GeoStudies 1: 1–10 (2024)
DOI: 10.3897/geostudies.1.e109372

Research Article

Assessment of the national emission reduction strategies effects for Bulgaria (2020–2029 and after 2030) on surface FPRM and CPRM concentrations

Kostadin Ganev[1], Georgi Gadzhev[1], Ivelina Georgieva[1], Vladimir Ivanov[1], Nikolay Miloshev[1]

1 *National Institute of Geophysics, Geodesy and Geography – Bulgarian Academy of Sciences, Acad. G. Bonchev str., bl. 3 1113 Sofia, Bulgaria*
Corresponding author: Ivelina Georgieva (iivanova@geophys.bas.bg)

Abstract

Bulgaria has developed national emission reduction strategies for the period from 2020 to 2029 and the years after 2030, in accordance with EU Directive 2016/2284. Our fundamental aim in this study is to assess the effects of the strategy on the PM near surface concentrations in Bulgaria. All the simulation was done by the modeling system U.S. Environmental Protection Agency (US EPA) Models-3 for 2008 to 2014 period and with 9 km horizontal grid resolution for the selected region – Bulgaria. The meteorological background that was used is with 1°x1° resolution from the National Centers for Environmental Prediction (NCEP) Global Analysis Data. There are 5 emission scenarios structured: 2005 emissions (reference period), 2020–2029 emissions projected with existing measures (WEM) and with additional measures (WAM), projected after 2030 WEM and WAM emissions, as parallel calculations were performed with all of the scenarios. Making parallels between the concentrations, with different scenarios simulated, gives the possibility to evaluate the national emission reduction strategies' effect.

Key words: emission reduction strategies, emission scenarios, numerical simulation, pollution modeling, PM near surface concentrations

Academic editor: Reneta Dimitrova
Received: 17 July 2023
Accepted: 6 October 2023
Published: 29 January 2024

Citation: Ganev K, Gadzhev G, Georgieva I, Ivanov V, Miloshev N (2024) Assessment of the national emission reduction strategies effects for Bulgaria (2020–2029 and after 2030) on surface FPRM and CPRM concentrations. GeoStudies 1: 1–10. https://doi.org/10.3897/geostudies.1.e109372

Introduction

In 2016, a revised directive on national emission ceilings was adopted – Directive (EU Directive 2016/2284). The Directive contributes to the EU's targets for reducing emissions from anthropogenic sources as set out in Union legislation and progress towards the Union's long-term objective of achieving ambient air quality (AQ) levels according to AQ guidelines by the World Health Organization. All the national air pollution control programs have to formulate their own policies and measures. They should be applicable to all relevant sectors (agriculture, energy, industry, road transport etc.). Every member state is free to decide what measures and policies (UNFCCC 2016) it takes to meet the emission reduction obligations set out in (EU Directive 2016/2284). Member States shall provide for each pollutant an "as taken" forecast (i.e., measures taken) and, if applicable, a forecast 'with additional measures taken' (i.e., planned measures) under the guidelines set out in the (EMEP/EEA Guidance

2019). The projections are a tool for assessing what might happen if countries committed to ”With Existing Measures” (WEM) and what else could be done ”With Additional Measures” (WAM). These scenarios should be evaluated using a range of economic forecasts and using numerical modeling methods. For this research purpose, a set of models for modeling the state of pollutants in the atmosphere was used – the US EPA Models 3 System. The system is based on 3 models – Weather Research and Forecasting Model (WRF) v.3.2.1 (Shamarock et al. 2007), (https://ncar.ucar.edu/what-we-offer/models/weather-research-and-forecasting-model-wrf), The Community Multiscale Air Quality Modeling System (CMAQ) v.4.6 – (Byun and Ching 1999), (Byun 1999), (https://cmascenter.org/), and Sparse Matrix Operator Kernel Emissions Processing System (SMOKE) – (CEP 2003). The used models already were adapted and validated for Bulgaria, as can be followed in our previous work about Particulate Matters (PM) modeling in Bulgaria (Gadzhev et al. 2015), (Georgieva. and Miloshev 2018), (Kirova et al. 2021), (Todorova et al. 2011).

Methods

An extensive database was created and used for this paper based on 3D modelling. The study was conducted using computer simulations with the already mentioned system US EPA Models-3. Ensemble (a set of computer run results), sufficiently exhaustive and representative to make reliable conclusions for atmospheric composition typical and extreme situations with their specific space and temporal variability was created by using of computer simulations. The computer-simulated ensemble is sufficiently large and comprehensive enough to allow a variety of statistical treatments. The meteorological background that was used is with 1°x1° resolution from the NCEP Global Analysis Data. The simulations start from the whole of Europe with a resolution of 81km, gradually downscaling the resolution to 9 km for the territory of Bulgaria. The emissions used in the paper are from Netherlands Organization for Applied Scientific research (TNO) inventory (Denier van der Gon et al. 2010) outside Bulgaria and for the inside domain from the National inventory (Bulgarian Executive Environmental Agency). In accordance with (EU Directive 2016/2284), Bulgaria has developed national emission reduction strategies for two periods: from 2020 to 2029 and after 2030. Also, according to the legislation, it must report a set of projected emission scenarios (EEA Technical Report 2015). The simulations were run day-by-day, and the results were averaged over the entire period and ensemble was created. In that way the “typical” annual estimates were obtained. The calculations were carried out on the supercomputer system “Avithol” situated at the Institute of Information and Communication Technologies at the Bulgarian Academy of Sciences (IIKT-BAS), as the simulations were organized in different jobs (Atanassov et al. 2017, Karaivanova et al. 2022).

According to the Guidance for the development of national air pollution control programs under (EU Directive 2016/2284) and (Guidance 2019/C77/01), the WEM forecast covers policies and measures implemented and adopted (UNFCCC 2016). WEM stands for projections of anthropogenic greenhouse gases (GHGs) or air pollutant emissions from sources that capture the effects of currently implemented or adopted policies and measures.

The WAM scenario takes into consideration projected pollutant emissions and the potential for reductions of their dispersion into ambient air when incorporating planned policies and measures (UNFCCC 2016), which will achieve the 2030 national priorities. Emissions projections are inherently less specific than historical emissions inventories because they require additional assumptions about future activity growth (e.g., production, transport, population) and technology uptake. The assessment of the impact of the estimated emissions for 2020–2029 and after 2030, according to the commitments of Bulgaria to reduce emissions of atmospheric pollutants under (EU Directive 2016/2284), is listed in Table 1.

The National Air Pollution Control Program 2020–2030, was carried out with the means of computer simulations. Table 2 shows the emissions forecast for the period 2020–2029 and after 2030, under the WEM and WAM scenario. Emissions from all source categories have been renormalized, both for the period 2020–2029 and after 2030, according to (EU Directive 2016/2284) according to emission values for the base year 2005.

Results

The results from the simulations below show the relative differences (in %) between surface concentrations of Coarse and Fine Particulate Matters (CPRM and FPRM) simulated with various emissions scenarios (WEM/WAM) and for periods 2020–2029 and after 2030. Particles with a size below 2.5 μm are called fine (FPRM), and those with a size from 2.5 μm to 10 μm – are called coarse particles (CPRM). CPRM = ACORS + ASEAS + ASOIL – Coarse Particulate Matters (CPRM) and FPRM = SO_4 + NH_4 + NO_3+EC+ (ORGA+ORGB) + $PM_{2.5}$. The comparison with the year 2005, which was set as our basis year, demonstrates the

Table 1. Air pollutant emissions forecast.

Pollutant	Emissions according to the 2016 inventory, kt			Emission reduction vs based 2005, %			Obligation to reduce emissions, %	
	2005	2020	2030	2020	2025	2030	2020–2029	2030+
SO_2	771.3	79.6	83.4	90	90	89	78	88
NO_x	183.2	93.8	74.7	49	54	59	41	58
NMVOC	80.7	62.1	46.3	23	34	43	21	42
NH_3	51.6	45.0	43.0	13	15	15	3	12
$PM_{2.5}$	30.9	22.2	7.8	28	57	75	20	41

Table 2. Air pollutant emissions forecast for the period 2020–2029 and after 2030, WEM and WAM scenario.

	Emissions						
Pollutant	2005, kt	2020–2029 WEM, kt	2030 WEM, kt	Reduction WEM %	2020-2029 WAM, kt	2030 WAM, kt	Reduction WAM %
SO_2	771.3	84.8	85.6	89	99.2	68.6	87 / 91
NO_x	183.2	86.2	85.4	53	81.4	67.8	56 / 63
NMVOC	80.7	58.2	55.9	28	53.9	47	33 / 42
NH_3	51.6	46.8	47	9	44.1	43.8	15
$PM_{2.5}$	30.9	21.0	18.5	32 / 40	14.4	8.8	53 / 72

effect of emission reduction measures and their effectiveness. Five emission scenarios (only for Bulgarian emissions) are considered in the paper:

1. Emissions in 2005 (basis year) for Bulgaria, according to the inventory 2005);
2. Emissions for 2020–2029 projected with existing measures (WEM) and
3. Emissions for 2020–2029 projected with additional measures (WAM),
4. Emissions after 2030 projected with existing measures (WEM) and
5. Emissions after 2030 projected with additional measures (WAM).

The emissions outside Bulgaria remain unchanged for all the scenarios. All the relative differences in scenario x, shown below, are calculated according to the formula:

$$R_{scenariox} = \frac{C_{scenario1} - C_{scenariox}}{C_{scenario1}} \text{ [\%], (1)}$$

where $C_{scenario1}$ and $C_{scenariox}$ are the surface concentrations for the respective scenarios. Thus, the positive relative difference values mean concentration reduction for the respective scenario.

Fig. 1a) The maps show the relative differences in changes in CPRM concentrations with emissions from 2005 to 2029 for the WAM and WEM measures. It is clearly seen that for this period, the relative differences are positive, with the additional measure WAM outperforming by about 30% over the whole country and 60% over the sources, while WEM shows a 20% relative difference over the eastern and surrounding areas.

For the period after 2030 Fig. 1b), the relative differences between the two scenarios are even more noticeable, registering about 60% over all sources throughout the day with WAM, compared to those of the scenario WEM (about 20% over the whole area and reaching 40% over some sources).

In Fig. 2a), positive relative differences show that concentrations under the WEM scenario are higher, indicating that the WAM scenario is effective. For 2020–2029, the relative differences in CPRM concentration change are around 20% across the country, reaching up to 30% at specific points, mainly above sources. For the period after 2030, the relative differences are again positive, reaching 40% above sources and big cities in the country throughout the day. The WAM scenario for emissions after 2030 has a positive effect on CPRM surface concentration changes compared to the results of the WEM scenario.

Fig. 2b), the relative differences in CPRM concentration changes obtained from WEM are positive, about 10–15% above sources in the country. For the scenario WAM, the relative differences are also positive, with values up to 20% across the entire country and up to 40% above sources. The results show that the WAM (with additional measures) gives better results than the WEM (with existing measures).

Fig. 3a) presents the relative differences in FPRM surface concentration changes with emissions from 2005 to 2029 under the WAM and WEM measures. It is clear that for this period, the relative differences are positive, with the scenario including WAM measures and providing better results by about 10% across the entire country and 20% over the sources, while without additional WEM measures – a 10% relative difference over the eastern and surrounding regions.

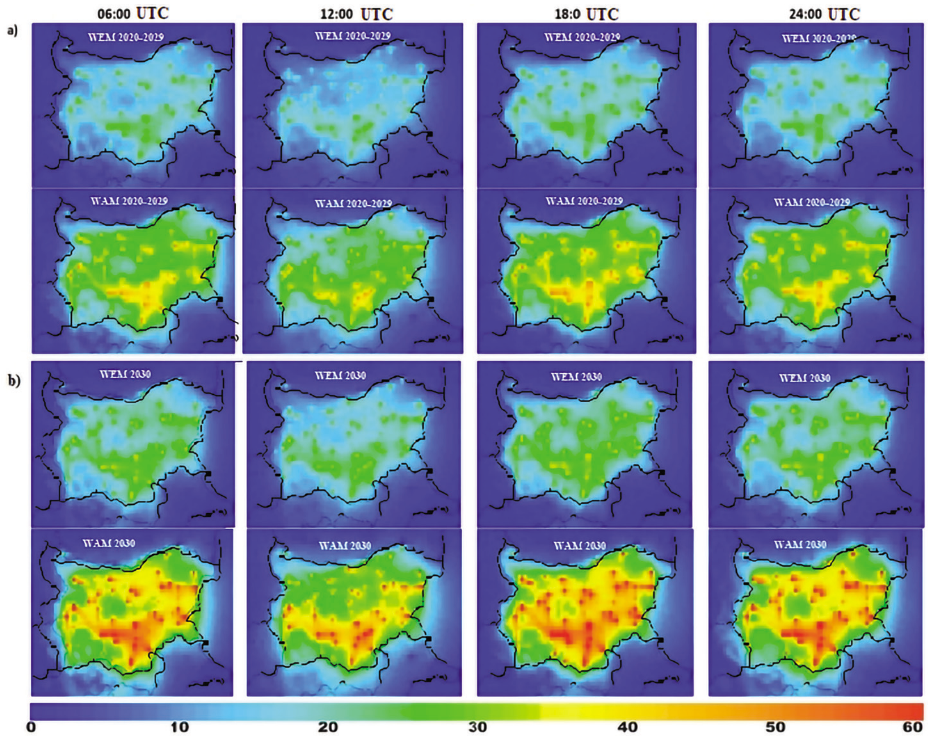

Figure 1. Maps of relative differences of CPRM surface concentrations [%]: a) Relative differences with applied different measures (WEM/WAM) for 2020 to 2029 and b) after 2030, relative to the reference period (2005). All simulations are annually averaged over the ensemble in 6, 12, 18 and 24 UTC.

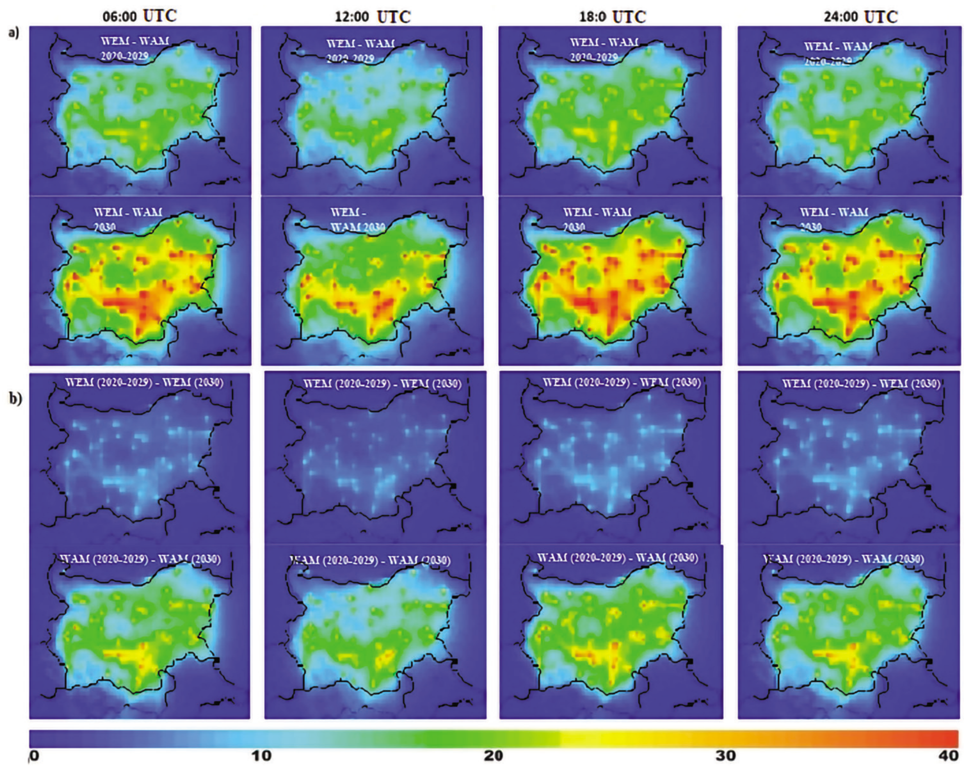

Figure 2. Comparison of the effects of WEM and WAM scenarios: a) Surface relative differences obtained with emissions from WEM and WAM scenarios for 2020-2029 and after 2030 and b) Surface relative differences obtained with emissions for 2020-2029 and after 2030, for the WEM and WAM scenarios. All simulations are annually averaged over the ensemble in 6, 12, 18 and 24 UTC.

Fig. 3b): For the period after 2030, the relative differences between the two scenarios are even more significant, about 20% over the entire country in the morning and afternoon, 20% above the sources at midday and evening hours. For the WAM scenario compared to the WEM, about 10% over the entire region and reaching up to 20% only in the area of the Upper Thracian Plain in the morning and afternoon.

Fig. 4a): For 2020–2029, the relative differences in FPRM concentrations are about 5% over the whole domain, reaching up to 15% during the morning and afternoon hours in Sofia and Upper Thracian Plain regions. For the period after 2030, the relative differences are once again positive, reaching 15% for the Sofia and Upper Thracian Plain regions throughout the day and 8% above the rest of the country. The WAM scenario after 2030 has a greater positive effect on changes in FPRM concentrations than the results from the WEM scenario.

Fig. 4b): The relative differences in FPRM concentration changes obtained with emissions from the scenarios for both periods with WEM are positive at around 5% above the point sources in the country and the region of the Upper Thracian Plain. For the scenario WAM, the relative differences are also positive, with values of up to 8% across the entire country and reaching up to 15% above the Upper Thracian Plain and the region of Sofia. Once again, it is obvious that the WAM measures gives better results compared to the WEM.

Conclusion

Contrasting the PM near surface concentrations, under simulations with different scenarios according to the national emission reduction strategies, gives a good assessment of the measures, whether they are already in effect or planned compared to the results of 2005, and shows the impact of the strategy itself on the territory of the country. The conclusions here are as follows: The relative differences for changes in CPRM concentrations with emissions from 2005 to 2029 for the WAM and WEM measures are positive. The WAM shows about 30% relative difference over the entire country and 60% over the sources, while WEM shows a 20% relative difference over the eastern and surrounding areas. For the period after 2030, the relative differences between the two scenarios are even more noticeable. The WAM scenario is more effective than the WEM scenario. When comparing the effects of WEM and WAM scenarios, positive relative differences show that concentrations under WEM are higher than under WAM, indicating that the WAM measure is effective, which is the case for CPRM surface concentration changes. The relative differences in FPRM surface concentration changes with emissions from 2005 to 2029 under the WAM and WEM measures are positive. The scenario includes additional WAM measures providing better results than those without additional WEM. For the period after 2030, the relative differences between the two scenarios are even more significant; again, they are positive, and again the WAM scenario is more effective compared to the reference 2005. When comparing the effect between WEM and WAM, the WAM scenario after 2030 has a greater positive effect on changes in FPRM concentrations than the results from the WEM scenario. When comparing both periods: It is obvious that the WAM measure gives better results than the WEM measure.

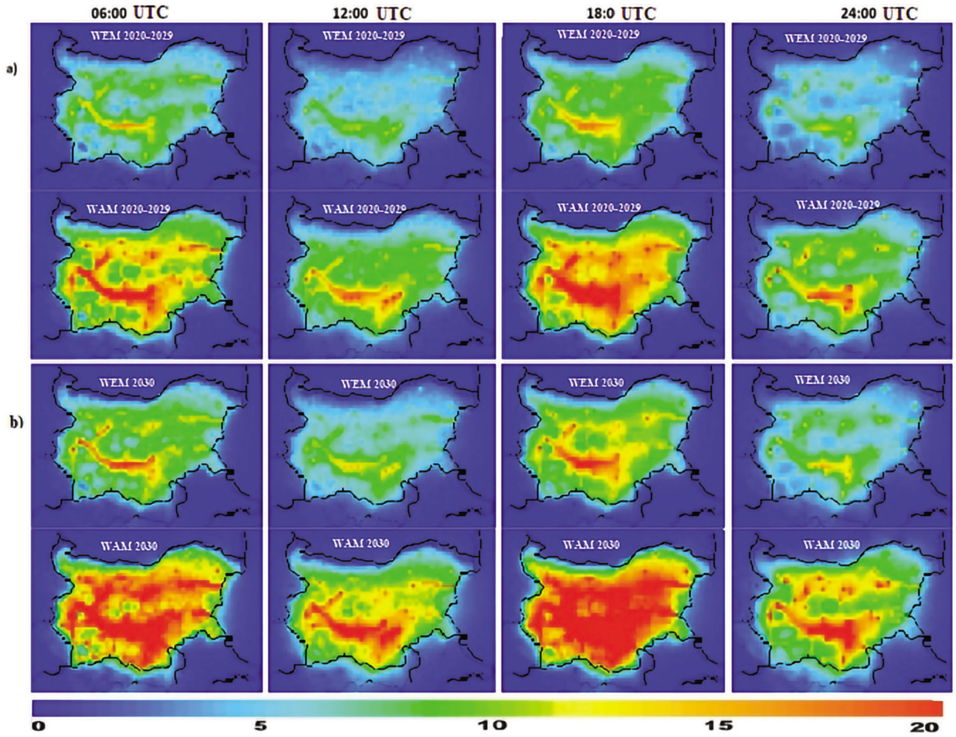

Figure 3. Maps of relative differences of CPRM surface concentrations [%]. a) Relative differences with applied different measures (WEM/WAM) for 2020 to 2029 and b) after 2030, relative to the reference period (2005). All simulations are annually averaged over the ensemble in 6, 12, 18 and 24 UTC.

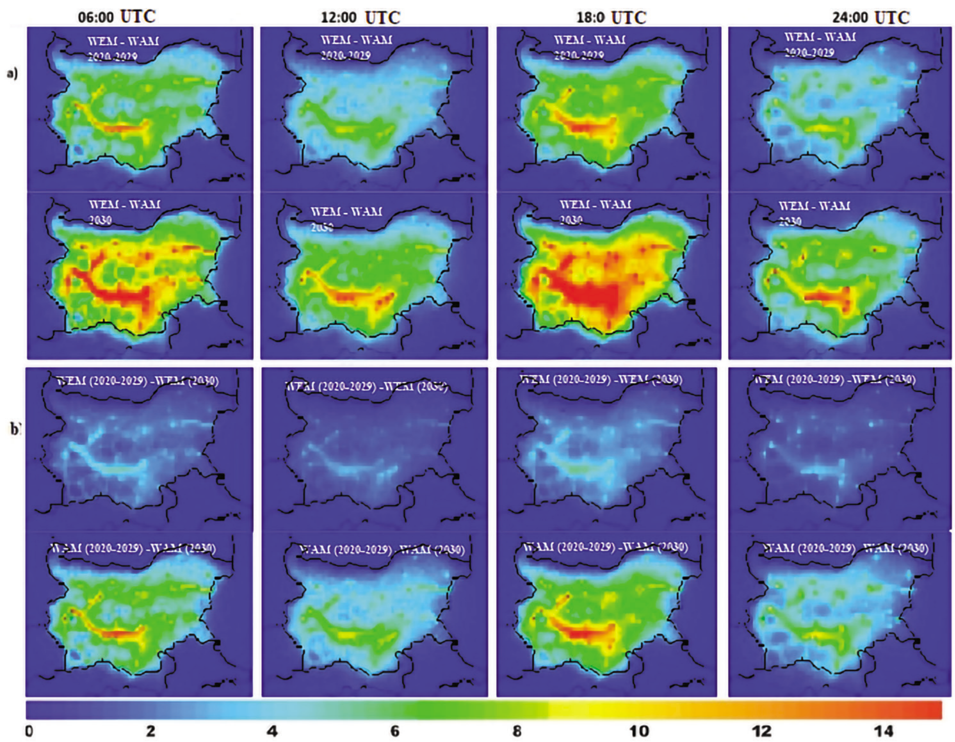

Figure 4. Comparison of the effects of WEM and WAM scenarios: a) Surface relative differences obtained with emissions from WEM and WAM scenarios for 2020-2029 and after 2030 and b) Surface relative differences obtained with emissions for 2020-2029 and after 2030, for the WEM and WAM scenarios.

Acknowledgments

This work was done in the framework of the National Science Program "Environmental Protection and Reduction of Risks of Adverse Events and Natural Disasters", approved by the Resolution of the Council of Ministers No 577/17.08.2018 and supported by the Ministry of Education and Science (MES) of Bulgaria (Agreement No D01-271/09.12.2022). This work was partially supported by the National Center for High-performance and Distributed Computing (NCHDC), part of National Roadmap of RIs under grant No D01-168/28.07.2022 and by Contract No D01-164/28.07.2022 (Project "National Geoinformation Center (NGIC)" financed by the National Roadmap for Scientific Infrastructure 2020–2027 of Bulgaria. Special thanks are due to the Netherlands Organization for Applied Scientific research (TNO) for providing the high-resolution European anthropogenic emission inventory and to US EPA and US NCEP for providing free-of-charge data and software.

Additional information

Conflict of interest

No conflict of interest was declared.

Ethical statement

No ethical statement was reported.

Funding

This work was done in the framework of the National Science Program "Environmental Protection and Reduction of Risks of Adverse Events and Natural Disasters", approved by the Resolution of the Council of Ministers No 577/17.08.2018 and supported by the Ministry of Education and Science (MES) of Bulgaria (Agreement No D01-271/09.12.2022).

This work was partially supported by the National Center for High-performance and Distributed Computing (NCHDC), part of National Roadmap of RIs under grant No D01-168/28.07.2022 and by Contract No D01-164/28.07.2022 (Project "National Geoinformation Center (NGIC)" financed by the National Roadmap for Scientific Infrastructure 2020-2027 of Bulgaria.

Author contributions

The authors jointly shared the workload of conceptualization, methodology, analysis and investigation, putting together figures and writing the manuscript.

Conceptualization, K.G. and G.G.; methodology, K.G., G.G., and NM; software, K.G., G.G. and V.I.; formal analysis, K.G., G.G., I.G., V.I. and N.M.; investigation, K.G., N.M. and G.G.; resources, G.G. and I.G.; data curation, G.G. and V.I.; writing—original draft preparation, K.G., G.G., I.G., V.I. and N.M.; writing—review and editing, K.G., G.G., I.G., V.I. and N.M.; visualization, G.G., I.G. and V.I.; supervision, K.G. and G.G.; project administration, K.G., G.G. and N.M; funding acquisition, G.G. and N.M. All authors have read and agreed to the published version of the manuscript.

Author ORCIDs

Georgi Gadzhev https://orcid.org/0000-0002-6159-3554
Ivelina Georgieva https://orcid.org/0009-0003-9370-3521
Vladimir Ivanov https://orcid.org/0000-0001-9768-1049

Data availability

All of the data and Supplementary materials that support the findings of this study are property of the authors. The data presented in this study are available on request from the corresponding author.

References

Atanassov E, Gurov T, Ivanovska S, Karaivanova A (2017) Parallel Monte Carlo on Intel MIC Architecture. Procedia Computer Science 108: 1803–1810. https://doi.org/10.1016/j.procs.2017.05.149

Byun D, Ching J (1999) Science Algorithms of the EPA Models-3 Community Multi- scale Air Quality (CMAQ) Modeling System. EPA Report 600/R-99/030, Washing- ton, D.C., EPA/600/R-99/030 (NTIS PB2000-100561). https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=63400&Lab=NERL

Byun D (1999) Dynamically Consistent Formulations in Meteorological and Air Quality Models for Multiscale Atmospheric Studies part I: Governing equations in a generalized coordinate system. Journal of the Atmospheric Sciences 56: 3789–3807. https://doi.org/10.1175/1520-0469(1999)056<3789:DCFIMA>2.0.CO;2

CEP (2003) Sparse Matrix Operator Kernel Emission (SMOKE) Modeling System, https://www.cmascenter.org/smoke/

Denier van der Gon H, Visschedijk A, Van de Brugh H, Droge R (2010) A high resolution European emission data base for the year 2005. TNO-report, TNO-034-UT-2010-01895 RPT-ML, Apeldoorn.

EEA Technical Report (2015) EEA Technical report No 4/2015, Projections in hindsight an assessment of past emission projections reported by Member States under EU air pollution and GHG legislation. https://www.eea.europa.eu/publications/projections-in-hindsight

EMEP/EEA Guidance (2019) EMEP/EEA Guidance. https://www.eea.europa.eu/publications/emep-eea-guidebook-2019

EU Directive 2016/2284 (2016) Directive (EU) 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2016.344.01.0001.01.ENG

Gadzhev G, Ganev K, Miloshev N, Syrakov D, Prodanova M (2015) HPC simulations of the fine particulate matter climate of Bulgaria, 8th International Conference on Numerical Methods and Applications, Borovets (Bulgaria) August 2014, 178–186. https://doi.org/10.1007/978-3-319-15585-2_20

Georgieva I, Miloshev N (2018) Computer Simulations of PM Concentrations Climate for Bulgaria, International Conference on "Numerical Methods for Scientific Computations and Advanced Applications" Hisarya (Bulgaria), May 2018, 46–49.

Guidance 2019/C77/01 (2019) Guidance for the development of National Air Pollution Control Programmes under Directive (EU) 2016/2284 of the European Parliament and of the Council on the reduction of national emissions of certain atmospheric pollutants (2019/C77/01). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52019XC0301%2801%29

Karaivanova A, Atanassov E, Gurov T (2022) On the HPC/HPDA/AI Competences in Bulgaria, 12th International Conference on Digital Presentation and Preservation of Cultural and Scientific Heritage, Burgas (Bulgaria), September 2022, Sofia, Institute of Mathematics and Informatics at the Bulgarian Academy of Sciences. 291–298. https://doi.org/10.55630/dipp.2022.12.28

Kirova H, Neykova N, Georgieva E (2021) Performance of Operational Chemical Transport Models for Particulate Matter Concentrations in Bulgaria. In Dobrinkova N and Gadzhev G (Eds) Studies in Systems Decision and Control 361: 107–122. https://doi.org/10.1007/978-3-030-70190-1_8

MOEW [Ministry of Environment and Water] (2020) National Air Pollution Control Program 2020–2030. https://www.moew.government.bg/bg/dulgosrochna-strategiya-za-smekchavane-na-izmenenieto-na-klimata-do-2050-g-na-r-bulgariya/

Skamarock WC, Klemp JB, Dudhia J, Gill DO, Barker DM, Wang W, Powers JG (2005) A Description of the Advanced Research WRF Version 2 (No. NCAR/TN-468+STR). University Corporation for Atmospheric Research. https://doi.org/10.5065/D6DZ069T

Todorova A, Gadzhev G, Jordanov G, Syrakov D, Ganev K, Miloshev N, Prodanova M (2011) Numerical study of some high PM10 level episodes. International Journal of Environment and Pollution 46(1/2): 69–82. https://doi.org/10.1504/IJEP.2011.042609

UCAR/NCAR (2023) Weather Research & Forecasting Model v4.5. https://ncar.ucar.edu/what-we-offer/models/weather-research-and-forecasting-model-wrf

UNFCCC (2016) Revision of the "Guidelines for the preparation of national communications by Parties included in Annex I to the Convention, Part II: UNFCCC reporting guidelines on national communications". https://unfccc.int/resource/docs/2016/sbi/eng/l22.pdf