environmental sciences proceedings

MDPI

Proceeding Paper

The Influence of Meteorological Parameters on $PM_{2.5}$ Concentrations on the Aegean Islands †

Kyriaki-Maria Fameli [1,*], Anna-Maria Kotrikla [1], Panayiotis Kalkavouras [2] and Amalia Polydoropoulou [1]

1 Department of Shipping, Trade and Transport, University of the Aegean, 82132 Chios, Greece; kotrikla@aegean.gr (A.-M.K.); polydor@aegean.gr (A.P.)
2 Institute for Environmental Research and Sustainable Development, National Observatory of Athens, 15236 Athens, Greece; pkalkavouras@noa.gr
* Correspondence: kmfameli@noa.gr
† Presented at the 16th International Conference on Meteorology, Climatology and Atmospheric Physics—COMECAP 2023, Athens, Greece, 25–29 September 2023.

Abstract: A network of low-cost sensors operates at six islands in the Aegean Sea (Lemnos, Lesvos, Chios, Samos, Syros and Rhodes) providing real-time $PM_{2.5}$ concentrations to the public. In the present study, the effect of the prevailing meteorological conditions on the local air quality was examined. For this reason, data about wind direction, dry and wet temperature, wind speed and sunlight were provided by the Hellenic National Meteorological Service for the period from January to September 2022. The analysis of the hourly $PM_{2.5}$ concentrations revealed different air quality patterns on each island, as well as seasonal changes for the same islands (e.g., higher concentrations in Samos during the cold period). Temperature was found to contribute significantly to the $PM_{2.5}$ measurements since it affects the anthropogenic activities related to emissions. For instance, higher temperatures in winter result in limited residential heating needs.

Keywords: air quality; particulate; Aegean; Greece; meteorology

check for updates

Citation: Fameli, K.-M.; Kotrikla, A.-M.; Kalkavouras, P.; Polydoropoulou, A. The Influence of Meteorological Parameters on $PM_{2.5}$ Concentrations on the Aegean Islands. *Environ. Sci. Proc.* **2023**, *29*, 125. https://doi.org/10.3390/environsciproc2023026125

Academic Editors: Konstantinos Moustris and Panagiotis Nastos

Published: 29 August 2023

1. Introduction

Air quality remains among the most crucial issues since it affects human health and the environment [1]. Despite the measures taken, exceedances of the EU standards about pollutants' concentrations are still recorded in many European cities. Air quality is affected by the dispersion of pollutants emitted by local anthropogenic activities (traffic, residential heating, port activities, industry) and natural sources. The prevailing meteorological conditions play an important role in the formation and distribution of the different pollutants [2]. Many cities with similar population densities and emission sources can have totally different environmental problems due to the existence of different meteorological conditions [3,4]. For instance, extreme ozone pollution episodes are usually recorded in the Mediterranean during summer due to sunlight and low wind speeds [5], as well as tropopause folds and stratosphere-to-troposphere transport [6]. However, many areas suffer from particulate pollution in wintertime because of the burning of biomass in combination with a low boundary layer (PBL) that prevents the dispersion of particulates [7,8]. Moreover, under favorable meteorological conditions, air masses can be transported from areas characterized by increased pollutants concentrations to nearby small towns [9]. Thus, the study of the correlation of the prevailing meteorological parameters with the measuring concentrations is of great importance.

Temperature and wind profiles, extreme wind speed, sunlight and humidity are among the meteorological parameters that contribute to formation of the measured pollutants' concentrations [10]. In the present study, a statistical approach was followed to understand the impact of meteorology on the local air quality. The area of interest comprises six islands in the Central (Syros) and East Aegean Sea (Chios, Lemnos, Lesvos, Rhodes and Samos) on which a network of seven PurpleAir sensors has been established.

2. Materials and Methods

In this research, $PM_{2.5}$ hourly concentrations were measured by low-cost Purpleair sensors located at six islands in the Aegean Sea (Figure 1). On Chios Island, two sensors were established at an urban and a suburban area of Chios City to further study the differences in the air quality at two areas characterized by different population densities and local sources. The Chios_urban sensor is located closer to the port area. Measurements were corrected based on the below equation:

$$PM_{2.5,\,corr} = 11.051 + 0.423 * PM_{purpleair} - 0.117 * RH, \quad (1)$$

where $PM_{purpleair}$ is the average $PM_{2.5}$ concentration measured by the two channels, A and B, of the sensor and RH is the relative humidity.

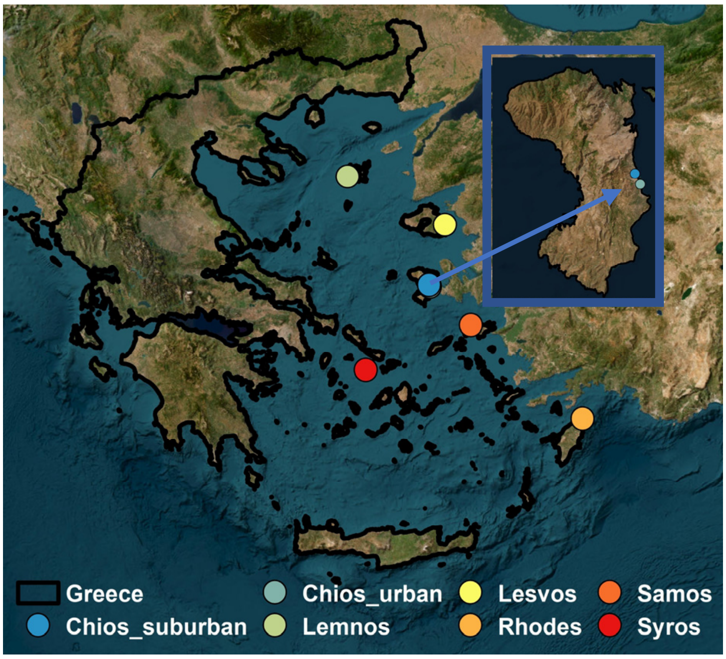


Figure 1. The network of air quality monitors in the Aegean Sea.

For the correlation of the meteorological parameters with the particulate measurements, wind speed and direction, dry and wet temperature data were provided upon request by the Hellenic National Meteorological Service (www.emy.gr). Both time series (concentrations and meteorological data) cover the January–14 September 2022 period.

3. Results and Discussion

Summary statistics for several meteorological parameters, as well as $PM_{2.5}$ concentrations, are presented in Table 1. The mean dry temperature ranges from 17.1 °C (Samos) to 20.1 °C (Rhodes), while the maximum wind speeds are recorded in Syros. Northern winds prevail in Chios, Lemnos, Samos and Syros, while multiple wind directions are recorded in Lesvos and Rhodes. It is obvious that the lowest concentrations are measured on Syros Island (mean value: 8.5 μg/m^3). This is because it is an area of small population density, so the emissions from anthropogenic activities are low. In summer, even though the population increases due to tourism, the prevailing northern strong winds (called Etesians) disperse the pollutants. However, the Etesian winds can also negatively affect the local air quality by transporting polluted air masses from nearby large cities located in Eurasia (Istanbul, Black Sea) [11,12]. Lesvos (the city of Mytilene in particular, where the PurpleAir sensor is established) appears to be the most polluted area among the six islands (mean annual $PM_{2.5}$ concentration: 14.3 μg/m^3). In general, for all islands, mean annual $PM_{2.5}$ concentrations are below the limit value set by the EU Air Quality Directives (25 μg/m^3) but are higher than the 5 μg/m^3 mean annual value proposed by the WHO Air Quality Guidelines. They are also lower than the ones measured in other urban areas in Greece (Athens [13], Thessaloniki [14], Patras [15]).

Table 1. Mean values of the dry and wet temperature, wind speed, the prevailing wind direction and $PM_{2.5}$ concentration on six islands in the Aegean Sea for the 1 January–15 September 2022 period.

Sensor	Dry Temperature (°C)	Wet Temperature (°C)	Wind Speed (knots)	Max Wind Speed (knots)	Wind Direction	Concentration (μg/m^3)
Chios	19.7	11.8	7.8	16.3	N (52.8%)	13.5
Lemnos	17.1	10.3	6.6	14.7	N (41.4%)	11.8
Lesvos	19.5	15.0	7.2	14.4	E (19.4%)	14.3
Rhodes	20.1	16.2	8.7	15.0	SW (24.2%)	12.2
Samos	17.1	14.6	7.0	14.4	N (49.5%)	13.4
Syros	19.0	11.4	11.5	21.0	N (36.9%)	8.5

3.1. $PM_{2.5}$ Concentrations and Temperature

The relationship between the $PM_{2.5}$ concentrations and dry temperature are presented in Figure 2 (the Chios_urban sensor was used for Chios Island). Most concentrations are below 20 μg/m^3, indicating that this amount of $PM_{2.5}$ is due to background concentrations and local sources that remain rather stable throughout the year (e.g., local traffic). In Samos, Lesvos and Chios, and to a lesser extent in Rhodes, peaks appear when the temperature is less than 12 °C (wintertime). A further study of the $PM_{2.5}$ concentrations revealed that the values reach their maximum in the evening during wintertime. Probably, they are related to the fuel used for residential heating. Higher particles concentrations during the cold period compared to the warm period were also found by [16] in Lesvos. It is considered that wood burning contributes significantly to particulate pollution [17], and the maximum concentrations recorded during nighttime have been attributed to wood burning for residential heating by other researchers as well [18]. The estimation of the possible sources in the area of interest and the locals' perception about air quality was attempted through the conduction of a survey. Responses revealed that in Samos, Lesvos and Chios, people usually use fireplaces and stoves and, consequently, biomass (e.g., wood, pellets) for residential heating. In general, the preference for residential heating means depends on the temperatures, the economic conditions and the availability of fuel. On the northern Aegean islands (with low GDP per capita and lower temperatures), stoves, fireplaces and central heating with oil are used. On the southern Aegean islands (high GDP per capita and higher temperatures), air-conditioning or heat pumps (both for winter and summer) are used. In addition, whereas Lesvos, Chios and Samos are islands with quite high forest cover and/or olive groves, Lemnos is mainly covered by bushes and low vegetation, so people prefer central heating (fuel used: oil), which is mainly associated with NOx emissions [17]. So, despite the low temperatures in winter, no exceedances of $PM_{2.5}$ concentrations are recorded in Lemnos. It should also be mentioned that the island's capital, Myrina, where the sensor is located, is a small town (approx. 6000 inhabitants). Rhodes (Figure 2b) is characterized by mild winters; thus, the heating period is short, and people prefer to use air-conditioning (or heat pumps) as the main heating source and central heating and stoves secondly. As a result, low $PM_{2.5}$ concentrations are recorded even though the city of Rhodes is the most populated among all (approx. 50,000 inhabitants). No extreme values were measured on Syros during the cold period. Since brushes occupy a large part of the island, people use central heating and air-conditioning. In addition, the high winds on Syros (Table 1) disperse the pollution.

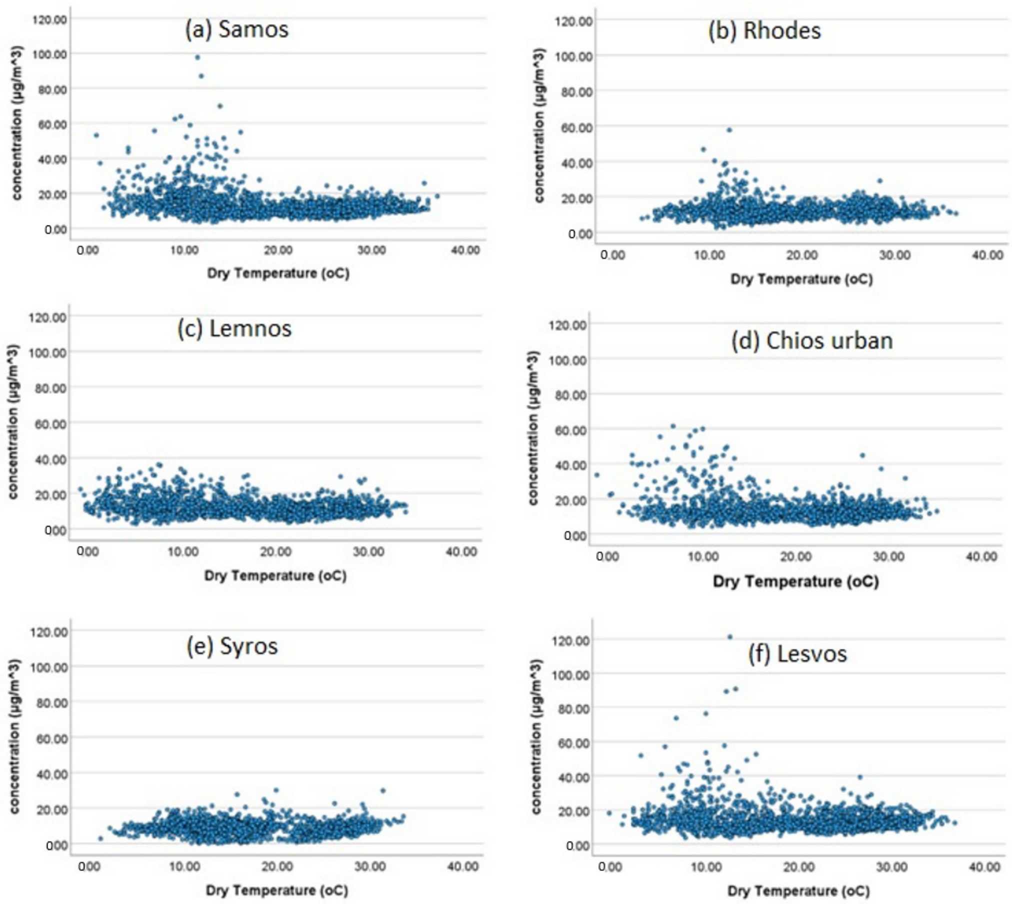
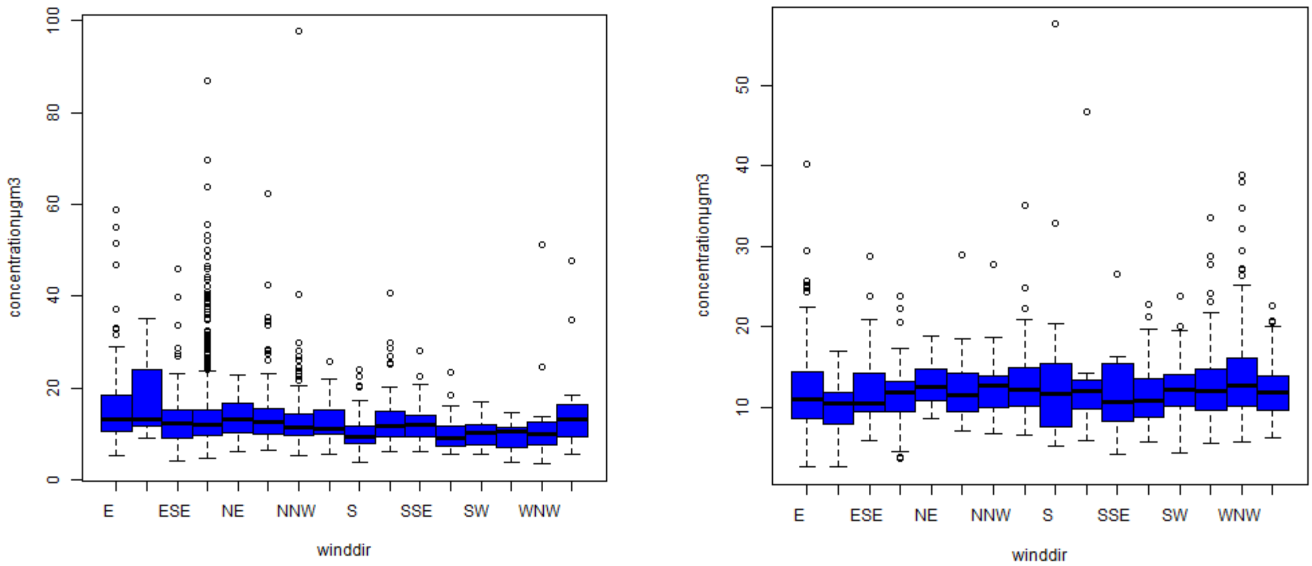


Figure 2. Scatter plots of hourly $PM_{2.5}$ concentrations (in µg/m^3) and dry temperature (in °C) for monitoring stations: (**a**) Samos, (**b**) Rhodes, (**c**) Lemnos, (**d**) Chios_urban, (**e**) Syros and (**f**) Lesvos.

3.2. $PM_{2.5}$ Concentrations and Wind Direction

Box plots of $PM_{2.5}$ concentrations in relation to wind direction are presented in Figure 3 for two selected islands, Samos and Rhodes, since they are characterized by different climatological conditions (warmer winters in Rhodes, sunny and hot summers), landscapes (the city of Karlovasi in Samos, where the sensor is located, is surrounded by a woody area, while there is low vegetation in the city of Rhodes) and population (Rhodes has approx. 50,000 inhabitants, Karlovasi has 7000 inhabitants). Increased concentrations on Samos are connected to low wind speeds (0–1 knots) from the northern direction (the fourth box plot in Figure 3a) and secondly from the NNW direction. On the other hand, on Rhodes, the outliers shown in Figure 3b (30 µg/m^3 < values < 40 µg/m^3) were recorded in February under the prevalence of strong southern and northwestern winds (>10knots). However, values above 40 µg/m^3 are related to low eastern and southern winds (<4 knots). So, it is more likely, for both islands (Samos and Rhodes), that local sources contribute to the formation of the highest concentrations since the prevalence of low wind speeds prevents the dispersion of pollutants.



(**a**) **Samos** (**b**) **Rhodes**

Figure 3. Box plots of hourly $PM_{2.5}$ concentrations (in μg/m^3) as distributed at different wind directions for (**a**) Samos and (**b**) Rhodes stations for the 1 January 2022–14 September 2022 period (wind direction: E stands for east, S for south, N for north, and W for west).

4. Conclusions

A network of low-cost sensors has been developed on six islands in the Aegean Sea (Lemnos, Lesvos, Samos, Chios, Syros and Rhodes) to examine the local air quality. In the present study, hourly $PM_{2.5}$ concentrations, as well as meteorological parameters, were collected for the period from 1 January to 14 September 2022. The correlation between $PM_{2.5}$ values and temperature indicated that the higher measurements are related to low temperature profiles and the use of biomass burning as fuel for residential heating. In areas where different appliances are preferred for heating (e.g., air-conditioning), there are no extreme $PM_{2.5}$ concentrations. Consequently, anthropogenic activities can highly affect the kind of pollutants emitted and thus the local air quality. Moreover, the prevalence of low wind speeds leads to increased concentrations due to the prevention of particle dispersion, while the existence of strong northern winds (Etesians) helps the transportation of the pollutants far from the source. A further investigation of the particles' chemical characteristics should provide evidence of the sources that determine the concentrations measured.

Author Contributions: Conceptualization, A.-M.K. and K.-M.F.; methodology, A.-M.K. and K.-M.F.; software, K.-M.F.; validation, A.-M.K., K.-M.F. and P.K.; formal analysis, A.-M.K. and K.-M.F.; investigation, A.-M.K. and K.-M.F.; resources, A.-M.K., K.-M.F. and A.P.; data curation, A.-M.K. and K.-M.F.; writing—original draft preparation, A.-M.K. and K.-M.F.; visualization, K.-M.F.; supervision, A.-M.K.; project administration, A.P.; funding acquisition, A.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research is financed by the Research Infrastructure EN.I.R.I.S.S.T.+ (MIS 5047041), implemented under the Action "Reinforcement of the Research and Innovation Infrastructure", funded by the Operational Programme "Competitiveness, Entrepreneurship and Innovation" (NSRF 2014–2020) and co-financed by Greece and the European Union (European Regional Development Fund).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are available upon request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. European Environmental Agency. Air Quality in Europe 2022. 2022. Available online: https://www.eea.europa.eu//publications/air-quality-in-europe-2022 (accessed on 20 May 2023).
2. Yang, J.; Ji, Z.; Kang, S.; Zhang, Q.; Chen, X.; Lee, S.Y. Spatiotemporal variations of air pollutants in western China and their relationship to meteorological factors and emission sources. *Environ. Pollut.* **2019**, *254*, 112952. [CrossRef]
3. Laña, I.; del Ser, J.; Padró, A.; Vélez, M.; Casanova-Mateo, C. The role of local urban traffic and meteorological conditions in air pollution: A data-based case study in Madrid, Spain. *Atmos. Environ.* **2016**, *145*, 424–438. [CrossRef]
4. Vardoulakis, S.; Kassomenos, P. Sources and factors affecting PM10 levels in two European cities: Implications for local air quality management. *Atmos. Environ.* **2008**, *42*, 3949–3963. [CrossRef]
5. Agathokleous, S.; Saitanis, C.J.; Savvides, C.; Sicard, P.; Agathokleous, E.; de Marco, A. Spatiotemporal variations of ozone exposure and its risks to vegetation and human health in Cyprus: An analysis across a gradient of altitudes. *J. For. Res.* **2022**, *34*, 579–594. [CrossRef] [PubMed]
6. Dafka, S.; Akritidis, D.; Zanis, P.; Pozzer, A.; Xoplaki, E.; Luterbacher, J.; Zerefos, C. On the link between the Etesian winds, tropopause folds and tropospheric ozone over the Eastern Mediterranean during summer. *Atmos. Res.* **2021**, *248*, 105161. [CrossRef]
7. Karagulian, F.; Belis, C.A.; Dora, C.F.C.; Pruss-Ustun, A.M.; Bonjour, S.; Adair-Rohani, H.; Amann, M. Contributions to cities' ambient particulate matter (PM): A systematic review of local source contributions at global level. *Atmos. Environ.* **2015**, *120*, 475–483. [CrossRef]
8. Florou, K.; Papanastasiou, D.K.; Pikridas, M.; Kaltsonoudis, C.; Louvaris, E.; Gkatzelis, G.I.; Patoulias, D.; Mihalopoulos, N.; Pandis, S.N. The contribution of wood burning and other pollution sources to wintertime organic aerosol levels in two Greek cities. *Atmos. Chem. Phys.* **2017**, *17*, 3145–3163. [CrossRef]
9. Lai, H.C.; Dai, Y.T.; Mkasimongwa, S.W.; Hsiao, M.C.; Lai, L.W. The Impact of Atmospheric Synoptic Weather Condition and Long-Range Transportation of Air Mass on Extreme PM_{10} Concentration Events. *Atmosphere* **2023**, *14*, 406. [CrossRef]
10. Zhang, Y. Dynamic effect analysis of meteorological conditions on air pollution: A case study from Beijing. *Sci. Total Environ.* **2019**, *684*, 178–185. [CrossRef] [PubMed]
11. Tombrou, M.; Bossioli, E.; Kalogiros, J.; Allan, J.D.; Bacak, A.; Biskos, G.; Coe, H.; Dandou, A.; Kouvarakis, G.; Mihalopoulos, N.; et al. Physical and chemical processes of air masses in the Aegean Sea during Etesians: Aegean-GAME airborne campaign. *Sci. Total Environ.* **2015**, *506–507*, 201–216. [CrossRef] [PubMed]
12. Triantafyllou, E.; Giamarelou, M.; Bossioli, E.; Zarmpas, P.; Theodosi, C.; Matsoukas, C.; Tombrou, M.; Mihalopoulos, N.; Biskos, G. Particulate pollution transport episodes from Eurasia to a remote region of northeast Mediterranean. *Atmos. Environ.* **2016**, *128*, 45–52. [CrossRef]
13. Paraskevopoulou, D.; Liakakou, E.; Gerasopoulos, E.; Mihalopoulos, N. Sources of atmospheric aerosol from long-term measurements (5 years) of chemical composition in Athens, Greece. *Sci. Total Environ.* **2015**, *527–528*, 165–178. [CrossRef] [PubMed]
14. Tolis, E.I.; Saraga, D.E.; Lytra, M.K.; Papathanasiou, A.C.; Bougaidis, P.N.; Prekas-Patronakis, O.E.; Ioannidis, I.I.; Bartzis, J.G. Concentration and chemical composition of $PM_{2.5}$ for a one-year period at Thessaloniki, Greece: A comparison between city and port area. *Atmos. Environ.* **2015**, *113*, 197–207. [CrossRef]
15. Kosmopoulos, G.; Salamalikis, V.; Matrali, A.; Pandis, S.N.; Kazantzidis, A. Insights about the Sources of $PM_{2.5}$ in an Urban Area from Measurements of a Low-Cost Sensor Network. *Atmosphere* **2022**, *13*, 440. [CrossRef]
16. Triantafyllou, E.; Diapouli, E.; Korras-Carraca Manousakas, M.; Psanis, C.; Floutsi, A.A.; Spyrou, C.; Eleftheriadis, K.; Biskos, G. Contribution of locally produced and transported air pollution to particulate matter in a small insular coastal city. *Atmos. Pollut. Res.* **2020**, *11*, 667–678. [CrossRef]
17. Fameli, K.M.; Papagiannaki, K.; Kotroni, V. Optimizing the knowledge on residential heating characteristics in Greece via crowd-sourcing approach. *Atmosphere* **2021**, *12*, 1178. [CrossRef]
18. Stavroulas, I.; Grivas, G.; Michalopoulos, P.; Liakakou, E.; Bougiatioti, A.; Kalkavouras, P.; Fameli, K.M.; Hatzianastassiou, N.; Mihalopoulos, N.; Gerasopoulos, E. Field evaluation of low-cost PM sensors (Purple Air PA-II) Under variable urban air quality conditions, in Greece. *Atmosphere* **2020**, *11*, 926. [CrossRef]