

# High particulate matter burden by cigarettes from the United Arab Emirates and Germany: Are there country-specific differences?

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## Research

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# Abstract

## Background

Although the big tobacco companies offer the same cigarette brands across countries, little is known about regional differences of particulate matter (PM) emissions of apparently equal brands. PM emissions of three cigarette brands (Marlboro, Winston, Parliament) from the United Arab Emirates (UAE) and Germany were analysed. Second-hand smoke was produced in a 2.88m<sup>3</sup> measuring cabin by an automatic environmental tobacco smoke emitter. PM size fractions PM<sub>10</sub>, PM<sub>2.5</sub> and PM<sub>1</sub> were detected in real time using laser aerosol spectrometry.

## Results

Depending on the PM fraction Marlboro and Winston cigarettes from UAE showed 28-35% higher PM amounts than the German counterparts. The “lighter” Parliament from UAE emitted 3-9% more PM than the German one. The measured PM<sub>2.5</sub> values laid between 777 µg/m<sup>3</sup> and 1161 µg/m<sup>3</sup>.

## Conclusion

PM emission of equal or similar tobacco products from different countries can differ distinctly. Hence, the declaration of PM emission values, beside nicotine, tar and carbon monoxide amounts, should be obligate worldwide. Furthermore, complete information about ingredients and production design of tobacco products should be provided to health officials and public. This can help to minimise or ban substances or production designs that make smoking even more harmful, and to enhance the awareness to risks of smoking.

## Background

The big players of the global tobacco market offer the same cigarette brands across countries. However, the apparently identical brands may differ in production site, origin of tobacco and, therefore, in ingredients. It is therefore to assume that also particulate matter (PM) emissions vary across countries.

PM, a mixture of solid and liquid airborne particles, is classified by the United States Environmental Protection Agency (EPA) in PM<sub>10</sub> (diameter ≤ 10 µm) and PM<sub>2.5</sub> (diameter ≤ 2.5 µm). The EPA defines particles between 2.5 and 10 µm as coarse inhalable particles and particles ≤ 2.5 µm as fine inhalable particles.(1) Such small particles can get deep into the respiratory system and even into the bloodstream. The smaller the particles the deeper the regions they can get in, and the more adverse are the potential health effects.(2) PM is associate with a variety of serious health effects especially heart and respiratory diseases, which can prove to be fatal.(3) In general, the higher the exposure to PM the higher are morbidity and mortality.(4) Lim et al.(5) estimated in a comparative risk assessment for the year 2010 about 3.1 mill. cases of death caused by PM worldwide.

Second-hand smoke (SHS), also known as environmental tobacco smoke, is mainly composed of smoke from the smouldering tobacco product and, with minor part, of exhaled mainstream smoke from the smoker. It is the main source of PM in households of smokers.(6)

The aim of the present investigation was to ascertain if any country-specific differences of PM emissions by tobacco smoke are detectable. Two apparently identical pairs of two cigarette brands (Marlboro, Winston), and additionally a “light” and a “normal” type of a same brand (Parliament) sold in the United Arab Emirates (UAE) and in Germany (GER) were examined regarding PM in SHS. This seems to be reasonable because previous studies showed a wide range of PM levels within different tobacco products. (7–9) The high-income countries UAE and Germany were chosen due to their similarities in a socioeconomic context.(10)

Nevertheless, UAE and Germany differ regarding tobacco consumption and its consequences in various ways. As maintained by The Tobacco Atlas of the American Cancer Society(11), in 2015, more than 1,342,000 adult people (15+ years old) in UAE used any tobacco product each day. That are 21.6% men and 1.9% women of its people. In Germany, it were more than 15,341,000 adult people (25.1% men and 17.1% women of its people), who use tobacco products daily. Thus, the prevalence of female smoking is in UAE much lower than in Germany. In 2016, deaths caused by tobacco were in UAE with more than 2900 of its people lower than on average in very high-HDI (Human Development Index) countries (male 12.84%, female 6.05% of total number of deaths). In Germany, the numbers are higher than on average in very high-HDI countries given that more than 124,800 people died owing to tobacco consumption (male 18.42%, female 8.93% of total number of deaths). By The Tobacco Atlas, smoke-free policies are in UAE stronger than in Germany, especially in healthcare and educational facilities. Additionally, bans on advertising are more extensive in UAE. For example, in Germany billboard and outdoor advertising, and advertising at selling points are still allowed.

## Materials And Methods

## Tobacco Products

The 3R4F reference cigarette developed by the *Kentucky Tobacco Research and Development Center* of the University of Kentucky, USA,(12) served as the standard of comparison for each three cigarette brands from UAE respectively Germany. The UAE cigarettes were bought at International Airport of Dubai and are as followed: Marlboro Gold,(13) Winston Red(14) and Parliament Platinum.(13) The cigarettes from Germany were bought at International Airport of Frankfurt and are as followed: Marlboro Gold,(13, 15) Winston Classic(14, 15), and Parliament Night Blue.(13, 15) Marlboro Gold and the two Parliament brands were produced by *Philip Morris GmbH* in Germany for the market of both countries. For the German market, Winston Classic were manufactured by *Japan Tobacco International (JTI)* in Germany, whereas Winston Red from UAE were produced by JTI in Switzerland. Table 1 shows some characteristics of all investigated tobacco products, whereby information on manufacturer, amounts of nicotine, tar and carbon monoxide were taken from the respective cigarette pack. Sizes and weights are given as measured means of five randomly chosen cigarettes of each brand.

## Automatic Environmental Tobacco Smoke Emitter

In order to generate SHS reproducibly, an Automatic Environmental Tobacco Smoke Emitter (AETSE) was used, that was developed for the Tobacco Smoke Particles and Indoor Air Quality (ToPIQ) studies (7, 16) and constructed by *Schimpf-Ing.* Trondheim, Norway.(17) The programmable microprocessor-controlled AETSE serves as a smoke pump and imitates the smoker. A 200 ml glass syringe, connected via a polyamide tube with the mouthpiece of the tobacco product, is moved by a stepper motor and take puffs of the tobacco product. After each puff, the smoke is pressed valve-controlled into the measuring chamber. The chamber with an internal volume of 2.88 m<sup>3</sup> is closed during the smoke processes, avoiding the exposure of any person to tobacco smoke.

## Smoking Protocol

The number of cigarettes analysed was n = 20 for each tested type. All investigated cigarettes were smoked following the same modified protocol according to the ToPIQ studies.(7, 16) The setting of the AETSE for the combustion phase, where each cigarette was lighted and smoked, was as followed: 40 ml puff volume; 13 ml/s puff flow rate; 2 puffs/min; duration 3 s/puff; two ignition puffs followed by 7 regular puffs. That corresponds to a 4 min 22 s combustion phase. After that, each cigarette was extinguished followed by the 5 min post-combustion phase. Then, the air in the measuring chamber was cleaned by ventilating with an industrial radial fan for at least 5 min. Subsequently, a new cycle began with a blank measurement in the pre-ignition phase.

## Laser Aerosol Spectrometer

The applied Laser Aerosol Spectrometer (LAS) and Dust Monitor Model 1.109 of Grimm Aerosol Technik GmbH & Co KG (Ainring, Germany)(18) is able to detect airborne particles every six seconds in real time. The measuring size ranges from 0.25 to 32 µm. The suction point of the LAS is placed 35 cm beside of the tobacco product at the same height. It is necessary to dilute the sample air pre-analytically using compressed air at a ratio of 1:10 to avoid blockage of the LAS measurement chamber. The dilution ratio was taken into account at the following data processing. Among others, the measured data can be represent in terms of occupational health according to the European Standard EN 481,(19) inhalable, thoracic, and alveolic in µg/m<sup>3</sup>, and according to US EPA as dust mass fractions PM<sub>10</sub>, PM<sub>2.5</sub>,(1) and additionally PM<sub>1</sub> in µg/m<sup>3</sup>.

## Data Processing

For all investigated cigarettes, the mean concentrations ( $C_{\text{mean}}$ ) and the area under the concentration-time curve (AUC), meaning the total PM exposition, were calculated for data received during the 4 min 22 s lasting combustion phase. All  $C_{\text{mean}}$  and AUC values were tested for Gaussian distribution that all data passed. Subsequently, one-way ANOVA-test and Tukey's multiple comparisons test were applied to show differences between different types of cigarettes among themselves. Finally, a two-way ANOVA test including Sidak's multiple comparisons test was done to examine country-specific differences. Level of significance was set on  $p = 0.05$ .

## Results

Table 2 listed the  $C_{\text{mean}}$  and AUC values of all investigated cigarette brands. Looking at the PM measurement results, both Marlboro and Winston cigarettes from UAE show significantly higher values than the German counterparts. The  $C_{\text{mean}}$  PM<sub>1</sub> value of Marlboro UAE is with 1074 µg/m<sup>3</sup> 35% higher than the mean value of the Marlboro GER (795 µg/m<sup>3</sup>). The Winston UAE show a 28% higher  $C_{\text{mean}}$  PM<sub>1</sub> value (929 µg/m<sup>3</sup>) than those from Germany (724 µg/m<sup>3</sup>). The  $C_{\text{mean}}$  value of 997 µg/m<sup>3</sup> for PM<sub>1</sub> of the Parliament UAE cigarettes is only a little higher (9%) than that of the German (917 µg/m<sup>3</sup>). The UAE cigarettes of all three brands show also higher PM<sub>10</sub> and PM<sub>2.5</sub>  $C_{\text{mean}}$  values. Accordingly Marlboro UAE shows 33% higher PM<sub>10</sub> and PM<sub>2.5</sub> values, and Winston UAE shows 31% respectively 30% higher values than the German counterparts. Both Parliament brands show very similar PM<sub>10</sub> and PM<sub>2.5</sub> measurement results with only 3% higher values of the UAE type. Regarding the AUC values similar findings emerged.

The two-way ANOVA test of the investigated pairs of cigarette brands revealed, that the origin of the tobacco product has a higher influence on PM emissions than the brand (Fig. 1). A pairwise comparison regarding the p values of the brands from UAE and Germany are shown in table 3. The country-specific significance for PM<sub>1</sub> is p < 0.0001 (brand: p = 0.0114). An interaction between brand and country is not significant (p = 0.123). Similar results pertain for PM<sub>2.5</sub> (country: p = 0.0005; brand: p = 0.0097; interaction: p = 0.0907) and PM<sub>10</sub> (country: p = 0.0006; brand: p = 0.0097; interaction: p = 0.0892).

The C<sub>mean</sub> and AUC values of Marlboro UAE do not differ significantly from the values of the Reference Cigarette. A little lower, but not significantly, are the values of Parliament UAE (-4.2% for C<sub>mean</sub> PM<sub>10</sub>), Parliament GER (-6.6% for C<sub>mean</sub> PM<sub>10</sub>) and Winston UAE (-1.4% for C<sub>mean</sub> PM<sub>10</sub>). Significant lower compared to the Reference Cigarette are the values of the Marlboro GER (-23.8% for C<sub>mean</sub> PM<sub>10</sub>; p = 0.0139) and the Winston GER (-32.2% for C<sub>mean</sub> PM<sub>10</sub>; p = 0.0002).

Regarding the distribution pattern of the particles PM<sub>10</sub>, PM<sub>2.5</sub> and PM<sub>1</sub> (Fig. 2), it was ascertained for all investigated brands, that the main part is represented by the PM<sub>1</sub> fraction with a percentage from about 85% to 93%. The proportion of PM<sub>10</sub> is far below 1% for all brands.

## Discussion

The measured C<sub>mean</sub> PM<sub>2.5</sub> values were between 777 µg/m<sup>3</sup> (Winston GER) and 1161 µg/m<sup>3</sup> (Marlboro UAE) and, therewith, about 31-fold to 46-fold higher than the World Health Organization (WHO) limit value (24-hour mean) for PM<sub>2.5</sub> of 25 µg/m<sup>3</sup>.(20) That means smoking in closed rooms causes PM burden with strong limit exceedance. It would take hours until the PM values decrease to a level below the limit. Semple and Latif (21) ascertained in an analysis of PM<sub>2.5</sub> amounts in SHS in households of smokers a PM half-life (50% PM decline) of about one hour.

The scenario of our study in the measuring cabin with an indoor volume of 2.88 m<sup>3</sup> is comparable to the situation in a compact car with closed windows and turned off ventilation. This car class has a passenger and cargo volume of 2.832 to 3.087 m<sup>3</sup> according to US EPA(22) and, hence, a similar internal volume. Considering the very high PM burden caused by smoking in such small closed rooms and the associated health risks a global ban on smoking in cars is to be in order. All the more, as children as car passengers are often affected.

Both tested Marlboro cigarettes, one type produced for the UAE sales market, and the other for the German market, were manufactured in Germany and had identical nicotine, tar and carbon monoxide amounts. Nevertheless, our findings show that the UAE type emitted significantly more PM. The second investigated brand Winston from UAE with lower amounts of nicotine, tar and carbon monoxide emitted more PM, too. Parliament GER and Parliament UAE showed very similar PM values, although the UAE type is a "lighter" version. Braun et al.(23) ascertained in an investigation of four cigarette types of one specific brand, all manufactured for the German market, that the lower the amounts of nicotine, tar and carbon monoxide, the less PM is in the SHS. However, the results of our study suggest, that smoking cigarettes from UAE lead to higher PM burden than smoking German cigarettes, especially at similar tobacco strength. Looking at the six investigated brands, the high statistical significance of the country-specific differences in contrast to the obvious lower significance of the influence of the brand on PM emissions has to be emphasised.

The reasons for the varying PM emission values are not clear. However, it can be assumed that tobacco companies use country-specific tobacco blends and/or filters and/or cigarette paper for the respective tobacco market. Different composition of additives, different tobacco blend or a combination of both are plausible reasons for our findings. The tobacco use in both countries differs in the choice of specific tobacco products as well as epidemiologically. First, it is to mention that in the UAE the proportion of female smokers is very low, but the male smoking rates are much higher and comparable to those of Germany. According to the *WHO Report on the Global Tobacco Epidemic, 2019*, (24) the prevalence in UAE of current smoking any tobacco product among persons aged ≥ 15 years is 14.8% (male 29.1%, female 0.6%), and of cigarette smoking 11.4% (male 22.5%, female 0.3%). The respective data for Germany related to smoking any tobacco product is 28.4% (male 30.4%, female 26.3%) and to cigarette smoking 26.3% (male 28.1%, female 26.3%). The in the Middle East traditional and centuries-old tobacco use with water pipe (i.e. hookah, shisha, narghile) becomes more and more popular worldwide. This trend started in the 1990s among the Arab youth.(25) Al-Houqani et al.(26) reported in a large cross-sectional survey from 2008 to 2010 among 170,430 UAE nationals aged ≥ 18 years that the prevalence of smoking water pipe was in total 0.76% (male 1.67%). This was trumped by the prevalence of smoking cigarettes (in total 8.55%, male 18.77%) and smoking Midwakh (in total 1.66%, male 3.64%). Midwakh, traditionally smoked by Bedouins and sailors of the Gulf States, is a small pipe for smoking dry tobacco (Dokha), often flavoured with spices and herbes.(26) In Germany, about smoking Midwakh exists no data, but the use might be certainly unusual. The prevalence of current smoking of water pipe among German persons aged ≥ 15 years is declared by the *Special Eurobarometer 385* survey with 5%.(27) Unfortunately, all this data is based on surveys and, therefore, are not consistent. In 2018, Al-Houqani et al.(28) compared in a pilot study the self-reported tobacco use of 399 UAE nationals with the validation of the smoking status via cotinine testing in urine samples. A cut-off of 200 ng/ml indicates a possible recent tobacco use. They found 42% of men and 9% of women were positive for cotinine versus the self-reported tobacco use of 36% men and 3% women. This indicates that especially women in UAE often conceal the use of tobacco. Nevertheless, all this elucidate significant differences in the use of tobacco between UAE and Germany.

Tobacco companies declare the exact composition, the “recipe” of the tobacco product, as “highly valuable trade secrets”.(13, 14, 29) O’Connor et al.(30) concluded in a comparison of cigarettes from ten different countries (low-, middle- and high-income) that the higher the country’s economic level the lower are the emission levels due to a higher engineering of cigarette design and filters. On the other side, Song et al.(31) demanded a generally ban on ventilated filters, which can be referred to as “highly engineered”. The reason therefore is the lower combustion temperature and the subsequent more incomplete combustion that increases the toxicity of tobacco smoke. Moreover, the smoker is tempted to inhale more intensive while smoking tobacco products with ventilated filters.

Previous study results regarding additives are inconsistent. On the one hand, Rustemeier et al.(32) stated in 2002, that additives in cigarettes increase PM levels in a range from 13 to 28%. Braun et al.(9) found higher PM burden by cigarettes with additives in comparison to those of the same brand without additives, too. An analysis of formerly secret documents of the tobacco industry, realised in 2011 by Wertz et al.(33), ascertained post hoc protocol alterations in four peer-reviewed publications conducted by Philip Morris. In this way, the initial statistical findings, that additives lead to an increase of toxicity as well as PM concentrations in tobacco smoke, should be obscured. On the other hand, Wasel et al.(8) found no statistical significant increase of PM amount in cigarette smoke caused by additives in an investigation of four L&M tobacco products, one type without additives. Gaworski et al.(34) and Gerharz et al.(35) examined cigarettes with the additive menthol. They either could not prove an increase of toxicity respectively PM burden caused by menthol.

A limitation of this study was that the used LAS Grimm Model 1.109 detects airborne particles in a size range from 0.25 µm to 32 µm, but not below. The detected particles of all brands were mainly composed by PM<sub>1</sub> (85% - 93%) depending on the brand. Only 0.13% to 0.56% were sized between 2.5µm and 10µm (Fig. 2). That implies, a part of submicronic particles (< 1 µm) and UFPs (< 100 nm) are not included in this analysis. Several studies reported different particle sizes (e.g. 0.1-1 µm or 0.02-2 µm) and mean diameters (e.g. 0.1 µm, 0.18 µm or 0.5 µm) of tobacco smoke.(36-41) Hence, it is to assume that the measured data of this study are slightly to low. Nevertheless, the applied LAS is able to detect most of PM in SHS. However, since health effects of UFPs come more and more into focus(42) an expansion of the measurement system would be useful.

The reference methods for measuring PM stated by the European Committee for Standardisation (see: standard EN 12341)(43) and the US EPA (see: Federal Reference Methods, FRM)(44) are mostly gravimetric methods. After a 24 h sample collection of PM the sample filters will be weigh out to determine the mass concentrations of PM<sub>10</sub> and PM<sub>2.5</sub> without declaration of PM<sub>1</sub>. The in this study used LAS Grimm Model 1.109 measures PM in real time via light scattering like the Grimm Model EDM 180 or the Tapered Element Oscillating Microbalance (TEOM) Monitor, which are both FRMs, too.(44) A study from 2009 showed very similar PM measuring data of gravimetric methods, TEOM Monitor, Grimm Model EDM 180 and Grimm Model 1.109.(45) Fromme et al.(46) noticed that PM values measured by LAS are lower than those of gravimetric methods but with a very high correlation of the data rank order. Thus, it is essential not to change the measuring method or device during the investigation. Hence, the measuring data of the used LAS can be considered as valid. In addition, it has to be emphasised that the applied LAS enables to investigate each single tobacco product in real time.

There are several protocols for smoking regimes, but no “gold standard”. Here, the standard of the *International Organization of Standardization* ISO/TR 17219:2013 for machine smoking of cigarettes(47) or the *Standard Operating Procedure for Intense Smoking of Cigarettes* provided by the WHO(48) shall be mentioned. The protocol underlying the current paper differs from these smoking regimes, but the provided results are likewise reliable and reproducible. The here applied AETSE produce SHS without exposing any person to tobacco smoke and concomitant health risks. The exact imitation of human smoking behaviour and SHS is not possible as true smoking humidifies the inhaled mainstream smoke in the respiratory tract. This leads to hygroscopic growth, and afterwards the particles of the exhaled smoke are about 1.5-fold larger. (49) As SHS is composite of about 85% side-stream smoke and only 15% mainstream smoke(50), the AETSE generates tobacco smoke very similar to SHS.

This study, likewise to previous ToPIQ studies, focused on comparison of the investigated tobacco products with a reference cigarette. (7-9, 16, 23, 35) Especially for comparison with guideline values or other investigations, absolute data are stated.

## Conclusions

Especially in small settings and non-aerated rooms, smoking leads to massive PM burden. Even though the manufacturing locations are equal, PM emissions of similar tobacco products from various countries can differ significantly. Tobacco products are manufactured for respective tobacco markets with different legal norms. Therefore, a global and consistent obligation to declare beside amounts of nicotine, tar and carbon monoxide also PM amounts is useful and necessary. Additionally, it should be obligatory for tobacco companies to fully inform health officials and the public about ingredients and production design of their tobacco products. This information can help to determine all characteristics of tobacco products (e.g. tobacco blend, additives or filter design) that make smoking even more harmful. Additionally, this knowledge would enable the regulation by law and the purposeful information of the public.

## Declarations

### Ethics approval and consent to participate

Not applicable.

### Consent for publication

Not applicable.

### Availability of data and materials

Datasets of this study are available from the corresponding author upon request.

### Competing interests

The authors declare no conflict of interest.

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### Authors' Contributions

This article is part of the thesis of R.A.Q., whereas M.B., D.K., R.M. and D.A.G. contributed significantly to the conception and design of the study. Moreover, they prepared the experiments, which were performed by R.A.Q.. R.A.Q., R.M. and M.B. analysed the data. The manuscript was written by M.B. and critically reviewed by all authors. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content. All authors agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All authors have read and approved the final manuscript.

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## Abbreviations

AETSE: automatic environmental tobacco smoke emitter

ANOVA: analysis of variance

AUC: area under the curve

EPA: Environmental Protection Agency

GER: Germany

HDI: human development index

JTI: Japan Tobacco International

LAS: laser aerosol spectrometer

PM: particulate matter

SHS: second-hand smoke

ToPIQ: tobacco smoke particles and indoor air quality

UAE: United Arab Emirates

US: United States

WHO: World Health Organization

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## Tables

**Table 1:** Features of the tested cigarette brands. Cigarette dimensions and weights are mean values of five randomised chosen cigarettes each brand.

	Reference Cigarette	Marlboro Gold (UAE)	Marlboro Gold (Germany)	Winston Red (UAE)	Winston Classic (Germany)	Parliament Platinum (UAE)	Parliament Night Blue (Germany)
Manufacturer	KTRDC Univ. of Kentucky (USA)	Philip Morris GmbH (Germany)	Philip Morris GmbH (Germany)	Japan Tobacco International (Switzerland)	Japan Tobacco International (Germany)	Philip Morris GmbH (Germany)	Philip Morris GmbH (Germany)
Nicotine [mg]	0.73	0.5	0.5	0.6	0.8	0.1	0.8
Tar [mg]	9.4	6	6	7	10	1	10
Carbon Monoxide [mg]	12	7	7	7	10	1	10
Total Length [mm]	84	83	83	84	83	83	98
Total Weight [mg]	988	807	797	807	767	807	1045
Tobacco Weight [mg]	775	599	580	653	642	600	755
Filter Length [mm]	27	27	27	21	21	22	22
Filter Diameter [mm]	8	8	8	8	8	8	8

**Table 2:** Mean concentrations ( $C_{\text{mean}}$   $PM_{10}$ ,  $PM_{2.5}$  and  $PM_1$ ) and Area Under the Curve (AUC  $PM_{10}$ ,  $PM_{2.5}$  and  $PM_1$ ) with standard deviation of all tested tobacco products. UAE = United Arab Emirates. GER = Germany.

	Reference Cigarette	Marlboro UAE	Marlboro GER	Winston UAE	Winston GER	Parliament UAE	Parliament GER
$C_{\text{mean}} PM_{10}$ [ $\mu\text{g}/\text{m}^3$ ]	1147 ± 131	1163 ± 165	874 ± 284	1016 ± 367	778 ± 140	1099 ± 230	1071 ± 332
$C_{\text{mean}} PM_{2.5}$ [ $\mu\text{g}/\text{m}^3$ ]	1143 ± 127	1161 ± 163	872 ± 282	1013 ± 365	777 ± 139	1095 ± 228	1065 ± 324
$C_{\text{mean}} PM_1$ [ $\mu\text{g}/\text{m}^3$ ]	1038 ± 83	1074 ± 119	795 ± 228	929 ± 301	724 ± 109	997 ± 183	917 ± 184
AUC $PM_{10}$ [ $\mu\text{g} \text{m}^{-3}\text{s}^{-1}$ ]	993,700 ± 114,216	982,886 ± 108,338	756,938 ± 245,919	879,302 ± 318,628	673,982 ± 121,369	945,533 ± 198,399	927,093 ± 287,701
AUC $PM_{2.5}$ [ $\mu\text{g} \text{m}^{-3}\text{s}^{-1}$ ]	989,999 ± 110,121	981,310 ± 107,531	755,173 ± 244,487	877,279 ± 317,060	672,827 ± 120,476	943,460 ± 197,337	922,547 ± 280,833
AUC $PM_1$ [ $\mu\text{g} \text{m}^{-3}\text{s}^{-1}$ ]	898,660 ± 72,073	913,681 ± 83,482	688,275 ± 197,675	803,915 ± 261,703	626,772 ± 94,302	863,535 ± 158909	793,771 ± 159,949

**Table 3:** P-values of statistical Sidak's multiple comparisons test of  $C_{\text{mean}}$  ( $PM_{10}$ ,  $PM_{2.5}$ ,  $PM_1$ ) for the three cigarette brand pairs from UAE and Germany. Statistical significance is highlighted by bold font type.

	Marlboro	Winston	Parliament
PM <sub>10</sub>	0.0026	0.0194	0.9838
PM <sub>2.5</sub>	0.0023	0.0185	0.9791
PM <sub>1</sub>	< 0.0001	0.0052	0.5171

## Figures

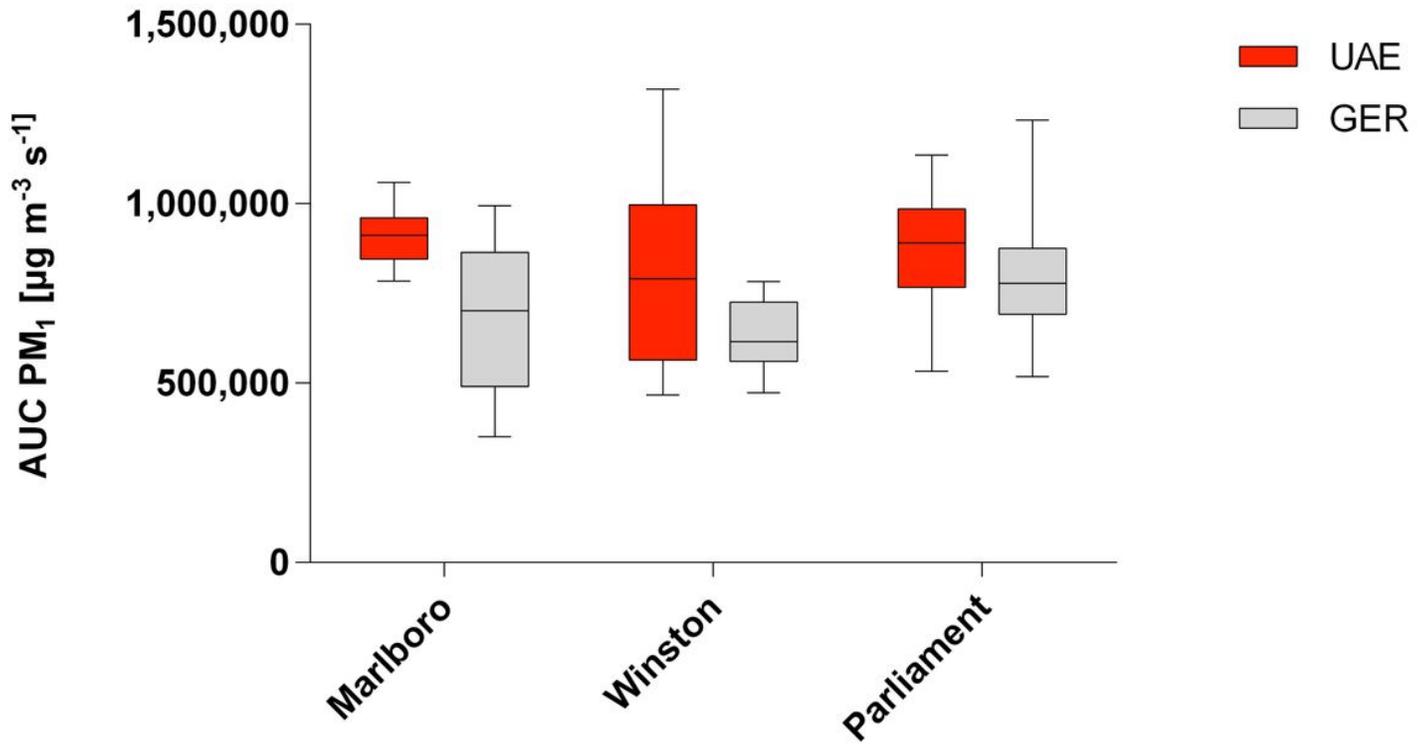


Figure 1

Comparative boxplot (min to max whiskers) of area under the curve (AUC) PM1 of country-specific brands. Based on statistical two-way Analysis of Variance (ANOVA) test.

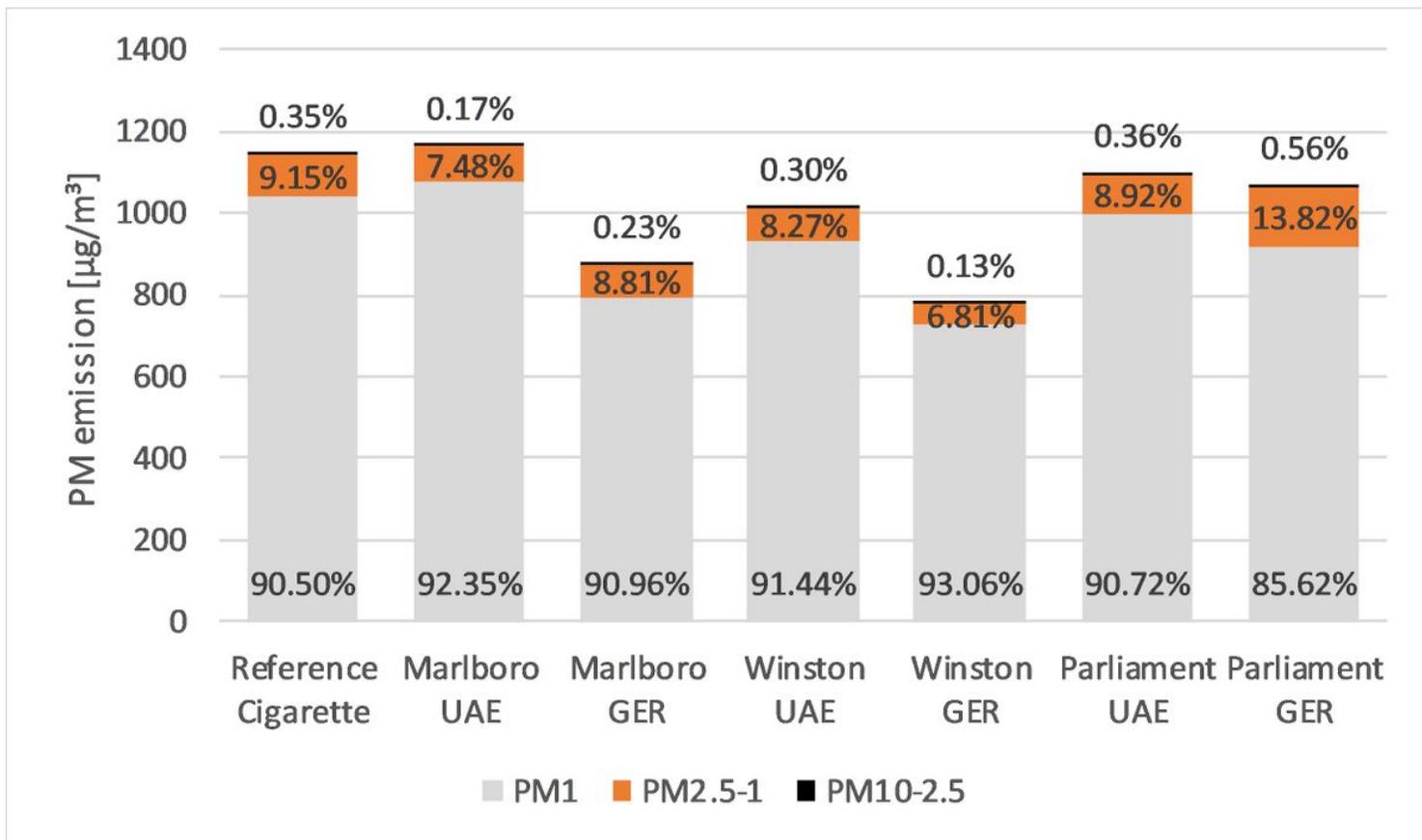


Figure 2

Distribution pattern of PM10-2.5, PM2.5-1 and PM1 of all investigated cigarettes.