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The cost of inaction in air pollution abatement policies

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Abstract: Two alternative air quality policies are compared: one is the application of only mandatory abatement measures from 2020 to 2030. The second is the definition of a more active and locally-based policy that will lead to a better air quality at the end of the decade. Using an integrated modelling system, we demonstrate that the active policy is quite more convenient from the economic viewpoint, at least for the specific situation of the Lombardy region, considered in the study. Improving particulate matter concentrations may however produce worse ozone values. A full view of all pollutants is thus necessary when planning for air quality at regional level.

Keywords: Integrated modelling; air quality; multi-objective optimization; pollutant trade-offs

1. INTRODUCTION

The problem of assessing the inaction costs or delayed costs in the adoption of environmental protection measures has been debated by many authors in the last decade. The large majority of these works look at the problem at global scale, and mainly evaluate the effects of delaying the adoption of energy measures to reduce GHG emission and/or to meet the international climate agreements (see, for instance: Scapecchi, 2008; Jakob et al., 2012; Luderer et al., 2013; Alberini et al., 2016; Tokimatsu et al., 2018; Chen et al., 2020; Vijay et al., 2020). On the opposite side, other papers deal with the measures to be taken at the scale of an individual building, again mainly with reference to fuel use and consequent CO2 emissions (e.g., Matschoss et al., 2013; Cho and Yoon, 2015; Desideri and Asdrubali, 2019). Only a few papers look at the problem at the local/regional scale (e.g., Kurnitski et al., 2014; Friedman et al., 2014), which, under many respects, is the proper spatial resolution to consider economic, energy and environmental aspects.

Most studies on the costs of postponing or completely avoiding the adoption of environmentally-friendly measures are just based on the comparison of different future scenarios (e.g., OECD, 2012; Yang et al., 2019) and disregards the evaluation of the path to reach the selected future conditions. In this paper, we address the problem by comparing two alternative paths to 2030. The first implies to continue along the so-called baseline or business-as-usual (BAU), which means to progressively adopt the mandatory measures foreseen by the legislation in force. The second proposes to reach in 2030 a condition that represents an efficient compromise between the measure implementation costs and a suitable index of air quality. To reach this result, we need to implement a fairly complete integrated assessment model that evaluates all the key economic impacts of a given set of actions together with the corresponding air quality. The factors to be computed include those related to the fuel spared, the reduction of morbidity and mortality due to the improved air quality, and the value of the reduced GHG emissions, besides the implementation costs of the pollution abatement measures.

We apply such an integrated assessment system to the Lombardy region in Northern Italy, which is well known for the severity and frequency of air pollution episodes especially in winter, when the meteorological conditions (stability of the atmosphere and lack of wind) prevent a significant dispersion of pollutants (Vecchi et al., 2004; Vecchi et al., 2007). Additionally, Caserini et al. (2017) showed that the situation would worsen in the near future due to the effects of climate change.

The paper is organized as follows. The next section explains how the two alternative pathways are computed and illustrates the main features of the regional case discussed later. Section 3 presents the features of the integrated assessment modelling system (IAM) used in the study. Finally, section 4 compares and discusses the results obtained, and section 5 draws some conclusions and perspectives for future research.

2. MATERIALS AND METHODS

2.1. *Defining the development pathways*

The problem of estimating the cost of inaction is dealt with by computing the difference of the net present values (NPV) of two alternative pathways. The first is limited to the adoption of the (EU and regional) legislation in force, i.e., it moves progressively from the mandatory abatement measures in 2020 (CLE2020) to those in force ten years later (CLE2030). The correspondent NPVcle is calculated with the classical actualization formula:

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$$\text{NPVcle} = \sum_{t=1}^{10}\left(-IC(t) + \frac{+H(t)+F(t)+GHG(t)}{(i+r)^t}\right) \quad (1)$$

where

- $IC(t)$ represents the implementation cost of the abatement measures at year t, between 2020 and 2030. Implementation costs are not discounted since they are already available from the GAINS website (http://gains.iiasa.ac.at) with an actualization rate of 4%. They will be measured in the following only as additional costs with respect to those of the mandatory measures in 2020.
- $H(t)$ is the reduction of health burden with respect to CLE2020 estimated on the base of the AQI of year t in monetary units.
- $F(t)$ is the reduction of fuel expenses due to the adoption of energy-saving measures.
- $GHG(t)$ is the cost reduction of the GHG emission with respect to CLE2020 computed at the estimated value on the EU allowance market in year t.
- r is a constant actualization rate, assumed to be 4% in this study to maintain the coherence with the GAINS cost estimate.

The second path is defined in two steps. First, a multiobjective problem is solved to determine the efficient trade-offs between the AQI and the implementation costs in 2030. Namely, we solve the problem:

$$\min_{x,z,s} J(x,z,s) = \min_{x,z,s}\left[\left(\text{AQI}(E(x,z,s)\right), IC(x,z,s)\right] \quad (2)$$

Subject to $\quad x,z,s$ feasible. (3)

In (2)

- x,z,s represent the three types of decision variables: the end-of-pipe measures, the energy-saving measures, and the (fuel) switch measures, respectively. The latter represent the possibility of replacing part of an activity with another that is (energetically) more efficient.

  Indeed, the emission $E^{d,p}(x,z,s)$ of a pollutant p in a cell d determined by the application of such measures can be written as:

$$E^{d,p}(x,z,s) = \sum_{k\in K}\left\{\left[A_k^d(1-(z_k+s_k))\right]\text{EF}_k^p\left(1-\sum_{t\in T_k}\text{EFF}_t^p x_k^t\right)\right\} \quad (4)$$

  where A_k^d is the level of the emission-producing activity k in cell d of the domain, EF_k^p is the emission factor of the precursor p for the activity k, EFF_t^p is the removal efficiency of the end-of-pipe measure t for the pollutant p.
- The feasibility constraints (3) represent the fact that all decision variables are limited to a specific set of values. For instance, end-of-pipe measures can be applied at most to 100% of the plants carrying out a certain activity. In some cases, the percentage may be even lower for specific reasons, e.g., old plants cannot adopt a new abatement technology.
- AQI is the selected Air Quality Index that clearly depends on the precursor emission values.
- $IC(x,z,s)$ is the implementation cost of the emission abatement measures.

The solution to problem (2)-(3) is the set of emission reduction measures that guarantee the maximum impact on air quality for any fixed cost, or, alternatively, the minimum costs that allows achieving a given level of air quality.

The second step of the procedure is thus to select a point on the Pareto front representing all the possible trade-offs between implementation costs and air quality. A classical criterion for this choice is to select the point close to the maximum curvature of the front.

Once this point has been selected, we can define the path between CLE2020 and such a point, as the second, alternative, development trajectory. In this case too, we can compute a NPVe with the same formula (1) assuming a progressive adoption of all the measures that produce the selected Pareto efficient solution.

Finally, the cost of inaction CI can be estimated as the difference between the value of the CLE path and that of the efficient path, i.e.,

$$\text{CI} = \text{NPVe-NPVcle} \quad (4)$$

2.2 *A regional example*

The IAM approach previously described has been tested for air quality control in Lombardy Region (Northern Italy), which is amongst the most polluted areas in Europe. This is due to both meteorological conditions and high emission levels. The domain has been gridded in cells with an area of $6 \times 6\ Km^2$(Figure 1).

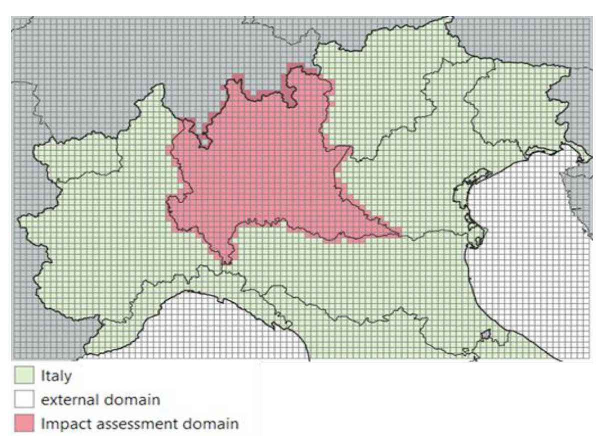

Figure 1. Map of the gridded domain used in the case study.

The air quality index considered in this work is the spatial average of the mean yearly $PM_{2.5}$ concentrations, since it is closely linked to the impacts on the health of the resident population.

3. THE IAM SYSTEM

The integrated assessment modelling system used in this study to solve the problem (2) (3) is MAQ (Turrini et al., 2018), a set of coordinated modules that closely follows the well-known DPSIR (Drivers-Pressures-State-Impacts-Responses) scheme, adopted by the EU (EEA 1999) as presented in Figure 2.
The scheme may be read starting from a set of measures (RESPONSES) that may be chosen externally for a scenario analysis or by an internal module that optimizes an objective function. These measures may modify the DRIVERS, acting for instance on the amount of energy used in a certain compartment, or modify the emission (PRESSURES) by the adoption of end-of-pipe measures. The overall emissions are due to the combined effect of remaining activities and adopted measures.

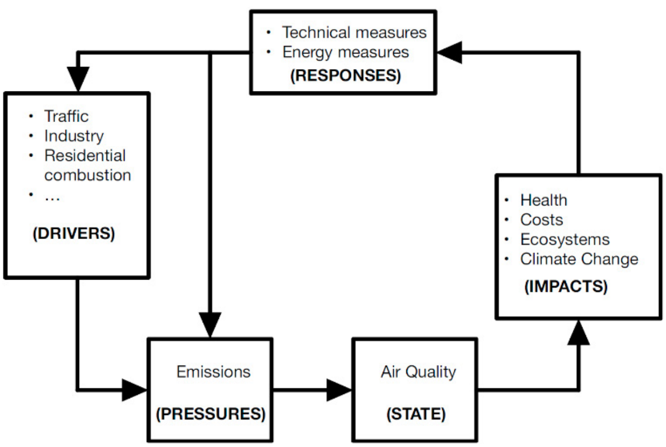

Figure 2. DPSIR Scheme adopted in the MAQ system.

The variation of the pressures determines a change in the STATE (air quality) of the territory under analysis. This critical step requires a model of the chemistry and transport of the pollutants (CTM) that is substituted, within MAQ, by a (set of) simple surrogate model(s). The surrogate modelling approach for the current case uses artificial neural networks to allow a quick calculation of the pollutant concentration based on local precursor emissions (NOx, VOC, NH_3, PM10, PM2.5, SO_2). The neural networks are calibrated on the output of a limited number of simulations of a full CTM, TCAM (Chemical Aerosol Transport Model) model (Carnevale et al., 2008) in the specific case. The Design of Experiment and methodology applied to train these surrogate models are extensively presented in (Turrini et al. 2018) alongside the validation results. The computed STATE determines a number of IMPACTS that are calculated in the specific module. Such impacts include the monetary evaluation of the improvement of people's health (traditionally measured in terms of years of life lost - YOLL). Other relevant impacts are those due to the reduction of fuel use (due to the reduction of energy consumed) and the reduced amount of greenhouse gases, written in terms of CO_2 equivalent. It is worth noticing the value of a ton of CO_{2eq} emitted on the EU emission market has topped 95 €/ton, more than doubling its value in a single year. Estimates of the future trend of this price vary a lot (see, for instance, Kober et al., 2020), but it may again double by the end of the decade.

4. RESULTS

Figure 3 presents the Pareto front of the two-objective problem defined in (2). It shows the optimal compromise solutions between average spatial PM2.5 yearly concentration (the selected AQI) and the additional implementation costs, besides those mandatory in 2020. The solutions in the figure are determined using the optimization algorithm of the MAQ system, by parametrically constraining the maximum implementation cost. Point P (126 M€/y, 12.6 μg/m^3) is selected as the target situation, being the point of maximum curvature, i.e., where the rate of change of the two objectives is higher.

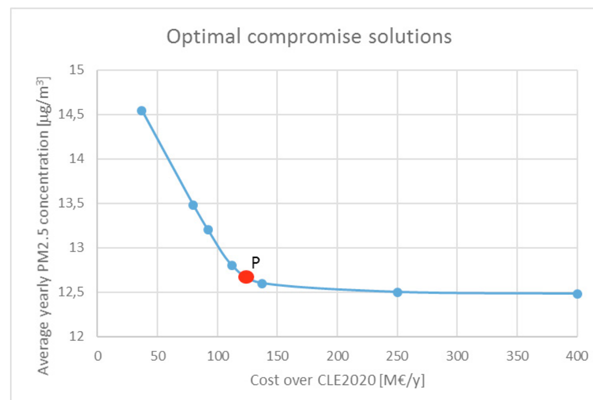

Figure 3. Pareto front of the cost-AQI problem.

Figure 4 shows the two alternative pathways to the CLE2030 and to solution P starting from CLE2020 in terms of AQI. It is evident that solution P represents a definite improvement of air quality in terms of the selected AQI, though corresponding to higher implementation costs. Overall, the NPV difference of the two paths is of about 3.2 G€ in the decade 2020-30, i.e., an average of 320 M€/y. This is the cost to be borne by the society for not taking more incisive actions in tackling air pollution problems.

Figure 4. Time evolution of the two pathways (continuous line to CLE2030, dashed line to target P).

The improvement of air quality is evident in the maps in Figure 5 that compares the AQI of CLE2030 and that of the target solution P. It shows a particularly strong PM2.5 reduction in the central area of the region where population is particularly dense. For this reason, this evolution corresponds to a strongly reduced health impact and to a slight reduction of CO_2 emission.

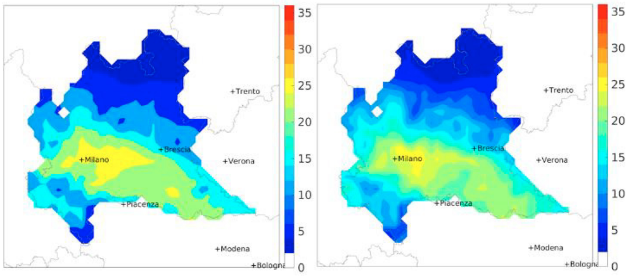

Figure 5. PM2.5 yearly mean concentration (μg/m^3) maps in CLE2030 (left) and in the target solution P (right).

The main differences in the measures to actuate solution P with respect to CLE2030 are illustrated in Figure 6 in terms of pollutants and SNAP macrosectors. They concern a reduction of particulate emissions in the manufacturing industry as well as in domestic heating (macrosector 2). Indeed, the main suggested action is to replace domestic biomass burning with gas fueled boilers. The drawback of this measure is to increase net CO_2 emissions and this explains why the reduction of GHG is only marginal.

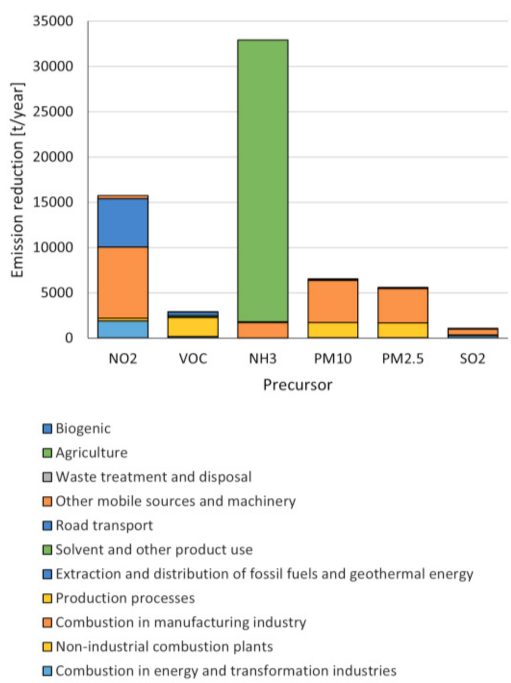

Figure 6. Precursor emission reductions per CORINAIR macrosectors between CLE2030 and target solution P.

Another important measure is the reduction of NOx emissions (Figure 7) by road transport and other machinery. This provides the main contribution to the difference of nitrogen oxides emissions that total about 44.8 kt/y in comparison to the 60.5 kt/y of the CLE2030 scenario: a reduction of more than one fourth.

The other side of the coin is the situation of ozone. As is well known, ozone is a secondary pollutant that forms in the atmosphere due to complex reactions involving NOx and VOC as precursor gases. Ozone can be measured by various indicators such as SOMO35 or AOT40, both summing all the concentrations above a threshold during the year (though ozone only forms in summer because it needs ultraviolet radiation). The evaluation of such indicators requires specific surrogate models within the IAM, but an economic estimation has not been included in the current assessment of NPVs. Whatever indicator is selected, the efficient situation of point P corresponds to an increase of 3-5% with respect to CLE2030, which is in turn about 20-30% higher than in the CLE2020 scenario (see Figure 8).

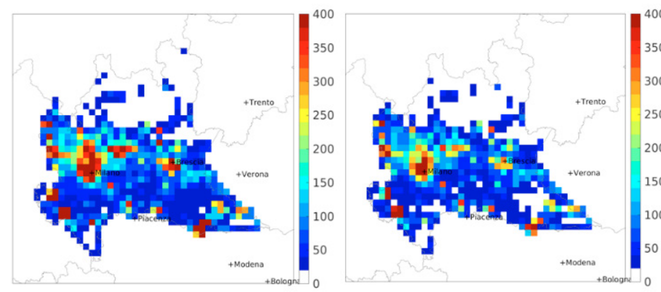

Figure 7. NOx emission (t/y) maps corresponding to CLE2030 (left) and target solution P (right).

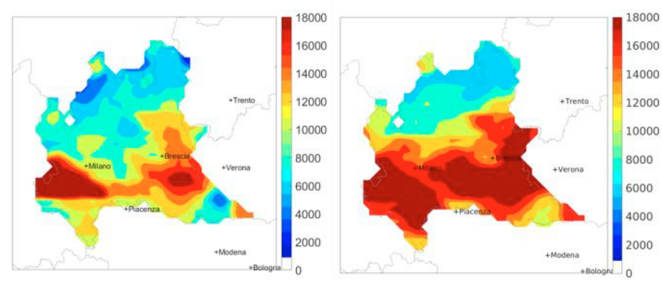

Figure 8. SOMO35 evolution from CLE2020 (left) to target solution P (right).

5. CONCLUSIONS

Two possible pathways of air quality management are compared in an Italian region. The two pathways represent the blind adoption of EU mandatory policy in the decade 2020-2030 and a local policy that involves more active actions to reduce air pollution. The cost of not adopting the second policy is of the order of 300 M€/y till 2030. Such a difference is due to the fact that the actions foreseen by the CLE are not optimized for the local/regional activities and thus different choices lead to better results.

The analysis suggests the measures that must be adopted and allows the determination of a number of relevant impacts through the use of an integrated modelling approach. This also points out some important consequences of the suggested policy that, in the case at hand, would increase ozone concentrations. A further integration is thus needed to include all the relevant phenomena in the analysis to fully support the choices of the local decision makers.

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