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# INFLUENCE OF FOUR POLICY MEASURES ON THE EMISSIONS OF ATMOSPHERIC POLLUTANTS AND GREENHOUSE GASES FOR A CENTRAL EUROPEAN CITY

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## ABSTRACT

In this study, the emission changes for the city of Brno in the Czech Republic following the implementation of four policy measures focused on transport and energy were assessed simultaneously for nine air pollutants and three greenhouse gases (GHGs). The policy measure related to the reduction of the motorised vehicles in the city and subsequent increase in use of soft transport was the one with the highest emission reduction potential for most of the compounds investigated (e.g. up to 13% decrease for $PM_{2.5}$ and $NO_x$). Such type of measures, which have a higher positive effect on human health and climate change than those on low-carbon vehicles, are difficult to implement as they require a behavioral change. Therefore, they should be implemented along additional measures which can be easily implemented such as those on the replacement of old coal-fired boilers. This study highlighted the need for an integrated impact assessment of policy measures, considering both air pollutants and GHGs.

**KEYWORDS:**
Emission Inventory, Air Pollution, Greenhouse Gases, Policy Measures

## INTRODUCTION

Air pollution and climate change are two major environmental concerns worldwide. With regard to human health, air pollution is responsible of the premature death of 2.4-8.9 million people per year at the global level [1], [2] and about 790,000 for Europe [1]. Cities, which are responsible for almost 70% of $CO_2$ emissions at the European scale [3], are also regularly exceeding the legal limits of several air pollutants. Given that more than half of the global population live in cities [3], it is crucial to decrease the exposure of urban citizens and their footprint in order to improve human health and to reduce the impacts of climate change. For this, efficient policy measures significantly reducing the primary emissions of air pollutants and greenhouse gases (GHGs) at the urban scale are needed. However, GHGs and air pollutants are regulated by different policies, globally in the case of GHGs, while air pollutants are regulated on city, national and/or regional levels. There is a urge to evaluate simultaneously GHGs and air pollutants and their impacts on air quality and climate change in order to minimise the environmental footprint and poor decision making [5,6].

This study is part of the H2020 European project "Integrated Climate forcing and Air pollution Reduction in Urban Systems" (ICARUS, http://www.icarus.eu), which aims to develop an integrated approach to identify the appropriate policies as well as the optimal combination of technical and non-technical measures with co-benefits in air quality and climate change mitigation. The ICARUS approach has been applied in different European cities of variable size starting from relatively small (Basel, Brno, Ljubljana) to mid-size (Stuttgart, Thessaloniki) to large cities (Athens, Milan and Madrid). They have been selected carefully to represent the mix of urban settings around Europe and cover the whole spectrum of "green urban management".

Here, we present the work done within the ICARUS project for the second largest city in the Czech Republic, Brno, with about 380,000 habitants. Our aim was to estimate the emission reduction potentials for nine air pollutants and three GHGs in 2020-2030 following the theoretical implementation in 2015 in Brno of four policy measures focusing on transport and energy.

## MATERIALS AND METHODS

The Brno emission inventory was estimated based on the bottom-up approach for nine air pollutants (i.e. $PM_{10}$, $PM_{2.5}$, black carbon (BC), organic carbon (OC), $NO_x$, $SO_2$, CO, $NH_3$ and non-methane volatile organic compounds (NMVOC)) and three GHGs ($CH_4$, $CO_2$ and $N_2O$) for the years 2015, 2020 and 2030, following a business as usual scenario. The details on the emission factors (EFs) and the activity data used are provided elsewhere [7]. Based on the different existing plans developed at the local, regional and national levels (i.e. plan for improving air quality, action plan for improving air quality, sustainable energy and climate action plan and sustainable urban mobility plan), four policy measures with a high potential towards the compliance of both air quality limit values and the reduction of GHGs emissions were identified (based on their effectiveness, efficiency and acceptability) and their emission reduction potentials, with different scenarios, were estimated [8]. These were: M1: Promoting low-carbon (i.e. electric) vehicles, M2: Reduction of the motorised vehicles and increase of the usage of non-motorised vehicles and public transportation, M3: Replacement of old coal-fired boilers in residential sector and M4: Implementation of energy saving measures.

Within M1, an optimistic (OPTI) and a realistic (REAL) scenarios were used. The traffic activities of low-carbon vehicles increased from < 1% in 2015 to 1% in 2020 and 8% in 2030 under the REAL scenario and to 7% in 2020 and 12.5% in 2030 for the OPTI scenario. Within M2, three scenarios (ZERO, PLAN and OPTI) were used. Within ZERO, PLAN and OPTI, the share of personal cars would decrease from 52.7% in 2015 to 38.5%, 31.8% and 25%, respectively, in 2030 while the shares of pedestrians and cyclists would increase in the same period from 4.7% to 14.8%, 17.6% and 35.2%, respectively. Within M3, it is assumed that 100% of the old coal-fired boilers would be replaced by 2030, with a SLOW and a FAST scenarios assuming that 20% and 60% of the old coal-fired boilers would be replaced by 2020, respectively. Within M4, an ECONOMIC and a TECHNICAL scenarios were used in which the extent of the implementation of measures improving the insulation and renovation depended on an economic or technical perspective, respectively.

## RESULTS

The emission changes of all compounds resulting from the implementation of the four policy measures are shown in Figure 1. For M1, the promotion of low-carbon vehicles in Brno would decrease the emissions of individual compounds investigated by most 7%. The most affected compounds were CO and $NH_3$. Moreover, an increase of the emissions of OC and BC in 2030 was observed, due to higher emissions from non-exhaust processes (resuspension), which are influenced by the vehicle weight which is 24% heavier for electric cars compared to conventional cars [9-10]. On average, for all pollutants, the OPTI scenario led to 7.2 and 1.6 times stronger decreases in emissions compared to the REAL scenario in 2020 and 2030, respectively. For M2, this measure resulted in 8-14% emissions reduction for $PM_{2.5}$, $PM_{10}$, $NO_x$ or $CO_2$ depending on the scenario and the year considered. Higher reduction potential (up to 21%) was observed for CO and $NH_3$. On average, the OPTI and the PLAN scenarios resulted in decreases 1.7-2.0 and 1.2-1.5 times higher, respectively, than those from the ZERO scenario. For M3, large decreases were observed for $SO_2$ (4-18%), $PM_{10}$ (2-8%), CO (1-8%) and $PM_{2.5}$ (1-5%). This measure led to slight increase of $NH_3$ and OC emissions (up to 2%) explained by the higher EFs of replacement fuels compared to coal. About three times higher emission reductions were found for the FAST scenario compared to the SLOW scenario by 2020. For M4, the largest reduction potential (up to 12%) was seen for BC, $CH_4$, NMVOC, OC and $SO_2$. On the other hand, for CO, $CO_2$, $CH_4$, $NH_3$, $NO_x$, $PM_{10}$ and $PM_{2.5}$, the decreases observed were in the order of 1-9%. The TECHNICAL scenario resulted in about 1.5 times higher reductions than those from the ECONOMIC scenario both in 2020 and 2030.

## DISCUSSION

Implementation of the first measure (M1 - Promoting low-carbon vehicles) would lead to a decrease of up to 7% for all pollutants, although it is negligible for particulate matter. An interesting review was recently published by Requia et al. [9] addressing the effects of electric mobility on air pollutants and GHGs emissions and human health. The authors showed that the emission changes related to the increasing numbers of electric vehicles in urban areas are significantly influenced by the compound considered, the source of energy generation, the type of electric vehicle and the driving conditions besides other city-specific parameters (e.g. amount and density of recharging stations, climate) [9]. Compared to other compounds, $CO_2$ emissions seem to be less sensitive to the variation in sources of energy generation [9] and significant reduction in $CO_2$ emissions up to 86% could be achieved with the introduction of electric vehicles [9,11–14]. Similarly, large decreases of CO emissions were found also in other studies [9,15]. For $NO_x$, PM and $SO_2$, the changes in emissions are strongly dependent on the energy mix [9], [11-12]. For example, in regions where electricity is generated primarily from coal, electric vehicles could significantly increase emissions of $SO_2$ [11,13-14,16], $NO_x$ [12-13,16] or PM [9,11–13,17]

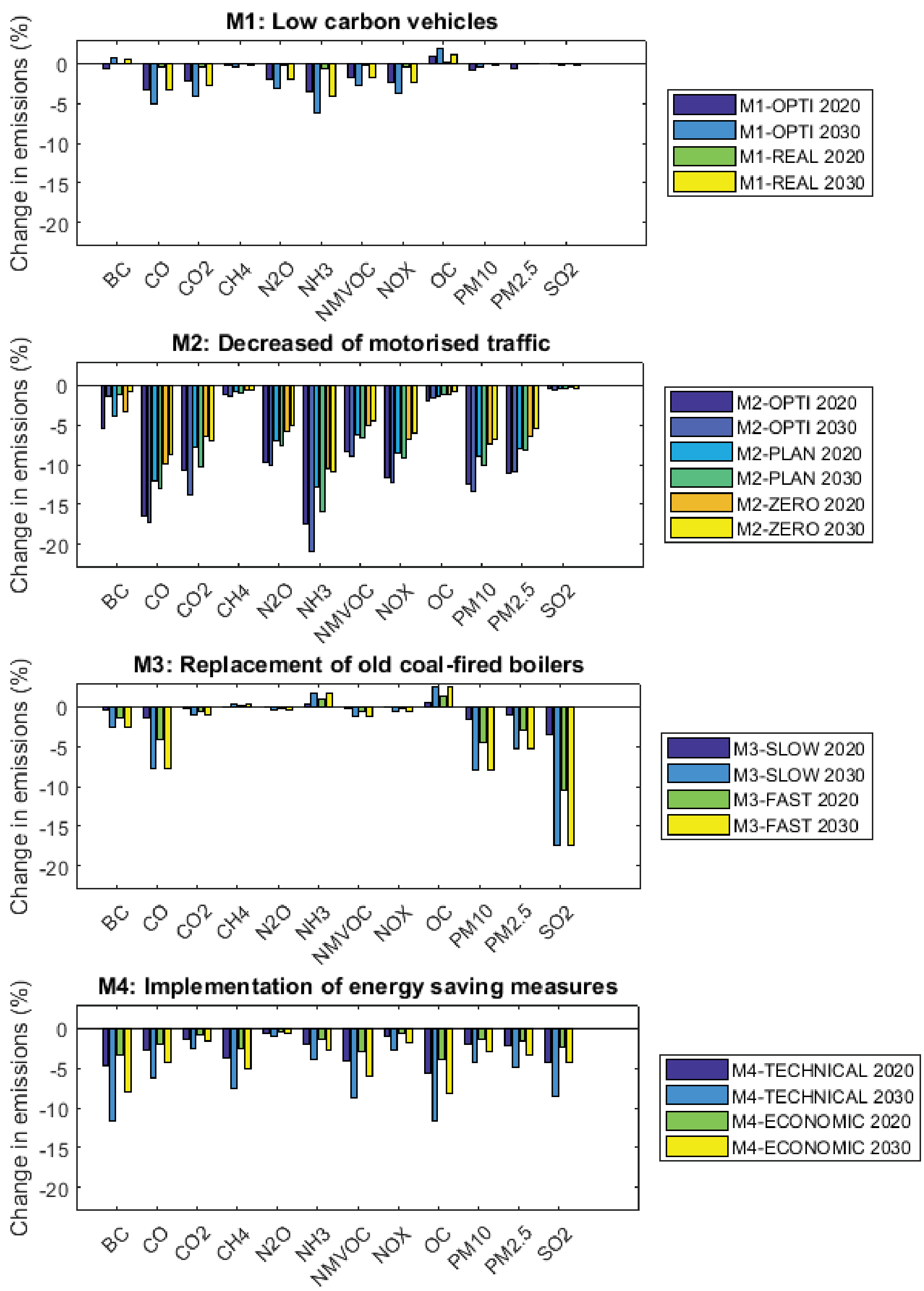


**FIGURE 1**
**Change in emissions of all compounds investigated in 2020 and 2030 associated with measure M1 (a), M2 (b), M3 (c) and M4 (d) under all scenarios considered.**

compared to conventional vehicles. This highlights the need to consider both GHGs and air pollutants when assessing such policy measures, as contradictory impacts on emissions could be found [13]. The energy mix in electricity production needed for electric vehicles was not considered here as it represents out-of-town emissions, which were not the scope of this study. Therefore, implementation of policy measures promoting electric vehicles in Brno would have a significant effect only if it were to be implemented alongside measures increasing the use of renewable energies in the Czech electricity mix. In case of an extreme scenario with more than 80% of electricity generated by renewable sources, large decreases (up to 85%) of GHGs and air pollutants could be observed, while for PM, the decreases were more moderate [11].

The second measure (M2 - Reduction of the motorised vehicles in the city and increase of the usage of non-motorised vehicles and public transportation) is the one with the highest emission reduction potential for most of the compounds investigated. The differences observed between the selected scenarios highlighted the large potential impact of such measure, if a small but significant fraction of the urban population switches to cleaner transportation on a daily basis. Woodcock et al. [18] estimated the emissions change for London and Delhi due to alternative scenarios linking transport patterns with physical activity and reported a larger health benefit of active travel and lower use of motor vehicles compared to the increased use of lower-emission motor vehicles, which is in line with our observations. Therefore policies aiming at increasing the acceptability, appeal, and safety of active urban travel such as public transport or bicycle as well as those discouraging travel in private motor vehicles should be implemented rather than measures focusing only on low-carbon vehicles [18] as they would have a stronger positive effect on human health [19]. The public transportation usually transfers large amounts of daily passengers while its contribution to the emissions of air pollutants and GHGs is low [12]. Therefore, the implementation of policy measures promoting the usage of public transportation would not only have a positive impact for the environment, but also from a social perspective as it has been shown that it can enhance the social cohesion [20].

The third measure (M3 - Replacement of old coal-fired boilers in residential sector) resulted in significant decreases in 2030 for $SO_2$ (18%), CO (8%), $PM_{10}$ (8%) and $PM_{2.5}$ (5%). Krůmal et al [21] compared the chemical composition of emissions from the old-type and modern-type boilers, which are the most frequently used in the Czech Republic for household heating, using different type of fuels. The emissions of CO, $NO_x$, $PM_{2.5}$, $PM_{10}$ and $SO_2$ were highest for coal, particularly for the old type boilers [21]. Therefore, policy measures promoting the replacement of old coal-fired boilers with more recent ones (particularly the automatic ones) should lead to a significant decreases in the emissions of both GHGs and air pollutants. This type of measure with a high mitigation potential can be easily implemented at the city level via subsidiaries compared to other measures (such as M2) requiring a behavioral change.

The last measure (M4 -: Implementation of energy saving measures) resulted in significant (i.e.>5%) emission changes of BC, $CH_4$, NMVOC, OC and $SO_2$. It is worth to note that the differences between the two investigated scenarios were small while the implementation costs related to the TECHNICAL scenario would be significantly higher than those of the ECONOMIC scenario.

Based on these results, we selected for each measure just one scenario. These were M1-OPTI, M2-ZERO, M3-SLOW and M4-ECONOMIC. For M1, the OPTI scenario was selected, because the emission changes were significantly higher when compared to the REAL scenario, while it could be easily implemented using various incentives at the national or local level. For M2, the ZERO scenario was selected, as it was considered to be the most realistic scenario. As no differences were observed between the two scenarios in 2030, the SLOW scenario was selected for M3, which seems to be more likely achieved by 2020. Finally, the ECONOMIC scenario was selected for M4, as it is the one most likely to be adopted, because the investments needed for the TECHNICAL scenario are too extensive for that measure to take place.

Figure 2 presents a summary of the emission reduction potential expected in selected scenarios of the four investigated measures. M2, reducing the activities of PCs, is the one showing for 2020 the highest reduction potential for all compounds investigated except for $CH_4$, OC and $SO_2$. For 2030, however, the contributions of each measure to the expected emission reduction are compound-specific. Reduction potential for $SO_2$, for instance, is largely

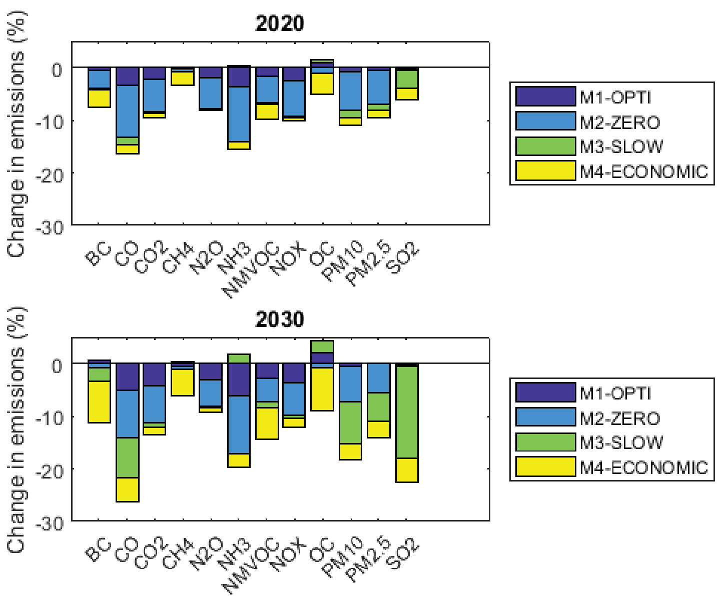


**FIGURE 2**
**Changes in Brno emissions (compared to BAU) related to selected measures in 2020 (a) and 2030 (b)**

driven by M3 focused on the replacement of old coal-fired boilers. For BC, $CH_4$ and OC, M4 on energy savings is dominating the reduction potential. For CO, $PM_{10}$ and $PM_{2.5}$, their emission reductions are largely affected by M2 decreasing the activities of PCs and by M3 on old coal-fired boilers. It is worth noting that for the remaining compounds, the decrease potential from M3 is negligible compared to the other measures, and for BC, $CH_4$, $NH_3$ and OC, the implementation of M1 and M3 would even lead to an increase of their emissions. This highlights the need for an integrated impact assessment of policy measures, considering both air pollutants and GHGs as some measures may result in a positive impact on one group but a negative one on another [5]. To summarise, the implementation of all four policy measures under the selected scenarios would result at most in 4.5% (OC) – 26.1% (CO) emission reductions in 2030. However, we should note that summing up all the reduction potentials on several individual measures may overestimate the overall positive effect as their interdependencies is not considered. For example, people switching to public transport (M2) will not drive an electric vehicle (M1).

## CONCLUSION

In this study, we have found that the policy measure related to the reduction of the motorised vehicles in the city and subsequent increase in use of soft transport (M2) was the one with the highest emission reduction potential for most of the compounds investigated (e.g. up to 13% decrease for $PM_{2.5}$ and $NO_x$). Therefore, in Brno as well as in other cities, policies aiming at increasing the use of public transport or bicycle as well as those discouraging travel in private motor vehicles should be implemented as they would have a higher positive effect on human health than those focusing only on low-carbon vehicles. However, these types of measures require a behavioral change, which is difficult to implement. Therefore, they should be combined with additional policy measures which can be easily implemented and have a significant impact such as the replacement of old coal-fired boilers (M3) which resulted in an emission reduction potential for Brno of 5% and 18% for $PM_{2.5}$ and $SO_2$, respectively.

This study highlights the need for an integrated impact assessment of policy measures, considering both air pollutants and GHGs as some measures may result in reduction of one of these two groups of stressors but enhancement of the other. Such an integrative assessment of policy measures required the close collaboration between various city authorities, administration services, policy makers and scientists. This collaboration established within the ICARUS project will support the city also in the future throughout process of development and implementation of the policy measures focused on protecting the environment and human health, improving the urban air quality, increasing resilience and combating impacts of climate change.

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