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# Stagnation and inequality: a pan-European analysis of structural determinants in smoking prevalence (2014–2019)

## Stagnacija i nejednakost: panevropska analiza strukturnih činilaca u prevalenciji pušenja (2014–2019)

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**Abstract**

**Background/Aim.** Although the global prevalence of smoking has been steadily declining, aggregate trends conceal substantial regional differences across Europe, as well as socioeconomic and education-level inequalities**.** The aim of this study was to assess the widening regional and educational inequalities in smoking prevalence in Europe and delineate structural barriers to tobacco control against the backdrop of aggregate trends. **Methods.** Using European Statistical Office (Eurostat) data from 32 countries (2014–2019), daily smoking rates, indoor environmental tobacco smoke exposure, and smoking intensity were analyzed. To account for demographic differences, European averages were calculated using population-weighted means. Pearson correlations and multivariate regression models were utilized to examine country-level associations between educational attainment indices and smoking outcomes. **Results.** While the weighted European Union (EU) average for daily smoking declined slightly, regional divergence intensified. Nordic countries maintained the lowest prevalence (~12%), whereas Eastern European nations and Türkiye (~27–29%) exhibited stagnation or increases. A strong country-level educational gradient persisted; nations with higher tertiary attainment rates exhibited significantly lower aggregate smoking prevalence. Marked cross-country differences in indoor secondhand smoke exposure were observed; daily indoor tobacco smoke exposure exceeded 19% in countries such as Greece and Croatia but remained below 3% in Finland. **Conclusion.** The decline in smoking has stalled in structurally disadvantaged regions, supporting the "hardening hypothesis" (the phenomenon where the remaining smoker population becomes more resistant to quitting) at the macro level. Generic tobacco control measures are losing efficacy. To bridge the widening health equity gap, future interventions must target high levels of heavy smoking and the enforcement of smoke-free environments in lagging regions.

**Keywords:**
**education; europe; prevalence; smoke-free policy; tobacco smoke pollution; tobacco smoking.**

**Apstrakt**

**Uvod/Cilj.** Iako se prevalencija pušenja na globalnom nivou postepeno smanjuje, ukupni trendovi maskiraju značajne nejednakosti između regiona u Evropi, kao i nejednakosti u zavisnosti od obrazovnog i socioekonomskog statusa. Cilj ove studije bio je da proceni da li se nejednakosti u prevalenciji pušenja u Evropi, koje zavise od regionalne pripadnosti i obrazovnog statusa, povećavaju i da identifikuje strukturne barijere za kontrolu upotrebe duvana u kontekstu ukupnih trendova. **Metode.** Korišćenjem podataka Evropskog zavoda za statistiku (*European Statistical Office* – Eurostat) iz 32 zemlje (2014–2019), analizirane su dnevne stope pušenja, izloženost duvanskom dimu u zatvorenom prostoru i intenzitet pušenja. Kako bi se uzele u obzir demografske razlike, evropski proseci su izračunati kao srednje vrednosti ponderisane prema broju stanovnika. Za ispitivanje povezanosti između indeksa nivoa obrazovanja i pokazatelja u vezi sa pušenjem na nivou zemlje korišćeni su Pirsonove korelacije i multivarijantni regresioni modeli. **Rezultati.** Iako je ponderisani prosek prevalencije svakodnevnog pušenja u Evropskoj uniji (EU) blago opao, regionalne razlike su se pojačale. Nordijske zemlje zadržale su najnižu prevalenciju (~12%), dok su u istočnoevropskim zemljama i Turskoj primećeni stagnacija ili porast (~27–29%). Velika obrazovna razlika na nivou zemalja je postojala; zemlje sa većim udelom visokoobrazovanog stanovništva imale su značajno nižu ukupnu prevalenciju pušenja. Uočene su izražene razlike među evropskim zemljama u izloženosti duvanskom dimu u zatvorenom prostoru; u Grčkoj i Hrvatskoj svakodnevna izloženost prelazila je 19%, dok je u Finskoj iznosila manje od 3%. **Zaključak.** Pad stope pušenja stagnirao je u strukturno nepovoljnim regionima, što podržava „hipotezu o očvršćavanju" (fenomen u kojem preostala

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populacija pušača postaje otpornija na prestanak pušenja) na makro nivou. Generičke mere kontrole duvana gube efikasnost. Da bi se premostio sve veći jaz u zdravstvenoj jednakosti, buduće intervencije moraju biti usmerene prema visokom nivou „teškog“ pušenja i sprovođenju okruženja bez duvanskog dima u regionima koji zaostaju.

**Ključne reči:**
**obrazovanje; evropa; prevalencija; pušenje, politika zabrane; zagađenje duvanskim dimom; pušenje.**

## Introduction

Tobacco smoking persists as a paramount global public health challenge, implicated in over 8 million deaths annually and imposing a massive burden of preventable disease and disability [1]. Since its adoption, the World Health Organization's (WHO) Framework Convention on Tobacco Control has provided a blueprint for evidence-based policy interventions, contributing to a gradual decline in global smoking prevalence (SP) [2]. However, this aggregate progress conceals a landscape marked by deep and persistent inequalities. The declining prevalence is not uniformly distributed across populations; instead, it is increasingly concentrated within specific socioeconomic and geographic groups, thereby exacerbating health disparities [3, 4]. The inverse social gradient of smoking is one of the most robust findings in social epidemiology [5]. Socioeconomic status (SES), frequently operationalized through educational attainment, functions as a "fundamental cause" of health outcomes, shaping access to resources, knowledge, and social networks that either protect against or promote health-risk behaviors [6]. Individuals with lower education are more likely to initiate smoking, less likely to quit, and suffer a disproportionately higher burden of tobacco-related morbidity and mortality [7, 8]. This gradient is not merely a reflection of individual choice but is embedded in a context of differential exposure to stress, targeted industry marketing, and varying social norms [9, 10]. Beyond individual socioeconomic positioning, the broader environmental and policy context plays a critical role. Exposure to secondhand smoke (SHS) in indoor environments is not only a direct cause of disease in non-smokers but also serves as a powerful cue that normalizes smoking behavior, potentially reinforcing social norms and undermining cessation efforts [11, 12]. The implementation and enforcement of comprehensive smoke-free legislation have been shown to reduce both exposure and consumption, yet the strength of these laws varies dramatically across and within regions, creating distinct geographical patterns of SP [13, 14]. Comparative studies within Europe consistently reveal a stark divide, with Nordic nations demonstrating sustained low prevalence–a success attributed to decades of comprehensive, multifaceted tobacco control–while countries in Eastern Europe (EE) often exhibit persistently high rates, linked to historical legacies and slower policy adoption [15, 16]. While the individual associations between education, policy, environment, and smoking are well-documented in siloed studies, there remains a critical need for integrated analyses that examine these multilevel factors concurrently. Such an approach allows for the quantification of their unique and combined contributions to SP, providing a more holistic understanding of the drivers of both overall trends and embedded inequalities [17, 18].

This study aims to address a critical research gap by conducting a comprehensive, cross-national analysis with four specific objectives: first, to delineate the descriptive epidemiology of smoking status and its correlation with education; second, to analyze temporal trends in the prevalence of daily smoking (DS) and non-smoking between 2014 and 2019; third, to investigate and quantify regional variations in DS rates across European sub-regions; and finally, to construct a multivariate model that integrates educational, environmental, and temporal factors to identify the key predictors of DS prevalence.

## Methods

Ethical approval for this research was not required as this study was conducted using publicly available data.

### *Study design and data source*

This study employed a longitudinal ecological design utilizing country-level aggregated data (dataset category: TOTAL) obtained from the Eurostat database [19]. The initial sample encompassed 32 European countries/regions. The analysis focused on two time points (2014 and 2019) and included countries based on data availability for the variables of interest. Given the ecological nature of the study, all analyses were conducted at the country level; consequently, the findings cannot be interpreted at an individual level.

### *Sample construction and management of missing data*

Different analytic procedures require different sets of variables; therefore, sample sizes vary across analyses. To ensure internal validity, a complete-case (listwise deletion) approach was used for each analysis, excluding countries with missing data on the variables used in each statistical test. The descriptive analysis (Table 1) included all available country-year observations with non-missing data, yielding up to 64 observations from 32 countries across both time points. For the paired samples *t*-tests (2014 vs. 2019), the analysis was based on a balanced panel of 28 countries with complete data for both time points (n = 56 country-year observations). Countries with missing data in either year–such as the United Kingdom (UK) for 2019 and Serbia for 2014–were excluded from this specific analysis. The regression analysis encompassed 32 countries (n = 62 country-year observations). This sample reflects available data for all predictors, allowing for the partial inclusion of countries

**Table 1**

**Descriptive statistics of smoking behavior, exposure, and educational attainment in the sample**

| Variable (n) | Mean ± SD | Min–Max |
|---|---|---|
| Cigarette smokers (64) | | |
| daily | 19.58 ± 5.92 | 6.40–29.20 |
| occasional | 5.12 ± 1.95 | 1.70–8.30 |
| non-smokers | 75.30 ± 5.41 | 63.70–88.70 |
| Former smokers (32) | 27.31 ± 11.21 | 10.70–66.30 |
| Indoor tobacco smoke exposure daily (48) | 10.89 ± 7.45 | 1.50–37.90 |
| Cigarette consumption | | |
| E-cigarettes daily (32) | 1.59 ± 1.12 | 0.30–4.60 |
| < 20 cigarettes/day (64) | 12.79 ± 3.15 | 5.30–19.60 |
| ≥ 20 cigarettes/day (64) | 6.54 ± 3.92 | 0.00–15.80 |
| Education level (32) | | |
| low | 19.28 ± 5.12 | 11.30–31.80 |
| medium | 21.89 ± 6.78 | 14.20–34.10 |
| high | 13.45 ± 6.23 | 3.60–23.80 |

**n – number of observations; SD – standard deviation; Min – minimum; Max – maximum; E-cigarette – electronic cigarette.**
**All values are represented in percentages.**

where only one time point was available, such as the UK in 2014 and Serbia in 2019. Furthermore, the SHS exposure sub-sample was restricted to 24 countries with complete education-stratified SHS exposure data for both years (n = 48 observations). Separately, the regional analysis of variance (ANOVA) was conducted utilizing the same balanced 28-country panel as in the paired samples *t*-tests (n = 56 observations) to evaluate geographical variations. Finally, the education-stratified descriptive analysis was limited to 32 country-level observations for 2019 only, as comparable stratified data were unavailable for 2014.

This method maintains consistency within each statistical process while maximizing the use of available data for each specific analysis. The decision not to include regional grouping in the regression model was made to prevent multicollinearity, as regional context significantly overlaps with education structure and exposure patterns. Regional differences were instead analyzed separately using ANOVA to maintain the interpretability of structural factors at the cross-national level.

*Variable definitions*

The primary outcome variable is the prevalence of daily smokers (%). The predictor variables are described below. First, education level was categorized according to the International Standard Classification of Education (ISCED) as low (levels 0–2), medium (levels 3–4), and high (levels 5–8). Second, SHS exposure was defined as the percentage of the population exposed to tobacco smoke indoors on a daily basis. Finally, tobacco control policy scores were obtained from the Association of European Cancer Leagues' Tobacco Control Scale (TCS) [20] to assess national legislative strength [21]. The TCS is a composite indicator that evaluates national tobacco control policy based on six criteria: price increases through taxation, smoke-free legislation in public places, budget for public information campaigns, advertising bans, health warning requirements, and cessation treatment availability. Regional groupings were classified into four distinct geographical zones. The Nordic region comprised Denmark, Finland, Iceland, Norway, and Sweden. Western Europe included Austria, Belgium, France, Germany, Ireland, Luxembourg, the Netherlands, and the UK. Southern Europe (SE) encompassed Croatia, Cyprus, Greece, Italy, Malta, Portugal, Serbia, Slovenia, Spain, and Türkiye. Finally, EE consisted of Bulgaria, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, and Slovakia.

*Statistical analysis*

Statistical analyses were performed using SPSS (v26.0). Descriptive statistics are presented as means and standard deviations for continuous variables. To ensure regional representativeness and account for population disparities, European Union (EU) averages were calculated as population-weighted means using the following formula:

$$\overline{x}_w = \frac{\sum_{i=1}^{n}(w_i x_i)}{\sum_{i=1}^{n}(w_i)}$$

Where $x_i$ represents the specific smoking or exposure prevalence rate in country $i$, and $w_i$ represents the adult population (aged 15+) of that respective country.

Differences in SP between 2014 and 2019 were analyzed using paired samples *t*-tests based on the consistent panel of 28 countries. Regional variations were tested using one-way ANOVA. Finally, a multiple linear regression model was constructed to identify structural predictors of SP, treating country-year observations as the unit of analysis. Model assumptions were evaluated through residual diagnostics, including tests for normality and homoscedasticity. Multicollinearity was checked using variance inflation factors (VIF), with values below 2.0 indicating no signs of mul-

ticollinearity. A *p*-value of < 0.05 was considered statistically significant.

## Results

The data presented in Table 1 demonstrate that while the vast majority (75%) of the studied population are non-smokers, a significant segment (20%) consists of daily smokers, the majority of whom consume fewer than 20 cigarettes *per* day. The smoking rate is markedly lower in the highest education group (13%), while it is more prevalent in the medium (22%) and low (19%) education groups. Although the average exposure to indoor tobacco smoke is 11%, this figure rises to as high as 38% in some groups.

Normality tests (Table 2) indicated that the distributions for both the daily smoker and non-smoker variables did not significantly deviate from normality ($p > 0.05$ for both tests). While the Shapiro-Wilk test for SHS exposure indicated a significant deviation ($p = 0.045$), the Kolmogorov-Smirnov test was non-significant ($p = 0.073$). Given the sample size (n = 48), the Central Limit Theorem's applicability, and the Q-Q plot results supporting overall normality, parametric tests were deemed appropriate.

The paired samples *t*-test indicated a statistically significant decrease in the percentage of daily smokers from 2014 (mean = 19.89) to 2019 (mean = 18.98) [$t(55) = 2.341$, $p = 0.023$]. Conversely, there was a statistically significant increase in the percentage of non-smokers over the same period [$t(55) = -2.156$, $p = 0.036$] (Table 3).

The results of the ANOVA for daily SP by educational attainment are shown in Table 4, demonstrating statistically significant differences in DS rates among education levels.

There was no significant difference between the low and medium education groups ($p = 0.183$) (Table 5). Comparing low vs. high education groups revealed a significant difference ($p < 0.001$), with a higher prevalence in the low education group. Similarly, a significant difference was found between medium and high education groups ($p < 0.001$), with the medium education group exhibiting higher SP.

Descriptive statistics for daily SP stratified by European region are presented in Table 6a.

A one-way ANOVA (Table 6b) was conducted to compare the differences across regions on DS prevalence. There was a statistically significant difference in smoking rates between at least two regions [$F(3, 52) = 6.11$, $p < 0.001$]. The

**Table 2**

**Tests of normality for primary outcome and predictor variables**

| Variable | Kolmogorov-Smirnov test | *p*-value | Shapiro-Wilk test | *p*-value |
|---|---|---|---|---|
| Daily smoker | 0.064 | 0.200 | 0.978 | 0.089 |
| Non-smoker | 0.058 | 0.200 | 0.984 | 0.234 |
| Secondhand smoke | 0.078 | 0.073 | 0.967 | 0.045 |

**Table 3**

**Paired samples *t*-test comparing national prevalence rates of daily smoking and non-smoking between 2014 and 2019**

| Variable | Mean ± SD | | SE mean | | *t*-test | *df* | *p*-value | MD |
|---|---|---|---|---|---|---|---|---|
| | 2014 | 2019 | 2014 | 2019 | | | | |
| Daily smoker | 19.89 ± 5.67 | 18.98 ± 5.94 | 0.76 | 0.70 | 2.341 | 55 | 0.023 | 0.91 |
| Non-smoker | 74.98 ± 5.21 | 75.68 ± 5.29 | 0.79 | 0.71 | -2.156 | 55 | 0.036 | -0.70 |

**SD – standard deviation; SE – standard error; *df* – degrees of freedom; MD – mean difference.**

**Table 4**

**One-way analysis of variance (ANOVA) of daily smoking prevalence by educational attainment**

| Source | Sum of squares | *df* | Mean square | *F* | *p*-value |
|---|---|---|---|---|---|
| Between groups | 1,156.34 | 2 | 578.17 | 15.89 | 0.000 |
| Within groups | 3,278.45 | 93 | 36.38 | | |
| Total | 4,434.79 | 95 | | | |

***df* – degrees of freedom.**
***Note: F* (2, 93) = 15.89, *p* < 0.001.**

**Table 5**

***Post hoc* comparisons – Tukey HSD test of daily smoking prevalence by educational attainment**

| (I) Education | (J) Education | MD (I-J) | SE | *p*-value | 95% CI |
|---|---|---|---|---|---|
| Low | Medium | -2.61 | 1.51 | 0.183 | -6.12–0.90 |
| | High | 5.83 | 1.51 | 0.000 | 2.32–9.34 |
| Medium | High | 8.44 | 1.51 | 0.000 | 4.93–11.95 |

**HSD – honestly significant difference; MD – mean difference; SE – standard error; CI – confidence interval.**
***Note:* I and J stand for MD between groups I and J.**

mean scores show a clear gradient, with the lowest SP in Nordic countries (12.35%) and the highest in EE countries (22.89%).

As shown in Table 7, the correlation reveals several significant relationships. There is a very strong negative correlation between daily smoker and non-smoker rates ($r$ = -0.95, $p < 0.001$). DS is positively correlated with SHS exposure ($r$ = 0.456, $p < 0.001$) and negatively correlated with education level ($r$ = -0.401, $p < 0.001$), indicating that higher education is associated with lower smoking rates. The significant negative coefficient for education level (β = -0.401, $p < 0.001$) indicates that as the education level increases from low (coded as 1) to high (coded as 3), the predicted prevalence of DS decreases.

A multiple regression was conducted to predict DS percentage from SHS exposure, education level, and year (Table 8). The model was statistically significant [$F$(3, 58) = 22.37, $p < 0.001$] and explained 51.2% of the variance ($R^2$ = 0.512). All three variables emerged as significant predictors: SHS exposure (β = 0.367, $p < 0.001$), education level (β = -0.401, $p < 0.001$), and year (β = -0.167, $p$ = 0.037). These findings confirm that higher SHS exposure predicts higher smoking rates, higher education attainment predicts lower smoking rates, and smoking rates were significantly lower in

**Table 6a**

**Descriptive statistics for daily smoking prevalence stratified by European region**

| Region | Mean ± SD | SE | 95% CI |
|---|---|---|---|
| Nordic countries (n = 8) | 12.35 ± 3.45 | 1.22 | 9.42–15.28 |
| Western Europe (n = 16) | 18.92 ± 4.78 | 1.20 | 16.35–21.49 |
| Southern Europe (n = 12) | 20.56 ± 5.23 | 1.51 | 17.23–23.89 |
| Eastern Europe (n = 20) | 22.89 ± 4.12 | 0.92 | 20.96–24.82 |
| Total (n = 56) | 19.24 ± 5.87 | 0.78 | 17.66–20.82 |

**SD – standard deviation; SE – standard error; CI – confidence interval.**
***Note:*** **n indicates the number of country–year observations in each group. The analysis includes data from 28 countries across two time points (2014 and 2019), yielding 56 country-year observations.**

**Table 6b**

**One-way analysis of variance (ANOVA) results for differences in daily smoking prevalence across European regions**

| Source | Sum of squares | *df* | Mean square | *F* | *p*-value |
|---|---|---|---|---|---|
| Between groups | 2,156.78 | 3 | 718.93 | 6.11 | < 0.001 |
| Within groups | 6,123.45 | 52 | 117.76 | | |
| Total | 8,280.23 | 55 | | | |

***df* – degrees of freedom.**

**Table 7**

**Bivariate Pearson correlations among key study variables**

| Variable | Daily smoker | Non-smoker | Indoor tobacco smoke exposure | Electronic cigarette | Education level |
|---|---|---|---|---|---|
| Daily smoker | 1.000 | | | | |
| Non-smoker | -0.95*** | 1.000 | | | |
| Indoor exposure | 0.456*** | -0.389*** | 1.000 | | |
| E-cigarette | 0.234* | -0.198 | 0.312** | 1.000 | |
| Education level | -0.401*** | 0.367*** | -0.289** | -0.156 | 1.000 |

****** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.***

**Table 8**

**Multiple linear regression model predicting daily smoking prevalence (2014–2019)**

| Variable | Standardized coefficients (β) | *p*-value |
|---|---|---|
| Indoor tobacco smoke exposure | 0.367 | < 0.001 |
| Education level | -0.401 | < 0.001 |
| Year (2019) | -0.167 | 0.037 |
| Model summary | $R^2$ = 0.512; $F$(3, 58) = 22.37 | < 0.001 |

**Dependent variable: daily smoking prevalence (%).**
**Year reference category: 2014. Education level: ordinal (1 = low to 3 = high). Supplementary model parameters: indoor exposure: B = 0.241, standard error (SE) = 0.058, 95% confidence interval (CI) (0.125, 0.357), variance inflation factor (VIF) = 1.42; education level: B = -2.18, SE = 0.46, 95% CI (-3.11, -1.25), VIF = 1.31; year (2019): B = -0.91, SE = 0.43, 95% CI (-1.77, -0.05), VIF = 1.09. All VIF values < 2.0, indicating no multicollinearity concerns.**

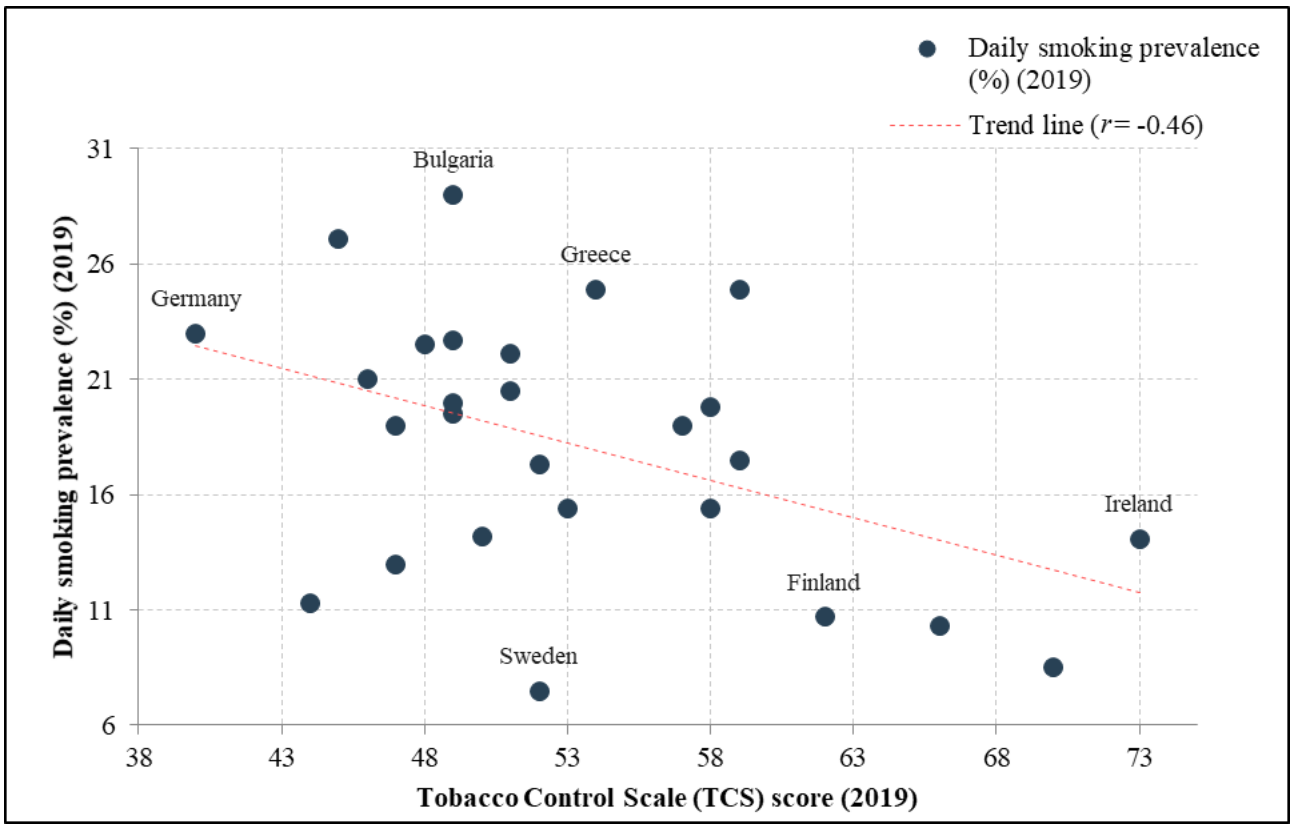


**Fig. 1 – Correlation between TCS scores and daily smoking prevalence (2019). Higher TCS scores are associated with lower smoking rates ($r$ = -0.46, $p$ < 0.05). Countries with stricter policies (e.g., Ireland) have significantly lower prevalence compared to those with weaker enforcement (e.g., Germany, Bulgaria). Sources: Eurostat [19] and Joossens and Raw (2020) [20].**

2019 compared to 2014. Full model parameters, including unstandardized coefficients, standard errors, and 95% confidence intervals, are detailed in Table 8. Multicollinearity was assessed using VIF; all VIF values were below 2.0 (SHS: VIF = 1.42; education level: VIF = 1.31; year: VIF = 1.09), indicating no problematic multicollinearity. Model assumptions were verified: residuals were approximately normally distributed (Shapiro-Wilk $p$ = 0.18) and homoscedastic (Levene's test $p$ = 0.21).

Although the TCS is utilized descriptively to contextualize cross-national policy variations (Figure 1) [19], it was deliberately excluded as a predictor in the multivariate regression model for two distinct methodological reasons. First, TCS scores were available only for 2019, precluding the use of TCS as a time-varying predictor across the longitudinal sample (n = 62 observations). Second, given that TCS is structurally correlated with both regional affiliation and educational attainment, its inclusion would introduce multicollinearity, thereby risking the distortion of the independent contributions of education and SHS exposure that the model was designed to quantify. Consequently, the association between TCS and overall SP is examined solely through the visual and descriptive analysis presented in Figure 1.

A detailed country comparison presented in Table 9 identifies Türkiye's persistently high SP as a particular concern. In Türkiye, DS remained stagnant at around 28% between 2014 and 2019, and a deeply entrenched 14.8% of the population was classified as heavy smokers. This stagnation, combined with a substantial increase in indoor SHS exposure from 14.2% to 16.7%, demonstrates a sharp divergence from nations with aggressive tobacco control policies. Furthermore, Türkiye exhibited one of the lowest smoking cessation rates in Europe; its former smoker rate stood at just 17.5%, surpassing only Cyprus (17.4%), Greece (15.7%), and Romania (10.7%). The situation stands in sharp contrast to positive trends in countries like Greece, which saw significant reductions in smoking and SHS exposure, highlighting a critical need for Türkiye to strengthen smoke-free policy enforcement and enhance cessation services to avert rising tobacco-related diseases.

*Regional disparities and the 'East-West' divide*

A stark regional divide persists. While Nordic countries such as Sweden (7.4%) and Finland (10.7%) reached tobacco endgame prevalence levels in 2019, EE and SE nations faced stagnation. Türkiye, for instance, showed no meaningful change in daily SP between 2014 (27.3%) and 2019 (28.0%). Of greater concern, the intensity of smoking in Türkiye remains high; in 2019, 14.8% of the population consumed 20 or more cigarettes daily─a rate unchanged from 2014 and more than double the EU average of approximately 6%. Similarly, Bulgaria reported a slight increase

**Table 9**

**Tobacco use comparison: Türkiye vs. EU average and selected reference countries representing high (Bulgaria, Greece) and low (Sweden) prevalence rates (2014–2019)**

| Country | Daily smoker | Non-smoker | 20+ cig/day | Indoor SHS exposure | Former smoker |
|---|---|---|---|---|---|
| Türkiye | | | | | |
| 2014 | 27.3 | 67.5 | 14.8 | 14.2 | - |
| 2019 | 28.0 | 68.6 | 14.8 | 16.7 | 17.5 |
| EU average | | | | | |
| 2014 | 19.2 | 76.1 | 5.8 | 10.8 | - |
| 2019 | 19.3 | 75.8 | 5.9 | 10.3 | 30.7 |
| Bulgaria | | | | | |
| 2014 | 28.2 | 65.2 | 12.7 | 20.0 | - |
| 2019 | 29.1 | 63.8 | 12.9 | 17.1 | 19.7 |
| Greece | | | | | |
| 2014 | 27.3 | 67.4 | 15.1 | 37.9 | - |
| 2019 | 24.9 | 71.4 | 10.8 | 19.4 | 15.7 |
| Germany | | | | | |
| 2014 | 15.9 | 78.3 | 5.0 | 7.7 | - |
| 2019 | 22.9 | 71.7 | 7.8 | 9.9 | - |
| France | | | | | |
| 2014 | 22.4 | 71.7 | 4.6 | 11.3 | - |
| 2019 | 18.5 | 76.0 | 4.1 | 7.8 | 30.9 |
| Sweden | | | | | |
| 2014 | 9.8 | 83.3 | 1.2 | 2.3 | - |
| 2019 | 7.4 | 87.4 | 1.0 | 2.6 | 32.5 |

**EU – European Union; Cig – cigarettes; SHS – secondhand smoke.**
**Values are given in percentages.**
***Note:*** **All 'EU average' values presented in this table were calculated as population-weighted means, consistent with the data aggregation method described in the Methods section. Former smoker data for Germany were not available for the years studied.**

in DS to 29.1%. These findings indicate heterogeneity in smoking patterns across European regions and suggest persistent differences in tobacco use intensity and prevalence between countries.

*The environmental factor (indoor exposure)*

SHS exposure data indicates gaps in the implementation or enforcement of protection policies in specific regions. While daily SHS exposure in Finland remained low at approximately 2%, it increased significantly in Türkiye from 14.2% (2014) to 16.7% (2019). High exposure rates were also observed in Greece (19.4%) and Croatia (26.1%) in 2019. This correlates strongly with overall prevalence, suggesting that non-enforcement of smoke-free laws in private and semi-private spaces creates an "environmental lock-in" that may hinder cessation.

*Correlation with Tobacco Control Scale scores*

To complement the statistical analysis, we visualized the relationship between policy strictness and prevalence directly (Figure 1). The analysis reveals a consistent inverse pattern between TCS scores and SP across countries. Countries with high TCS scores, such as Ireland (score: 73) and the UK, have successfully suppressed smoking rates to below 15%. Conversely, nations with lower scores, including Germany (score: 40) and Bulgaria (score: 48), continue to struggle with high prevalence (> 22%). These patterns are consistent with the hypothesis that differences in the strength and enforcement of tobacco control policies contribute to observed cross-national variation in SP. However, given the ecological design of the study, these associations should be interpreted as descriptive and hypothesis-generating rather than causal.

## Discussion

This study provides a comprehensive, integrated analysis of the multilevel determinants of SP across a diverse set of nations. The results powerfully illustrate that smoking is not merely an individual behavior but a socio-ecological outcome, deeply embedded within educational structures, environmental contexts, and regional policy landscapes. The profound educational gradient observed aligns strongly with the theory of "fundamental causes" of health inequalities [6, 22]. The 8.44 percentage point gap between the medium and high education groups is a stark manifestation of how socioeconomic resources translate into health behaviors. Countries with higher educational attainment tend to show lower aggregate SP, consistent with evidence that higher education is associated with greater health literacy, future-oriented thinking, and access to social environments where healthy choices are normative and supported [8, 23]. The absence of a significant difference between the low and medium education groups is a critical nuance, suggesting that the most powerful protective effect of education may operate as a threshold, likely

at the tertiary level. This finding resonates with studies indicating that university education, in particular, imparts critical cognitive skills and social networks that are highly effective in mitigating health-risk behaviors [24]. The stark regional gradient from Nordic to EE countries provides a vivid illustration of the impact of policy path dependency and political commitment. The success of Nordic countries is not accidental; it is the result of a long-term, consistently applied, and comprehensive strategy encompassing high taxation, extensive smoke-free laws, plain packaging, and public education campaigns [15, 24, 25]. Conversely, the high prevalence in EE countries has been linked to the historical influence of the tobacco industry, slower transposition of EU tobacco directives into national law, and weaker enforcement mechanisms [16, 26]. This regional pattern underscores that national and supra-national policy environments create a "risk regime" that powerfully shapes population-level health outcomes [27]. Given the ecological nature of this analysis, however, these country-level associations should not be interpreted as reflecting direct causal mechanisms at the individual level. The public health significance of these findings for EE countries is substantial. The mean daily SP of 22.89% observed in this region substantially exceeds estimates reported in prior comparative studies of Central European and EE populations. Those earlier investigations documented rates in the range of 20–25% during the same period, noting that the burden was heavily concentrated among lower-educated and economically disadvantaged groups [16, 26]. Critically, our data indicate that this elevated prevalence is not merely a historical legacy but an active, ongoing phenomenon: Bulgaria recorded an increase from 28.2% to 29.1% between 2014 and 2019, while no meaningful reduction was observed across the EE sub-region as a whole. These findings are consistent with documentation by Schaap et al. [16] that nationwide tobacco control policies have disproportionately benefited higher-educated groups in Europe, leaving low-SES populations in structurally disadvantaged regions with fewer gains. Taken together, the evidence points to a widening intra-European health equity gap that demands region-specific policy responses: accelerated transposition of EU tobacco directives, targeted cessation programs for low-education populations, and strengthened cross-border enforcement coordination within EE member states. Our analysis utilizes TCS, a quantitative instrument that evaluates the implementation of tobacco control policies across European countries based on six criteria: price increases, smoke-free public places, budget for information campaigns, advertising bans, health warnings, and cessation treatment availability. The strong negative correlation between TCS scores and prevalence confirms that comprehensive legislative frameworks are essential for reducing smoking rates [21]. As noted in the Methods section, TCS was examined descriptively rather than incorporated into the regression model, due to the availability of its scores for 2019 only and the risk of multicollinearity with regional and educational variables. The patterns observed in Figure 1 are therefore presented as hypothesis-generating. The significant role of SHS exposure reinforces its dual nature as both a consequence and a cause of SP. Its persistence as a strong predictor in the multivariate model indicates that it exerts an independent environmental influence, likely by reinforcing the social normalcy of smoking and creating cues that trigger relapse among quitters [11, 28]. This finding provides a robust evidence base for the continued expansion and stringent enforcement of smoke-free legislation beyond public spaces to include semi-private areas like multi-unit housing and vehicles, as recommended by leading public health bodies [29]. Our updated data analysis also reveals alarming trends in non-EU SE countries. For instance, in Serbia, daily SHS exposure to tobacco smoke was recorded at 33.9% in 2019, a rate significantly higher than the EU average and even exceeding that of Greece. This suggests a critical regional gap in the enforcement of smoke-free legislation in the Balkans [19]. The modest but significant temporal decline in smoking, net of other factors, is consistent with global reports and reflects the cumulative impact of decades of tobacco control efforts [1, 2]. Our regression model confirmed this trend, showing that SP in 2019 was significantly lower than in the 2014 baseline, even after controlling for education levels and SHS exposure. While the overall trend points to a decline, this pattern was not uniform across all nations, underscoring the uneven nature of progress in tobacco control. A notable deviation from the general decline was observed in Germany, where daily SP rose from 15.9% in 2014 to 22.9% in 2019. While methodological integration of the Microcensus in German survey systems in 2019 may account for some statistical noise, this sharp increase cannot be dismissed merely as an artifact. Rather, it aligns with Germany's historically low ranking on TCS, which is characterized by weaker tobacco advertising bans and lower taxation compared to its Western European neighbors. This suggests that without stringent policy enforcement, economic development alone is insufficient to curb smoking rates. The observed increase in SP in Germany warrants a nuanced interpretation. Beyond methodological changes in the Microcensus, sociodemographic factors likely play a role. Germany hosts a significant population of immigrants from high-prevalence regions, including EE countries and Türkiye. Studies suggest that acculturation processes can be complex; while some immigrant groups adopt the healthier behaviors of the host country, first-generation immigrants often retain the higher SP typical of their countries of origin, which correlates with lower SES. This demographic composition, combined with Germany's comparatively lenient tobacco control policies, creates a specific vulnerability [30]. This outlier serves as a critical reminder that aggregate progress can mask significant setbacks in individual countries, and it highlights the necessity for continuous monitoring and context-specific policy evaluations to understand and reverse such adverse trends. It should be noted that former smoker data for Germany were not available in the dataset for the years studied, limiting a more complete analysis of smoking cessation dynamics in this specific case. Crucially, while the associa-

tion between SES and smoking is established, our findings highlight a critical "hardening" of the landscape. The divergence between nations like Sweden and Türkiye suggests that the European region is moving at two different speeds. Unlike trends observed in countries such as Poland (4.6% daily use) or Iceland (4.1%), daily e-cigarette use in Türkiye remains negligible at 0.4% [19]. This suggests that the stagnation in SP is not due to a substitution effect towards novel products, but rather a persistent reliance on combustible tobacco. The debate regarding novel products remains complex; while some evidence suggests potential for harm reduction, the concurrent use of combustible tobacco and e-cigarettes undermines cessation efforts, particularly in environments with weak regulatory enforcement [31]. While cessation rates in the Nordic countries show strong socioeconomic gradients, Türkiye exhibits consistently low cessation rates across all income quintiles [19]. This suggests limited reach or effectiveness of cessation support services across socioeconomic boundaries, contrasting with the targeted success seen in Nordic regions. The stagnation in high-prevalence countries, coupled with rising SHS exposure rates in countries like Türkiye, indicates that current legislative frameworks have limited influence on private social norms. This supports the hypothesis that we have reached the limits of "generic" tobacco control. Recent global analyses affirm that while standard policies like taxation have driven past successes, their impact is plateauing in high-prevalence demographic pockets, necessitating more targeted, equity-focused strategies [32]. The remaining disparity is structural and requires targeted enforcement rather than broad education campaigns. This group is marked by intense nicotine addiction, a lack of response to standard cessation messages, and a significant overrepresentation among lower SES groups. These characteristics render future public health efforts substantially more challenging [33, 34]. This underscores the imperative to move beyond generic campaigns to more intensive, targeted cessation support. The findings collectively argue for a strategic evolution in tobacco control, from a primarily universal approach to one that explicitly prioritizes equity. Addressing the educational gap requires upstream interventions that begin early in the life course. Strengthening educational systems and improving graduation rates, particularly at the secondary and tertiary levels, can itself be a powerful tobacco control strategy [35]. Cessation services must be proactively integrated into settings that serve low-SES populations, such as vocational training centers, social service agencies, and community health clinics. These services should be low-cost or free, easily accessible, and culturally tailored [36, 37]. The fight for comprehensive smoke-free laws must continue, requiring vigilance against industry-backed exemptions. Public health advocacy should focus on closing loopholes and extending protections to all indoor and some outdoor public spaces [14]. The regional disparities call for enhanced technical and financial support for policy adoption in high-prevalence regions. Mechanisms for policy learning and collaboration, facilitated by bodies such as the WHO and the EU, are essential to accelerate progress in lagging regions [38]. Moving forward, adopting a tobacco endgame strategy–aiming for less than 5% prevalence–requires not only structural changes but also strict regulation of new nicotine delivery systems to prevent a new generation of addiction [39].

*Limitation of the study*

This study has several limitations. First, the analysis relies on country-level aggregated data, which precludes individual-level inference and risks the ecological fallacy. Due to the ecological design, the associations observed between education, SHS exposure, and SP at the country level cannot be interpreted as causal relationships at the individual level. Country-level correlations may not reflect individual-level associations, and unmeasured confounding at the country level remains possible. Second, while the three-tier International Standard Classification of Education (ISCED) framework and its ordinal coding were operationalized appropriately, this broad measure may not capture critical nuances in educational quality, specific attainment thresholds, or the specific mechanisms linking education to health behaviors. Third, despite the model's substantial explanatory power ($R^2 = 0.512$), it omits other potent determinants of smoking, such as tobacco taxation, marketing exposure, and mental health factors. The measure of SHS exposure, though a significant predictor, is based on self-report and may be susceptible to bias. Fourth, our multivariate regression model was designed to identify the independent predictive power of key socio-economic and environmental factors—education and SHS exposure on SP. While regional differences were a central descriptive finding of our study, the 'Region' variable was not included in the final regression model. This decision was made to avoid potential multicollinearity, as educational attainment and smoke exposure are often structurally embedded within regional contexts. Including region risked obscuring the specific, cross-national effects of education and environment that we aimed to quantify. Similarly, TCS was not included in the regression model due to the availability of scores only for 2019 and the structural overlap with both regional affiliation and educational attainment, which would have introduced multicollinearity. Its role was therefore examined descriptively. Finally, data on novel nicotine products (e.g., e-cigarettes) were too limited for a thorough analysis of their role in smoking disparities, representing an important avenue for future research.

## Conclusion

This multinational study confirms that while overall smoking prevalence has declined, profound inequalities based on education, region, and environmental exposure persist. At the country level, lower educational attainment and widespread indoor secondhand smoke exposure are associated with higher smoking rates. Current tobacco control efforts have not yet fully mitigated these disparities. Future progress requires a strategic shift from blanket ap-

proaches to an equity-oriented framework that explicitly prioritizes low-socioeconomic status populations, implements stringent smoke-free policies, and fosters cross-regional policy learning. Given the ecological nature of this study, these findings should be interpreted as descriptive and hypothesis-generating; future individual-level and multilevel analyses are warranted to further elucidate the mechanisms underlying the observed associations.

**Conflicts of interest**

The authors declare no conflict of interest.

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