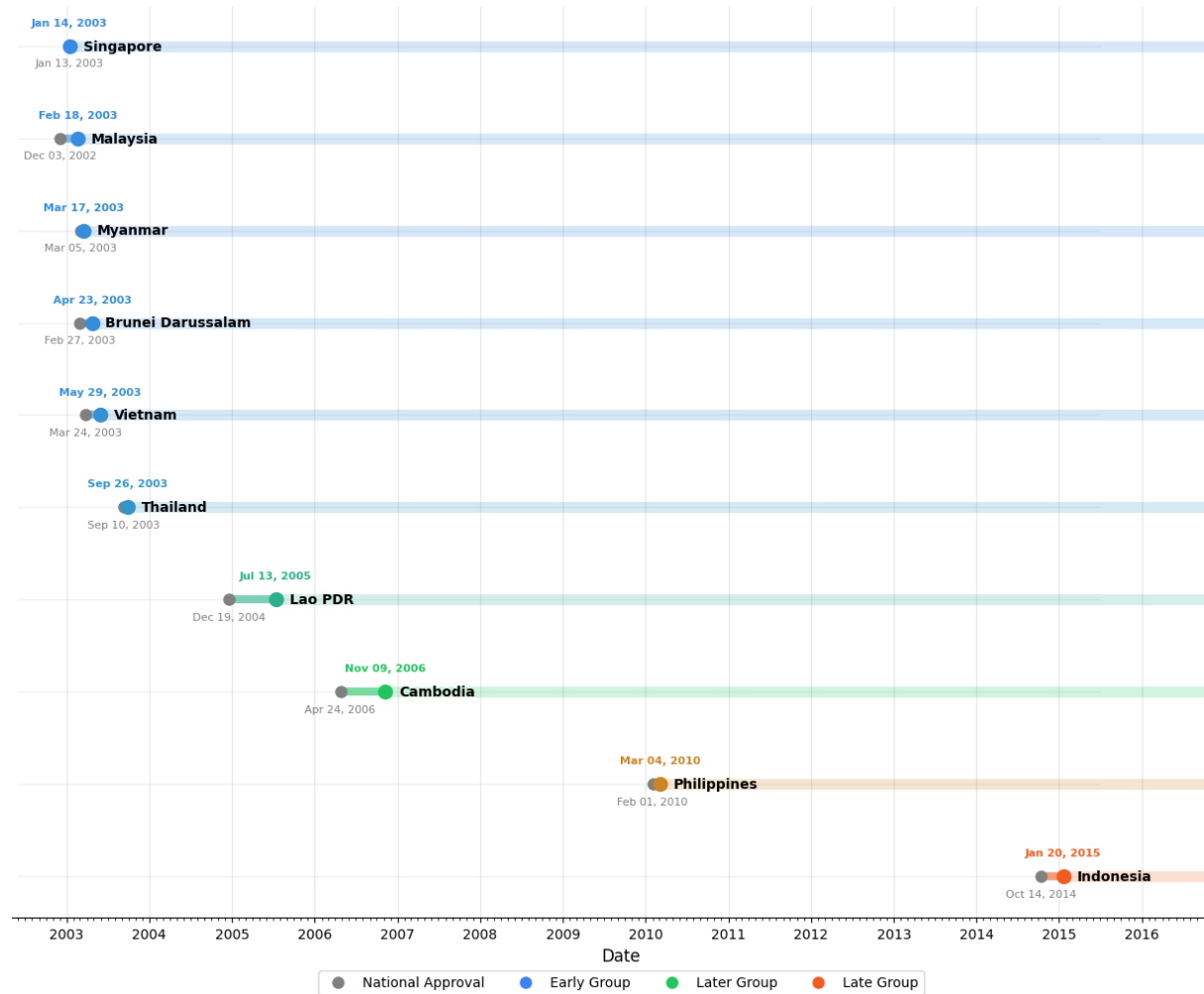


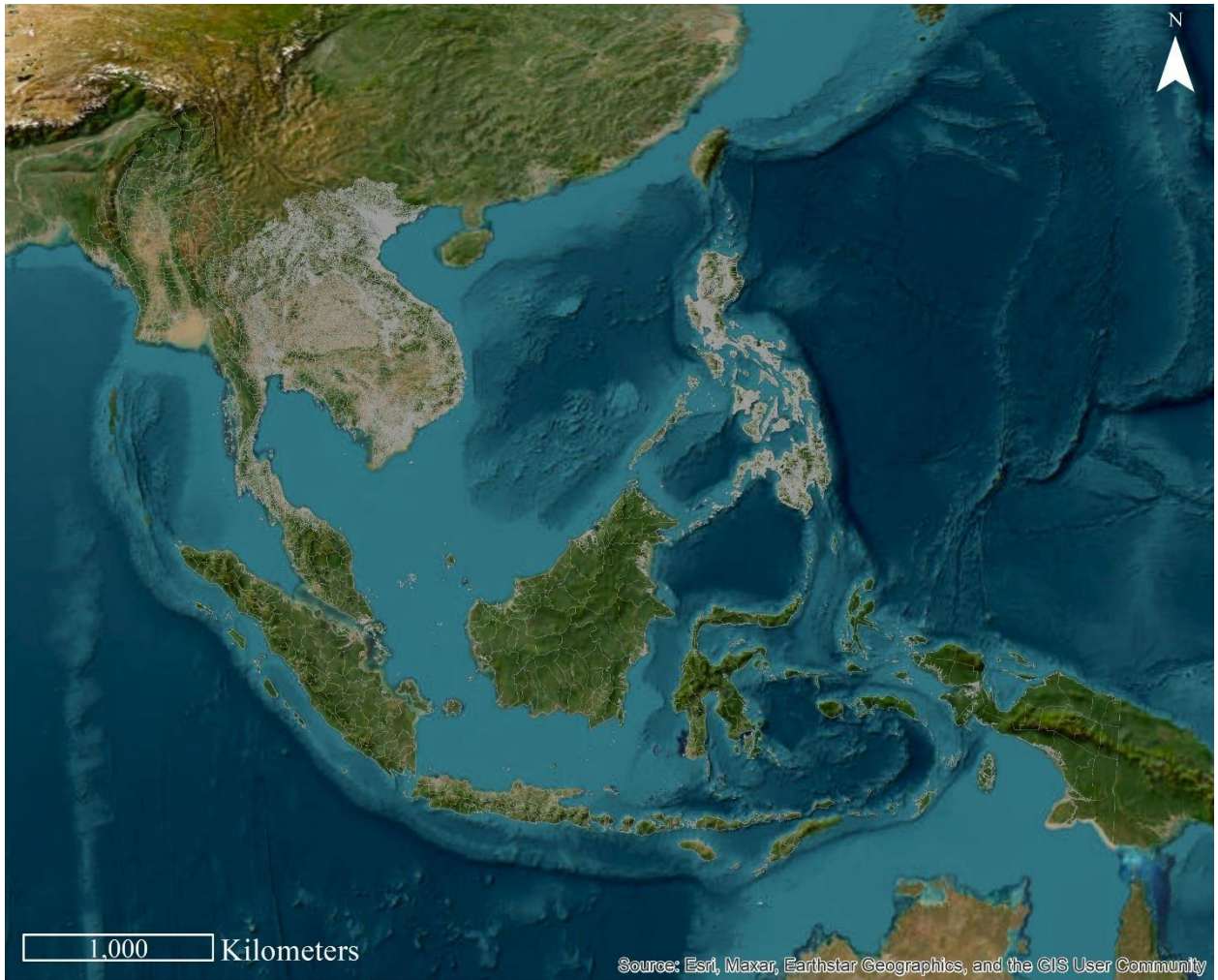
The Effectiveness of the ASEAN Agreement on Transboundary Haze Pollution

Supplementary Information

Supplementary Fig. 1: AATHP adoption timeline by each ASEAN member state



Supplementary Fig. 2: Map of the Study Area



Note: The study area consists of 41,932 delineated community units, depicted in light gray lines.

Supplementary Table 1. Full DiD-RDiT regression estimation of the Association of Southeast Asian Nations Agreement on Transboundary Haze Pollution effect on haze levels with varying bandwidths

bandwidth	Haze (± 3month)	Haze (± 6month)	Haze (± 1 year)	Haze (± 2 year)	Haze (± 3 year)	Haze (± 5 year)	Haze (± 10 year)
treated	-3.337*** (0.105)	-2.871*** (0.095)	-2.774*** (0.089)	-2.885*** (0.083)	-2.903*** (0.083)	-2.844*** (0.081)	-2.838*** (0.083)
wind speed	-0.127*** (0.012)	-0.118*** (0.008)	-0.083*** (0.006)	-0.074*** (0.005)	-0.067*** (0.005)	-0.063*** (0.005)	-0.062*** (0.004)
wind direction	-0.034*** (0.012)	-0.016** (0.006)	0.019*** (0.004)	0.041*** (0.004)	0.050*** (0.004)	0.063*** (0.003)	0.071*** (0.003)
drought index	0.022*** (0.007)	0.019*** (0.007)	0.008** (0.004)	0.012*** (0.003)	0.010*** (0.003)	0.003 (0.002)	-0.003** (0.001)
precipitation	0.135*** (0.010)	0.064*** (0.007)	0.110*** (0.004)	0.080*** (0.004)	0.102*** (0.003)	0.102*** (0.003)	0.116*** (0.003)
temperature	0.009 (0.014)	-0.027*** (0.010)	-0.062*** (0.009)	-0.080*** (0.008)	-0.090*** (0.008)	-0.082*** (0.007)	-0.073*** (0.007)
population density	-0.024*** (0.007)	-0.023*** (0.005)	-0.014*** (0.005)	-0.009** (0.004)	-0.016*** (0.004)	-0.007** (0.004)	-0.001 (0.003)
urbanization	0.069*** (0.008)	0.073*** (0.008)	0.070*** (0.007)	0.065*** (0.007)	0.065*** (0.007)	0.056*** (0.006)	0.048*** (0.005)
urban population	-1.961*** (0.708)	-1.214*** (0.449)	0.545 (0.337)	-0.119** (0.058)	0.090** (0.042)	0.500*** (0.040)	-0.049*** (0.013)
burn index	-0.001 (0.002)	0.001 (0.002)	0.001 (0.002)	-0.001 (0.001)	-0.002 (0.001)	0.003*** (0.001)	0.005*** (0.001)
forest coverage	-0.122*** (0.006)	-0.130*** (0.005)	-0.135*** (0.005)	-0.134*** (0.005)	-0.131*** (0.005)	-0.128*** (0.004)	-0.127*** (0.004)
GDP per capita	-2.453*** (0.330)	-0.250 (0.241)	-0.012 (0.073)	0.188*** (0.019)	0.061*** (0.011)	0.008 (0.005)	-0.009** (0.004)
economic growth	-0.266** (0.018)	-0.126** (0.014)	-0.051** (0.008)	-0.054** (0.003)	-0.032** (0.002)	-0.031*** (0.002)	-0.028*** (0.001)
educational attainment	-6.570*** (0.450)	-4.058*** (0.226)	-1.084*** (0.100)	0.095*** (0.037)	0.028 (0.026)	-0.103*** (0.025)	-0.089*** (0.008)
government effectiveness	0.224* (0.136)	0.106 (0.082)	-0.128** (0.064)	0.190*** (0.015)	0.336*** (0.013)	0.103*** (0.009)	0.038*** (0.004)
HDI	-0.015 (0.034)	-0.004 (0.030)	-0.366*** (0.066)	-0.245*** (0.036)	-0.285*** (0.033)	-0.259*** (0.022)	0.083*** (0.007)
constant	-35.728*** (3.149)	-22.905*** (1.622)	-3.181*** (0.789)	1.360*** (0.168)	1.185*** (0.132)	0.557*** (0.107)	0.951*** (0.051)
<i>n</i>	366,442	668,830	1,273,104	2,459,837	3,557,937	5,592,738	10,142,330
<i>R</i> ²	0.289	0.261	0.210	0.206	0.219	0.216	0.225

Note: The dependent variable is the standardized level of haze. The bandwidth indicates the time before and after each ASEAN state ratified the agreement. Each coefficient in the model represents a beta coefficient due to standardization methods. Standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Supplementary Table 2a. Full DiD-RDiT regression estimation of the Association of Southeast Asian Nations Agreement on Transboundary Haze Pollution effect on haze levels of coastal communities

bandwidth	Haze (± 3month)	Haze (± 6month)	Haze (± 1 year)	Haze (± 2 year)	Haze (± 3 year)	Haze (± 5 year)	Haze (± 10 year)
treated	-3.809*** (0.158)	-3.277*** (0.142)	-3.228*** (0.133)	-3.342*** (0.124)	-3.334*** (0.127)	-3.256*** (0.124)	-3.177*** (0.127)
wind speed	-0.075*** (0.016)	-0.108*** (0.011)	-0.044*** (0.007)	-0.034*** (0.006)	-0.025*** (0.006)	-0.031*** (0.006)	-0.028*** (0.005)
wind direction	-0.042** (0.021)	0.015 (0.010)	0.037*** (0.007)	0.068*** (0.006)	0.071*** (0.005)	0.093*** (0.005)	0.095*** (0.004)
drought index	0.049*** (0.009)	0.048*** (0.009)	0.038*** (0.006)	0.042*** (0.005)	0.040*** (0.004)	0.019*** (0.003)	-0.002 (0.002)
precipitation	0.145*** (0.018)	0.068*** (0.010)	0.113*** (0.006)	0.086*** (0.005)	0.102*** (0.004)	0.103*** (0.004)	0.116*** (0.004)
temperature	-0.057*** (0.021)	-0.091*** (0.014)	-0.099*** (0.013)	-0.136*** (0.011)	-0.144*** (0.010)	-0.124*** (0.011)	-0.099*** (0.011)
population density	-0.001 (0.006)	-0.005 (0.006)	-0.001 (0.005)	0.001 (0.005)	0.000 (0.005)	0.001 (0.005)	0.001 (0.004)
urbanization	0.091*** (0.012)	0.096*** (0.013)	0.090*** (0.012)	0.083*** (0.012)	0.081*** (0.011)	0.070*** (0.010)	0.055*** (0.007)
urban population	3.671*** (0.353)	1.376* (0.788)	1.192*** (0.290)	0.066 (0.155)	0.093 (0.058)	0.481*** (0.033)	0.049** (0.020)
burn index	0.005 (0.003)	-0.001 (0.002)	0.010*** (0.002)	0.006*** (0.002)	0.005*** (0.002)	0.007*** (0.002)	0.005*** (0.002)
forest coverage	-0.116*** (0.007)	-0.128*** (0.007)	-0.134*** (0.006)	-0.137*** (0.006)	-0.137*** (0.006)	-0.137*** (0.006)	-0.137*** (0.005)
GDP per capita	-5.436*** (0.292)	-2.850*** (0.241)	-0.347*** (0.059)	0.170*** (0.034)	0.111*** (0.017)	0.034*** (0.007)	0.019*** (0.005)
economic growth	-0.179** (0.025)	-0.149** (0.023)	-0.034** (0.007)	-0.048** (0.005)	-0.031** (0.003)	-0.029** (0.003)	-0.028** (0.002)
educational attainment	-3.903*** (0.487)	-2.467*** (0.220)	-1.739*** (0.147)	0.267*** (0.063)	0.128*** (0.043)	-0.122*** (0.025)	-0.111*** (0.010)
government effectiveness	1.394*** (0.089)	0.876*** (0.060)	-0.086** (0.041)	0.243*** (0.025)	0.322*** (0.019)	0.163*** (0.009)	0.029*** (0.005)
HDI	-0.197* (0.102)	-0.447* (0.265)	-0.741*** (0.284)	-0.787*** (0.152)	-0.513*** (0.083)	-0.426*** (0.049)	0.019 (0.017)
constant	-13.660*** (1.778)	-12.998*** (1.218)	-6.787*** (0.916)	1.182*** (0.275)	1.181*** (0.169)	0.363*** (0.117)	1.256*** (0.077)
<i>n</i>	160,655	296,778	565,735	1,101,801	1,615,300	2,606,527	4,823,718
<i>R</i> ²	0.318	0.296	0.226	0.221	0.222	0.212	0.222

Note: The dependent variable is the standardized level of haze. The bandwidth indicates the time before and after each ASEAN state ratified the agreement. Each coefficient in the model represents a beta coefficient due to standardization methods. Standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Supplementary Table 2b. Full DiD-RDiT regression estimation of the Association of Southeast Asian Nations Agreement on Transboundary Haze Pollution effect on haze levels of non-coastal communities

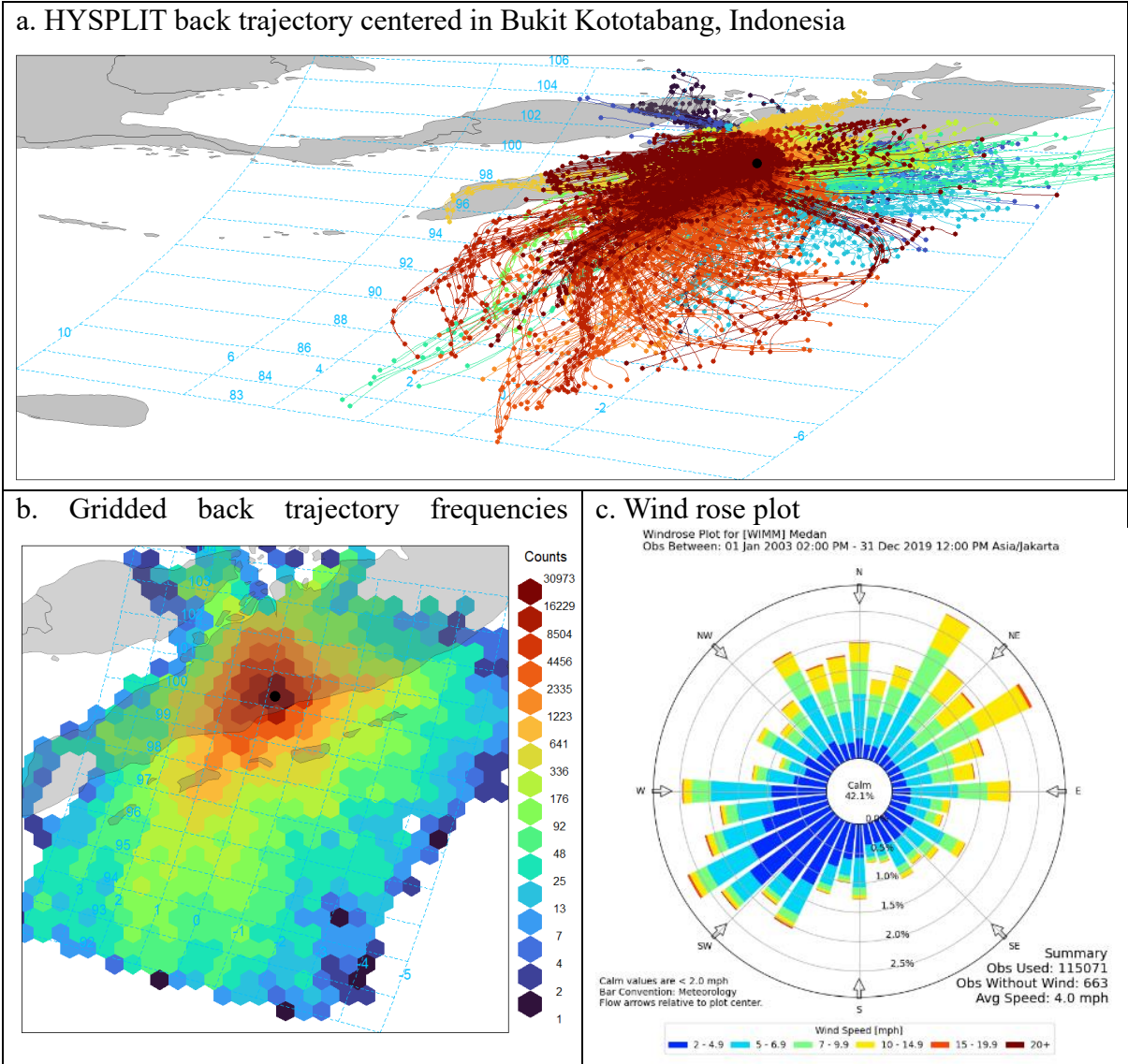
bandwidth	Haze (± 3month)	Haze (± 6month)	Haze (± 1 year)	Haze (± 2 year)	Haze (± 3 year)	Haze (± 5 year)	Haze (± 10 year)
treated	-2.949*** (0.122)	-2.604*** (0.112)	-2.482*** (0.103)	-2.591*** (0.095)	-2.640*** (0.094)	-2.588*** (0.091)	-2.626*** (0.093)
wind speed	-0.184*** (0.015)	-0.150*** (0.010)	-0.138*** (0.009)	-0.129*** (0.007)	-0.130*** (0.006)	-0.116*** (0.006)	-0.115*** (0.005)
wind direction	-0.039*** (0.015)	-0.037*** (0.008)	0.012** (0.006)	0.031*** (0.005)	0.040*** (0.005)	0.043*** (0.004)	0.054*** (0.004)
drought index	0.012 (0.009)	0.006 (0.010)	-0.016*** (0.006)	-0.012** (0.005)	-0.012*** (0.005)	-0.011*** (0.004)	-0.004** (0.002)
precipitation	0.063*** (0.013)	0.050*** (0.009)	0.083*** (0.006)	0.053*** (0.006)	0.081*** (0.005)	0.083*** (0.004)	0.105*** (0.004)
temperature	0.029 (0.018)	-0.002 (0.013)	-0.058*** (0.011)	-0.063*** (0.009)	-0.080*** (0.010)	-0.078*** (0.009)	-0.077*** (0.008)
population density	-0.036*** (0.010)	-0.028*** (0.007)	-0.020*** (0.006)	-0.013** (0.005)	-0.023*** (0.005)	-0.009** (0.004)	-0.000 (0.003)
urbanization	0.056*** (0.011)	0.053*** (0.009)	0.050*** (0.009)	0.045*** (0.010)	0.044*** (0.010)	0.034*** (0.008)	0.031*** (0.006)
urban population	-3.281*** (0.459)	-2.007*** (0.118)	0.478 (0.329)	-0.092 (0.058)	0.106** (0.052)	0.496*** (0.055)	-0.030 (0.019)
burn index	-0.001 (0.002)	0.001 (0.002)	-0.002 (0.002)	-0.002 (0.002)	-0.003* (0.002)	0.002* (0.001)	0.005*** (0.001)
forest coverage	-0.113*** (0.008)	-0.120*** (0.007)	-0.126*** (0.007)	-0.125*** (0.007)	-0.121*** (0.007)	-0.117*** (0.006)	-0.115*** (0.006)
GDP per capita	-0.813 (2.044)	0.868*** (0.189)	0.261*** (0.085)	0.221*** (0.020)	0.005 (0.017)	-0.029** (0.012)	-0.048*** (0.013)
economic growth	-0.310** (0.088)	-0.125** (0.009)	-0.054** (0.010)	-0.051** (0.004)	-0.034** (0.003)	-0.029** (0.003)	-0.025*** (0.002)
educational attainment	-9.802*** (0.583)	-5.414*** (0.314)	-0.648*** (0.123)	0.110** (0.049)	0.045 (0.040)	-0.056 (0.041)	-0.067*** (0.013)
government effectiveness	-0.028 (0.294)	-0.275*** (0.077)	-0.142* (0.076)	0.099*** (0.019)	0.325*** (0.018)	0.063*** (0.013)	0.047*** (0.006)
HDI	-0.037 (0.034)	-0.050** (0.020)	-0.329*** (0.061)	-0.180*** (0.032)	-0.250*** (0.035)	-0.217*** (0.027)	0.088*** (0.008)
constant	-56.666*** (4.305)	-31.490*** (2.092)	-0.380 (1.044)	1.730*** (0.225)	1.313*** (0.193)	0.722*** (0.168)	0.704*** (0.069)
<i>n</i>	205,787	372,052	707,369	1,358,036	1,942,637	2,986,211	5,318,612
<i>R</i> ²	0.271	0.235	0.198	0.195	0.217	0.215	0.224

Note: The dependent variable is the standardized level of haze. The bandwidth indicates the time before and after each ASEAN state ratified the agreement. Each coefficient in the model represents a beta coefficient due to standardization methods. Standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

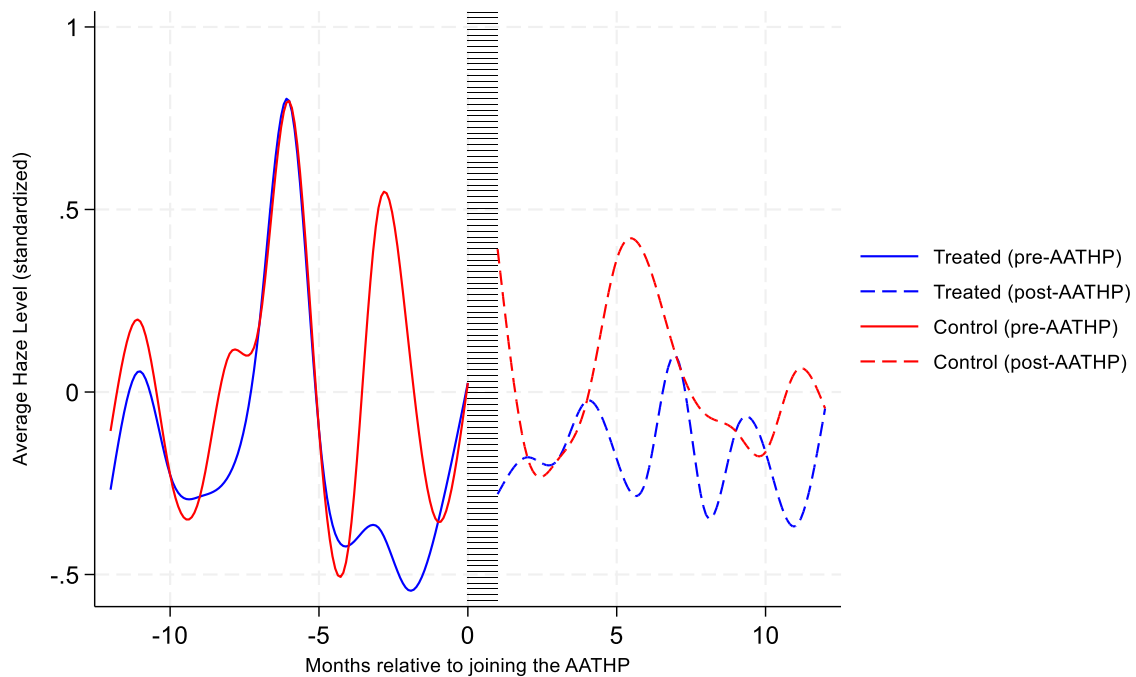
32 **Supplementary Table 3. Variable definitions and summary statistics**

Variable	Description	Mean	S.D.	Min	Max
haze	Aerosol Optical Depth 47	248.15	117.77	0	568.41
time ($R_{it} - R^*$)	Months relative to joining the agreement	2.05	6.35	-14	16
treated (T_{it})	agreement ratification *	0.51	0.50	0	1
<i>Climate</i>					
wind speed	Speed of wind (m/s)	1.63	1.28	0	11.39
wind direction	Direction of wind **	138.77	87.65	0	360
drought	Drought severity	0.14	0.39	0	3
precipitation	Total precipitation (mm)	206.37	170.44	0	1872.89
temperature	Average temperature (°C)	25.49	2.37	-1.67	34.23
<i>Urban Development</i>					
population density	100 persons per km ²	2.69	23.55	0	945.18
urbanization	Nighttime light index (0 - 63)	8.96	14.16	0	63
urban population	% of population living in urban areas	42.79	8.62	18.70	100
burn index	Severity of burnt area (0 – 500) ***	1.49	18.00	0	366
forest coverage	% coverage of forest area	15.85	14.70	0	40.33
<i>Socioeconomic Institutional Capacity Indicators</i>					
GDP per capita	GDP per capita (USD 100)	26.39	39.15	1.31	668.59
economic growth	% of economic growth rate	4.12	2.05	-3.70	12.70
education	Tertiary school enrollment % of all eligible children	30.71	9.12	2.38	91.09
government effectiveness	Government effectiveness index (0 – 6)	3.00	0.30	1.38	5.43
HDI	Human Development Index (0 - 100)	67.43	4.29	30.5	94.3

33 Note: $*T_{it}$ is a treatment variable indicating whether a country ratified the ASEAN Agreement on
34 Transboundary Haze Pollution (1 if treated, 0 otherwise).
35 ** Wind direction is expressed in degrees, with 0° representing wind from the north, 90° from the east, 180°
36 from the south, and 270° from the west.
37 *** Burn index values above 0 represent burned areas, with 0 representing unburned areas.

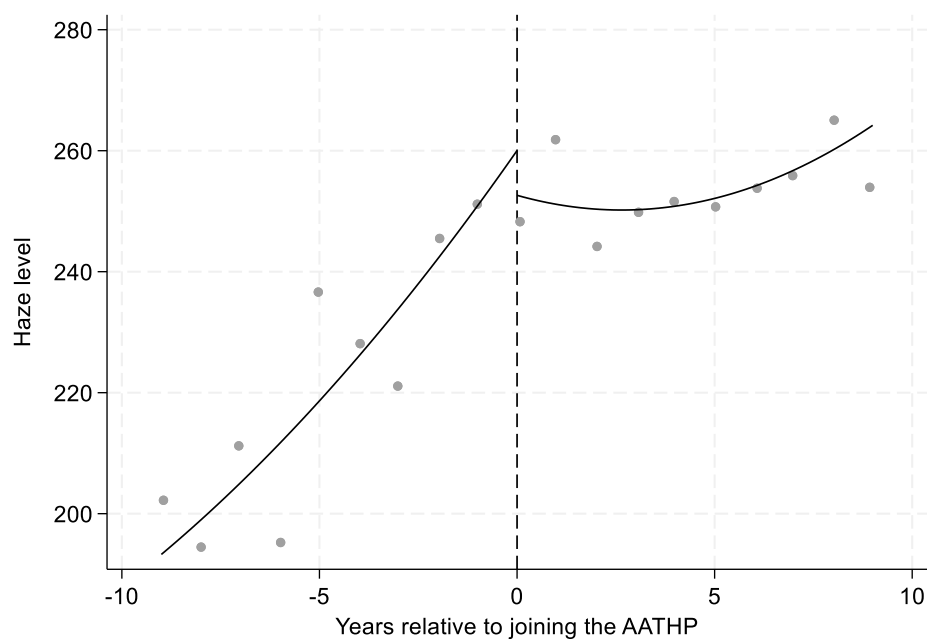


Supplementary Fig. 4: Staggered Difference-in-Differences Parallel Trends



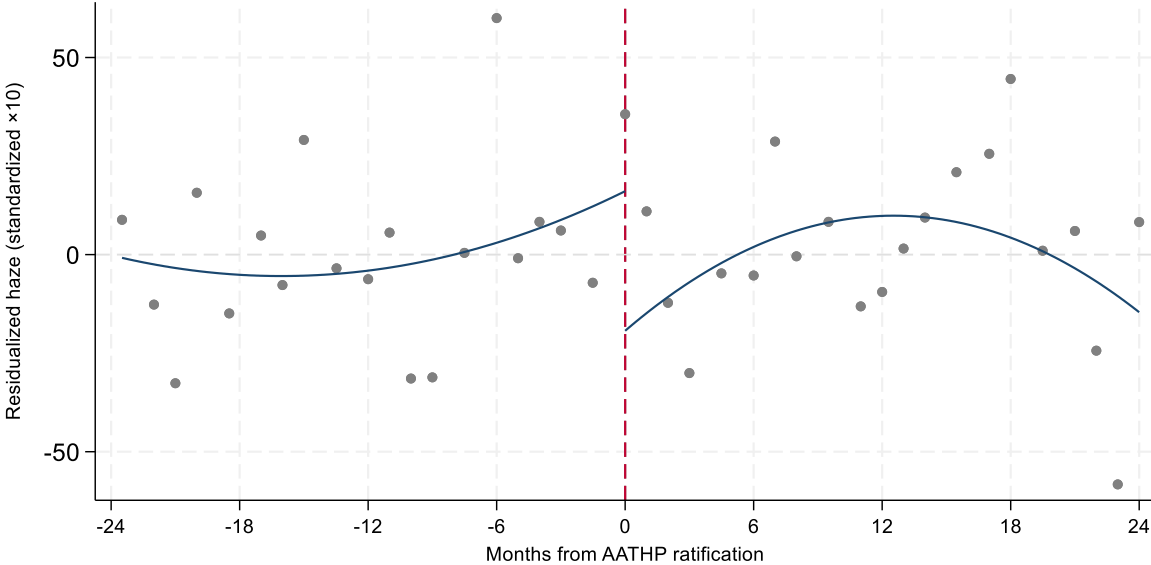
Note: Joining the AATHP takes a value of 0 on the x-axis. The level of haze is the standardized mean. The dashed area covers 0 - 1 month after the AATHP in effect.

Supplementary Fig. 5: Regression Discontinuity Plot of Haze Levels across the ASEAN region
a. Yearly Plot



Note: The graph illustrates 4,117,443 observations of haze level prior to joining the AATHP and 5,925,094 observations post-AATHP effect.

52 b. Monthly Plot



53
54 Note: Each dot represents the mean haze within bin. Haze has been residualized on all covariates,
55 with time and location fixed effects.

56 **Supplementary Table 4.** Data sources

Variable	Description and source
Administrative boundaries	Brunei Survey Department https://github.com/thewheat/brunei_map
	OCHA Common Operational Datasets https://data.humdata.org/dataset/
	Open Development Laos https://data.laos.opendevlopmentmekong.net/dataset/laos-administrative-boundaries-country-province-and-district
	geoBoundaries www.geoboundaries.org
	Government of Singapore https://legacy.data.gov.sg/dataset/subzone-census-2010
	University of California, Berkeley https://purl.stanford.edu/dk039bc2779
Haze	MCD19A2 v.6.1 https://lpdaac.usgs.gov/products/mcd19a2v061/
Wind, Temperature	ERA5-Land reanalysis https://doi.org/10.24381/cds.68d2bb30
Precipitation	CHIRPS 10.1038/sdata.2015.66
Drought	Copernicus Climate Change Service Climate Data Store https://doi.org/10.24381/cds.11dedf0c
Population density	WorldPop Hub https://hub.worldpop.org/geodata/listing?id=30
Urbanization Index	DMSP & VIIRS https://eogdata.mines.edu/products/dmsp/
Forest cover	Landsat 10.1126/science.1244693
GDP per capita	World Bank https://data.worldbank.org/indicator/NY.GDP.PCAP.CD
Education level	UNESCO Institute for Statistics https://data.worldbank.org/indicator/SE.TER.ENRR
Government effectiveness index	Data Bank https://databank.worldbank.org/source/worldwide-governance-indicators/
HDI	Global Data Lab https://globaldatalab.org/shdi/shdi/

58 **Supplementary Table 5. Pre-treatment Trends Test**

	haze
treated (T_i)	-2.953*** (0.081)
running variable (R_i)	-0.021*** (0.003)
$T_i * R_i$	-0.015 (0.009)
Other variables	YES
Time dummies	YES
location fixed effects	YES
N	1,710,295

59 Note: Sample restricted to pre-treatment periods only.

60 The interaction term tests for differential trends before ratification.

61 Standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

63 **Supplementary Table 6. RDiT Results with various Polynomial Specifications**

64 (a) Linear

bandwidth	Haze (± 3month)	Haze (± 6month)	Haze (± 1 year)	Haze (± 2 year)	Haze (± 3 year)	Haze (± 5 year)	Haze (± 10 year)
treated	-3.101*** (0.089)	-2.884*** (0.087)	-2.937*** (0.082)	-2.906*** (0.082)	-2.878*** (0.081)	-2.871*** (0.084)	-2.854*** (0.087)
constant	-34.251*** (2.916)	-15.566*** (1.346)	-4.470*** (0.990)	0.287** (0.126)	-0.358*** (0.107)	1.236*** (0.068)	0.910*** (0.049)
n	366,442	668,830	1,273,104	2,459,837	3,557,937	5,592,738	10,142,330
R^2	0.281	0.251	0.209	0.205	0.217	0.215	0.225

65 (b) Cubic

bandwidth	Haze (± 3month)	Haze (± 6month)	Haze (± 1 year)	Haze (± 2 year)	Haze (± 3 year)	Haze (± 5 year)	Haze (± 10 year)
treated	-3.333*** (0.105)	-2.869*** (0.095)	-2.773*** (0.089)	-2.889*** (0.083)	-2.902*** (0.083)	-2.844*** (0.080)	-2.830*** (0.083)
constant	-38.055*** (3.306)	-28.096*** (1.817)	-3.759*** (0.801)	0.787*** (0.167)	1.184*** (0.131)	0.678*** (0.102)	1.254*** (0.053)
n	366,442	668,830	1,273,104	2,459,837	3,557,937	5,592,738	10,142,330
R^2	0.291	0.268	0.211	0.208	0.219	0.217	0.226

66 c) Quartic

bandwidth	Haze (± 3month)	Haze (± 6month)	Haze (± 1 year)	Haze (± 2 year)	Haze (± 3 year)	Haze (± 5 year)	Haze (± 10 year)
treated	-3.592*** (0.119)	-3.020*** (0.104)	-2.748*** (0.094)	-2.789*** (0.089)	-2.817*** (0.084)	-2.872*** (0.083)	-2.795*** (0.080)
constant	-32.962*** (3.252)	-24.270*** (1.835)	-5.487*** (0.789)	0.285 (0.190)	0.672*** (0.140)	1.418*** (0.116)	0.774*** (0.060)
n	366,442	668,830	1,273,104	2,459,837	3,557,937	5,592,738	10,142,330
R^2	0.293	0.270	0.212	0.208	0.220	0.217	0.226

67 Note: The dependent variable is the standardized level of haze. Standard errors are in parentheses.

68 * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

69

70 **Supplementary Table 7. Donut Hole Tests**

	(a)	(b)	(c)	(d)	(e)
hole at (month)	haze 0	haze 1	haze 2	haze 3	haze 4
treated	-2.906*** (0.082)	-2.893*** (0.082)	-2.930*** (0.082)	-2.957*** (0.081)	-2.988*** (0.081)
Other variables	YES	YES	YES	YES	YES
Time dummies	YES	YES	YES	YES	YES
location fixed effects	YES	YES	YES	YES	YES
Constant	1.371*** (0.167)	1.195*** (0.165)	1.351*** (0.165)	1.497*** (0.167)	1.417*** (0.170)
N	2,459,837	2,406,836	2,304,650	2,198,418	2,093,395
r2	0.206	0.207	0.212	0.216	0.222

71 Note: The dependent variable is the standardized level of haze. Standard errors are in parentheses.

72 * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

73 **Supplementary Table 8. Robustness check: random cutoff (placebo test)**

	(a)	(b)
	haze (1-year window around 2006)	haze (2-year window around 2006)
treated	0.970 (0.684)	-0.007 (0.100)
Other variables	YES	YES
Time dummies	YES	YES
location fixed effects	YES	YES
Constant	1.553 ** (0.730)	0.467 * (0.194)
N	1,318,696	2,512,491
R ²	0.236	0.232

75 Note: The dependent variable is the standardized level of haze. Standard errors are in parentheses.

76 * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.