorial units of Uzbekistan's Khorezm region between 2017 and 2024, and asks how effective regional environmental management has been. Drawing on official statistics for emissions and gross regional product (GRP), it applies five tools: an emission-intensity index measured against real GRP, the Tapio decoupling elasticity, concentration indices, a cross-district convergence regression, and correlation analysis of structural drivers. The picture is one of real but fragile decoupling. Emission intensity relative to real output fell by roughly 73 per cent between 2017 and 2023, then rebounded sharply in 2024; five of the seven annual observations qualify as strong decoupling under the Tapio classification. Emissions are highly concentrated in space, with a Herfindahl index between 0.24 and 0.50 and the largest single source accounting for up to 70 per cent of the regional total, and the districts show no significant convergence. Intensity is negatively correlated with the renewable-energy share, reclaimed land, real output and electricity use, and the main pattern survives the removal of the dominant emitter. The paper argues for a shift from uniform to spatially differentiated environmental policy and for bringing natural-capital accounting into regional economic decisions.

Keywords: Air pollution, decoupling, natural capital, emission intensity, Tapio elasticity, spatial concentration, regional economy, Khorezm, Uzbekistan, sustainable development.

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1. Introduction

Few questions in regional economics matter more than whether an economy can grow without steadily degrading its environment. Air pollution is one of the sharpest versions of that trade-off. It damages health, farm output and ecosystem services, and those costs rarely appear in ordinary measures of production [1]. The stakes are highest in dry, water-short, farming-dependent regions, where the natural-resource base is at once the main asset and the main limit on development.

Uzbekistan has combined rapid modernisation with a stated commitment, under its green-economy strategy, to make growth less resource- and emission-intensive [2]. Khorezm, in the lower Amu Darya basin next to the stressed Aral Sea zone, is a good place to test that commitment. Its economy runs on irrigated agriculture, its ecology is fragile, and its make-up of eleven districts and two cities gives enough internal variation to see how the pollution burden is shared and how it moves as the economy expands [3].

Even so, sub-national evidence for Central Asia is scarce. Most work on the growth and pollution link in the region stays at the national level and misses the large differences between territories inside a single region. And where regional studies do consider natural capital, air pollution is often treated apart from the growth that produces it, so the key policy question, how tightly the two are coupled, goes unanswered at the local scale [4].

This paper sets out to close part of that gap. It has three aims: to describe how air pollutant emissions moved across Khorezm's districts and cities between 2017 and 2024; to measure how far those emissions decoupled from real regional growth, how concentrated they are, and whether the districts are converging; and, on that basis, to judge how well environmental management has worked and what it implies for a place-based regional policy. The object of study is the territorial units of Khorezm; the subject is the relationship between their economic growth and their air pollution [5-6].

Three strands of research inform this study. The first is the theory of natural capital, which treats the environment as an asset that yields a flow of services and can be built up or run down. Costanza and Daly placed natural capital at the centre of sustainable development, and Costanza et al. put the valuation of ecosystem services on the agenda. Ostrom showed how institutions govern shared natural resources, while Helm and, more recently, the World Bank's wealth-accounting work have pressed the case for measuring natural capital and folding it into national accounts. Seen this way, clean air is part of a region's environmental capital, and its loss is an economic cost rather than a side issue [7].

The second strand concerns the shape of the growth and environment relationship. The Environmental Kuznets Curve (EKC) hypothesis, associated with Grossman and Krueger, suggests that pollution first rises and then falls as incomes grow [8]. The empirical record is mixed. Dinda surveys the many conditions under which the pattern does or does not appear, and Stern warns that the curve is neither automatic nor econometrically robust. What most authors now accept is that any downturn in pollution depends on structural change, cleaner technology and deliberate policy, not on income alone [9].

The third strand supplies the measurement tools. The OECD framework and, above all, Tapio's decoupling elasticity make it possible to ask directly whether environmental pressure is growing faster or slower than output. The elasticity is the ratio of the two growth rates, and it sorts the relationship into states running from strong decoupling, where output rises while pressure falls, to expansive negative decoupling, where pressure outpaces output [10]. Applying this to 192 countries, Wang and Su found a persistent gap between richer economies, which tend to decouple, and emerging ones, which often do not. Renewable energy, for its part, has repeatedly been shown to pull emissions down [11].

Evidence for Central Asia is thinner and mostly national. Apergis and Payne examined the post-Soviet states, and for the five Central Asian republics Zhang found no reliable inverted-U but did find that renewable energy lowers emissions while urbanisation raises them. For Uzbekistan in particular, Nuriddinova and Ahmad place the country on the rising branch of the EKC, and the IEA sets out both the scale of its decarbonisation task and the promise of its renewable resources [12]. Recent regional work has begun to link green and energy resources to development across Central Asia and to examine the drivers of its carbon emissions [13]. What is still missing, and what this paper provides, is a district-level reading of decoupling for a single arid Uzbek region, where a few large emitters sit on top of a low-emitting farming base.

2. Data and methods

Data

The analysis uses official figures from the National Statistics Committee of the Republic of Uzbekistan and the Khorezm Regional Statistical Department. Two datasets are involved. One gives total air pollutant emissions, in thousand tonnes, for each of the region's thirteen territorial units (eleven districts and the cities of Urgench and Khiva) for every year from 2017 to 2024. The other gives annual indicators for the region as a whole: gross regional product (GRP) at current prices, the official real GRP growth rate, electricity use, the renewable share of energy supply, and the area of farmland whose reclamation condition improved. The emissions series is a single aggregate of pollutants as recorded by the statistical office, not a speciated measure such as carbon dioxide; the implications of this are taken up in the limitations [14].

One point about the GRP series needs care. Because it is measured at current prices in som, its nominal rise over the period is heavily inflated by price growth and cannot stand in for real activity. To avoid overstating decoupling, the study builds a real GRP volume index (2017 = 100) from the official real growth rates and runs all intensity and decoupling calculations against that index rather than against nominal GRP [15].

Methods

The study uses five tools.

(i) Emission intensity, total emissions per unit of real output, expressed as an index (2017 = 100):

$$EI_t = [(E_t / GRP_{real,t}) / (E_{2017} / GRP_{real,2017})] \times 100$$

(ii) The Tapio decoupling elasticity (Tapio, 2005), the annual percentage change in emissions divided by the annual percentage change in real GRP:

$$e_t = \% \Delta E_t / \% \Delta GRP_{real,t}$$

With output growing, the outcome is strong decoupling ($e < 0$), weak decoupling ($0 \leq e < 0.8$), expansive coupling ($0.8 \leq e \leq 1.2$) or expansive negative decoupling ($e > 1.2$).

(iii) Spatial concentration. Three measures are computed for each year: the share of the largest single emitter, the Herfindahl–Hirschman index (HHI, the sum of squared shares of all units), and the coefficient of variation (CV) of emissions across units. Higher values mean the burden falls on fewer places [16].

(iv) Cross-district convergence. To test whether high- and low-emitting districts are moving closer together, a β -convergence regression is estimated across the twelve units with a complete series: the mean annual growth rate of emissions over 2017–2024 is regressed on the natural logarithm of 2017 emissions. A negative slope would indicate convergence [17].

(v) Association with structural drivers. Because the candidate drivers (the renewable-energy share, the reclaimed-land area, real GRP and electricity use) are available only at the regional level, their link with emission intensity is examined through Pearson correlations over the eight annual observations [18]. With so few years these coefficients are read as descriptive associations, not as causal estimates; a district-level panel of causes and a formal decomposition are left for future work.

3. Results

Spatial and temporal dynamics of emissions

Table 1 reports emissions for the thirteen territorial units over 2017–2024. Two things stand out: the dominance of the regional centre and the unsteadiness of the series from year to year.

Table 1. Air pollutant emissions by territorial unit, Khorezm region, 2017–2024
(thousand tonnes)

Territorial unit	2017	2018	2019	2020	2021	2022	2023	2024	2024/2017, %
Urgench city	4.15	4.32	4.30	4.67	5.04	2.76	1.52	6.30	151.8
Khiva city	1.80	0.11	0.29	0.14	0.17	0.14	0.12	0.12	6.7
Bogot	0.07	0.08	0.06	0.04	0.09	0.06	0.06	0.06	85.7
Gurlan	0.20	0.19	0.20	0.14	0.15	0.13	0.12	0.17	85.0
Qoshkopir	0.22	0.17	0.14	0.14	0.12	0.10	0.12	0.10	45.5
Urgench (district)	0.38	0.43	0.56	0.29	0.40	0.27	0.24	0.29	76.3
Khazarasp	0.73	0.24	0.63	0.18	0.13	0.09	0.11	0.10	13.7
Tuprakkala	–	–	–	0.32	0.40	0.39	0.49	0.37	–
Khonqa	0.15	0.18	0.17	0.18	0.15	0.15	0.17	0.15	100.0
Khiva (district)	0.11	0.09	0.08	0.11	0.09	0.08	0.11	0.13	118.2
Shovot	0.23	0.21	0.17	0.15	0.17	0.14	0.15	0.18	78.3
Yangiariq	1.12	0.94	0.46	0.48	0.18	0.12	0.12	1.83	163.4
Yangibazar	0.10	0.10	0.11	0.06	0.15	0.06	0.05	0.07	70.0
Khorezm region	9.25	7.05	7.16	6.92	7.23	4.49	3.38	9.87	106.7

Source: compiled by the author from data of the National Statistics Committee of the Republic of Uzbekistan and the Khorezm Regional Statistical Department. Data for Tuprakkala are available only from 2020.

Total regional emissions fell from 9.25 thousand tonnes in 2017 to just 3.38 thousand tonnes in 2023, a drop of almost two-thirds, before jumping back to 9.87 thousand tonnes in 2024. The net change across the whole period is therefore small, at 6.7 per cent, but that figure hides a clear downward path through 2023 that the last year abruptly undoes. Figure 1 sets the emissions series against the real GRP index and shows the gap that opens up between the two lines through 2023.

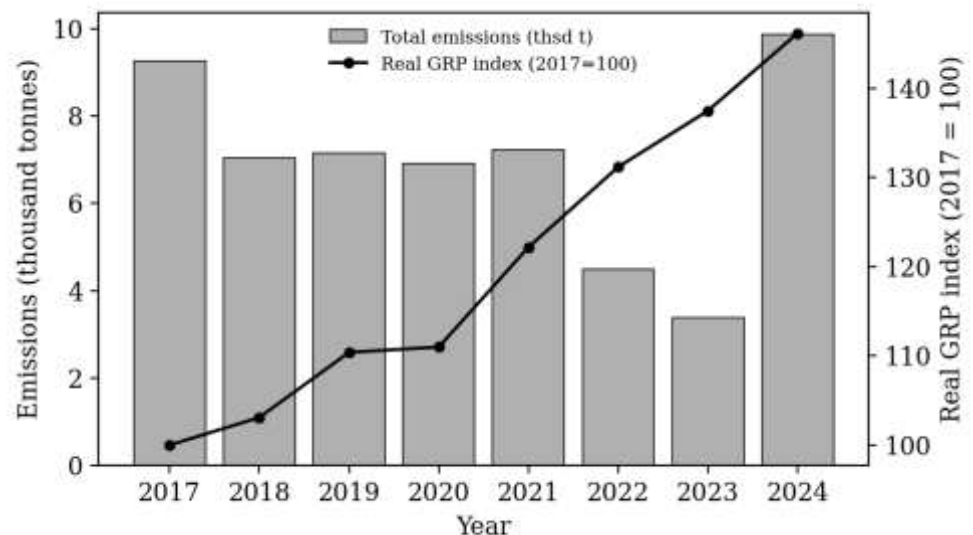


Figure 1. Total air pollutant emissions and the real GRP index, Khorezm region, 2017–2024.

The geography is very uneven. Urgench city, the administrative and industrial hub, is the largest source throughout, and its weight grows over time: its share of regional emissions rises from 44.9 per cent in 2017 to 63.8 per cent in 2024. By that year Urgench city and Yangiariq district together produce 82.4 per cent of the regional total [19]. Several

districts cut their emissions sharply, among them Khazarasp (down to 13.7 per cent of its 2017 level), Qoshkopir (45.5 per cent) and Khiva city (6.7 per cent), while Urgench city (151.8 per cent), Yangiariq (163.4 per cent) and Khiva district (118.2 per cent) moved the other way.

Emission intensity and decoupling

To connect emissions to economic activity, Table 2 sets them alongside the region's main indicators and reports the emission-intensity index measured against real GRP.

Table 2. Regional aggregates and emission intensity, Khorezm region, 2017–2024.

Year	Emissions (thsd t)	GRP, current prices (bln som)	Real GRP growth (%)	Real GRP index (2017=100)	Emission intensity index (2017=100)	Renewable energy share (%)	Improved reclaimed land (thsd ha)
2017	9.25	13 548.2	5.6	100.0	100.0	1.8	52.4
2018	7.05	18 184.2	3.1	103.1	73.9	2.4	54.8
2019	7.16	22 262.8	7.1	110.4	70.1	3.1	57.6
2020	6.92	24 668.3	0.5	111.0	67.4	4.5	60.3
2021	7.23	30 907.3	10.1	122.2	64.0	6.8	63.7
2022	4.49	38 927.4	7.4	131.2	37.0	9.7	66.5
2023	3.38	45 358.6	4.8	137.5	26.6	13.2	69.8
2024	9.87	53 640.0	6.3	146.2	73.0	17.5	72.4

Source: compiled and calculated by the author. The real GRP index is built from official annual real growth rates.

Against real output, intensity fell a long way over most of the period. With 2017 set at 100, the index reached 26.6 in 2023, which means the economy was then producing barely a quarter as much air pollution per unit of real output as six years earlier [20]. This is genuine relative decoupling: real GRP grew by about 46 per cent between 2017 and 2024 while emissions rose by less than 7 per cent. The catch is the 2024 value of 73.0, which erases roughly two-thirds of the improvement in a single year (Figure 2). The gain is real, but it is not yet locked in.

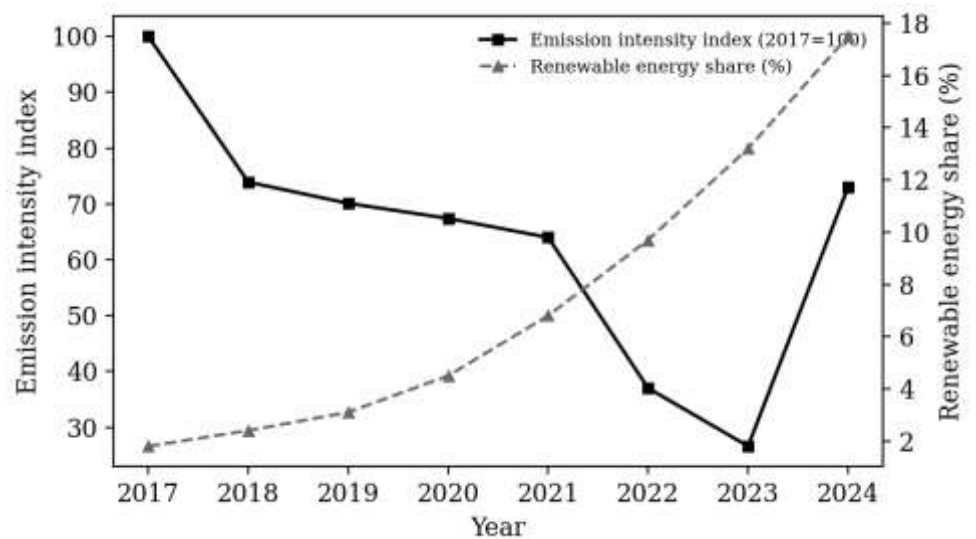


Figure 2. Emission intensity index and the renewable-energy share, Khorezm region, 2017–2024.

The Tapio elasticities in Table 3 tell the same story in sharper form.

Table 3. Tapio decoupling elasticity between emissions and real GRP, Khorezm region, 2018–2024

Year	Change in emissions (%)	Real GRP growth (%)	Elasticity, e	Decoupling state
2018	–23.8	3.1	–7.67	Strong decoupling
2019	+1.6	7.1	0.22	Weak decoupling
2020	–3.4	0.5	–6.70	Strong decoupling
2021	+4.5	10.1	0.44	Weak decoupling
2022	–37.9	7.4	–5.12	Strong decoupling
2023	–24.7	4.8	–5.15	Strong decoupling
2024	+192.0	6.3	30.48	Expansive negative decoupling

Source: calculated by the author following Tapio.

Strong decoupling, the best outcome, appears in five of the seven years, with weak decoupling in the two early exceptions. That looks like a good record, but two points qualify it. The large elasticity values in the strong-decoupling years are mainly an arithmetic effect of dividing big, jumpy changes in emissions by small single-digit growth rates, so the sign and the Tapio category matter here, not the size of the number. More seriously, the run ends with expansive negative decoupling in 2024, when emissions grew far faster than output. Table 1 traces this to sudden rises in Urgench city, from 1.52 to 6.30 thousand tonnes, and in Yangiariq, from 0.12 to 1.83. A jump of that size points either to new emission sources coming on line or to a change in how emissions were measured or reported, and it should be checked against the primary monitoring records before too much weight is placed on it [21].

Spatial concentration and convergence

Table 4 turns the uneven geography of Section 4.1 into numbers. Concentration is high throughout: the Herfindahl–Hirschman index stays between 0.24 and 0.50, above the 0.25 level usually taken to mark a concentrated distribution, and the coefficient of variation never falls below 1.5. Both measures climb from 2017 to a peak in 2021, ease back in 2023, and rise again in 2024, closely following the single largest emitter, whose share moves in the same pattern (Figure 3). The burden of air pollution in Khorezm is therefore not only heavy in a few places but persistently so, and its year-to-year swings are driven mainly by one urban source.

Table 4. Concentration of emissions across territorial units, Khorezm region, 2017–2024

Year	HHI	CV	Largest-emitter share (%)
2017	0.263	1.54	44.8
2018	0.401	2.04	61.2
2019	0.382	1.98	60.0
2020	0.470	2.35	67.7
2021	0.495	2.43	69.6
2022	0.395	2.12	61.5
2023	0.240	1.52	45.0
2024	0.446	2.28	63.8

Source: calculated by the author. HHI is the sum of squared unit shares; CV is the coefficient of variation of emissions across units.

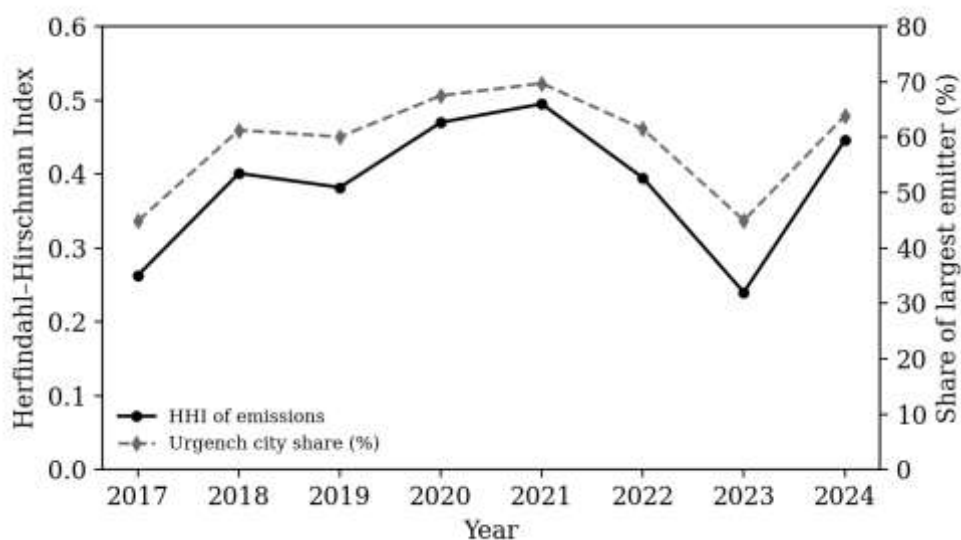


Figure 3. Concentration of emissions: Herfindahl–Hirschman index and the share of the largest emitter.

Whether the districts are drifting together or apart is a separate question. A β -convergence regression across the twelve units with a complete series gives a slope of -0.027 (standard error 0.033 , $R^2 = 0.06$). The sign is negative, as convergence would require, but the coefficient is far from statistically significant ($p = 0.43$). On this evidence the districts are neither clearly converging nor clearly diverging; the distribution of emissions is holding its shape rather than levelling out, which fits the persistence of high concentration in Table 4.

Structural drivers and robustness

Emission intensity moves in the expected direction against every candidate driver. Over 2017–2024 it is negatively correlated with the renewable-energy share ($r = -0.53$), the reclaimed-land area ($r = -0.67$), real GRP ($r = -0.63$) and electricity use ($r = -0.63$). The correlations with reclamation and with real output come closest to conventional significance ($p \approx 0.07$ and 0.09), while the others fall short, which is unsurprising with only eight years of data. The signs line up: as the economy grew, greened its energy mix and improved its land, it produced less pollution per unit of output. Given the short series, these are associations worth noting rather than effects to rely on.

A simple robustness check addresses the worry that the whole story rests on the single dominant emitter. Recomputing the regional totals without Urgench city leaves the pattern intact: emissions still fall by 63.5 per cent from 2017 to 2023 and still rebound, by 91.9 per cent, in 2024. The 2024 spike is thus not an artefact of the city alone, since Yangiariik contributes heavily to it as well, and the core finding of a real but fragile intensity improvement interrupted in the final year does not depend on any one unit.

Discussion

The findings give a mixed but readable picture of growth and pollution in an arid farming region. The main result is relative decoupling: real output grew by nearly half over 2017–2024 while total emissions stayed roughly flat, and for most of the period each unit of output carried less pollution. In the language of natural-capital theory, this is a partial success, since the region added economic value without running down the air-quality part of its environmental capital to the same degree [22].

It is worth setting this against the existing Central Asian evidence. National studies put Uzbekistan on the rising branch of the EKC, with emissions still climbing as income

grows, and find no clean inverted-U for the region as a whole [23]. The Khorezm results do not contradict that. Intensity decoupling, a fall in pollution per unit of output, can happen well before the absolute peak the EKC implies, and it is quite compatible with an economy still on the way up. The district evidence therefore adds a sub-national, intensity-based footnote to the national EKC story, and it fits the broader finding that emerging economies tend to decouple more weakly and less steadily than mature ones [24].

Three caveats keep the reading from being too rosy, and each points to a policy conclusion. The first is that the decoupling is unstable. The 2024 reversal shows how quickly the gains of earlier years can be undone by one or two large sources, and the robustness check confirms that even without the dominant city the series both falls and rebounds. Decoupling here is not yet built into the structure of the economy; it depends on how specific facilities behave, so management should target those large sources directly rather than work from region-wide averages [25].

The second caveat is that the pollution burden is concentrated and staying that way. The Herfindahl index and the coefficient of variation remain high throughout, and the absence of significant convergence means the gap between heavy and light emitters is not closing. The region's environmental pressure is largely an urban and industrial matter laid over a low-emitting farming base, so a single standard applied everywhere is a poor fit. Policy would do better to separate the urban and industrial nodes, where emission controls and cleaner production belong, from the farming districts, where the pressing needs are land reclamation, water efficiency and soil and ecosystem quality [26].

The third caveat is that the tie between falling intensity and the growth of renewables and reclamation, though visible in the correlations and consistent with cross-country work, is not established as cause and effect here, and the short series keeps those coefficients short of significance. The trend will hold only if the structural shifts continue. Should renewable capacity and reclamation stall while activity and its point sources expand, the 2024 reversal may turn out to be the start of re-coupling rather than a one-off [27].

Read together, these points argue for two changes in how the region is governed: a move from uniform to spatially differentiated policy, and a move from watching pollution after the fact toward building natural-capital accounting, air quality included, into planning and investment [28]. That would let the environmental cost of growth be set explicitly against its economic gain, the very comparison the decoupling record suggests the region has so far made only loosely.

4. Conclusion

This paper tracked air pollutant emissions across the thirteen territorial units of Uzbekistan's Khorezm region over 2017–2024 and judged the effectiveness of regional environmental management using emission intensity, Tapio decoupling, concentration indices, a convergence regression and correlation analysis, all applied to official statistics.

Three findings stand out. The region decoupled air pollution from growth to a real but unstable degree: intensity against real output fell by about 73 per cent between 2017 and 2023, most years count as strong decoupling, yet roughly two-thirds of the gain was lost in 2024, a reversal that survives the removal of the dominant emitter. Emissions are highly and persistently concentrated, with no significant convergence between districts, so pollution in Khorezm is mainly an urban and industrial matter over a low-emitting farming base. And intensity is negatively correlated with the rising renewable share, the wider reclamation programme and real output, which points to the green-economy transition as a likely driver even though the short series keeps the link from being proven. On that basis the paper recommends differentiating environmental policy by place, tightening controls on the identified large urban and industrial sources while giving priority to land and water restoration in the farming districts, and bringing natural-capital

accounting into regional decision-making so that the environmental cost of growth is weighed openly. The study has limits that mark out where work should go next. The emissions figure is a single aggregate of pollutants rather than a speciated series such as carbon dioxide, which limits comparability with carbon-based studies; the annual series is short, so the driver correlations and the convergence test are indicative rather than conclusive; and the structural drivers are observed only at the regional level, which rules out a district-level panel of causes. Extending the work to individual pollutants, to a longer series, to source- and sector-level decomposition, and to comparison across the Aral Sea regions would help pin down what actually drives decoupling and would carry the conclusions further. Funding. This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors. Conflict of interest. The author declares no conflict of interest. Data availability. The data analysed here come from the official publications of the National Statistics Committee of the Republic of Uzbekistan and the Khorezm Regional Statistical Department and are available from those sources. Declaration of generative AI. The author used an AI assistant to help edit language and organise the presentation of the analysis. The data, calculations and conclusions are the author's own; the author reviewed and revised the text and takes full responsibility for it.

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