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Evaluation of long-term temporal variations in Hungarian PM_{10} and $PM_{2.5}$ emissions based on national inventories applied for air quality management

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Abstract—Accession to the European Union has resulted in a remarkable step forward in air quality protection in Hungary. At present, particulate matter means the most significant environmental health risk, and it is Hungary's most problematic pollutant: its concentration exceeds the EU limit values for longer periods under certain conditions. It is presented how the rates and contributors of the PM_{10} and $PM_{2.5}$ emissions varied in Hungary during the two decades of the 2000-2021 period. Special attention is paid to the residential combustion sector which is a key category in particulate matter emissions. Price elasticity of demand of natural gas and other fuels are investigated together with the latest comprehensive population census on conventional stoves and boilers used in the Hungarian households to determine the possible measures that could be taken to improve and change the residential heating habits.

Key-words: air quality measures, particulate matter emissions, residential combustion, heating habits, Hungary.

1. Introduction

Accession to the European Union has resulted in a significant step forward in air quality protection in Hungary. Industrial emission and pollution related electricity and heat production have been significantly reduced. Consequently, residential solid fuel combustion, transport, agriculture, and illegal waste combustion have become the most significant emission sources (e.g., European Environment Agency, 2023).

In Hungary, three important factors have essential effects on PM concentrations: local anthropogenic emissions, long-range transboundary transport and meteorological conditions (*Ferenczi et al*., 2021). Compiling national emission inventories based on comparable international standards of UN and EU is a basic associated tool for harmonizing model estimations on the level of air pollution and rate of deposition. Further, it can contribute to evaluate the risks for human health and ecosystems (*Przybysz et al.,* 2014; *Simon et al.,* 2020). Among pollutants of anthropogenic origin, PM_{10} and $PM_{2.5}$ play a distinguished role in many European countries.

2. Trend of PM emissions in the Hungarian inventory

Particulate matter (PM) is the general term used to describe solid particles and liquid droplets suspended in the air. The chemical composition and size of these airborne particles vary widely. Four types of particles should be reported in the inventory: TSP (total suspended material, i.e. the mass concentration of particulate matter), PM_{10}, $PM_{2.5}$, and BC (black carbon).

Small aerosol particles, especially black carbon, play an important role in the formation of smog. In winter, in addition to sulfur-dioxide, one of the characteristic components of smog during the heating period is black carbon, which is formed during the imperfect combustion of carbonaceous fuels. Greater particles are emitted into the air directly, mainly from residential heating and construction sites of buildings and roads.

Particulate matter contains microscopic solids or liquid droplets that are so small that they can be inhaled and cause serious health problems (*Saini et al*., 2022). Some particles, less than 10 micrometers in diameter, can get deep into the lungs and some may even get into the bloodstream. Of these, particles less than 2.5 micrometers pose the greatest risk to health, as other risky substances (heavy metals, bacteria, carcinogens) can bind on their surface.

At present, particulate matter means the most significant environmental health risk and it is Hungary's most problematic pollutant: its concentration exceeds the EU limit values for longer periods under certain conditions. *Fig. 1* shows the trend of aerosol particle emissions between 1990 and 2021 in Hungary,

compared to the level of 2000. There is no definite trend for particulates, emissions vary from year to year. However, between 2015 and 2020, particulate emissions were characterized by a decrease, which began to increase again by the year 2021.

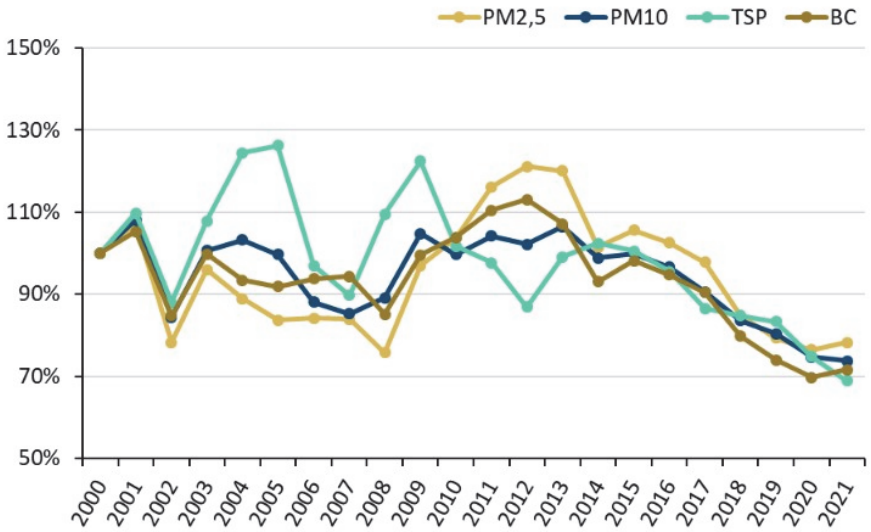

Fig. 1. Changes in particulate emissions in Hungary, compared to the level of 2000.

Hungary still has a lot of work to do in reducing PM emissions. According to the latest inventory report, the assumed reduction compared to the 2005 level will not be realized based on the current trend. *Fig. 2* shows the reduction commintment made by Hungary compared to the level of 2005 and the real emissions.

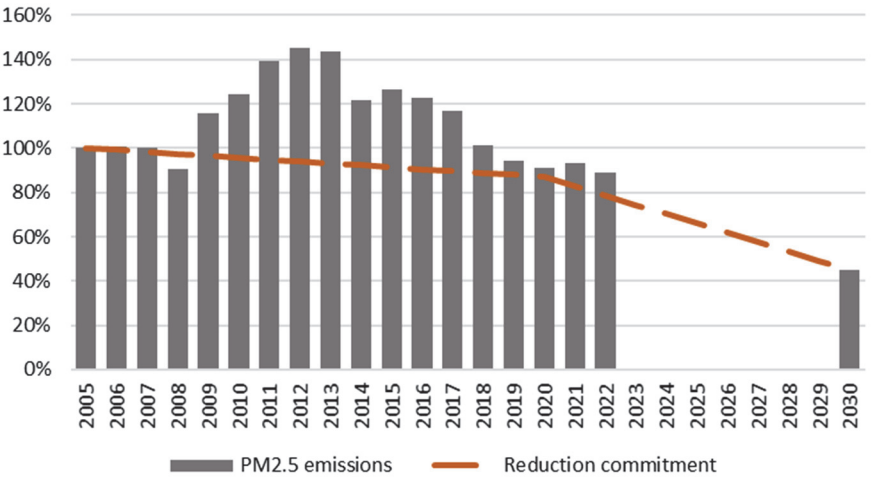

Fig. 2. $PM_{2.5}$ reduction commitment compared to the level of 2005 and emissions in Hungary.

3. Distribution of PM emissions between inventory sources

In the next few figures, instead of the official breakdown of the four main sectors, emission ratios of the sectors according to the actual end users are shown in more detail. Graphs show the dominant role of non-industrial combustion in particulate emissions. Non-industrial combustion contains the use of fuels by households and institutions as well as agricultural heatings. *Figs. 3* and *4* show PM_{10} and $PM_{2.5}$ emissions, respectively, between 2000 and 2021 in Hungary in sectorial splitting.

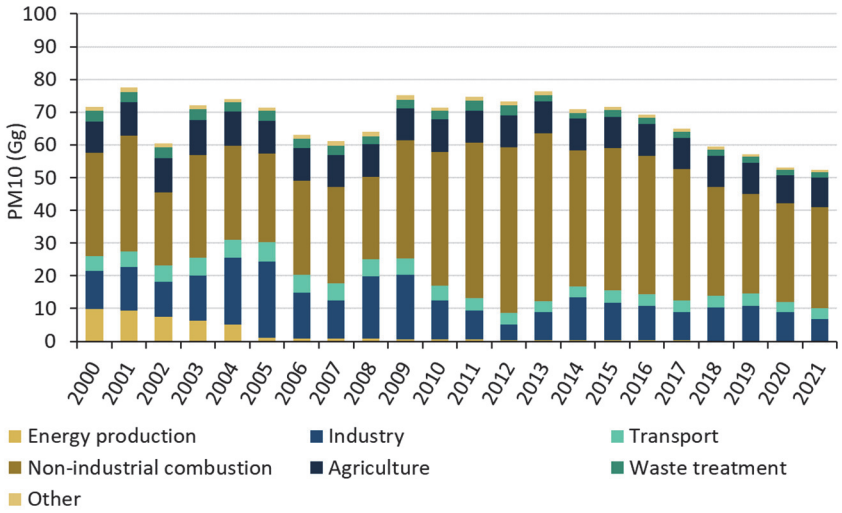

Fig. 3. PM_{10} emissions between 2000 and 2021 (in a sectorial splitting different from the official four sectors).

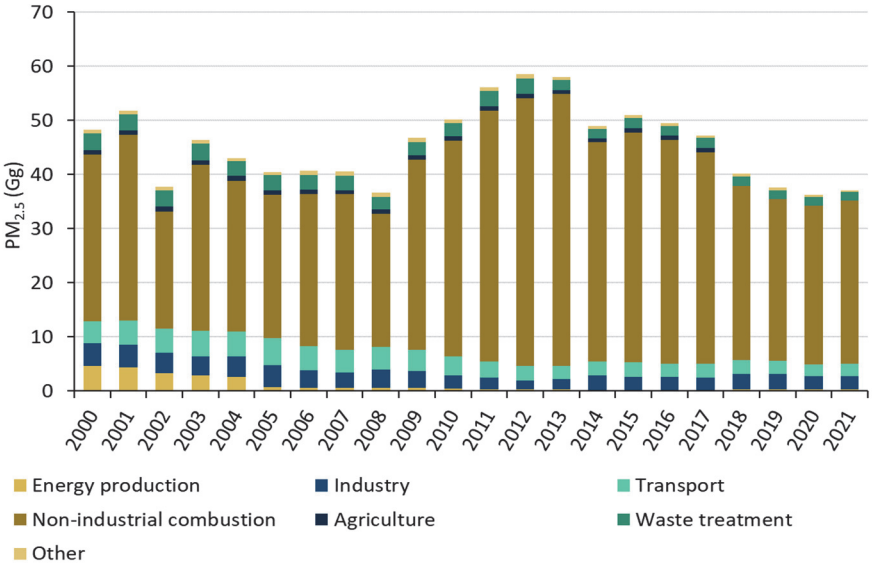

Fig. 4. $PM_{2.5}$ emissions between 2000 and 2021 (in a sectorial splitting different from the official four sectors).

Both figures, but especially $PM_{2.5}$ emissions, which have more dangerous health effects, show the dominant role of household burning. Based on the 2021 data, more than half of the total PM_{10} emissions (58%) come from non-industrial combustion (mainly from residential heating), the same ratio for $PM_{2.5}$ is 78%, and 68% of BC (soot) emissions can be linked to this source.

4. Composition of fuels used in residential heating in Hungary

Fortunately, natural gas is the dominant fuel in Hungary. According to the 2016 microcensus survey, natural gas was used in nearly 62% of homes. In addition, 38% of the apartments (this means almost one and a half million apartments) are heated with wood (also) and 3% with coal (also). If we add to this the 16% share of district heating, 2% of electricity, etc., we are well over 100%, which means that an apartment can have several types of heating materials. Almost one-fifth of households, therefore, use both piped gas and firewood, and can even switch between heating materials according to their price changes.

Particulate emissions must be considered in the case of solid burning (coal, wood and wood waste, or possibly other waste). Given that the vast majority of solid fuel heating devices currently operating in Hungary are decades old, while the prevalence of modern, low-emission technologies (e.g., eco-fireplaces, pellet burning, wood gasification boilers) can be put at a maximum of a few percent, the trend of emissions is basically determined by the amount of fuel used. *Fig. 5* shows the evolution of the coal and biomass fuel amounts used in households and the emissions from them between 2005 and 2021 in Hungary.

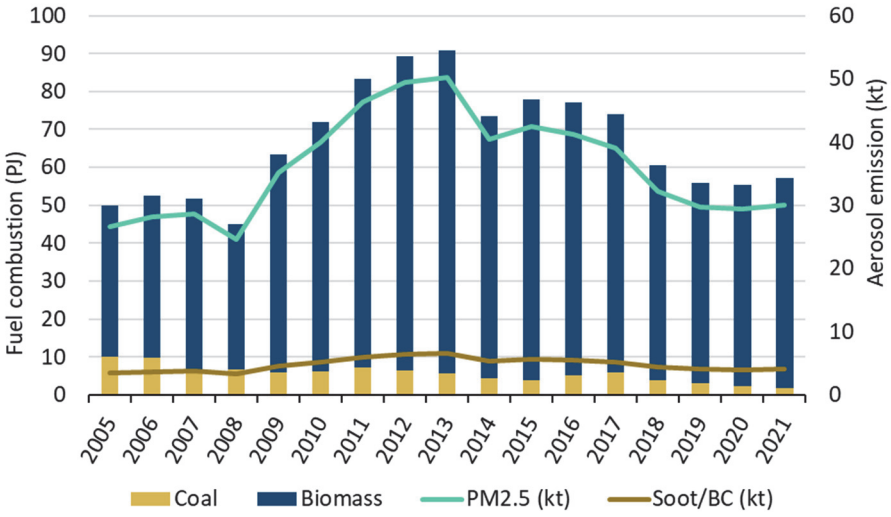

Fig. 5. Aerosol ($PM_{2.5}$ and BC) emissions from residential solid burning between 2005 and 2021 in Hungary.

Let us examine the effects of price changes. *Fig. 5* indicates an increase of biomass combustion in households. The price of natural gas started to increase in 2005 which may have caused the increase in the use of fuel wood/biomass, which was relatively cheaper compared to natural gas. This led to increasing PM emissions from 2008. After 2014, however, the price advantage of wood gradually decreased, so the use of natural gas increased again, and the use of firewood – and with it the emission of particles – began to slowly decrease. *Fig. 6* indicates the changes in the usage and prices of natural gas and fuel wood.

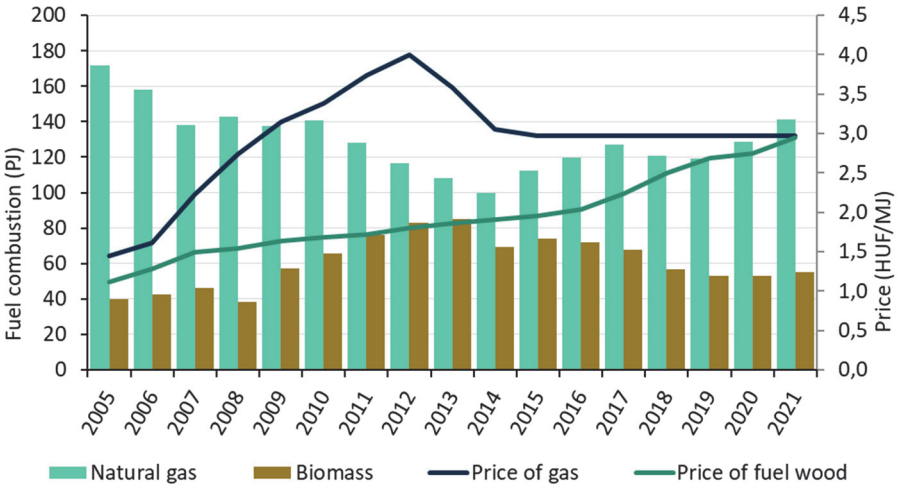

Fig. 6. The effect of fuel price changes on consumption between 2005 and 2021 in Hungary.

5. Waste burning in Hungarian households

Based on the investigations of the Clean Air Action Group of Hungary (2015), unfortunately one third of the population burns waste in Hungary with changing frequency during the year. Most people burn garden waste, 13% burn household garbage, 6% burn treated wood, rags, clothing, and footwear. Plastics (in addition to household waste) are burned by 3% and rubber by 1%. In a representative poll, 54% of the respondents considered that lack of knowledge, 35% that irresponsibility, and 15% that poverty are the main causes of irregular residential waste burning. The poll data is confirmed by the experiences of a 'Do not burn campaign': in the examined area of Eastern Hungary, a third of the waste disappears in the winter - in the stoves. *Fig. 7* shows the amount (in tons) of municipal waste collected by the waste collecting company during the year.

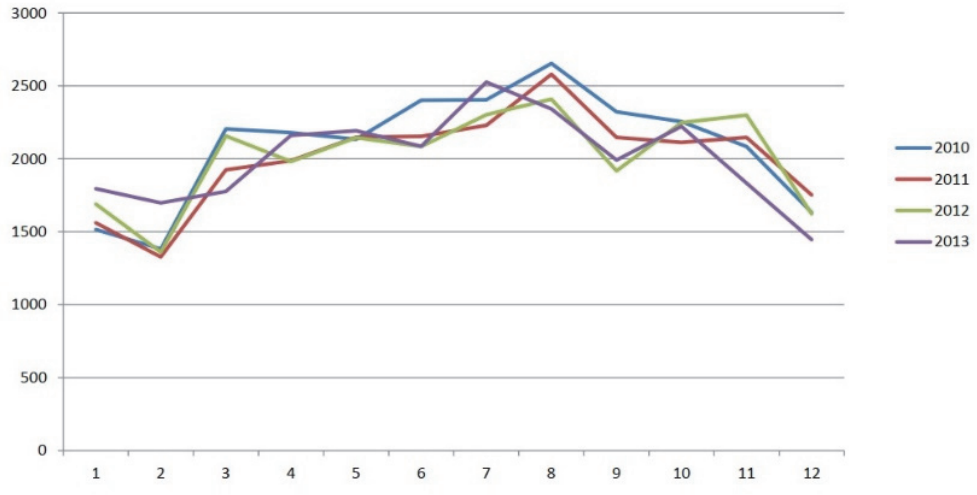

Fig. 7. Amount of officially collected municipal waste in four years in Hajdúság, Eastern Hungary. Vertical axis indicates the quantity in tons, while horizontal axis indicates the months of the year.

6. Conclusions

Particulate matter can be considered as the most significant environmental health risk in Hungary: its concentration exceeds the EU limit values for longer periods under certain conditions. It is obvious that Hungary still has a lot to do in reducing PM emissions. It should be taken into account that meteorological conditions have significant influence on the measured PM concentrations and their temporal variations. In addition, on annual average, the influence of transboundary contributions in PM concentrations could be dominant, and local regulatory policy may only bring limited results (*Ferenczi* and *Bozó*, 2017). State of the atmospheric environment could be evaluated through involving relevant monitoring and modeling activities, partly based on official emission inventories.

Public opinion formation might help to persuade the population on cleaner wood burning and the cessation of illegal waste burning. Many municipalities set good examples in front and prohibits the debris and garden waste burning. Legislation is needed to prohibit the sale of low-calorific and high-sulfur coals for residential heating purposes. Support for energy modernization of buildings is to be continued so that air pollution from heating could be reduced by half or even a third, if adequate thermal insulation of the buildings is also supported.

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