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Changes in emissions of NOx and PM2.5 as a result of the implementation of measures in sectors close to the population: energy efficiency in residential buildings, and passenger cars substitution

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***Abstract*— This paper examines different strategies for reducing air pollution through measures implemented in key sectors. Current environmental and energy policies at the European and Spanish levels are focused on increasing energy efficiency and the penetration of renewable energy sources. In this study, changes in emissions of two major pollutants affecting human health — nitrogen oxides (NOx) and fine particulate matter (PM2.5) — are quantified as a result of implementing a set of planned measures, considering Spain's 2030 policy targets and using 2021 as the reference year. The measures target sectors that are directly connected to the population: residential buildings and passenger cars. The results indicate that the greatest benefits in terms of emission reductions are achieved through the replacement of combustion-based passenger road transport with electric vehicles, as well as through improvements to building envelopes, particularly once the electricity mix reaches the 2030 renewable energy penetration target.**

***Keywords*— Air quality; emissions; mitigation measures; atmospheric pollutants**

I. Introduction

Given the urgent need to move toward a decarbonized society, the impacts associated with the deployment of national strategies must ensure co-benefits that achieve both environmental and social welfare. The development of coherent policies across issues is one way to maximise the greatest potential for welfare in the coming decades. The double benefit of decarbonising the economy, considering the benefits of the measures to ensure the improvement of the air quality, should be assured. The OECD's working paper "Co-Benefits of Climate Change Mitigation Policies: Literature Review and New Results" (OECD, 2009) discusses how greenhouse gas mitigation efforts can lead to local air pollution benefits, thereby lowering the net costs of emission reductions and potentially strengthening incentives for global climate agreements. Similarly, other studies (Colette et al., 2012; Karlsson et al., 2020) highlight that a stringent global climate policy can lead to considerable improvements in local air quality and public health, emphasizing that integrating strategies to tackle both climate change and air pollution can reduce policy costs and generate net welfare benefits at the global level. Additionally, some recent studies (Beevers et al., 2025; Milner et al., 2023; Vandyck et al., 2020) have quantified the air quality co-benefits of climate policies, underscoring the importance of coherent policies that address both environmental and social welfare.

There are synergies between air pollution control and climate policies, as they share emission sources and, to a large extent, solutions, while most air pollutants also affect the climate to some extent (with both negative and positive effects). In Spain, National Integrated Energy and Climate Plan 2021-2030 (NIECP)(MITECO, 2020) and its updated version for the period 2023-2030 (MITECO, 2024), as well as the first National Air Pollution Control Programme (I-NAPCP)(Spanish Government, 2019) provide a pathway for the development of strategies and measures to be applied from 2020 to 2030. These policies prioritize strategies and measures related to energy and transportation. Key measures include mandating that all new cars be

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zero-emission by 2040, and requiring municipalities with over 50,000 inhabitants to establish low-emission zones. These policies are designed to reduce emissions from both residential and transportation sectors, among others.

The benefits associated with decarbonizing both sectors have been assessed in the literature. McDiffie (McDuffie et al., 2021) assesses the impacts of ambient PM2.5 and identifies fossil fuel combustion as a significant contributor, emphasizing the health benefits of reducing emissions by eliminating fossil-fuel-related emissions from sectors like residential heating and transportation. The impact of the I-NAPCP policy has been assessed previously (Gamarra et al., 2020; Vivanco et al., 2021) as well as the impact on air quality and health of the individual measures on transportation of passengers associated to the former NIECP 2021-2030 (Gamarra et al., 2021). Research on the impact at the urban or city level of electric car policies on electric vehicles has been developed (Agarwal et al., 2024; Andre et al., 2020; Choma et al., 2020; Gago, 2017; Piccoli et al., 2025; Soret et al., 2014). In general, they conclude that electrification leads to large benefits in terms of pollution mitigation, but the benefits vary widely among metropolitan areas. However, there are a few studies that have assessed the impact of specific measures at a national scale. In Qatar, Alishqq & Mehliq (Alishaq & Mehlig, 2024) calculates the potential reduction in NOx and PM2.5 emissions resulting from substituting Internal Combustion Engine Vehicles (ICEVs) with Battery Electric Vehicles (BEVs) in Qatar, considering ICEV ban scenarios in 2030, 2035, and 2040, alongside five policy pathways of transition, and they found reductions for NOx and PM2.5 for the 2030 of approximately 20% and 9% lower, respectively, compared with BAU in total for the country. In Poland, Zimakowska-Laskowska and Laskowski (Zimakowska-Laskowska & Laskowski, 2022) compared the emissions from vehicles including ICEVs (internal combustion engine vehicles) with equivalent emissions from BEVs (battery electric vehicles). They found that emissions from road transport of CO, CO2, and TSP emissions would decrease, while NOx and SOx emissions would increase. However, the reason behind it is mainly the Polish electricity mix with a high contribution of hard coal power plants.

In this paper, we explore the benefits of some of the close-to-population strategies for reducing air pollution through measures that also decrease carbon emissions. The main goal is to assess the impact on the two pollutants NOx and PM2.5 of the implementation of a set of eight planned measures for decarbonization in Spain, considering the updated target policies for 2030 and comparing them to the reference year 2021. We have quantified the change in emissions of two of the main pollutants affecting health, NOx and PM2.5. According to the European Environmental Agency (EEA, 2023) the mortality related to all-natural causes (i.e., excluding accidental and other non-natural causes) attributable to key air pollutants in 2021 in the European Union has been estimated as 253,000 deaths due to exposure to PM2.5 concentrations above the recommended World Health Organisation (WHO) guideline level, and 52,000 deaths due to exposure to NOx concentrations above WHO's guideline level recommendation (WHO, 2021). Because of that, we focused on those two pollutants.

The paper is structured as follows: First, the measures and scenarios as well as calculations and sources of data are described in the Method's section. Second, the Results and Discussion section presents the results in terms of the relative change in emissions from the assessed pollutants and includes a spatial distribution analysis. Lastly, the Conclusions section provides a summary of the key aspects to consider in light of the results.

II. Methods

A. *Description of measures*

The measures and scenarios proposed for the assessment of the emissions reduction of NOx and $PM_{2.5}$ for the year 2030 have been chosen considering that the activity in both sectors, the residential sector and the sector of the transport of passengers, are close to the population and therefore to the exposure. Table 1 summarizes the sectoral measures and scenarios.

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Table 1. Summary of measures and scenarios of emissions reduction assessed.

Measure	Sector	Scenario
Energy efficiency increase in buildings	Residential sector	Improvement of the envelope of buildings considering the foreseen electricity mix in 2030
		Improvement of the envelope of buildings considering the current electricity mix
		Replacement of boilers by more efficient ones
		Replacement of fossil fuel boilers by electric heat pumps considering the foreseen electricity mix in 2030
		Replacement of fossil fuel boilers by electric heat pumps considering the current electricity mix
Use of electric vehicles	Transport sector (Passengers)	Scenario A considering the foreseen electricity mix in 2030: Substitution of the 5.500.000 fossil fuelled passenger cars
		Scenario B considering the foreseen electricity mix in 2030: Substitution of the 11.000.000 fossil fueled passenger cars
		Scenario C considering the foreseen electricity mix in 2030: Substitution of the 22.000.000 fossil fueled passenger cars

The measures based on the energy efficiency increase in the residential sector are specific to buildings for residential use:

- Improvement of the envelope of buildings. The NIECP includes among its targets the improvement of the energy efficiency (thermal envelope) of a total of 1.2 million households by 2030. In this way, reduced energy loss means a reduction in energy and fuel demand and consumption, and thus a reduction in emissions associated with residential thermal uses. The measure is focused on thermal use for heating and domestic hot water, primarily involving on-site combustion in residential buildings, where the population is more vulnerable to pollutants due to closer exposure.
- Replacement of boilers with more efficient ones. The arrival on the market of more efficient boilers to replace conventional boilers with lower fuel efficiency leads to a reduction in fuel demand and consumption, and thus to a reduction in emissions associated with residential heating uses. For this purpose, the reference scenario and objectives of the Long-Term Strategy for Energy Rehabilitation in the Building Sector in Spain (MITMA, 2020) are considered.
- Replacement of fossil fuel boilers by heat pumps using electricity from the grid, which is expected to be cleaner due to the higher penetration of renewables in the grid, as is foreseen in the NIECP.

Regarding the sector of transport involving passenger cars, the use of electric vehicles to substitute a portion of the current passenger car fleet is proposed. This measure is included in the package of emission reduction measures for transporting the I-NAPCP, but the scenario is based on the figures from updated NIECP. Different electric car penetration scenarios are studied, considering the replacement of current diesel and gasoline vehicles (except hybrids) with electric vehicles, resulting in a corresponding change in fuel consumption and, consequently, in the emission of various air pollutants. In addition, the additional electricity production to support the operation of electric vehicles is considered.

B. Emissions reduction calculation

The general framework is based on the estimation of emission reduction at the source as a result of the measure implementation. Each measure involves one or more sources of emissions. Using the Tier 1 factors of the EMEP guidelines (EEA, 2019), the emissions before (the year 2021 as reference) and after the implementation (the year 2030) considering the differences in energy consumption and changes in energy sources have been estimated.

The change in emissions due to measures based on the energy efficiency promotion in buildings of the residential sector was calculated departing from data on the consumption of fuels used for residential

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thermal uses in Spain. This consumption was characterised using literature and official sources [1,6] to determine which of the fuels and energy sources. Table 2 shows the data about residential consumption of energy for heating, cooling, and hot water (HW) from (IDAE, 2024). For the cooking consumption, the data reported in the study SPAHOUSE-II (IDAE, 2019).

Table 2. Residential Consumption of Energy for Heating, Cooling, and Domestic Hot Water (DHW) from [6 and 7] in KEP.

Type of source	Heating	Cooling	DHW	Cooking	Total
Electricity	475	151	482	142	1,107
Natural Gas	1,269	0	1,172	313	2,442
Solid fuels	56	0	4	0	60
Oil products	1,966	0	606	329	2,572
LPG	393	0	0		857
Other kerosene	0	0	0		0
Fuel oil	1,574	0	0		1,715
Renewable energy	2,490	2	297	0	2,790
Solar thermal	19	0	0		262
Biomass	2,466	0	0		2,517
Geothermal	5	2	0		11
TOTAL	6,256	153	2,561	784	8,970

Once the initial consumption and reduction of fuels used in residential buildings for thermal uses have been characterized, the emission reductions caused by the decrease of combustion of these fuels are estimated using the emission factors and methodology according to the EMEP guidance specific to "Small Combustion Plants" for residential uses:

- Improvement of the envelope of buildings: Reduction of energy demands due to the improvement of building envelopes for other uses (such as reduction of natural as for heating or the electricity consumption for cooling) is considered. The NIECP and the corresponding strategy (the Long-Term Strategy for Energy Rehabilitation in the Building Sector in Spain (MITMA, 2020) estimated the reduction in energy demand as 8%. The electricity consumption has been assessed, including two scenarios: 1) the current electricity mix, and 2) the cleaner electricity mix foreseen for 2030 (e.g., the target electricity mixes foreseen in the NIECP for 2030).
- Replacement of boilers with more efficient ones. The reference scenario and objectives of the Long-Term Strategy for Energy Rehabilitation in the Building Sector in Spain [4] were considered: improvement of energy efficiency (renovation of heating and DHW systems) in 300,000 dwellings/year on average for 10 years between boilers (30% of replacements) and heating pumps (70% of replacements). This translates to the replacement of 900,000 boilers in single-family and multi-family houses with individual heating. That means the replacement of fossil fuel-fuelled boilers in dwellings (with an average efficiency of 85%) by condensation boilers (95% efficiency at least) will achieve a 1.1% energy saving in the global figures of heating and DHW.
- Replacement of fossil fuel boilers by heat pumps that use electricity from the grid considering 1) the current electricity mix and 2) the cleaner electricity mix outlined in the NIECP for 2030). Once again, we assess the reference scenario and objectives of the Long-Term Strategy for Energy Rehabilitation in the Building Sector in Spain [4], which aims to improve energy efficiency by renovating heating and DHW systems in 300,000 dwellings annually on average for 10 years, with boilers and heating pumps accounting for 30% and 70% of replacements, respectively. That means that 2,100,000 boiler systems would be replaced by hat-pumps in single-family and multi-family

houses with individual heating. Thus, the replacement of fossil fuel-fuelled boilers in dwellings (with an average efficiency of 85%) by heat pumps (300% efficiency) will achieve a 22.5% energy saving in the global figures.

Regarding the measure to assess the impact of substituting fossil (diesel and gasoline) fuelled passenger cars with electric vehicles, the scenarios proposed were three:

- Scenario A: Substitution of the 5,500,000 fossil-fuelled passenger cars (the updated NIECP).
- Scenario B: Substitution of the 11,000,000 fossil passenger cars (two times the NIECP target)
- Scenario C: Substitution of the 22,000,000 fossil passenger cars (four times the NIECP target)

The reference scenario relied on official fleet characterization data(DGT, 2023). The data on the number of passenger cars per type of fuel and other relevant data for the calculation is shown in . In the assessed scenarios only, the gasoline and diesel-fuelled fleet was substituted as those represented almost the complete fleet.

Table 3. Data on the reference fleet of the year 2021.

	Fleet 2021	Average km/vehicle	vkm	FC (t)	FC (TJ)
Gasoline (Inc. hybrids)	11,592,724	6,160.23	7.14E+10	4.58E+06	1.90E+05
Diesel	14,224,585	15,858.76	2.26E+11	1.24E+07	5.28E+05
LPG	83,924	16,197.31	1.36E+09	8.32E+04	3.82E+03
CNG	16,617	31,494.57	5.23E+08	3.79E+04	1.83E+03

First, the number of vehicles km (vkm) per type of fuel (diesel and gasoline) and region of the current fleet was estimated. Second, the amount of replaceable vkm by electric cars was estimated, i.e., the vkm that the electric cars can replace in each scenario, per type of fuel. The geographical distribution of the fleet by region (NUTS-3 level[1]) was also considered to estimate the scenarios of replacement(DGT, 2023; MITERD, 2021). Finally, knowing the amount of vkm per fuel and region replaced, the energy consumed by type of fuel was calculated in terms of the mass of fuel consumed in the reference and the assessed scenarios were calculated. The emission reductions for each pollutant associated with the substitution were calculated by applying the emission factors of the EMEP/EEA emission guidelines. The factors of the guidelines are expressed in terms of the mass of pollutants per mass of fuel.

Additionally, the various options for increasing the number of electric vehicles in the country's fleet are responsible for the indirect emissions generated to produce the electricity to power electric vehicles. The assumed average of annual travel for electric cars is 8,554 vkm, and the average power consumption is 0.199 kWh/km (EV Database, n.d.). We estimated these indirect emissions by considering future electricity generation forecasts, such as the target electricity mix outlined in the NIECP for 2030. Similar approaches were studied recently in Spain (Gamarra et al., 2021).

C. Spatial distribution study

The location of the emissions and corresponding reductions along the domain (the Iberian Peninsula and Balearic Islands) has been carried out. The spatial distribution of the sources of emissions along the domain is assumed by using the data from the Spatial National Emissions Inventory of the reference year (2021) reported according to the EEA/EMEP CORINAIR guidelines [9, 12]. These guidelines mandate the estimation of atmospheric emissions from selected or representative samples of the main sources and source types. The basic model for estimating emissions involves multiplying (at least) two variables, such as an activity statistic

[1] The NUTS classification (Nomenclature of territorial units for statistics) is a hierarchical system for dividing up the economic territory of the EU. NUTS-3 level corresponds to small regions for specific diagnoses. More info at: https://ec.europa.eu/eurostat/web/nuts/background.

and a typical average emission factor for the activity, or measuring emissions over a period of time and counting the number of emissions from those periods within the required estimation period. For example, to estimate annual emissions of NOx in micrograms per year from an oil-fired power plant, use the annual fuel consumption (in tonnes of fuel/year) and an emission factor (in micrograms of NOx emitted/tonne fuel consumed). The Ministry for the Ecological Transition and Demographic Challenge (MITERD) developed the National Inventory, which contains data on emission sources. Therefore, the activities and processes classified according to the different sectors of activity are linked with the estimated emissions and the location. This allows the allocation of the change in emission when acting on a sector by implementing measures in the representative sources of emission of the sector.

III. Results and discussion

The results of the change in emissions of NOx and $PM_{2.5}$ are graphically shown in and , respectively. In both figures, the map noted as (a) the assessment of the baseline year has been included (absolute emissions in Mg in the year 2021). It can be seen that the highest levels of NOx are located in cities (the central area in green and even the orange colour in fig. 1), which correspond to three main areas. First, there are areas in the northern region with heavy industries, such as those around Gijón and Avilés, where annual emissions range from 7,000 to 8500 Mg of NOx. Second, the city of Madrid in the central area, where most of the area is in green (1,000 to 1,500 Mg) but with some points in which the reached level is between 2,500 and 5,000 Mg of annual emission. And third, other coastal cities (such as Barcelona with yellows, which indicates that reaching the range between 1,500 to 2,500 Mg of annual emission of NOx).

Regarding the changes in emissions due to the implementation of measures in residential buildings from 2021 to 2030, the figures (b) to (f) in Fig. 1 illustrate the results for NOx. The building's measures would yield the greatest benefits when heat pumps replace boilers, followed by envelopment improvements, both of which are expected to contribute to a cleaner electricity mix by 2030. The change to a more efficient one would have less impact on total emissions. As for the results of replacing fossil fuel-powered passenger cars in the fleet of 2021 with electric cars, the maps (g) to (i) in Fig. 1 and Fig. 2 illustrate the changes in NOx. As expected, scenario C, which replaces 22 million fossil fuel vehicles with electric cars covering the same vkm, achieves the highest reductions in NOx emissions. The reduction reaches the range of 50–75%, and there are large areas with reductions in the range of 25-50%. The North-western area clearly represents the region that benefits from the phase-out of carbon power plants for electricity production. Therefore, the impact of the improvement of the mix is seen as quite relevant, as found in previous studies (Gamarra et al., 2021).

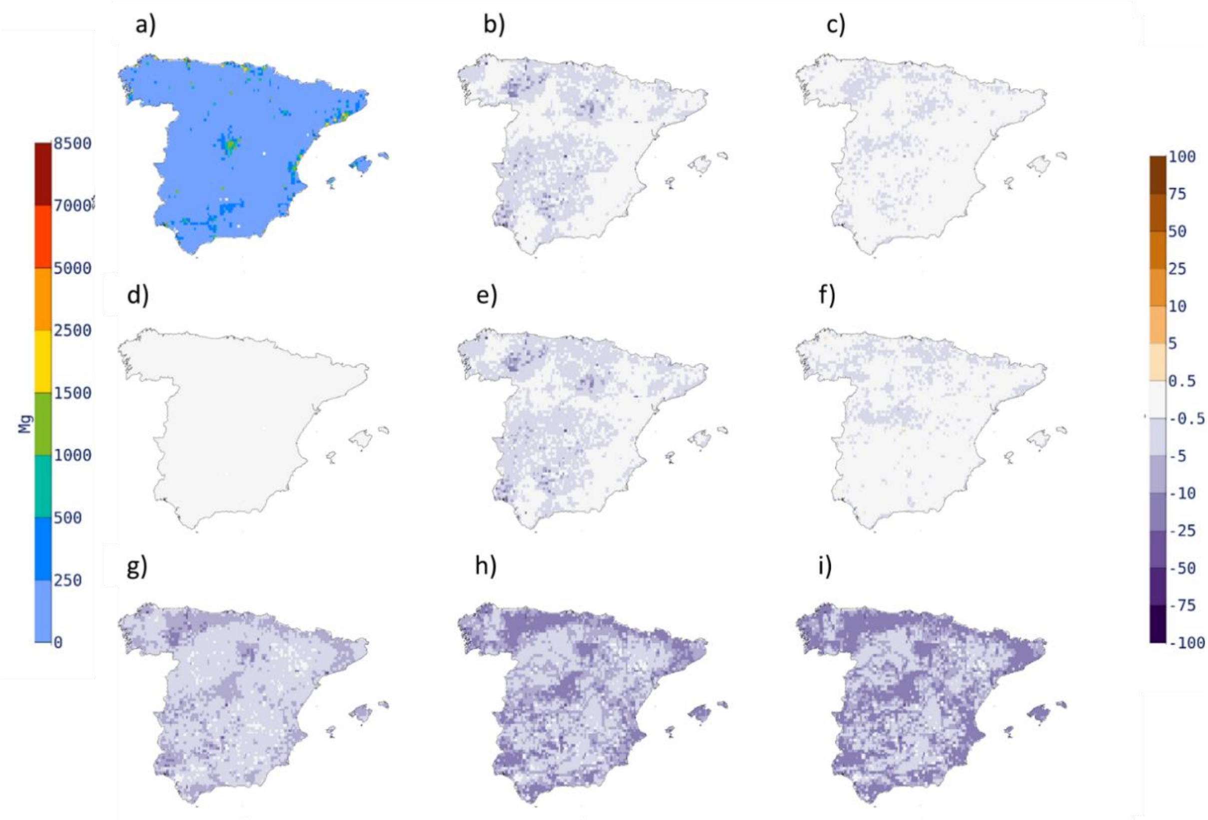

Fig. 1. Map of NOx concentration in the baseline scenario (a) in Mg (the legend is on the left), and maps (b to i) of changes in the NOx emissions in percentage (%) of variation for each measure along the domain (the legend is on the right). The percentages range from 100% (increases) to -100% (decreases). The maps display the following scenarios: (b) Improvement of the envelope of buildings considering the foreseen electricity mix in 2030; (c)Improvement of the envelope of buildings considering the current electricity mix; (d) Replacement of boilers by more efficient ones; (e) Replacement of fossil fuel boilers by electric heat-pumps considering the foreseen electricity mix in 2030; (f)Replacement of fossil fuel boilers by electric heat-pumps considering the current electricity mix, (g) Passengers car substitution scenario A considering the foreseen electricity mix in 2030; (h) Passengers car substitution scenario B considering the foreseen electricity mix in 2030; and (i) Passengers car substitution scenario C considering the foreseen electricity mix in 2030.

In the baseline scenario shown in Fig. 2(a), the highest levels of $PM_{2.5}$ emissions are found in some parts of the northern area. These are again near the cities of Gijón and Avilés, where 2,000 to 2,500 Mg of $PM_{2.5}$ are released each year, or in the Basque Country region. The central area and the coastal cities also exhibit levels of emission between 50 and 100 and between 50 and 500 Mg of $PM_{2.5}$ respectively. In addition, there is a larger area along the axis of the Guadalquivir Valley, from the Sierra Cazorla (Mountain range) to the city of Córdoba, where agriculture predominates as economic activity and burning of pruning could be happening.

The measure of building envelope improvement would have the highest benefits for $PM_{2.5}$, even more considering the cleaner electricity mix of 2030. The measure of increasing heat pumps by replacing boilers would produce some negative effects (an increase of emissions between 0.5% and 5% in some locations when the current mix of electricity is assumed). Therefore, this measure must be promoted as much as the change of the power mix is able to be cleaner.

Regarding the electric cars set of measures, the decreases of $PM_{2.5}$ would be smaller than those for NOx, but they would still be significant, with reductions reaching up to 25% in certain areas and falling within the range of 0.5% to 5% in a large portion of the territory. This is further explained by the impact the change in the electricity mix will have on the results. Such a change in the electricity mix would lead to a higher penetration of biomass technology, which, even with the best available technology, is associated with the highest levels of emissions of particulate matter. Similar results were found in the literature highlighting the synergy between electric vehicles and electricity generation mix as a pathway to a more sustainable transportation (Singh & Namrata, 2025). In Qatar, the study of Alishqq & Mehliq (Alishaq & Mehlig, 2024)

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calculates the potential reduction in NOx and PM2.5 emissions resulting from substituting Internal Combustion Engine Vehicles (ICEVs) with Battery Electric Vehicles (BEVs) in Qatar, considering ICEV ban scenarios in 2030, 2035, In addition, the analysis encompasses five distinct policy pathways for transition, offering a comprehensive framework for evaluating the potential environmental impact of the transition to electric vehicles. The study's findings indicate that the adoption of an ICEV ban in 2030 would result in substantial reductions in NOx and $PM_{2.5}$ emissions. Specifically, the analysis projects a 20% and 9% decrease, respectively, in NOx and $PM_{2.5}$ emissions compared to the status quo scenario (BAU) for Qatar.

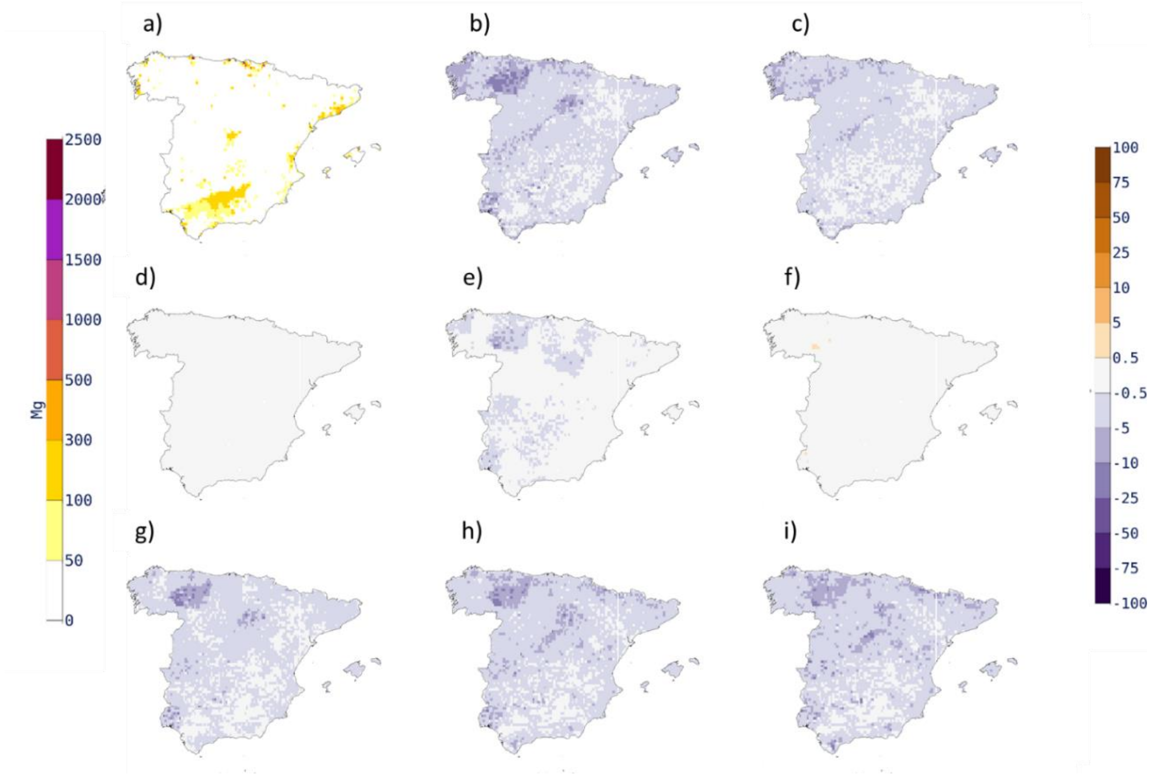

Fig. 2. Map of $PM_{2.5}$ concentration in the baseline scenario (a) in Mg (the corresponding legend is on the left), and maps of changes in the NOx emissions in percentage (%) of variation for each measure along the domain (the corresponding legend is on the right) and range from 100% (increases) to -100% (decreases), representing the scenarios: (b) Improvement of the envelope of buildings considering the foreseen electricity mix in 2030; (c) Improvement of the envelope of buildings considering the current electricity mix; (d) Replacement of boilers by more efficient ones; (e) Replacement of fossil fuel boilers by electric heat-pumps considering the foreseen electricity mix in 2030; (f) Replacement of fossil fuel boilers by electric heat-pumps considering the current electricity mix, (g) Passengers car substitution scenario A considering the foreseen electricity mix in 2030; (h) Passengers car substitution scenario B considering the foreseen electricity mix in 2030; and (i) Passengers car substitution scenario C considering the foreseen electricity mix in 2030.

Beyond the benefits of achieving such scenarios in Spain in terms of clean energy consumption and lowering emissions, other potential benefits should be stated in a pathway to a more sustainable passenger transportation and residential building. First the benefits for health, ecosystems, biodiversity, agriculture and materials (EEA, 2024) due to the lower exposure to pollution in the short term, and to the change in climate in the long terms due to the GHG emission mitigation. Second, the associated decrease of the costs for society of those damages to human health. In addition, the decrease of the fossil fuel consumption in households and transportation of people could have positive effect on the foreign dependency on fossil fuels imports. However, also some drawbacks can arise, such as the needs of critical materials to manufacture vehicles and the challenge to improve the batteries recycling.

Some limitations must be mentioned. The factors for the Tier 1 default approach of the EMEP/EEA guidelines are used, while Tier 2 and Tier 3 are much more detailed in terms of particularities of the emission processes and conditions. The application of the tier depends on the available activity data, being the more exigent the tier 3 and the less the tier 1. Next steps will include the characterisation of the car fleet in order to apply the tier 2 approach. Regarding the method of calculation of changes in emissions of the electric vehicle substitution, the limitation is related to the particular matter variation. We assume that while emission from the engine will be reduced, non-exhaust emissions will be kept. Recent research indicates that the electric vehicle can increase the emissions of non-exhaust (coming from brakes wear, tyres wear, road abrasion and resuspension) due to the high weights of electric vehicles (in average)(EMEP/EEA, 2024; Woo et al., 2022). Future research should include the impact of those particular matter emissions changes. Regarding the scenarios of electricity, alternative scenarios could be developed considering the alternatives of energy production and given the strong impact on the results. Finally, the assessment of a wide range of pollutants should be assessed, such as PM10 and Polycyclic Aromatic Hydrocarbons (PAHs), which also have an impact on health, and can be also reduced by the decrease of combustion processes in residential ambient due to heating systems substitution by electric pumps and by the transition to a cleaner electricity mix of power technologies supplying the grid to charge electric vehicles.

IV. Conclusions

The study you referenced examines the impact of decarbonization measures in the residential and passenger car sectors on emissions of nitrogen oxides (NO_x) and fine particulate matter ($PM_{2.5}$) in Spain, comparing projected 2030 levels to those in 2021. It highlights that significant emission reductions are associated with transitioning passenger road transport from combustion engines to electric vehicles (EVs) and enhancing building envelopes, especially as the electricity mix achieves the renewable energy targets set for 2030.

This study quantifies the change in emissions of two of the main pollutants affecting health, NOx and PM2.5, as a result of the implementation of a set of eight planned scenarios considering the target policies for 2030 in Spain. The results show that the biggest benefits in terms of lowering emissions come from switching from gas-powered cars to electric ones and making buildings better once the number of renewable energy sources in the electricity mix reaches the 2030 goal. Therefore, the more renewable electricity scenario is crucial to maximise the benefits.

The value added of this research is that the approach focused on measures in which the relevant role of population in the co-beneficial action is determinant to facing the decarbonization and the improvement of air quality (and prevention of their impact on health) allows emphasising this role for the success of the policies implementation. The specific measures assessed are planned by policy frameworks but both sets (electric vehicles and energy efficiency improvements) are highly dependent on how the population will incorporate the electric vehicle into their mobility patterns and needs, as well as how they decide to move to more efficient equipment in their homes (and buildings) in the next years. The second aspect to be highlighted is that the electric mix is also determinant, the transition to the planned deployment of renewables to electricity production is crucial to achieve the benefits.

In conclusion, implementing energy efficiency measures in residential buildings and promoting the adoption of electric vehicles to reduce carbon emissions are effective strategies for reducing NO_x and $PM_{2.5}$ emissions. These actions not only contribute to environmental sustainability but also offer substantial public health benefits. However, the population should be encouraged to undertake those changes in transportation and buildings.

As future lines of research, the application of the Tier 2 approach of the EEA/EMEP guidelines and the inclusion of non-exhaust emissions will be addressed for the electric vehicles, as well as the impact of the policies in the emissions of other relevant pollutants on health. Also, the results of reductions of the emissions of pollutants in origin and their spatial allocation along the domain will be useful to feed the atmospheric modelling. The results of the modelling, including the rest of the model components such as meteorology, dispersion, and chemical interaction, will allow us to assess the impacts of the measures on air quality and population exposure and develop the health impact assessment. New contributions of emissions of particulate matter will be researched to be included, including the potential drawbacks.

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REFERENCES

Agarwal, S., He, J., Ren, Y., & Shen, X. (2024). Air quality improved by new energy vehicles penetration. SSRN Electronic Journal. https://doi.org/10.2139/SSRN.4851007

Alishaq, A., & Mehlig, D. (2024). Towards Sustainable Mobility: Assessing the Benefits and Implications of Internal Combustion Engine Vehicle Bans and Battery Electric Vehicle Uptake in Qatar. Atmosphere, 15(6), 677. https://doi.org/10.3390/ATMOS15060677/S1

Andre, M., Sartelet, K., Moukhtar, S., Andre, J. M., & Redaelli, M. (2020). Diesel, petrol or electric vehicles: What choices to improve urban air quality in the Ile-de-France region? A simulation platform and case study. Atmospheric Environment, 241, 117752. https://doi.org/10.1016/J.ATMOSENV.2020.117752

Beevers, S., Assareh, N., Beddows, A., Stewart, G., Holland, M., Fecht, D., Liu, Y., Goodman, A., Walton, H., Brand, C., Evangelopoulos, D., Wood, D., Vu, T., & Dajnak, D. (2025). Climate change policies reduce air pollution and increase physical activity: Benefits, costs, inequalities, and indoor exposures. Environment International, 195, 109164. https://doi.org/10.1016/J.ENVINT.2024.109164

Choma, E. F., Evans, J. S., Hammitt, J. K., Gómez-Ibáñez, J. A., & Spengler, J. D. (2020). Assessing the health impacts of electric vehicles through air pollution in the United States. Environment International, 144, 106015. https://doi.org/10.1016/J.ENVINT.2020.106015

Colette, A., Koelemeijer, R., Mellios, G., Schucht, S., Péré, J.-C., Kouridis, C., Bessagnet, B., Eerens, H., Van Velze, K., & Rouïl, L. (2012). Cobenefits of climate and air pollution regulations The context of the European Commission Roadmap for moving to a low carbon economy in 2050 The European Topic Centre on Air Pollution and Climate Change Mitigation (ETC/ACM) is a consortium of European institutes under contract of the European Environment Agency RIVM UBA-V ÖKO AEAT EMISIA CHMI NILU INERIS PBL CSIC 2. http://acm.eionet.europa.eu/

DGT. (2023). DGT - DGT en cifras resultados. https://www.dgt.es/menusecundario/dgt-en-cifras/dgt-en-cifras-resultados/?q=parque&tema=vehiculos&pag=1&order=DESC%C2%A0

EEA. (2019). EMEP/EEA air pollutant emission inventory guidebook 2019 | European Environment Agency's home page. https://www.eea.europa.eu/en/analysis/publications/emep-eea-guidebook-2019

EEA. (2023). Harm to human health from air pollution in Europe: burden of disease 2023 — European Environment Agency. https://doi.org/10.2800/721439

EEA. (2024). Technical note. Estimating the external costs of industrial air pollution-Trends 2012-2021. https://www.eea.europa.eu/publications/the-cost-to-health-and-the/technical-note_estimating-the-external-costs/view

EMEP/EEA. (2024). EMEP/EEA air pollutant emission inventory guidebook 2023 1 Category Title NFR 1.A.3.b.vi-vii.

EV Database. (n.d.). Energy consumption of full electric vehicles cheatsheet - EV Database. Retrieved March 4, 2025, from https://ev-database.org/cheatsheet/energy-consumption-electric-car

Gago, E. J. (2017). Electric vehicles: Case study for Spain. Electric Vehicles: Prospects and Challenges, 287–316. https://doi.org/10.1016/B978-0-12-803021-9.00008-2

Gamarra, A. R., Lechón, Y., Vivanco, M. G., Garrido, J. L., Martín, F., Sánchez, E., Theobald, M. R., Gil, V., & Santiago, J. L. (2020). Benefit Analysis of the 1st Spanish Air Pollution Control Programme on Health Impacts and Associated Externalities. Atmosphere 2021, Vol. 12, Page 32, 12(1), 32. https://doi.org/10.3390/ATMOS12010032

Gamarra, A. R., Lechón, Y., Vivanco, M. G., Theobald, M. R., Lago, C., Sánchez, E., Santiago, J. L., Garrido, J. L., Martín, F., Gil, V., & Rodríguez-Sánchez, A. (2021). Avoided Mortality Associated with Improved Air Quality from an Increase in Renewable Energy in the Spanish Transport Sector: Use of Biofuels and the Adoption of the Electric Car. Atmosphere 2021, Vol. 12, Page 1603, 12(12), 1603. https://doi.org/10.3390/ATMOS12121603

IDAE. (2019). SPAHOUSEC II: Análisis estadístico del consumo de gas natural en las viviendas principales con calefacción individual.

IDAE. (2024). Consumo por usos residencial. https://informesweb.idae.es/consumo-usos-residencial/informe.php

Karlsson, M., Alfredsson, E., & Westling, N. (2020). Climate policy co-benefits: a review. Climate Policy, 20(3), 292–316. https://doi.org/10.1080/14693062.2020.1724070

McDuffie, E. E., Martin, R. V., Spadaro, J. V., Burnett, R., Smith, S. J., O'Rourke, P., Hammer, M. S., van Donkelaar, A., Bindle, L., Shah, V., Jaeglé, L., Luo, G., Yu, F., Adeniran, J. A., Lin, J., & Brauer, M. (2021). Source sector and fuel contributions to ambient PM2.5 and attributable mortality across multiple spatial scales. Nature Communications 2021 12:1, 12(1), 1–12. https://doi.org/10.1038/s41467-021-23853-y

Milner, J., Turner, G., Ibbetson, A., Eustachio Colombo, P., Green, R., Dangour, A. D., Haines, A., & Wilkinson, P. (2023). Impact on mortality of pathways to net zero greenhouse gas emissions in England and Wales: a multisectoral modelling study. The Lancet Planetary Health, 7(2), e128–e136. https://doi.org/10.1016/S2542-5196(22)00310-2

MITECO. (2020). Plan Nacional Integrado de Energía y Clima 2021-2030. Ministerio Para La Transición Ecológica y El Reto Demográfico, Gobierno de España, 25.

MITECO. (2024). Plan Nacional Integrado de Energía y Clima ACTUALIZACIÓN 2023-2030. In Ministerio para la Transición Ecológica y el Reto Demográfico (MITECO), Spanish Government. https://www.miteco.gob.es/es/energia/estrategia-normativa/pniec-23-30.html

MITERD. (2021). Sistema Español de Inventario de Emisiones: Metodologías de estimación de emisiones. https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/temas/sistema-espanol-de-inventario-sei-/volumen2.html

MITMA. (2020). Long-Term Strategy for Energy Rehabilitation in the Building Sector in Spain. https://www.mitma.gob.es/recursos_mfom/paginabasica/recursos/eresee_2020.pdf

OECD. (2009). Co-Benefits of Climate Change Mitigation Policies (OECD Economics Department Working Papers, Vol. 693). https://doi.org/10.1787/224388684356

Piccoli, A., Agresti, V., Bedogni, M., Lonati, G., & Pirovano, G. (2025). Modelling the air quality impacts of a zero-emission zone scenario in the city of Milan. Atmospheric Environment: X, 25, 100318. https://doi.org/10.1016/J.AEAOA.2025.100318

Singh, P., & Namrata. (2025). The synergy between electric vehicle and electricity generation mix: A path to sustainable transportation. Energy Policy, 200. https://doi.org/10.1016/j.enpol.2025.114558

Soret, A., Guevara, M., & Baldasano, J. M. (2014). The potential impacts of electric vehicles on air quality in the urban areas of Barcelona and Madrid (Spain). Atmospheric Environment, 99, 51–63. https://doi.org/10.1016/J.ATMOSENV.2014.09.048

Spanish Government. (2019). Programa Nacional de Control de la Contaminación Atmosférica. https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/temas/atmosfera-y-calidad-del-aire/emisiones/pncca.html

Vandyck, T., Keramidas, K., Tchung-Ming, S., Weitzel, M., & Van Dingenen, R. (2020). Quantifying air quality co-benefits of climate policy across sectors and regions. Climatic Change, 163(3), 1501–1517. https://doi.org/10.1007/S10584-020-02685-7/FIGURES/3

Vivanco, M. G., Garrido, J. L., Martín, F., Lechón, Y., Gamarra, A. R., Sánchez, E., Theobald, M., Gil, V., & Santiago, J. L. (2021). Assessment of the effects of the Spanish National Air Pollution Control Programme on air quality. Atmosphere, 12.

WHO. (2021). WHO global air quality guidelines, Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. https://www.who.int/publications/i/item/9789240034228

Woo, S. H., Jang, H., Lee, S. B., & Lee, S. (2022). Comparison of total PM emissions emitted from electric and internal combustion engine vehicles: An experimental analysis. Science of the Total Environment, 842. https://doi.org/10.1016/j.scitotenv.2022.156961

Zimakowska-Laskowska, M., & Laskowski, P. (2022). Emission from Internal Combustion Engines and Battery Electric Vehicles: Case Study for Poland. Atmosphere 2022, Vol. 13, Page 401, 13(3), 401. https://doi.org/10.3390/ATMOS13030401

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Spremembe emisij ključnih onesnaževal kot posledica izvajanja ukrepov v sektorjih, ki so blizu prebivalstvu: stanovanjske stavbe in osebna vozila

Povzetek - Članek obravnava različne možnosti za zmanjšanje onesnaženosti zraka z ukrepi, ki se izvajajo v ključnih sektorjih. Trenutne okoljske in energetske politike na evropski in španski ravni so usmerjene v povečanje energetske učinkovitosti ter spodbujanje uporabe obnovljivih virov energije. V študiji smo ob upoštevanju ciljev za leto 2030 v Španiji, v primerjavi z izhodiščnim letom 2021, količinsko ocenili spremembe emisij dveh glavnih onesnaževal, ki vplivata na zdravje – dušikovih oksidov (NOx) in drobnih delcev (PM2,5) – kot posledico izvajanja načrtovanih ukrepov. Ti ukrepi so osredotočeni na sektorje, ki so neposredno povezani s prebivalstvom: stanovanjske stavbe in osebna vozila. Rezultati kažejo, da največje koristi v smislu zmanjšanja emisij izvirajo iz zamenjave cestnega potniškega prometa, ki temelji na izgorevanju, z električnimi vozili ter iz izboljšav energijske učinkovitosti stavb, zlasti kadar mešanica električne energije doseže ciljni delež obnovljivih virov do leta 2030.

Ključne besede - kakovost zraka; emisije; ukrepi in blažitev; onesnaževala ozračja

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APPENDIX 1: LOCATIONS OF THE IBERIAN PENINSULA MENTIONED IN THE MANUSCRIPT

Figure A. 1. Locations of the Iberian Peninsula mentioned in the manuscript.